MASTER THESIS

<Repair/replace decision for ultra-precision milling machine>

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Repair/replace decision for ultra-precision milling machine

A case study at NTS Norma

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Abstract

This master thesis gives an insight in designing a model used to get an overview needed to make a well-founded repair / replace decision. That is done by answering the questions of how NTS Norma can gain overview and make a well-founded repair / replace decision regarding milling machines and which input is needed for this decision in the future.

This is done by using the method asset management as a guide. Asset management divides an asset into different topics: Organization strategic plan; Organization and people; Asset knowledge; Risk and review. Concluded is that the knowledge within the organization and people is high at NTS Norma, but the other topics need more clarification to design a well-founded repair / replace decision. This clarification is given by dividing the process into three categories: Vision, technical life model and economical life model.

The first category is tackled by visualizing the vision of the company by ways of performing a stakeholder analysis.

The technical life model gives insight into the difference between technical capabilities of the current machines and the possible new technical capabilities available at the marked. This difference in capabilities can change the vision and strategy of the company, resulting in different requirements regarding the used machines. To indicate this difference, success factors are designed that give a clear overview of the current technical capabilities of the machine and expectation or vision of the machine from the company. For each success factor, based on the vision of NTS Norma, unique key performance indicators are developed to indicate the difference in technical capabilities.

The economic life model gives insight in the cash flows of the machines, gathered over the lifetime of a machine. These cash flows are gathered using data from NTS Norma and can be translated into the average benefits per year graph. In this graph, the economical life is reached when the graph is at its maximum. During the process of gathering data, which is used to analyze, is concluded that important data is missing or defined as unusable, resulting in a unusable model.

A roadmap is made to gather the required data in the future, divided into two phases. The first phase is used to gather data required for the economic life model, where the second phase is used to define how to improve datalogging which is not specifically required for the economic life model.

In this way, a new repair / replace model is made. This repair / replace model is specifically designed for NTS Norma and can only be used by this company. The method to design this repair / replace model can be used as a guide by other companies to design their own repair / replace model.

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1 INTRODUCTION

In a manufacturing environment, the availability of an operating machine decreases over time. Wearing and aging of the machine parts can results in sudden failure of the machine, resulting in downtime. Maintenance actions should keep the machine in a good as new state and reduce the downtime to its maximum. Aging and degradation of the machine will at a given moment cause availability issues and additional costs to keep the machine up and running. In the long run, the machine will reach its useful life. This useful life can be different between different companies, depending on the vision, strategy and capabilities of the company. To make such decision, the company should make a choice whether the machine is repaired or replaced. Replacement will reduce additional costs such as maintenance or downtime costs, but will also increase the initial investment. For many manufacturers, it is unknown when and why a deteriorating machine should be replaced to maximize the profit.

NTS Norma unique selling points

NTS Norma is an high-tech first line supplier, who designs, produces and assembles complete mechatronic systems. They are specialized in ultraprecision activities and have a unique position in precision machining and ultraprecision modules. The company is one of the few companies in the world that can guarantee a precision of less than a thousand of a millimeter.

NTS Norma offers triple A-products to triple A-clients and is known as a company that goes further where others would stop. A unique aspect of NTS Norma is that the company and the company culture is focused on making the impossible possible. For this reason, clients are not afraid to bring up a complex problems, because they know that NTS Norma invest time and effort to gain the best possible solution.

An precision of less than a thousand of a millimeter is needed for the market NTS Norma works in. NTS Norma makes core components for machines in the semiconductor and analytical markets. For instance machines that produce or measure computer chips. Other products to think of are for the aviation or navy. Some ultraprecise products can at the moment only be made on the machines and environment of NTS Norma. This gives NTS Norma an exceptional marked position. The challenge is to keep this exceptional position. Customers are more demanding every day. To keep the business profitable, constant improvement is needed in the high-tech competences to keep producing these ultraprecision products in the Netherlands and to stay ahead of the competition.

History NTS Norma

NTS Norma was established in 1954 by an Austrian named Georg Blaim. NTS Norma is an abbreviation of ‘nie ohne richtiges messen arbeiten‘. The meaning of this abbreviation is that NTS Norma never works without a correct measurement. Blaim was quirky, something that is still visual in the company. The company was taken over by Henk Oude Mulders. After that, his son Stan Oude Mulder takes over the company together with René Vlaskamp in 2004. The change of direction was noticeable, because of the great entrepreneurship and courage that was added to the company.

In 2006, NTS Norma misses a large order, because the company was ‘too small’. For that reason, NTS Norma makes the decision to take over other companies to grow in size. Short after 2006, the machine factory of electronica concern Thales is taken over. Also, the machine factory of Philips in Drachten is taken over. In May 2014, another company called engineering office Mecon is taken over. In a period of 2006 till 2014, NTS Norma has grown from 80 to more than 400 workers and consist out of 4 locations. In 2016, NTS Norma became an part of the NTS group and the name of the company was changed from Norma to NTS Norma. After that, in 2017, NTS Norma Hengelo has built a new location to expand the factory.

NTS Norma background

NTS Norma has at the moment more than 400 employees and four locations. They are part of a NTS Group. NTS Group is located worldwide and has around 18 locations and more than 1700 employees. NTS Norma has a variating machining park. Machines that can be found can be seen in Table 1. The full map of the machining park can be found in appendix A.

Process	Quantity
Milling	39
Mill-turn	9
Turning	11
Grinding	14
Sparkdischarge	11
Measuring	15

TABLE 1: MACHINING PARK NTS NORMA

1.1 Motivation

As described in the introduction, NTS Norma is under continuous pressure to improve. The current machining park is very variating with a lot of different manufacturing machines from different ages, sizes and suppliers. This is mainly caused by a takeover of a factory of Thales in 2006. Currently, NTS Norma is working on a new structure and layout of the machine park. For this new structure and layout, it should be known which manufacturing machines are within the requirements of the company and which machines should be replaced for new or used machines, to meet the customers' demands and competition. For the future, NTS Norma seeks for a method to decide when and why a machine should be replaced, based on facts and data.

Currently NTS Norma uses the experience and workmanship of the people and implicit personal criteria to determine these repair / replace decisions. They already use criteria such as age, spindle rotation hours, unscheduled maintenance, maintenance costs and end of lease contract to make a machine discussable for replacement. Important in the current strategy is the expertise of the people. The knowledge of the people together with available data and assumptions will lead to a decision. NTS Norma does not know when and by what reasons a machine must be replaced, resulting in old machines that are still producing products. Are these machines still profitable, or is the lifetime of these machine reached?

To improve the repair / replace decision and making sure that the best decision is taken at the right time, NTS Norma seeks for an repeatable approach that will use relevant data and knowledge rules. This approach will be a decision support tool that still needs a technical assessment but less in-depth NTS Norma specific expertise. This repeatable approach will help NTS Norma to choose the optimal repair / replace decision in the right moment of time. This will prevent NTS Norma to produce products on machines with low availability and high costs to maintain this availability and will strengthen the marked position.

1.2 Preliminary investigation

1.2.1 REPAIR/REPLACE DECISION

The current repair/replace decision is mainly based on the expertise of people in combination with the available set of data. NTS Norma uses multiple criteria to indicate if a machine should be considered for replacement. This list is based on the lifetime of a machine, the spindle rotation hours, yearly maintenance costs in comparison with the total investment, availability of spare parts and end of lease contract. All criteria are shown in Table 2, and are used to determine if a machine is discussable for replacement. The term discussable is used because after this step, the expertise and experience of the people is used to make the final decision. This list is provided by the decision maker of the repair / replace decision.

Machine category	Decision criteria	Quantitative measure
Milling machine	Lifetime: Spindle rotating hours: % yearly maintenance cost of total investment of the machine. Spare parts available? End of lease:	<10 years 40.000 hours 5% No
Turing machine Mill-turn machine	Lifetime: Spindle rotating hours: % maintenance cost of total investment of the machine. Spare parts available? End of lease:	<15 years 40.000 hours 5% No
Grinding machine Sparkdischarge machine Measuring equipment	Lifetime: Spare parts available? End of lease:	<20 years No
Oven	Lifetime:	<35 years

TABLE 2: DECISION CRITERIA REPAIR/REPLACE

These criteria are based on fixed numbers that are usage independent. In other words, these criteria look at the lifetime or spindle rotating hours, but do not conclude for instance the way of using the machine, crashes or deteriorating. These criteria are static and do not visualize the true life of a machine, resulting in an imperfect repair / replace decision.

1.2.2 ULTRA PERCISION MANUFACUTRING

NTS Norma is an high-tech first line supplier, who designs, produces and assembles complete mechatronic systems. They are specialized in ultraprecision activities and have a unique position in precision machining and ultraprecision modules. The semiconductor and analytical end suppliers deliver low volumes of expensive machines to their customers. These machines contain a high number of different ultraprecise modules. For most of these products, small series are required. This results in a customer base where a high mix of products are delivered with low volumes. The company has adjusted the manufacturing process to this high mix, low volume vision. The goal is to ensure a fast throughput time that is on time in full delivery.

To ensure that all products have a fast throughput time, a lot of flexibility in the production process is needed. When a machine has failed, another machine should be able to make the remaining products of the failed machine. The result is a slightly longer throughput time for all products, instead of having all products on time except of one product group that is delayed for days. To ensure this fast throughput time, different aspects of the production process should be robust, fast and standardized: Setup times; Output at changing manufacturing programs; Cutting tools; Clamping die.

To produce ultra-precision products, a lot of variables should be stable within a certain range to ensure a certain accuracy of the machine. To get a better feeling of the complexity of manufacturing ultra-precision products, some variables are shortly discussed. These variables are:

- Machine.
- Maintenance
- Machining strategy.
- Temperature.
- Foundation.

Production engineering

The first step to make ultra-precision products is choosing a precise machine that is capable to work within the specified precision of the customer. This machine must remain in this specified precision, but over time, the machine will deteriorate, which results in lower accuracies. To ensure that the machine can produce with reliable accuracies, preventive and corrective maintenance is needed. Good maintained machines is one key of the chain, but the weakest link will determine the accuracy. The machining strategy is another key that is important. A product can be produced in very different ways, with a lot of different tool and different cutting speeds.

NTS Norma designs the most optimal machining strategy to produce the products in a reliable but fast way, without losing the accuracy of the machine. If the right machine is chosen and maintained properly, the right machining strategy is designed, this is no guarantee that the product can be produced within the required accuracy.

Temperature impact on yield

The accuracy of manufacturing machines is very sensitive for temperature change. A small change of temperature will result in different accuracy and scrap products. To gain a constant temperature is very difficult for every manufacturing company, because a combination should be found between the production of heat through the manufacturing machines and the reduction of heat through the air conditioning. To gain an equal temperature on every place in the machining hall is a challenge, because temperature can change when measuring close to a heated machine or further away of the machine. Are a couple of machines clustered in a small area or are the machines located close to a window that produce extra heat in the summer or reduction of heat in the winter. These are all factors that are important.

Machine stability

The last topic that will be discussed is foundation. Due to heavy machines with a lot of dynamic motions, foundations must be strong and stiff. If the foundation of a machine is not strong and stiff enough, the machine can bend in all directions, resulting in changes in the accuracy.

As can be seen, only a small number of topics includes a lot of variables that can influence the accuracy of the machine. NTS Norma seeks for the best solutions and optimizations to improve every link of the chain, to gain the best possible accuracy. This includes the lifetime of the machine.

1.3 Research questions

NTS Norma does not have a clear, uniform understanding of when and why machines need to be replaced. This understanding is low because there is limited hard evidence or reliable data available to get a founded decision. As an alternative, they make use of the broad experienced production craftmanship. Decisions are based on observations from the production department and known situations from the past. Due to the high mix, low volume marked of the company, it is hard to compare different machines with each other, because one machine will have different products with different product requirements, which can result in inaccurate comparisons. Due to these reasons, it can be hard to make a founded decision to repair or replace a machine.

The goal of this project is to give insight in the repair / replace decision, by visualizing the important factors that will influence the repair / replace decision. This will be done by designing a repair / replace model that uses data in combination with experienced production craftmanship. The data is transferred to a repair / replace model that should give overview of the current state of the machine. This overview can be used, together with the experience and knowledge of the decision maker to come to a founded decision that is aligned with the vision and strategy of the company.

To verify this repair/replace decision model, a case study will be performed, based on a chosen set of machines from NTS Norma. From this set of machines, the required data will be gathered. This data is used to check if the required data is available and how the data can be used for the repair replace model.

The main research questions to be answered are:

How can NTS Norma gain within 28 weeks overview and a well-founded repair / replace decision regarding milling machines?

Which input is needed to get overview and a well-founded repair / replace decision and how can this data be gathered in the future?

To answer these main research questions, information is needed from different topics. At first, the current situation should be investigated. What is the vision of NTS Norma, in what field is NTS Norma working and how is a repair / replace decision made right now?

After that, field research is done to investigate in different models to determine a repair / replace model that is suited for NTS Norma. This model should be filled with data, but there should also be room to use the experience and knowledge from the company. For that reason, a data assessment is done to search for important, reliable data that can be used in the repair / replace model. Important is that this data is or can be made available within NTS Norma. The last step is to combine all information and translate this into a repair / replace model. This model should be user friendly to the decision maker and understandable for the company.

The sub questions needed to answer the main research questions are:

- Preliminary investigation
  - What is the vision / strategy of NTS Norma?
  - What are specific machine related challenges within ultra-precision manufacturing?
  - What are current criteria for the repair / replace decision of NTS Norma?
  - Which researches are performed on the topic “equipment replacement” and what is the gap in these researches?
- Field research
  - What are management models for assessing technical and economic aspects.
- Data assessment
  - Which data or parameters are important to visualize the technical and economical repair / replace decision?
  - Are the required data or parameters available within NTS?
  - Is it possible to gather missing data or parameters in the future within NTS Norma?
- Repair / replace model
  - How can the gathered data and parameters be translated into a repeatable functional repair / replace model?
  - How can the repair / replace model be used?

1.4 Method

In order to give structure to the thesis, different methods are looked into. From these methods, the best suitable method is chosen.

The first method that looked into in is House of excellent maintenance (HoEm) [2]. This method uses eight mail pillars to design and improve the maintenance plan. These pillars are: Mission, vision and main goals for maintenance; Selection of the right assets to apply or to serve a company; Maintenance policy; Maintenance execution; Continuous improvement; computerized maintenance management system; maintenance organization; Personnel skills and competencies. As can be seen in these main pillars, this method is mainly based to design and improve the management plan, rather than designing a repair / replace method.

Another method that can be used is total productive maintenance (TPM) [2]. This method is also based on eight main pillars, now with other topics. The goal of TPM is to have process with 0% unsafety, 0% quality issues and 0% errors. To gain this, the eight pillars should be designed and improved: autonomous maintenance; process and machine improvement; Preventive maintenance; early management of new equipment; process quality management; administrative work; education and training; safety and sustained success. Topics as early management of new equipment, process quality management and safety and sustained success can help to design a good repair / replace model. Unfortunately, there were no suitable guidelines found that can help in the repair / replace model, so this model is not very helpful to guide this thesis.

Asset management is a method that search for possible direct and indirect costs of the whole lifetime of an asset [3]. The definition of asset management is [2]: ‘asset management involves the balancing of costs, opportunities and risks against the desired performance of assets, to achieve the organizational objectives.’ This method is very suitable to use for the repair / replace method, because this method uses information of the whole lifetime. As can be seen in Figure 1, asset management is divided into different topics. Those are: Organizational strategic plan; Organization and people; Asset knowledge; Risk and review; Asset management decision making; Asset management strategy and planning; Lifecycle delivery. For the repair / replace decision, multiple inputs are needed such as organization and people in red, asset knowledge in purple and risk and review in orange. With this knowledge, a decision over the repair / replace decision can be made using the organizational strategic plan.

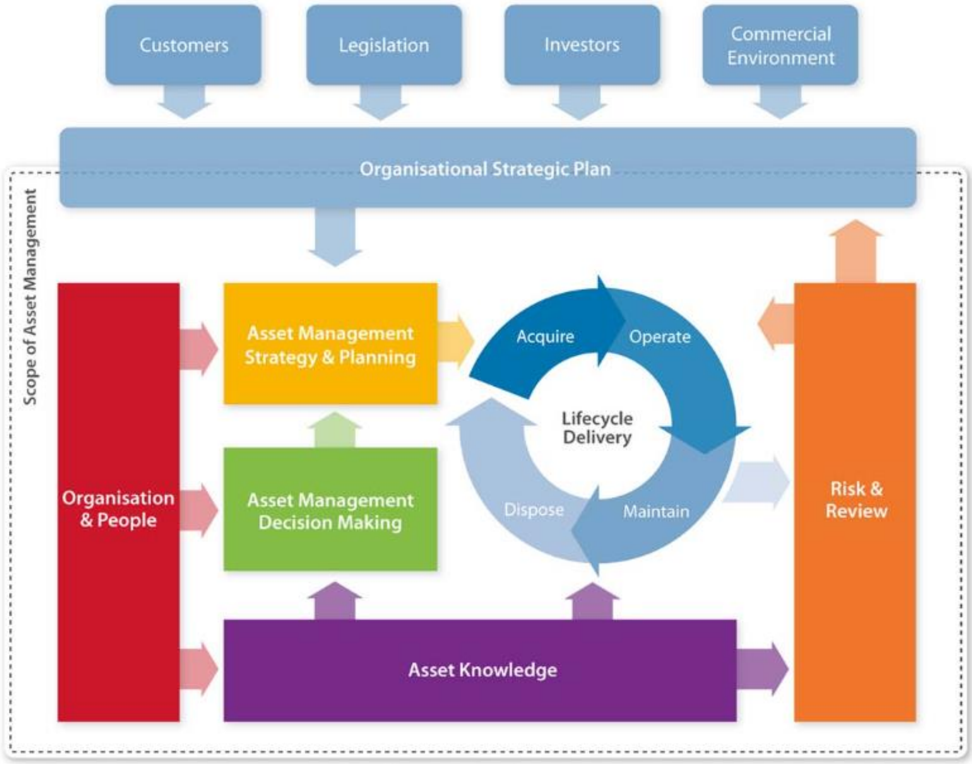

FIGURE 1: ASSET MANAGEMENT [6]

As described in the previous paragraphs, NTS Norma makes repair / replace decisions mainly based on the knowledge of the organization and people, indicated in red. The organizational strategic plan indicated in blue is partly known, not visualized, nor well known between all colleagues. The knowledge about asset knowledge in purple and risk and review in orange related to the repair / replace decision are low. To improve the repair / replace decision, the goal is to visualize the organizational strategic plan and increase the knowledge of the asset and risks.

1.5 Methodology

In this study, a method is designed to gain a well-founded repair / replace decision. This is done using the method asset management. From this method is learned that the repair / replace decision can be divided into two main topics, the technical life and economical life, both equally important. Both topics require a different approach. The technical life is determined using a quantitative approach, the economical life using a qualitative approach.

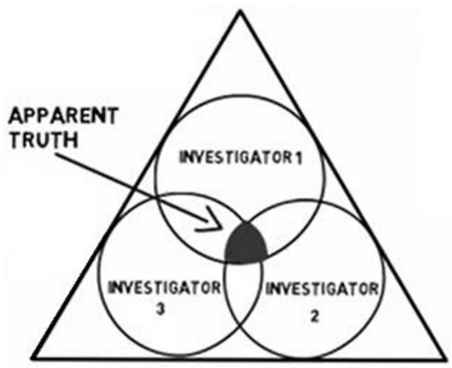

FIGURE 2: INVESTIGATOR TRIANGULATION

The technical model is determined using the information available from papers and colleagues. In the first stage, a list is made using different papers and literature to determine different key performance indicators that could be important for the technical model. In the second stage, this list is used to gain practical information about the machine, by questioning colleagues from different departments, for instance maintenance manager, milling specialist or operators. This information is gathered in a new list. This new list is revised multiple times, due to new information from discussions and questioning my colleagues. After multiple revisions, my colleagues could not give any more information, nor could they ask new questions about the list, indicating that all topics are gathered within the current knowledge. This process of working is described in the method of investigator triangulation [12]. This method uses information from different perspectives or investigators to determine a certain truth. This truth is the overlap of research or thoughts from different people, as can be seen in Figure 2.

Qualitative research is done to get information about the economical part of the repair / replace model. The economical life is determined by searching for available and usable data within NTS Norma from different databases or resources. This data is then sorted and reviewed on human errors or false information. Human errors can be seen by irregularities or sudden unexpected changes in the data. This can be a result of a typing error or wrong written information. The found data was based on a variable time scale, so the time between data points is variable. To make good graphs, the time between data points is made equal, using extrapolation. The result of the data remained the same, but graphs had better quality in this way.
After that, the quality of the data is determined, using the information and knowledge of my colleagues. With this information and knowledge, all assumptions could be made, resulting in a clean as possible data set with all important assumptions and information.

In this study, a test is performed to investigate if the stability of the machine influences the lifetime of cutting tools. To indicate this, all variables are reduced till they could be neglected, resulting in a test with only one variable, the machine stability. To indicate the lifetime of the cutting tool, the flank wear is measured using an optical microscope. These measured data is plotting in a graph, which indicates the flank wear graph. Every tool and machine can have a different flank wear graph.

During the testing, some problems are faced with the cutting parameters. The cutting parameters where based on previous tests where these cutting parameters where determined. This was done for a mill with diameter 8 and 12 mm. The milling parameters with a diameter of 10 mm where calculated, using extrapolation. Apparently, this calculation was wrong, because the lifetime of the mills where only 10 minutes, instead of the preferred 1 – 2 hours. In the current stability test, the cutting parameters are adjusted, using previous exciting programs from the company. Unfortunately, these programs are considered very conservative, because the lifetime of the tooling was more than 3 hours and did not break during the test. Because of this conservative parameters, the full wear graph could not be determined, resulting in an incomplete test.

1.6 Thesis structure

The first chapter described the motivation, context and methodology. In chapter 2, the gap in the literature is indicated and based on this gap, this thesis master is made. Chapter 3 gives the vision and strategy of NTS Norma. In chapter 4, the theoretical model is explained. Chapter 5 gets into the data and information of NTS Norma, to find all required data and determines the usage and reliability of this data. Chapter 6 is a roadmap to give guidelines and improve the found data of chapter 5, to make sure the model can be used in the future. In chapter 7, the final model is presented, using a fictive set of data. Chapter 8 discusses the validity of the research. Lastly, chapter 9,10, and 11 concludes the research by answering the research questions, discussion about the master thesis and recommendations about future work.

2 LITERATURE REVIEW

Equipment generally deteriorates with use and age, resulting in lower benefits and higher operating and maintenance costs. As a result of this lower benefits and higher operating and maintenance costs, it is often economical to replace equipment after a certain period of usage [4]. For most repair / replace models, the optimum economical life is determined, resulting in the highest profit and lowest operating and maintenance costs. In other words, the equivalent annual costs are determined. This can be done using the following formula [4]:

$$EAC(n) = \left(\frac{r(1+r)^n}{(1+r)^n - 1} \right) \left(p + \frac{s_n}{(1+r)^n} + \sum_{i=1}^{n} \frac{o_i}{(1+r)^i} \right),$$

Where EAC is the equivalent annual costs of an equipment with a service life n periods, r is the period interest rate, p is the purchase price of a new equipment, sn is the salvage value of an n-period-old equipment, and oi is the cost of operating and maintaining across period i. As can be seen in the formula, the operating an d maintaining costs and the salvage reduction are constant. In most manufacturing companies, this is not true, due to changing usage profiles. This method also assumes that the problem has stationary costs, meaning that for instance the technological progress is zero. In cases with non-stationary costs, it can be more beneficial to replace the equipment before the economic life, to take advantage of newer available equipment with higher yield and lower costs.

Non-stationary cost equipment replacement is often challenging. They are often based on reasonable cost estimates of equipment in the distant future, but this information is often not available.

Most repair / replace calculation models found rely on assumptions in combination with data. The goal of most models is to determine the economical life, within certain definitions and assumptions. Without these definitions and assumptions, the calculation cannot be performed, resulting in deviations from the reality. In all models, some important measures are not taken into account, for instance the safety of the operator, changing requirements of the company or sub-systems that cannot cooperate with the current equipment.
There are multiple reasons to replace equipment:

- Costs.
- Performance.
- New equipment.
- Safety.
- Changing company vision.

The first reason to replace the equipment is covered in multiple models (costs). Most models are using complete data sets in combinations with different assumptions, like failures are instantly detected and repaired, or that replacements are instantaneous to calculate the economical life of a system. In these calculations, the other topics, like performance of changing company vision are not covered. This means that the repair / replace model is only based on costs and in some calculations the deviation between old and new equipment is partly covered, but in none of the models, safety or a changing vision is included. Furthermore, the made assumptions in these calculations are not always aligned with the true situation from the company, resulting in different results than optimal.
Oeltjenbruns et al describe the repair replace decision as a combination between economical, analytic and strategic justification approaches [5]. These justification approaches are visualized in Figure 3. The combination between all three topics should give a broad overview of the repair / replace decision, by approaching the problem from different topics. The economic approach is covered with some different methods, like payback period, return on investment (ROI), incremental rate of return (IRR), MAPI-formula, and net present value (NPV). The analytic approach is using more factors and subjective judgments into account. Analytic approach requires a lot of data and most often leads to time consuming analysis and difficulty in understanding. Some examples are value analysis, risk analysis, non-numeric models, methods of linear programming, and scoring models, like the analytical hierarchy process. The strategical approach is the less technical in terms of usage in comparison with the other two approaches. The strategical approach is based on the requirements and goals of the company, and uses factors like technical importance, business objectives, competitive advantage, and importance for research and development.

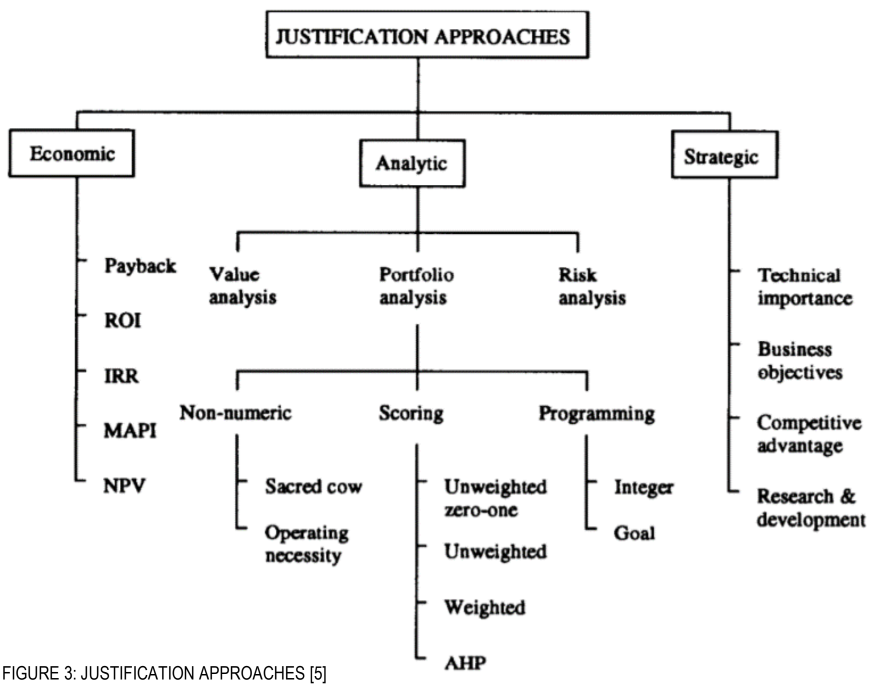

FIGURE 3: JUSTIFICATION APPROACHES [5]

From the current literature review can be concluded that NTS Norma needs an alternative method to determine the repair / replace decision. Repair / replace calculations based on assumptions is not optimal for the situation within NTS Norma. NTS Norma owns a lot of different machines. Due to this high difference and the fact that assumptions are needed to calculate an exact economic life, a lot of different assumptions and calculations must be made in order to determine the repair / replace decision. This will take a lot of time and must be performed for all the machines. On top of that, the assumptions can differ per machine, so calculations can change between machines or the result can be wrong if the made assumptions does not represent the real world.

From the paper of Oeltjenbruns et al can be learned that the repair / replace decision requires knowledge and information from different topics within the company. The requirements and important topics can differ between different machines, resulting in unique repair / replace decisions based on the company needs and requirements. Based on this information, a new repair / replace decision method will be made, based on the requirements and needs within NTS Norma. This repair / replace method is unique and only usable within NTS Norma. The general approach can be used to design a new unique repair / replace model specific for another company when needed.

There are many methods to approach a repair / replace decision. Most methods try to use formula's and assumed maintenance policies to determine the best moment in time to replace a manufacturing machine. One of the most used assumptions is that failures are instantly detected and repaired, or that replacements are instantaneous, which is not realistic for production systems, given that repairing a machine requires a considerable amount of time [1].
In this paper, the repair / replace decision is tackled in a different way, using economical and technical data to get overview of the repair / replace situation for the decision maker. The decision maker can use this information to make a founded decision. This decision can be different from a calculated optimal replacement decision. The big advantage of approaching the repair / replace decision in this different way, is that the decision maker can anticipate on the current situation and based on that, make a founded decision that is aligned with the companies vision and strategy.

3 VISION & STRATEGY NTS NORMA

The vision of the company is made using the information of the stakeholder analyses. This stakeholder analyses can be found in appendix B. The paper of Rajabalinejad, Dongen and Ramtahalsing is used as a guideline to sort all topics that are included into the vision [6]. In the paper of Rajabalinejad et all, the vision is divided into different levels from small to large. The lowest level of that paper starts with the technical system integration. In that case, they have chosen a train system, rails subsystem and catenary subsystem. One level higher is the human system, so how is the technical system used by the human system. After that, they choose a system of system integration, sociotechnical system integration, political system integration and global integration. This process can be used to look at the vision from a high point of view and the goal is to gain a wide overview of the vision of the company. For the vision of NTS Norma, the following levels are used from low level to high level: Output; Machine; Machine system; Market; Company; Government. The vision will be discussed in general. A more extend explanation including a visualization can be found in appendix C. All information about the vision is gained with a stakeholder analysis, that can be found in appendix B.

As described in the introduction, NTS Norma is an high-tech first line supplier, who designs, produces and assembles complete mechatronic systems. For the customer, it is really important that NTS Norma guarantees a high predictability and deliver reliability. In other words, the customer seeks for products that are always within the specified boundaries and delivered in time. In this branch, the amount of products needed by the customer can fluctuate. This results in a fluctuating product yield per machine per week and a changing production mix per day. To deal with these situations, NTS Norma seeks for a logistic flexible process, where the product can be made on multiple machines. In such situations, NTS Norma is flexible to make changes in demand and produce more from one product on a machine where capacity is available. To gain this flexible process, the production process need to be standardized, so products can be switched between machines without reducing the predictability.

24/7 production is a key word within NTS Norma. Every step and choice that is made is to stimulate a 24/7 production, where the machines can produce a variety of products with low operating handling. In this way, high yield and low operating costs can be guaranteed.
Safety is another key word. For all machines, the safety of the operator must be guaranteed. If this is not the case, an repair action will be performed or the machine will not be used anymore.

The market of NTS Norma consist out of a high product mix with low volumes. This means that NTS Norma produces a lot of different products of small series. Most of these products are ultra-precision parts, meaning that the tolerances of the products are between 1 – 10 µm. These high-tech products are made with a lot of steps. That means that the chain of operations is long and can exceed easily 5 or more steps.

Fast time to market is an unique selling point for the end customers of NTS Norma. This means that, despite the long chain of operations, the lead times should be short. To guarantee a fast throughput time, high predictability and deliver reliability, high end machines are needed. These machines must be suitable for different product groups to stimulate the logistic flexibility. An high-end machine is described by NTS Norma as a machine that has a reliable accuracy over the whole lifetime of the machine. Also, a high yield is expected from a high end machine. As said before, the predictability of the products is very important. This predictability is depended of the machine, process and environment. This chain is as strong as the weakest link, so if one of these topics is not predictable, the outcome is not predictable. That’s why these machines need to predictable and thus high end.

4 THEORETICAL MODEL

The design of the final product is made by analyzing different methods. As described in paragraph 1.5, the writer is inspired by asset management, a method that identify and optimize the life cycle of a plant [2]. In this method, a flowchart was presented that shows choices within a repair/replace decision, see Figure 4. In this flowchart, two main topics can be seen, the technical life and economic life of the asset, described in the two top blocks in Figure 4. Technical life is described as the dominant reason, such as: Loss of performance; Loss of reliability or availability; upgrade requirement; safety; environment; risk; capacity requirement. If all these points are within the requirements of the company, the economic life will be discussed. In this research, these two topics are discussed in detail. They can be used to raise the asset knowledge and the knowledge of risks. This will give an better overview in the repair / replace decision.

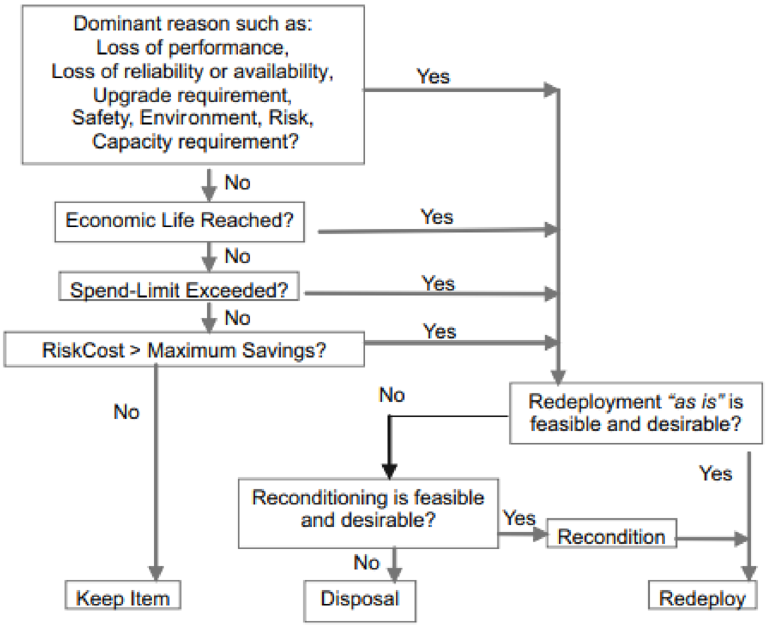

FIGURE 4: ASSET MANAGEMENT: REPAIR / REPLACE DECISION [2]

4.1 Technical life

As described in the previous paragraph, in the technical life the requirements of the company are tested on the machines, so the machine can work conform the requirements of the company? There can be multiple factors that can influence the technical life of a machine, independent of the economical life. These factors are mainly focused on the difference between technologies from the current machine and potential new machines. This difference is visualized in Figure 5. In this figure, the writer made two expected developments in technological development, the first red line is where a machine is bought new and the second black line is a continuous development at the marked. When a machine is bought, a certain level of technology is bought. In the first years of use, the knowledge about this machine will raise, resulting in small technological developments. The company learns to work with the machine in an optimal way. After some time, the supplier can update the software of the machine to ensure that the machine can cooperate with all the new features that are engineered. Sometime later, the machine will be too old for the supplier to support and software updates will not be made anymore. At this time, the support from the supplier is expired and the technology development is "frozen" in time. At the same time, new technologies are made, resulting in new machines with new features, faster production times or more reliable systems. When a new machine is bought, the gap between new and existing technologies is small, but after some years, this gap begins to grow. The existing machine can work in the same way it did years ago, but due to new technologies, this machine cannot be competitive against new technologies. To get insight in the technical life, the difference between the existing machines and new technologies are made visual. What are the new expectations from the company and does the machine meet these expectations?

To answer this question, the writer has used the method asset performance assessment, see Figure 6. This method describes the performance of an asset using success factors and key performance indicators (KPI's). The first step is to determine the strategy and objectives of the company. After that, success factors are used as an umbrella to determine all KPI's. These KPI's are then compared to the strategy and objectives of the company. In this way, the technical performance are made visual.

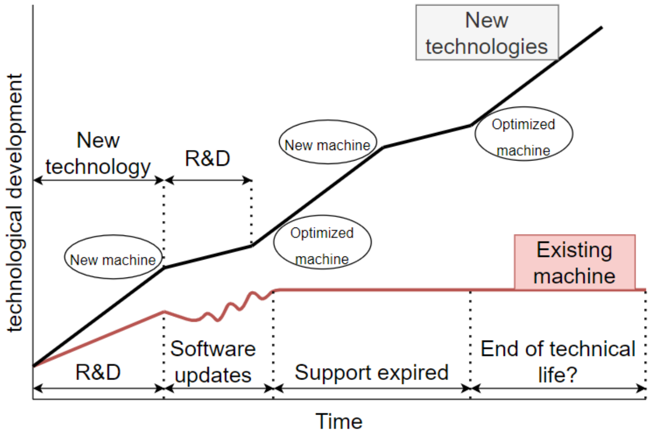

FIGURE 5: TECHNICAL DEVELOPMENT

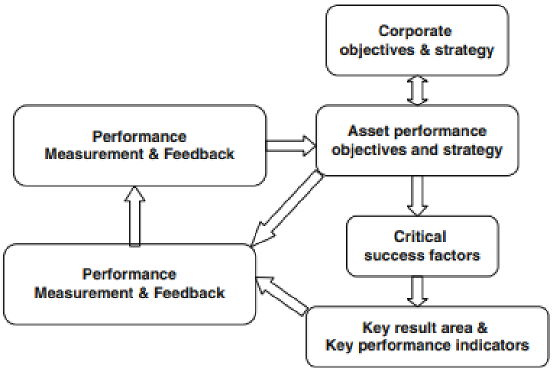

FIGURE 6: ASSET PERFORMANCE ASSESMENT [6]

4.2 Economic life

Equipment life can be defined in three ways: Physical life, profit life, and economic life [7]. Figure 7 shows how these different definitions relate to the life cycle of equipment.

The physical life is the age where the machine is worn out and not able to reliably produce. When machines are aging, additional costs such as maintenance and downtime costs are increasing, as can be seen in Figure 7 where the profit graph is reducing, eventually getting negative profits. The length of the physical life is affected by the care it receives while in use, the forces it has to endure and the quality of the maintenance it receives [7]. This can result in two identical machines with a totally different physical life.

Profit life is the life over which the equipment can earn profit. In most situation, a combination between multiple costs that are rising cause a reduction in profit. At the end of the profit life, where the costs are the same height of the benefits, the machine seemingly spend more time in the repair shop than it is producing. This profit life can be seen in Figure 7 as the point where the profits reduces and hits the zero profit line.

Economic life is the life where the profit is maximized. Most manufacturing factories strife to maximize production benefits and reduce costs of production. In other words, manufactures are striving to the best economic life possible. To determine the economic life, all important costs and benefits must be visual.

As can be seen in Figure 7, the vision and strategy of the company decides when a machine should be replaced or repaired. When the company chooses to produce till the profit life is reached, the equipment life is longer compared to the

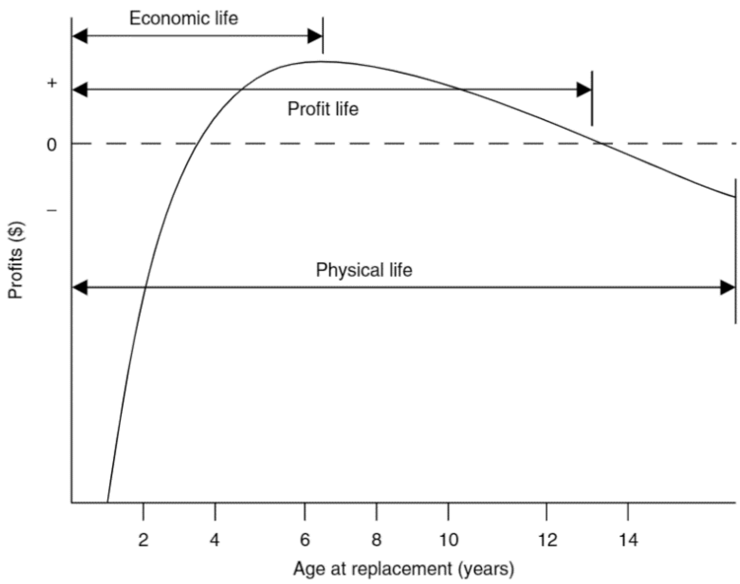

FIGURE 7: EQUIPMENT LIFE [7]

economic life. NTS Norma seeks for the economic life, where the profit is maximized over the lifetime of a machine. After this point, it is more profitable to replace a machine for a new, better machine.

To determine the economic life, a life cycle costing analysis (LCC) will be performed [8]. “The LCC of an item is the sum of all funds expended in support of the item from its conception and fabrication through its operation to the end of its useful life.” That means that the physical asset begins when its acquisition is first considered and ends when it is finally taken out of service for disposal or redeployment. In Figure 8, a graph can be seen that visualize LCC [9]. As can be seen, there are more costs than only the initial investment. Over the lifetime of the asset, a lot of expensive costs are generated. These costs can fluctuate and become higher over time.

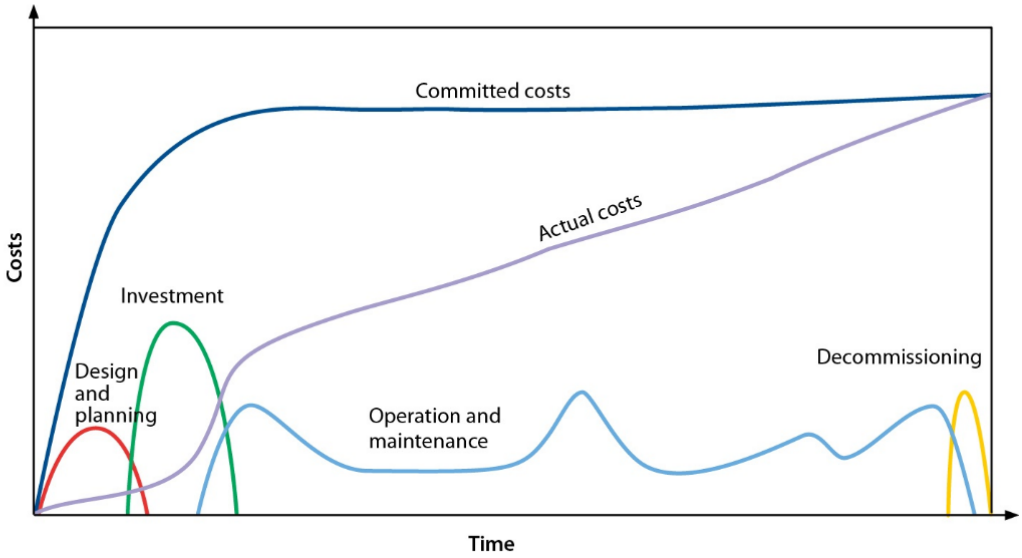

FIGURE 8: LIFE CYCLE COSTING GRAPH [9]

For a founded repair / replace decision, the important costs and benefits should be gathered and visualized into a LCC graph.
Figure 8 is translated into a graph with all important life cycle cash flows for NTS Norma, and can be seen in Figure 9. This figure shows the expected representation of the cash flows within NTS Norma. The visualization can be different when actual data is gathered. The important life cycle costs are defined by performing a stakeholder analysis and using the iceberg model, found in appendix B and D. In this process, the writer has searched for the biggest costs factors within NTS Norma that show changing cash flows over time, because these costs will influence the economic life the most. As a result, the following cost factors are found/needed:

- Depreciation costs
- Downtime due to failure
- Maintenance costs
- Tooling costs
- Human costs
- Disposal costs

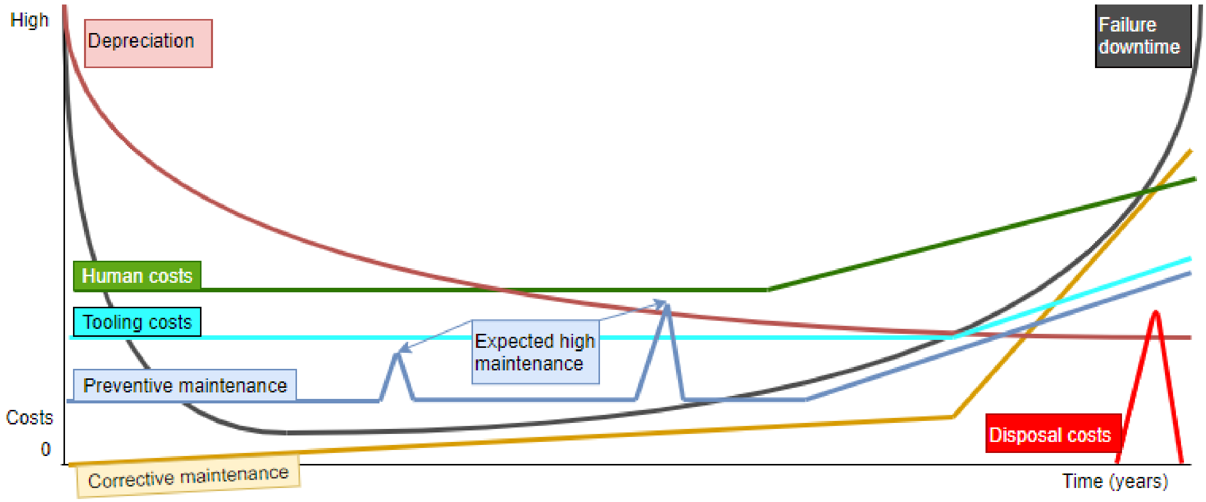

FIGURE 9: LCC GRAPH NTS NORMA

With all the cash flows available in a graph, the total cash flow over time can be calculated and plotted in a new graph. This total cash flow graph shows the cumulative cash flow of all cost factors of the asset. This graph can be used to determine the economic life of the machine, resulting in a founded repair / replace decision as is done in Figure 7.

5 CASE STUDY: REPAIR / REPLACE DECISION

The repair / replace model is made for NTS Norma. To get more understanding about the repair / replace policy and gain data from the company, six machines are chosen. These machines are stated in Table 3. An extended description and visualization about these machines can be found in appendix E. The machines that are chosen are all 5-axis milling machines and are producing in a 24/7 production process. These machines are from different quality and age.

- The Makino D500's are the newest machines and the biggest group within NTS Norma. Right now, there are 7 machines of this type with different ages, from 2011 till 2018. In the future, more Makino D500 will be bought, because of the accuracy and reliability of these machines.
- The Grob G550 is a smaller group of machines, consisting out of two identical machines, bought in 2013. The Grob G550 has high spindle power and coupling, but is less accurate in compared to the Makino D500. For this reason, the Grob G550 makes products with larger tolerances, compared to the Makino D500. The Grob G550 is used in situations where these high spindle powers are needed or when the products are too big for the Makino D500.
- The DMG DMU 50/70 are the oldest machines, and will be replaced by the company soon. The DMG DMU 50 is placed in 2003 and the DMG DMU 70 in 2006. In comparison with the Makino D500, the DMG DMU 50/70 are less stable and accurate. An indication of this stability and accuracy can be seen in the weight of the machine. Both machines have roughly the same working area, but the DMG DMU 50 weights roughly 9000 kg and the Makino D500 roughly 17500 kg [10]. Assumed is that this extra gain of weight is due to for instance bigger linear bearings, more robust frame or larger spindle guide.

Makino D500 - NOR-FR0003 Age: 2014	Grob G550 – NOR-FR0004 Age: 2013	DMG/DMU 50 - NOR-FR0007 Age: 2003
Makino D500 - NOR-FR0005 Age: 2013	Grob G550 – NOR-FR0006 Age: 2013	DMG/DMU 70 - NOR-FR00014 Age: 2006

TABLE 3: CHOSEN MACHINES

5.1 Technical life

As discussed in paragraph 4.1, the technical life is determined using a combination between KPI's and the strategy of the company. To determine all the KPI's, success factors are made. At first, the success factors where based on the safety cube, see Figure 10 [6]. This method is used to get the full picture of the problem when innovations are made. For this thesis, the safety cube is used as an umbrella to structure the search for KPI's suited to describe the technical life. The safety cube is divided into 6 faces of a cube. Every face of the cube represents its own topic. In this research, the 6 topics are: Machine; Human; Environment; Relation between machine and human; Relation between Machine and environment; Relation between human and environment. For all topics, KPI's are found that could be used to describe the technical life. This progress can be found in appendix I.

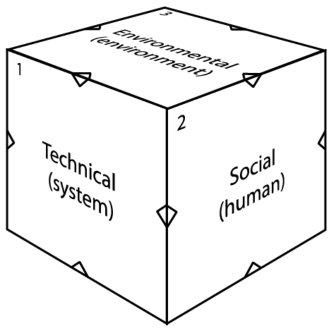

FIGURE 10: SAFETY CUBE [6]

After multiple conversations, the writer has asked two key questions that changed the whole vision on the technical life:

1. If there is infinite money, can the status of the machine be brought back to the original state?
   - Yes, with infinite money, this is in theory possible.
2. Is it possible to overcome the gap of technological knowledge between an old and new system?
   - No, this will require new design optimizations that are not suitable for the old machines.

With question 1 can be concluded that all deterioration of the machine is unimportant for the technical life of the system, because in theory all deterioration can be repaired if the money is available. With the economical life can be tested if the machine requires money for repairment or of the machine should be replaced.

With question 2 can be concluded that the technical life is reached if the machine does not function the way the company would like to function. This expectation will change over the years, because new innovations are developed, see Figure 11. The gap in technological development will grow every year. Due to these new innovations, the vision of the company can change, which results in new requirements for an older machine. If the current machine cannot reach these requirements, a decision can be made to replace the machine for a new machine with all new technological developments.

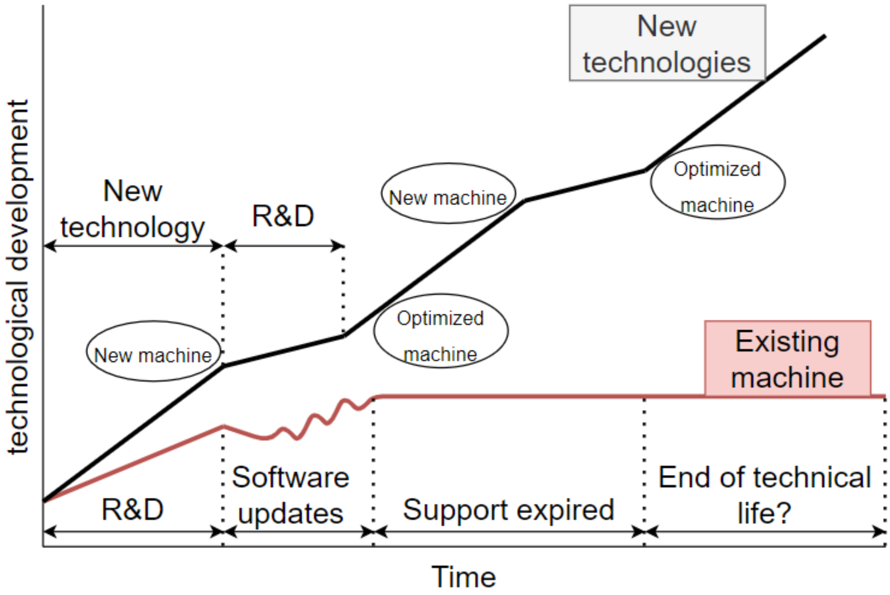

FIGURE 11: TECHNICAL DEVELOPMENT

With this new knowledge, new success factors are made to structure the process. These can be seen in Figure 12, and are based on the asset management repair / replace decision of Figure 4 in combination with the safety cube and Garvin's eight dimensions of quality.

For the technical life, different topics are investigated. To start, a reduced version of the safety cube is used, consisting of technical, human and environment. Technical is the machine itself, human the people that use the machine and environment all topics related to the machine. All topics that are not suited for technical and human will be discussed in the environment. To determine success factors, the method of Garvin's eight dimensions of quality, which is a method that describes the quality of a system with 8 different topics [11], is used as inspiration for the important success factors used for the category technical and environment. More information about Garvin's eight dimensions of quality can be found in appendix D. It consist out of:

- Performance;
- Features;
- Reliability;
- Conformance;
- Durability;
- Serviceability;
- Aesthetics;
- Perceived quality.

Some dimensions of Garvin's model are not taken into account. In the progress of making and adjusting KPI's, some dimensions of Garvin's model where unimportant or considered unnecessary for the technical life, because these dimensions where more related to products instead of machines/assets. Serviceability, Aesthetics and perceived quality is considered as unimportant or unnecessary.

Serviceability describes the ease to perform maintenance. This means the accessibility of the machine or the time to repair. Due to the scope of the technical life, the maintenance is unimportant for this model. Maintenance actions and time it takes can be seen in the economical life. If this is the case, the maintenance costs will be on average higher than a machine with a easy serviceability.

Aesthetics describes the looks of a product and are most of the time subjective. The looks of a machine will not influence the technical life and thus are considered unimportant.

The perceived quality is the expectation of a machine. This dimensions describes the quality of the brand and previous experiences. It is mostly used when new equipment is bought, to gain an indication of the quality of the product. For NTS Norma, this is not important, because it is not giving information about the technical life of the asset.

The other dimensions of quality are used as success factors, as can be seen in Figure 12. From the dimensions of quality, some important topics are missing, but important for the technical life model. For the topic human, safety is very important. In unsafe working environment will not be tolerated within NTS Norma, so every machine must be considered as safe. When this is not the situation, the machine will be shut down to prevent risks. For old machines, the knowledge and skills can become small, due to generation changes. Important for these old machine, is that there are employees that have the skills to operate and maintain the machines. The last topic is risk on downtime. This topic is introduced by the maintenance manager, because this can have big consequences for the technical life. The whole overview of the success factors can be seen in Figure 12.

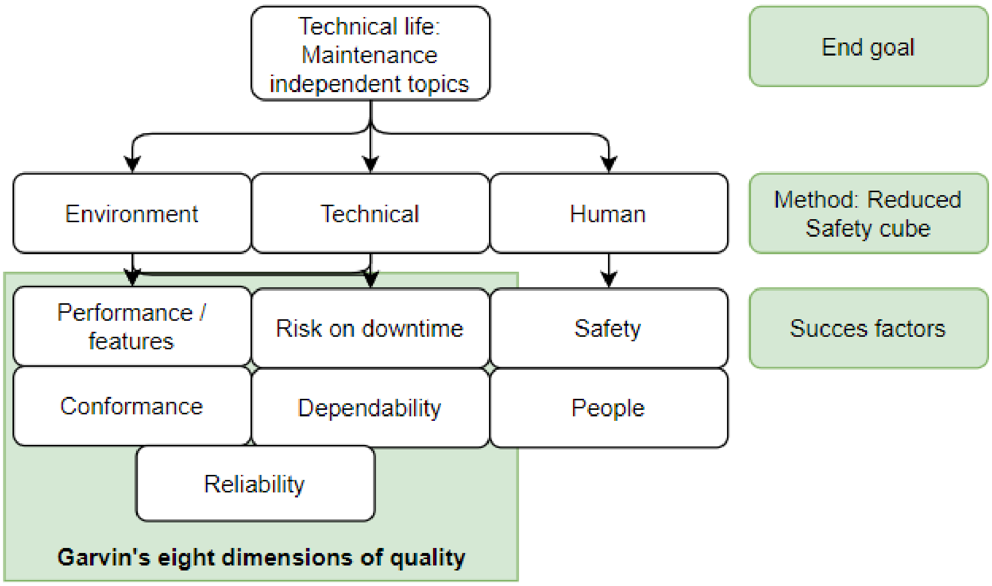

FIGURE 12: OVERVIEW SUCCES FACTORS

Method to indicate reality

In the process of designing the KPI list, the method investigator triangulation is used [12]. This method uses information from different perspectives or investigators to determine a certain truth. This truth is the overlap of research or thoughts from different people, as can be seen in Figure 13. In this thesis, the triangular method is used in a slightly different way, by gathering information from different stakeholders: maintenance engineer; project manager improvements; project manager machinery; operators; purchasing department. Using all the data, together with the KPI list, the technical life model is made. This technical life model is checked by all used stakeholders, resulting in a complete document, approached from different perspectives that can help to give overview and a well-founded decision in the technical life.

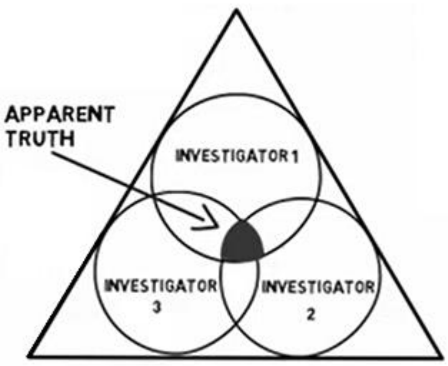

FIGURE 13: INVESTIGATOR TRIANGULATION [12]

Every topic will be discussed in the next paragraphs. The topics that are addressed are specifically made for NTS Norma, and are based on the vision and machines within NTS Norma. When this list is used at another company, with different competences and level of skill, other topics could be addressed. Important is that this list is not a static list, but can and must be changed when the vision within the

company changes. Some topics could become important and other topics unimportant, due to changes from the marked and vision of the company.
In the tables, a distinction is made between white and grey. Grey areas belong to the environment, white to technical or human, depending on the success factor. This distinction is made to indicate the difference between the different topics of the safety cube.

5.1.1 SAFETY

The safety of the machine is described using certifications. These certifications are required to be able to produce products for the aviation, space and defense. Assumed is that safety is guaranteed when the machine is conform all required certifications. If some aspects of the machine will not be safe, either in electrical or mechanical, the machine will not be confirm the certifications and deemed unsafe. The required certifications can be found in Table 4. Safety issues related to processes around the machine are not taken into account, because these can change independent of the quality and safety of the machine.

The certifications are used from the vision made in paragraph 3, and are not written out in detail, because this would take too much time and is out of the scope of this thesis. Assumed is that the people who are responsible for these certifications fully understand how these certificates can be achieved and preserved.

Safety	Description	Dimension
ISO 14001	The machine can fit in the ISO 14001 laws and regulations related to environmental impacts.	Yes / No
AS9100	The machine can fit in the AS9100 laws and regulations to ensure that the company is permitted to manufacture products for the aviation, space and defense.	Yes / No
NEN 3140	Electrical system is conform the rules of NEN 3140, which gives guidlines and rules about the electrical system.	Yes / No
CE certified	The machine is conform the rules of the CE certification.	Yes / No

TABLE 4: SAFETY KEY PERFORMANCE INDICATORS

5.1.2 PERFORMANCE / FEATURES

The technical life of performance and features are mainly depended on the vision of the company and thus the difference between the machine and the technological development. The bigger the difference between current machine and the technological development, the faster a machine's technical life can be reached, depending on the vision an concurrence of the company and other companies. This list of performance and features is based on the current situation within NTS Norma. Due to changes in the market and constantly improvements of new machines and new systems, this list can change faster over time in comparison with other success factors.
The first important factor is the overall equipment efficiency (OEE). The OEE gives insight in the downtime, cycles time and scrap of the machine. The OEE is a good indication of the performance of a machine. On top of that, the possibility to increase production is an important factor. The current machine is challenged with another machine. If another machine can produce faster that the current machine, this is the expected increase in process speed.
A future goal of NTS Norma is to implement industry 4.0. One of the requirements of industry 4.0 is the use of big data, which means that a lot of data is transferred into information. This data can be gathered using sensors that are added to the machine or using the existing sensors and gather those with data systems. To cooperate will all different systems, the machine should be able to communicate. For old machines, this can be difficult, because of the big differences in software and hardware. In the current situation, a machine within NTS Norma should cooperate with all systems stated in Table 5 in the 3th row, "cooperation features or systems".
The next three topics are indications that new machines perform better than the current machine. Those are thermal drift, chip removal and machine software. In new machines, new cooling systems are installed that perform better than the old systems, resulting in a more stable thermal drift and more accurate machines. During production, chips must be removed from the machine. Due to optimizations, the chip removal system is improved, resulting in a reliable chip removal system where human actions are minimized. For old machines, more human actions are involved to ensure a good production process

where chips are removed. Software systems are changed a lot. Calculation speeds are faster, precision is higher and memory capacity is increased due to increasing programming sizes.
Not all machines are automated or suitable for an automated process. The vision within NTS Norma is to maximize the automated machines and minimize human actions involved in the process. This can also be an indication for replacement of a machine and invest in a new, automated system. All topics are translated into KPI's, seen in Table 5.

Performance / features	**Description**	**Dimension**
Overall equipment efficiency (OEE)	Efficienty of the machine. Gives insight in the downtime, cycles time and scrap of the machine	[%]
Posibility to increase production yield	What is the expected increase in process speed in case a new machine is bought.	[%]
Cooperation features or systems Step to Industry 4.0.	**Machine can cooperate in a reliable way with all systems:** These systems are required for the data management of NTS Norma and will be a step towards industry 4.0.	Yes / No
	Manufacturing execution system (MES)	Yes / No
	Enterprse resource planning (ERP)	Yes / No
	Zoller tool measuring system	Yes / No
	Chips cutting tools	Yes / No
	Tool Data management (TDM)	Yes / No
	BLUM lazer measuring system	Yes / No
	Zero point clamping system	Yes / No
	Cad/cam system	Yes / No
	Post processor	Yes / No
Thermal drift	Is the cooling system of the machine conform the norm of NTS Norma to controll the termal drift	[pressure]
		[Temperture difference]
		[Internal machine cooling]
Chip removal	Chip removal of the machine. The reliability of the chip removal system, without human actions.	[bad - perfect]
Machine software	The reliability, calculating speed and precision of the machine software.	Calculation speed
		Precision [# numbers behind the comma]
		Memory capacity
Automation	Indication of the automation of the machine. There are two levels possible within NTS Norma: Dayshift, 24/7 production.	[Dayshift, 24/7 production]
		Upgrade to 24/7 possible?

TABLE 5: PERMORMANCE / FEATURES KEY PERFORMANCE INDICATORS

5.1.3 RISK ON DOWNTIME / RELIABILITY

The risk on downtime and reliability are put together as success factor, because the addressed topics are quite similar. Risk on downtime is as the name is called, the risk or chance to suffer a certain amount of downtime. The risk on downtime is high if the chance for downtime is high with short downtimes, for instance small electronic errors, or when the chance to suffer downtime is low, but when this happens, the downtime is very long, for instance when a singular machine is broken and spare parts are not available. The reliability of a system is coupled to this risk. Reliability can be described as the probability that a system will satisfactorily perform the task for which it was designed or intended, for a specified time and in a specified environment [13]. With this description can be seen that reliability is roughly the opposite of risk on downtime. So all negative reliability can be seen as risk on downtime. For NTS Norma, there are different risks that should be addressed. The reliability of machine software is depended on the type and version of the software. Another risk is a singular machine. A singular machine is a machine that has no backup capacity when the machine is broken or under maintenance. That means that if this machine suffers downtime, all produced products are delayed in time, resulting in delivery issues. Product group is somewhat similar to the singular machine. For product group, the question is if the whole product group can be transferred to other machines, with only small adjustment to the process, resulting in a reliable process. To use the full capacity of the machine, the production capacity should be high enough and available for NTS Norma. Very close to this topic is competition between other companies. If the machine is more expensive in comparison with other companies, the market capacity will get smaller. The last topic is performing and keeping track of a failure mode, effects, and criticality analysis (FMECA). This document can indicate the risk on downtime for several parts of the machine, depending on the level of detail. If the FMECA is coupled to a list of delivery times, where all delivery times are indicated for the critical parts, the risk on downtime can be calculated. All topics are translated into KPI's, seen in Table 6.

Risk on downtime - Reliability	Description	Dimension
Machine software	The reliability, calculating speed and precision of the machine software.	Reliability
Singular machine	Singular machine, so one available in the entire production hal. In case of downtime, no backup available for this machine.	Yes / No
Product group	Can the machine's product group be transferred to another machine, with only making small adjustments.	Yes / No
Strategy	Are there products produced that have a strategical position that cannot be transfered to another machine or outsourced to another company?	Yes / No
Marked product capacity	Is the marked demand high enough to fill the full capacity of the machine.	Capacity per year
Competitor	Can we compete with the current machine to the competitor	Yes / No
Failure mode, effects, and criticality analysis (FMECA)	Perform and keep track of the FMECA. With the FMECA, the risk of downtime can be made visual.	[Days]

TABLE 6: RISK ON DOWNTIME / RELIABILITY KEY PERFORMANCE INDICATORS

5.1.4 CONFORMANCE

Conformance is defined as how well something, such as a product, service or a system, meets a specified standard. In this case, conformance is defined as the status of the machine, so what is the quality of the current machine in comparison when it was in new state. Are there defects or risks that require actions and costs? This can also be seen in Table 7.

Conformance	Description	Dimension
Maintenance machine status	Get information about the status of the machine from the maintenance department. This will give an indication about the defects of the machine. Defects could be translated into maintenance actions and costs.	[Slecht - perfect]

TABLE 7: CONFORMANCE KEY PERFORMANCE INDICATORS

5.1.5 DEPENDABILITY

Dependability is a measure of a system's availability, reliability, maintainability and maintenance support performance [14]. In other words, can the user depend on the system? To translate this into topic that are important for the technical life, three topics are made. Spare part deliver is the first topic. Within NTS Norma is stated that spare parts must be delivered for at least 10 years after investment in a new machine. After this time, the supplier can decide to stop the production of spare parts. To gain more overview, a list with critical parts and the expected delivery time and stock should be visual. This will give an indication of the added risk when a part fails and must be replaced by a new one.

The last topic is the stability test for cutting tools. This test is a new test within NTS Norma, designed by the writer to test the stability of the machine. Assumed is that machines with lower stability have shorter tooling lifetime, resulting in a higher cutting tool costs. More information about this test can be found in paragraph 5.2.6.

Dependability	Description	Dimension
Spare part delivery	Spare parts must be delivered for at leasts 10 years after the investment. After this 10 year, more risk on long downtime.	[Year]
Delivery time spare parts	List with critical parts and expected delivery time and stock. Are there spare parts on the list that are longer than NTS Norma can accept?	[delivery time in days]
Stability test Cutting tools	Test setup that can be executed to test stability of the machine, using the expected lifetime of cutting tools.	[%]

TABLE 8: DEPENDABILITY KEY PERFORMANCE INDICATORS

5.1.6 PEOPLE

The success factor people is described as the knowledge and expertise available for a machine to be operated and maintained. For very old machines, it can be hard to find operators or mechanics with the appropriate level of skill. This can have serious impact on the machine availability, for instance when the only operator suitable to work with the machine has 4 weeks of vacation. Or when the machine is broken and all mechanics suited for the job are not available, because this group is so small. This is translated into KPI's, seen in Table 9.

People	Description	Dimension
Machine knowledge	How many operators have the knowledge to operate or programm the machine.	[#]
Maintenance knowledge	How many mechanics are available with enough knowledge to maintain the machine.	[#]
Maintenance reaction time	Time between identivication of the problem and the arrival of mechanics.	[hours]

TABLE 9: PEOPLE KEY PERFORMANCE INDICATORS

5.2 Economic life – Analyzing the data

In this paragraph, the required data for the economic life is analyzed and visualized. This is done as described in paragraph 4.2, by making a graph with all the cash flows, seen in Figure 14. The data will be based on the predefined machines stated in Table 3. For every dataset, all known assumptions and observations are described. If machine data is unavailable, this will also be described. For every topic, a part of the data is showed in the main report, all data can be found in appendix H.

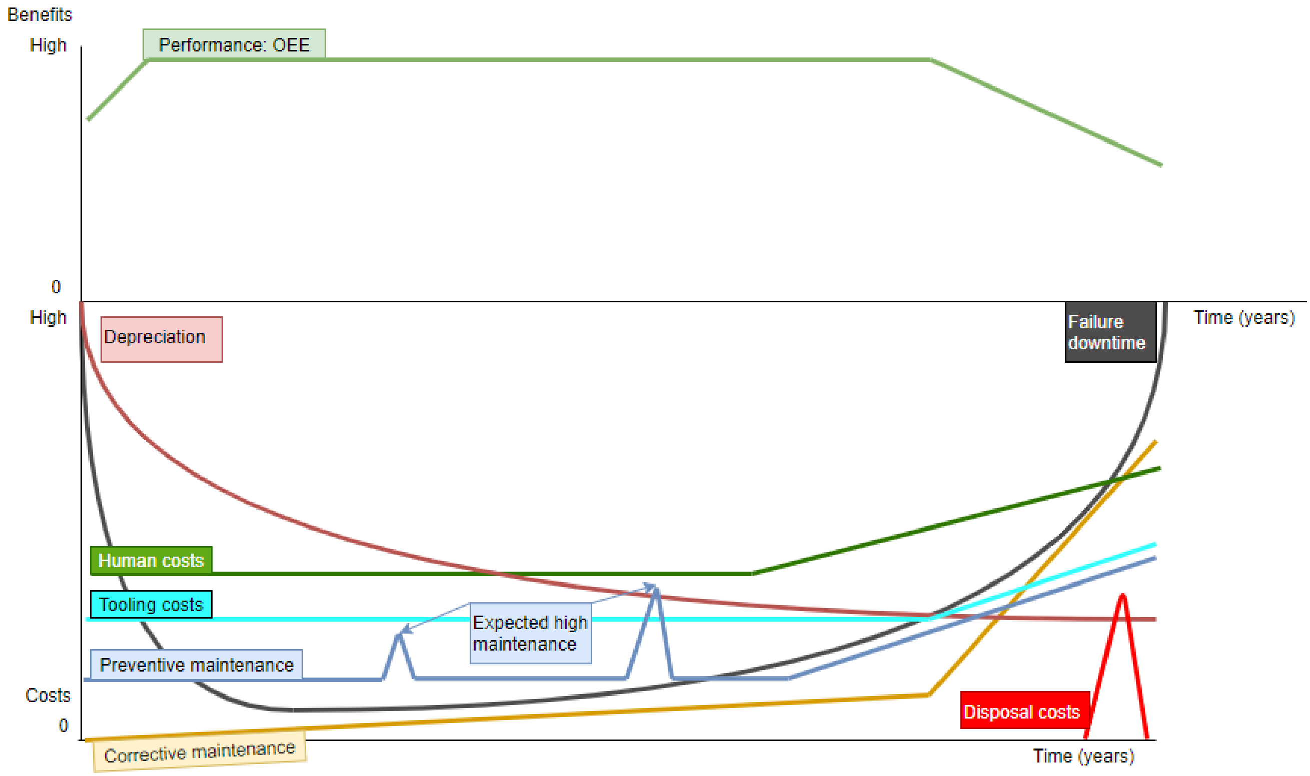

FIGURE 14: REQUIRED DATA ECONOMIC LIFE

5.2.1 UPTIME MACHINE

The uptime of the machine, in other words, how many hours per day can the machine produce products, is gathered in two different ways, using data from NTS Norma and the company "High tech maintenance" (HTM). HTM is a company that is performing maintenance for other companies. For NTS Norma, the management of the maintenance is done internally by NTS Norma, the execution of the maintenance is done by HTM. Both sets of data represents the uptime of the machine, but are measured in a different way. Both will be discussed, after that, the two data sets are compared with each other.

5.2.1.1 UPTIME MACHINE NTS NORMA

NTS Norma gathers the uptime of the machine using booking hours. Booking hours are the hours an operator used to produce a batch of products. When a batch of products is finished, the calculated time needed for this batch is booked on the calculated machine. This is done when the batch is finished. The booking hours are then stored in the data system of NTS Norma. In this data system, the booking hours can be found per machine, as can be seen in Figure 15. In this figure, the average booking hours per machine per day are shown. The found data is analyzed and all assumptions / errors in the data are written down.

Assumptions / errors

For every product within NTS Norma, the required production hours are calculated. This is done in three different stages. In the first stage, the first calculation is made to get a understanding about the required time to produce a product. This is done with a calculation sheet, together with information from the project manager and operators. After that, for complex products, a prototype is made. This is done to test if NTS Norma can make the required product. The prototype can also be used to improve the calculated time. In the last stage, a pilot is done. In a pilot, the product is made ready for series production. From this pilot, the calculated time can be fine-tuned, resulting in a calculation that is as good as possible. The calculation is divided into manned and unmanned production hours.

Manned hours are the expected hours needed for the operator to setup the process and start producing the product. Unmanned hours are the hours needed for the machine to produce the product. These hours are “human free”, so the operator has time for other tasks. For the 24/7 plein, the booked data is based on these calculated manned and unmanned hours, instead of the true production hours. As an exaggerated example, if the calculator calculated that the process takes 8 hours, but in real life it takes 12 hours, 8 hours are booked in the system, resulting in a difference of 4 hours. As a result, the pre-calculation and the re-calculation is the same, in Dutch called the “voorcalculatie – nacalculatie = 100% (vc-nc = 100%)”. Practically, these changes will be smaller, but are present in the data.
The company does not measure the actual used production hours at the 24/7 plein. As a result, the quality of the pre-calculation is not known exactly, because this cannot be compared to the re-calculation.

Every product is assigned to be produced at a certain machine. Due to machine groups, products can be easily changed between identical machines. When the planning is tight on one machine and there is some spare time available on another identical machine, operators can choose to switch the product to an alternative identical machine. This machine diverges from the calculated machine. When the production hours are booked in the system, the pre-calculated machine is used to book the production hours. This means that the calculated machine will gain double production hours, but the actual used machine will gain nothing. As a result, the booking hours per machine can differ from the actual machine hours.

The time of booking is also important. Right now, the operators are booking the production hours when a production batch is finished. When a batch took for instance 3 days and is finished on Friday, all production hours are booked on Friday, resulting in fluctuating results per day. This can also have small results on the average per week, because production from several days can be finished on Monday, resulting on low booking hours in week x but very high booking hours in week y.

Another change that is not mentioned before is a change in registration of the booking hours for the Grob G550 M161 and M162. In 2019, week 43 is decided that all booking hours from the M162 are booked at the M161. Due to this change, it is unknown how these production hours are divided between these two machines. This change can also be seen in Figure 15, indicated with the blue box.

The discussed assumptions and errors can also be seen in Figure 15, which is a visualization of the data from year 2021. The data represents the average booking hours per week, indicated as hours per day. So every data point is divided by 7 days to gain the average booking hours per day. In the red circles, odd data points are indicated. Those two data points are above 24 hours, indicating that these machines have produced more hours than are possible in one day for a whole week straight. This can be the result of the assumptions indicated above. It is possible that the pre-calculation was different from the re-calculation, the booking hours could be booked on the wrong machine and multiple days of production could be finished on the next week. As a result, this data is not reliable and a lot of assumptions are included which are influencing the results.

2021	Week 01	Week 02	Week 03	Week 04	Week 05	Week 06	Week 07	Week 08	Week 09	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19		Average
Makino D500 M181	7	13	7	10	10	23	9	20	15	29	17	12	13	8	12	21	11	2	5		13
Makino D500 M182	11	30	5	30	12	29	11	23	6	28	9	29	9	26	16	16	16	5	29		18
Grob G550 M161	9	21	18	16	18	36	18	9	27	32	14	28	6	19	16	5	16	22	18		18
Grob G550 M162	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
DMU/DMG 50 EVO	20	27	26	19	18	16	16	11	7	21	12	8	20	14	6	21	7	7	13		15
DMU/DMG 70 EVO	16	0	0	16	16	0	0	16	16	15	16	8	16	16	0	16	16	0	8		10

FIGURE 15: BOOKING HOURS, AVERAGE HOURS PER WEEK, INDICATED AS HOURS PER DAY, NTS NORMA

Data visualization

The data is translated into an graph. This can be seen in Figure 16. As can be seen in this figure, the average booking hours per day is fluctuating strongly every week and year. The fluctuations per week are discussed above, and are visualized with the small blue dots. The fluctuations per year are due to for instance optimizations of production processes, fluctuating marked capacity or downtime, and is indicated with the blue line, which is the average over multiple data points.

In the end of 2018, NTS Norma invested a lot in process optimizations, resulting in shorter production times. As a result, the production capacity is higher. This higher capacity is not filled with new products, resulting in less booking hours and "on paper", less benefits. This can also be seen in Figure 16, because the line is going down from the end of 2018. In reality, NTS Norma works more efficient, but did not gain any benefits of this efficiency because these extra available machine hours are not filled with new or more products. In 2020, a number of machines are shut down. The products that where made on these machines is divided on the exciting machines, resulting in machines that are making more production hours.

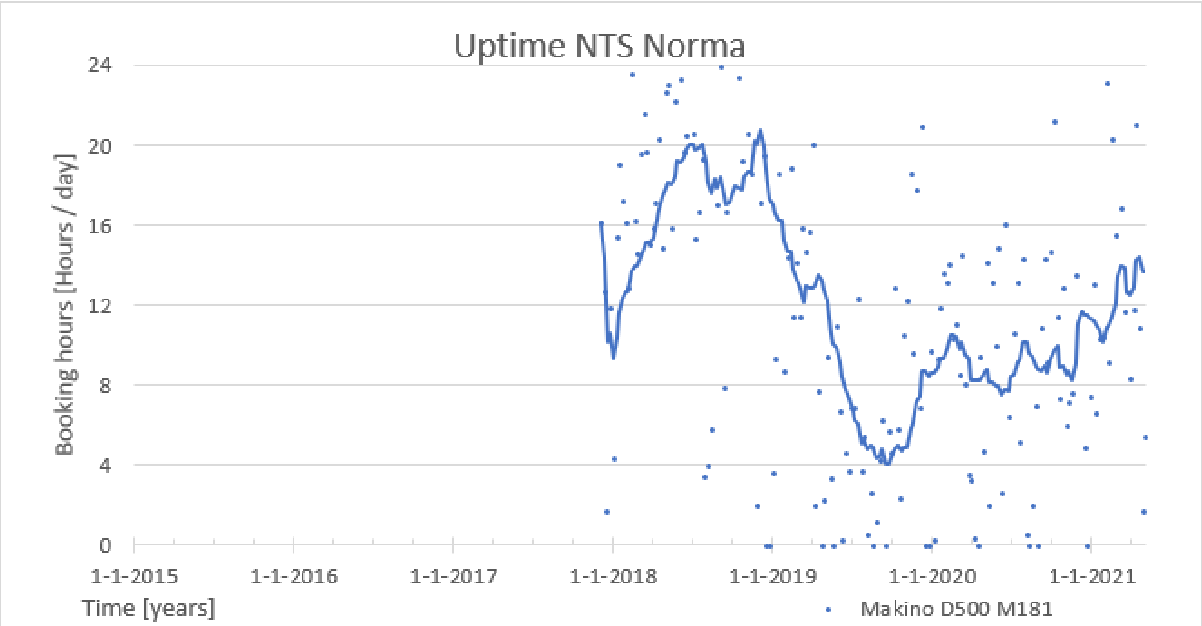

FIGURE 16: UPTIME NTS NORMA

Conclusion

Machine production hours is very dependend of the strategy of the company. "On paper" it can look that a machine is less beneficial, because it is making less production hours compared with another machine. An important measure is forgotten, how many products are made in these hours. If machine x produces 5 products per hour and machine y produces 2 products per hour. Both machines make 10 products. As a result, machine x has 2 booked hours and machine y 5 booked hours. "on paper", machine y is more benificial because it produced 5 hours instead of 2, but in reallity, this is not true! Another method is needed to measure the right yield of the machine and thus the benefits.

5.2.1.2 UPTIME MACHINE HTM

HTM takes care of the maintenance of the machines. They are also gathering a small amount of data from the machine, including the uptime of the machine. This uptime is based on the running hours of the machine. Running hours are the hours the spindle of the machine is turning around. Running hours can be divided into two different processes: Production hours and warmup hours. Production hours are hours that are used to produce products. Warmup hours are hours used to get the machine in a thermal stable condition, to ensure that the fluctuation in temperature is minimal. For warmup hours, the spindle of the machine is rotating force free at a constant speed. After several hours, depending on the machine, the machine has reached a stable temperature. In Figure 17, the average booking hours per machine per day are shown. The found data is analyzed and all assumptions / errors in the data are written down.

Assumptions / errors

As mentioned above, the data consists out of production hours and warmup hours. Unknown is the ratio between production and warmup hours. This ratio can also fluctuate per day, week or month. This means that it is unknown, based on the current information, how high the uptime of the machine is.

HTM gathers the data by hand and uploads it to the data system of HTM. This is normally done every weeks, but due to human errors, the time between data points is fluctuating between one week and a year, resulting in a big loss of data. In the most optimal situation, the data is gathered at a fixed moment in time, to eliminate this fluctuation and reduces the unknown information in the data. The situation where the time between data points is large can be seen in Figure 17 as long horizontal lines.

Due to human data gathering, the process is sensitive to human errors. The data is written down on paper and after that, reported into the data system of HTM. The mechanic from HTM can make an easy mistake, switching the data or write down wrong data. This wrong data will influence the information and results in faults in the data, which need to be avoided. All the data that is used for uptime machine, is checked by the writer for errors and irregularities.

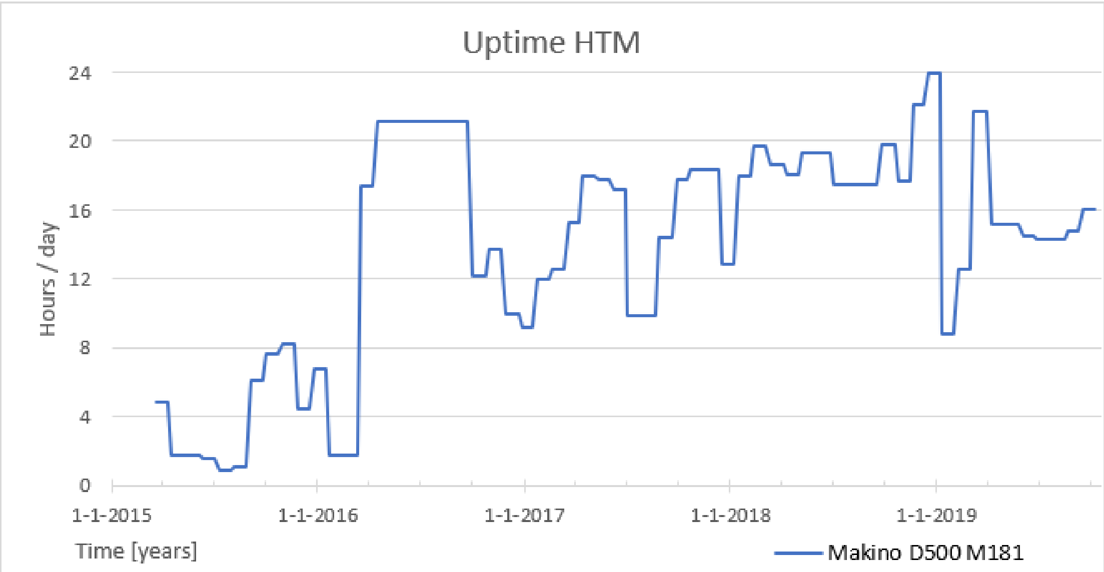

FIGURE 17: BOOKING HOURS HTM

Conclusion

The data of the uptime of HTM cannot be used to indicate the benefits of a machine. The data contains two sets of data, production hours and warm-up hours. Unknown is the ratio between these hours. This relation is important for the benefits of the machine. Production hours are profitable because products are produced. Warm-up hours are only made because the machine need to reach a thermically stable condition. In this process, products are not made, which results in zero profits. Due to this reason, the data is unusable for the benefits of the machine.

Overall, booking hours gathered by NTS Norma nor running hours gathered by HTM cannot be used to determine the benefits of the machine accurately. In the future, another method should be found in order to measure the benefits of a machine. In the time being, the data from NTS Norma is the most useful, because it is based on the calculated hours. Assumed is that the error between calculated and true hours is not extremely big, this data set is the most useful for the model. Important to know is that this data does not contain information about the efficiency of the production process, which can result in a unreliable situation where sub-productive machines have high benefits.

5.2.2 DEPRECIATION COSTS

Depreciation is the loss of value of an asset. Depreciation is dependent of the actual state of the machine and the market value. The first years of depreciation are in most situations the highest. The true value of the machine reduces very fast. After some years, the depreciation costs will become lower. Important to know is that in this master thesis, with depreciation costs is referred to the loss of market value of the asset. It is not based on for instance administrative models like linear, annuities or % of the booking value.

With advise of the tactical buyer, the expected depreciation of Table 10 are made, expressed in a percentage of the initial investment. These percentages are found using experience and a site that trade used machines. Furthermore, in an article of Makino is stated that for high-performance machines, the value retains about 50% after 3 years of production [15]. This is an indication that the found percentages are plausible.

Expected depreciation per year.			
Jaar 0	Jaar 3 [16]	Jaar 10	Jaar 20
100%	50%	20%	10%

TABLE 10: EXPECTED DEPRECIATION PER YEAR

With these percentages, the depreciation costs per year can be calculated, using the investment costs of the machine. The investment of the machines can be seen in Table 11. In this table, the costs are divided into three categories, machine, robot and setup. The machine is the actual milling machine, robot the robot cell attached to the machine and setup costs additional costs to install the machine and robot. Setup costs are for instance costs to install proper electronics, tool holders or installation costs. Assumed is that the setup costs are sunken costs, this means that these costs will lose its value instantly. The machine and robot costs are depreciated over time, using the expected depreciation per year. In Figure 18, the depreciation costs of the DMG DMU 50 evo are shown. As can be seen, are the depreciation costs is year 0 very high, due to the additional setup costs. In the first 3 years, the depreciation costs are the highest.

	Makino D500	**Grob G550**	**DMG DMU 50 evo**	**DMG DMU 70 evo**
Machine	530.000	650.000	400.000	450.000
Robot	140.000	150.000	150.000	150.000
Setup	100.000	100.000	100.000	100.000
Total	770.000	900.000	650.000	700.000

TABLE 11: INITIAL INVESTMENT

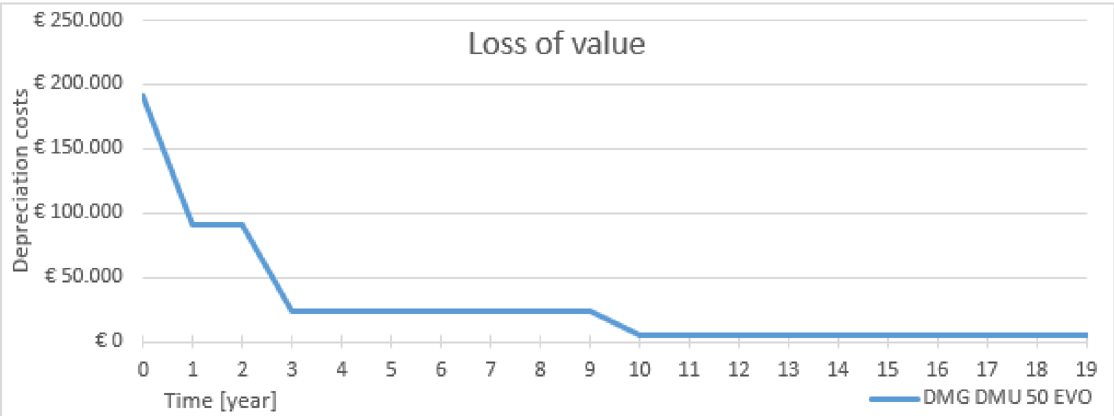

FIGURE 18: DEPRECIATION COSTS

5.2.3 MAINTENANCE COSTS

Maintenance costs are costs incurred by an individual or business to keep the assets in good working condition [17]. These costs can be seen as an investment in the availability of the asset. When a machine gets older, more parts can wear out, reliability of certain parts can reduce, all indicators that cause higher maintenance costs.

Process data gathering

The maintenance at NTS Norma is performed by the company HTM. HTM has multiple maintenance engineers working at NTS Norma that are responsible for maintaining the machines. Every maintenance action is reported in a data system of HTM. This is done in three different categories: Preventive, Corrective or Crash. NTS Norma can ask for this information, which will then be send by HTM. This can take a couple of days.

HTM reports all maintenance tasks that are done within a maintenance action, for instance that part x is exchanged and part y is repaired. Instead of using key words, this information is written down in text. A result of this is that the information cannot be used due to the excessive workload it would take to find the right information. For this reason, the mean time between failure for parts cannot be determined and this information is lost.

Visualization data

In Figure 19 and Figure 20, the maintenance costs per year can be found for two machines. All data can be found in appendix H. Figure 19 shows the DMG DMU 50 from 2003, Figure 20 shows the Makino D500 from 2014. In the past, maintenance within NTS Norma was only performed when something went wrong. This can be seen in Figure 19. The first 8 years are almost maintenance free. After these 8 years can be seen that the maintenance costs are 55.000 euros and remain high after those years. The maintenance costs of the Makino D500 are higher in the beginning of the lifetime due to better preventive maintenance, see Figure 20. Expected is that the maintenance costs will remain low for a couple of years, because proper maintenance is performed.

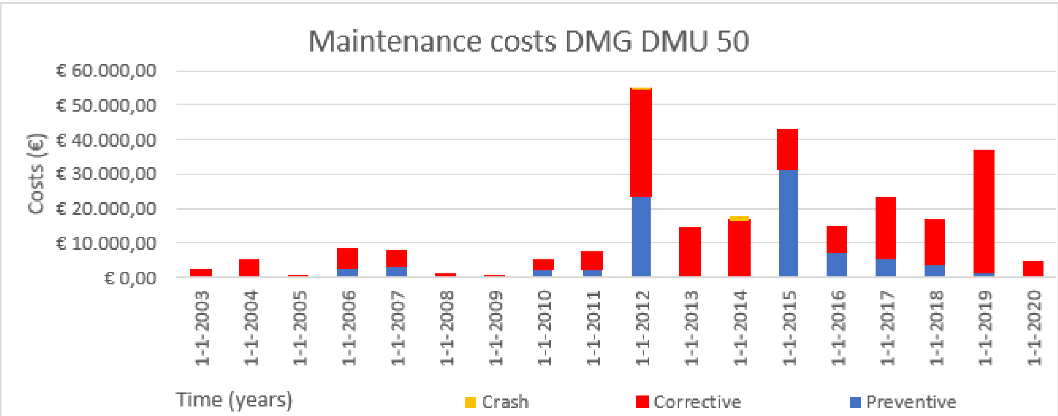

FIGURE 19: MAINTENANCE COST DMG DMU 50 EVO

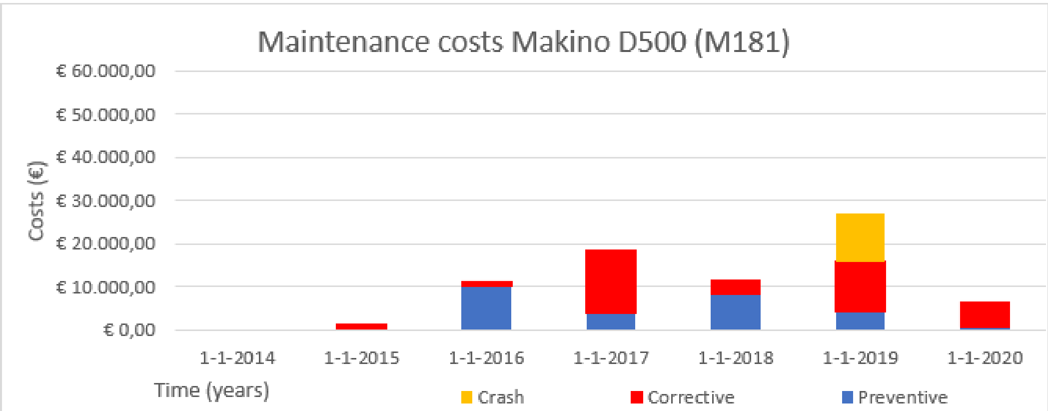

FIGURE 20: MAINTENANCE COSTS MAKINO D500 M181

5.2.4 DOWNTIME

Downtime in manufacturing is defined as any period of time when a machine is not in production. The total amount of downtime a factory experiences includes any stops during production that cause a loss of revenue for the company. Downtime can occur due to different factors: Preventive maintenance, corrective maintenance, no material available, no work or no operator available.

After a lot of conversations with many colleges, some data was gathered of the downtime due to maintenance actions. This data is only gathered as a total downtime in 2017 and 2018. This data cannot be used properly in the life cycle costs, because the quality of the data is unreliable. Downtime is measured using shift times, so the time the operator is at the company working. In real life, the machine endures downtime from the point it is not able to produce till the point where it is producing, including the time when the operator is not at work.

For the future, another method should be found in order to measure the downtime of a machine that is less work intensive and more reliable.

Machine	Downtime [hours] (2017)	Downtime [hours] (2018)
Makino D500 M181	129.7	32.0
Makino D500 M182	0.0	0.0
Grob G550 M161	35.4	30.0
Grob G550M162	254.1	517.0
DMG DMU 50 EVO	633.7	824.0
DMG DMU 70 EVO	31.0	283.0

TABLE 12: DOWNTIME COSTS 2017

5.2.5 TOOLING COSTS

The tooling costs are the costs of all cutting tools that are used during manufacturing, for instance mills or drills. From practical knowledge, NTS Norma can see a difference in tooling costs when a machine is degrading over time or when products are changed from an old unstable to a new stable machine.

Current data gathering approach

In the current situation (method 1), an overview of all tooling costs is made over the whole machining park, using the data from bought cutting tools. This data is not divided into different machines or machine groups, so the costs of the whole manufacturing park are used. In this overview, all costs of all machines are summed up and divided by all the booking hours of all machines. In this way, the company calculates the average tooling costs per booked hour. The result can be seen in appendix H.

Alternative data gathering approach

To get more insight in the tooling costs, an alternative method is used to gather the tooling data (method 2). Since 2019, the tooling costs are gathered using different tool cabinets that are locked using a software system, see Figure 21. When cutting tools are booked out for production, the operator or tool setter can login with his personal card into the computer. The booked out tools are then coupled with the operator or tool setters code, that is saved inside the chip of his/her name card. This card can be seen in Figure 22.

FIGURE 21: TOOL CABINET

FIGURE 22: NAME CARD

The second method uses the information of tooling costs per operator. Operators work most of the days at the same machine or machines. During the shift, they can help each other and thus work for several machines. Knowing this information, the data of the operators can be used to get the tooling costs per production plein. The machines that are used in this case study are all located in the 24/7 plein, the plein that is operating 24 hours, 7 days a week. At the 24/7 plein, only milling machines are used. The costs of all operators in this plein are gathered and analyzed, as can be seen in Figure 23.

	1-1-2019	1-1-2020
Operator 1	€ 15.033	€ 57.914
Operator 2	€ 5.791	€ 17.170
Operator 3	€ 9.321	€ 5.876
Operator 4	€ 14.574	€ 17.140
Operator 5	€ 1.233	€ 2.630
Operator 6	€ 12.589	€ 18.149
Operator 7	€ 3.250	€ 20.065
Operator 8	€ 121	€ 112
Operator 9	€ 56.721	€ 72.031
Operator 10	€ 9.316	€ 2.908
Operator 11	€ 24.369	€ 31.574
Operator 12	€ 16.299	€ 0
Operator 13	€ 2.435	€ 49.056
Operator 14	€ 11.665	€ 21.651
Operator 15	€ 1.346	€ 2.293
Operator 16	€ 53.059	€ 51.747
Operator 17	€ 27.649	€ 55.785
Operator 18	€ 11.112	€ 16.613
Operator 19	€ 2.869	€ 3.203
Operator 20	€ 777	€ 12.266
Operator 21	€ 30.751	€ 46.623
Operator 22	€ 14.158	€ 25.320
Operator 23	€ 57.938	€ 63.963
Tool setter 1	€ 11.391	€ 52.668
Tool setter 2	€ 16.944	€ 35.935
Tool setter 3	€ 32.492	€ 99.471
Total	€ 443.203	€ 782.166
Factor	3,4	2,55
Booking hours	60.915	77.878
Total machine park tooling costs	€ 1.499.886	€ 1.996.094
Averager costs per hour	€ 7,28	€ 10,04

FIGURE 23: TOOLING COSTS PER OPERATOR

Additionally, the costs of all tool setters are gathered. Tool setters make sure that the cutting tools are assembled into the tool holders. This is done for the whole machining park. Unknown is the ratio between the 24/7 plein and the rest of the machining park. In other words, how big is the portion of the costs of the tool setters assigned to the 24/7 plein? To make an assumption, the following calculation is made:

1. The costs of the tool setters is divided by a chosen number.
2. The operator costs and the tool setter costs are summed up.
3. The summed costs are multiplied with the same chosen number from step 1.
4. When the costs are roughly the same as the total tooling costs, a good assumption is made. Excels function "goal seek" can be used to determine the chosen number.

   This number is the portion of the costs of the tool setters to the 24/7 plein.

After this calculation, the 24/7 plein tooling costs per hour are calculated per year, beginning at 2019. The found data is analyzed and all assumptions / errors in the data are written down.

Assumptions / errors

First method used the total tooling costs of all machines divided by the total booking hours of all machines. In this way, the traceability of the costs is gone. Unknown are the actual costs per machine. Due to huge differences in the machining park, for instance sparkdischarge machines and milling machines, the tooling costs can be very different between machines. In method 1, this is not taken into account.

The second method uses the tooling costs per operator to determine the cost per hour per machine group. For this method, the ratio of tool setter costs is estimated. Unknown is the quality of this assumption. For later calculations, method 1 is used for all data before 2019. Method 2 is used for all data from 2019.

5.2.6 TOOLING TEST

NTS Norma has experienced differences in tool life between different machines. This became visual when products where changed from machine x to machine y. Method one and two cannot determine this change in tool life per machine, for this reason, a test setup is designed that can measure the tool life between different machines. The assumption from the operators is that this change in tool life is

influenced by the stability of the machine. For more understanding of this question, a book is used from SECO [18]. This book gives clear explanation of the different wear types of tool wear and shows practical changes that are possible to decrease the wear speed of cutting tools. The most common wear types are: Flank wear; Chipping; Notch wear; Build up edge; Crater wear; Plastic deformation. All wear types are discussed in appendix G. The most common and controllable wear is flank wear. Flank wear is also the most desirable wear condition. Flank wear can be expected in all materials, a cutting edge will normally fail due to flank wear if it doesn't fail by other types of wear first [18].
The assumption of the operators is that stability of the machine will influence the tool life. Different elements are stated that play an important role in the metal cutting process and thus the tool life. Those are [18]:

- The workpiece (material and geometry).
- The machine tool (power, feeds and speeds, stability, …).
- The process environment (cooling, stability, …).
- The fixturing system for the workpiece and the cutting tool.
- The cutting tool and the cutting conditions.
- The knowledge, experience and expertise of the machine tool operator.

To test if stability is indeed the critical factor causing more tool wear, a test setup is made. In this test, all other factors that can influence the tool life will be made as constant as possible and will be explained in the next paragraphs. The goal of the test is to determine if:

1. The tool life of cutting tools is variating over the lifetime of the machines.
2. The tool life of cutting tools is variating between different machines.

If the test is a success, it can be used to compare the tooling costs between machines and get a better insight of the tooling costs between different machines. The big advantage of this test is that it can be performed without the use of products, resulting in a product independent approach.

5.2.6.1 TEST MEASURE

Tool life is dependent on a lot of wear types, for instance flank wear, chipping, or notch wear. If the machining process is well designed, the tool should only suffer from flank wear [18]. Flank wear is the most common and predictable wear type. It is most commonly caused due to abrasive wear of the cutting edge against the machined surface. Flank wear can be divided into three stages, the initial wear zone, steady state region and accelerated wear zone, see Figure 24 [19]. In the first zone, the primary zone, the flank wear is high but decreases fast in speed. After the initial wear zone, the steady state region takes place. In this wear zone, the wear of the cutting tool is degrading constant over time. At the end of the steady state region, the accelerated wear zone takes place. In this zone, the flank wear occurs at a gradually increasing rate.

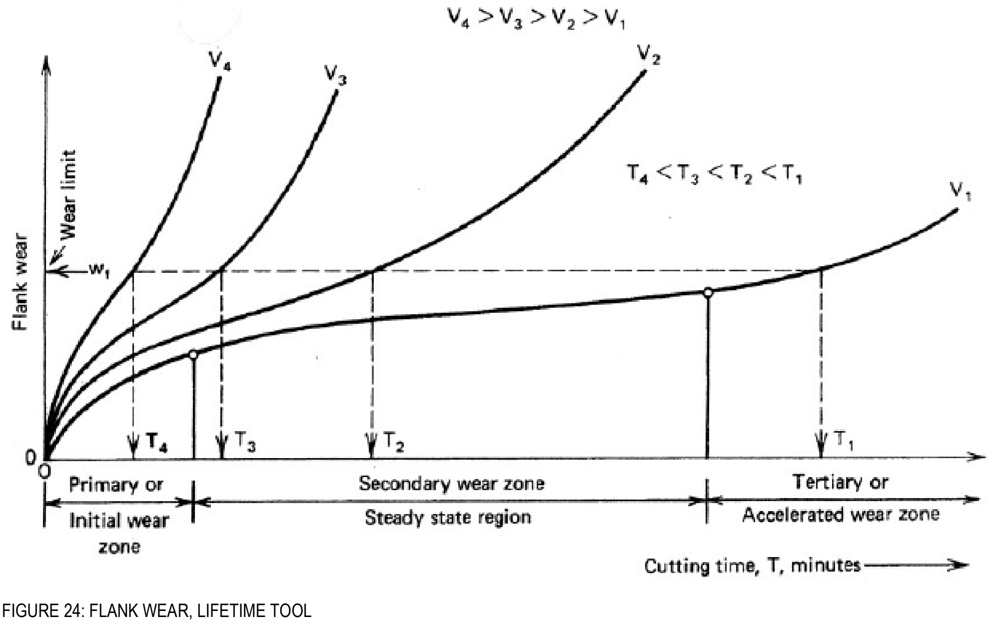

FIGURE 24: FLANK WEAR, LIFETIME TOOL

To determine this graph, a test setup is made. In this test setup, it is important that all elements that play an important role in flank wear are as constant as possible. The only variable will be machine stability.

5.2.6.2 PROCESS

Generally, the evaluation of cutting tool wear can be measured in two ways: direct and indirect methods [19].
The direct method involve measuring the state of tool wear in a visual way, by using a microscope or light interferometers. In the direct way, the production process must be stopped and the tool must be measured.
In the indirect method, the cutting tool wear can be evaluated using different sensors. In this method, the cutting tool wear is measured indirectly, using the signals of the sensors. This method is more difficult to use in a production process, due to the signal processing and translating this data into information.
For the test at NTS Norma, the direct method is the most suitable to measure the cutting tool wear. In the direct method, the wear can be measured easily and the picture gives an clear understanding of the wear type. This is done with the following test setup, seen in Figure 25.

An Dino – Lite digital microscope is used to make pictures of the cutting tool, using a magnification of 235. The tool was positioned on a tooling card. The tool can be rotated in the tooling card, without space between the tool and tooling card. In this way, the distance between the cutting tool and the microscope is always constant, resulting in a good quality picture. To make sure that the microscope is not moved within the test, a heavy object is placed on the table of the microscope.

For all tests, two teeth of the tool are measures, opposite to each other, indicated in the results with teeth 1 or teeth 2. Assumed is that the wear per teeth is equal. By measuring two teeth, possible human errors can be detected. When the spindle play is higher than the requirements of NTS Norma, all teeth will be measured to indicate if there is a difference per teeth. In the other tests, teeth 1 and 2 are the teeth's opposite to each other. The remaining two teeth's will be called teeth 1.5 and 2.5, which are in between teeth 1 and 2, opposite to each other.

At the start of the tests, a picture is made of the unused cutting edge, which can be seen in Figure 26. With the software of the microscope, the length of the cutting tool edge and flank wear can be measured. This is done by clicking on the edges of the cutting tool. Help lines will help the user to measure the length of the cutting tool edge or flank wear. To reduce errors, the writer used the microscope and made the pictures. In this way, only one person is involved in the process of making pictures and measuring them, making sure that the edge of the cutting tool and flank wear are indicated in the same way for all tests.

FIGURE 25: TEST SETUP

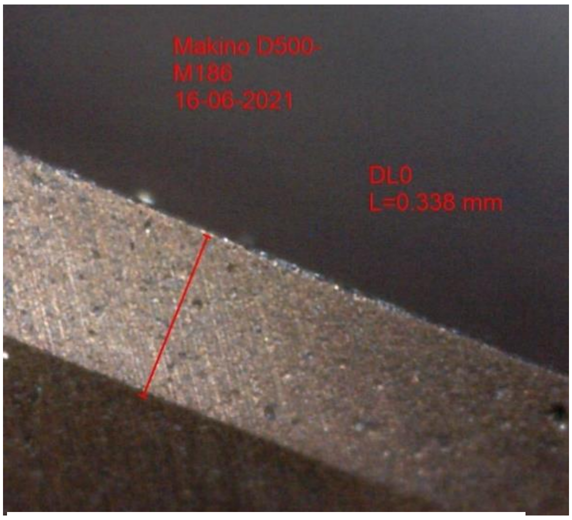

FIGURE 26: CUTTING EDGE, MAGNIFICATION 235

The test is performed on different machines, to test if machine stability is influencing the flank wear rate. To do this, four machines are chosen to use. Those are:

1. Makino D500 M186 (2017)
2. Makino D500 M184 (2017)
3. Makino D500 M180 (2011)
4. **DMG DMU 50 evo M155 (2003)**

5.2.6.3 HYPHOTHESIS

As said before, the goal of the test is to determine if:

1. The tool life of cutting tools is variating over the lifetime of the machines.
2. The tool life of cutting tools is variating between different machines.

In the past, a few products are changed from the DMG DMU 50 EVO to the Makino D500. In this change, the process to make the products is 100% the same, so the same cutting tools, cutting parameters, way of production. The operators have noticed a change in lifetime of the tooling. The operators are expecting that this is due to a higher machine stability of the Makino D500 in comparison with the DMG DMU 50 EVO.

From one product, data is found of the change in lifetime of the tooling. This data can be found in Table 13. The table shows the amount of products a cutting tool in the DMG DMU 50 EVO could produce and the amount of products a cutting tool in the Makino D500 could produce before reaching lifetime. From the data, two conclusions can be made. The first conclusion is that there has been a change in strategy in tool life. On the DMG DMU 50, the machine does not have a function to alarm the operator in case when the lifetime of a cutting tool is reached. Due to this reason, cutting tools are replaced in big clusters, to prevent risks on human errors and ensure a reliable process. This strategy is changed on the Makino D500. This machine is able to alarm the operator in case a cutting tool reaches its lifetime. For this reason, the lifetimes are optimized per tool, resulting in different lifetimes per tool. The second conclusion that can be made is that in the new situation where the product is made on the Makino D500, the lifetime of all tools is longer in comparison with the old situation on the DMG DMU 50. In Table 13 can be seen that the improvement from DMG DMU 50 EVO to Makino D500 a lifetime increase of factor 3 is.

	DMG DMU 50 EVO	Makino D500			DMG DMU 50 EVO	Makino D500	
Tool Number	# Products per lifetime		Improvement	Tool Number	# Products per lifetime		Improvement
9	12	24	2,0	27	12	36	3,0
10	12	20	1,7	28	12	45	3,8
11	12	54	4,5	33	12	30	2,5
12	12	32	2,7	34	12	30	2,5
13	12	12	1,0	35	12	24	2,0
14	12	72	6,0	36	12	42	3,5
15	12	18	1,5	37	12	120	10,0
16	12	36	3,0	38	12	36	3,0
20	12	24	2,0	39	12	30	2,5
21	12	12	1,0	42	12	36	3,0
22	12	24	2,0	43	12	24	2,0
25	12	36	3,0	Average	12,0	35,5	3,0

TABLE 13: TOOLING LIFETIME DMG DMU 50 EVO VS MAKINO D500

Makino D500 M186 (2017), Makino D500 M184 (2017)

The Makino D500 M186 and M184 are the newest Makino's in the production hall. Expected is that these machines will perform the best in the test and that the wear rate is the lowest. The result of wear rate between these machines should be roughly the same. For this reason, the results of these two machines are used to check whether the test is reproduceable.

Makino D500 M180

The Makino D500 M180 is the oldest Makino of the production hall. This machine has more spindle play than the other machines, and has exceeded the requirements of NTS Norma. Expected is that due to this spindle play, one teeth of the cutting tool will have a higher wear rate, resulting in a lower lifetime of the tool.

DMG DMU 50 evo

The DMG DMU 50 evo is an old machine from 2003. The machine stability is lower in comparison with the Makino D500. Expected is that this machine will have a higher wear rate than the Makino D500, resulting in lower lifetime of the tool.

5.2.6.4 MATERIAL

NTS Norma uses different materials to produce products, like aluminum, steel, RVS, or another material. To determine the wear graph, the lifetime of the cutting tool must be reached. To reach this lifetime, a material should be used that deteriorate the cutting tool fast, to prevent that the test is taking very long. For this reason, RVS 304 is the best choice, because in this material, cutting tools will wear faster in comparison with aluminum and steel. Another reason to choose RVS is because more tests within NTS Norma are performed in RVS 304, so more information and data is available to design the test. The geometry of the block is chosen to be 100x150x150 (length x width x height). This block can be seen in Figure 27. From previous tests is expected that with this geometry and data from the past, it will take roughly 8 - 10 minutes to remove one layer of RVS 304. Furthermore is expected that the lifetime of the tool is roughly 100 - 120 min, resulting in one RVS 304 block per test. The exact cutting parameters are discussed in a later paragraph.

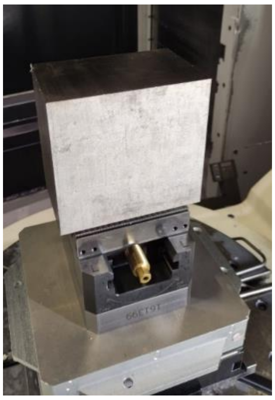

FIGURE 27: RVS 304 TEST MATERIAL

5.2.6.5 PROCESS ENVIRONMENT

Under process environment, the following topics are consider: Environment temperature; Cooling water temperature; Greasiness of cooling water; Machine stability; Foundation. All environments are as constant as possible within NTS Norma, to ensure a stable production process. In the production hall, a climate control system is installed to keep the environmental temperature at a constant temperature of 20 degrees. Within this 20 degrees, the temperature can change ±1 degree. The cooling water temperature is also as constant as possible, resulting in a temperature of 20 degrees ±1 degrees. This cooling water is used to cool down the cutting tool, spindle and frame of the machine, to ensure that the thermically change in geometry of the machine is constant. The greasiness of the cooling water is between 7 and 8 percent. The greasiness of the cooling water influences the cutting performance of the cutting tool, resulting in more or less wear over time. The last topic is the foundation of the floor. This foundation will ensure that the machine is standing stable on the floor, without excessive motion in the frame when it is producing products. Within NTS Norma, the foundation is made according to the suppliers recommendations, to ensure that the machine can stand on the floor as stable as possible.

5.2.6.6 FIXTURING SYSTEM

For the fixturing system, a clamp of Makro grip is used, as can be seen in Figure 28. This clamp can fixate products with a maximum width of 100mm. There is a profile on the edge of the clamp, to increase the friction between the clamp and product. To increase this friction, this same profile can be added to the material. This will increase the contact surface and thus the friction force between clamp and product. The clamp is fixated using a hydraulic system. On the hydraulic system, a pressure of 100Nm is added, to ensure a stable fixation of the material. Within NTS Norma, using this clamp is the most stable way of clamping a 100x150x150mm block of material. That’s why this clamp is used to fixate the material.

FIGURE 28: FIXTURING SYSTEM

5.2.6.7 CUTTING TOOL AND CONDITIONS

For the cutting tool, a facing cutter is used. In consultance with the machining specialist, a Guhring Ø 10mm is used. This tool is widely used within NTS Norma, and has good cutting conditions in RVS 304. The cutting tool is fixated in a HSK 63 clamping tool. This clamping tool is heated to a certain predefined temperature. This will cause an expenditure of the clamping tool. In this state, the cutting tool can be inserted into the clamping tool. When the clamping tool is cooled down, the cutting tool is fixated into the clamping tool. The exact assembly with measurements can be found in appendix J.

The cutting conditions are also made in consultance with the machining specialist. From tests in the pasts, the most optimal cutting parameters are:

Ap = 18mm	Ap = Cutting depth.
AE = 10% of diameter	AE = Cutting width.
Vc = 160 m/min	Vc = Cutting velocity.
Fz = 0.223 mm / teeth	Fz = Feed per teeth.

With these cutting parameters, the RVS block will be cut away. This is done in layers of 18mm deep. When one layer is removed, the cutting tool is inspected with the microscope. The flank wear will be noted into a excel file. This process is repeated until the cutting tool will break or two blocks of material is cut away. A cutting tool is broken if it is not able to function anymore. This is the case when:

- A part of the cutting tool is broken off. (Big failure)
- A part of the cutting edge is broken off. (Small failure)

5.2.6.8 OPERATOR KNOWLEDGE

The operator knowledge is in this test constant. For the test, the operator is used to insert and remove the cutting tool. Furthermore, the operator started and stopped the machine. To make sure all operators knows exactly what had to be done, one leading operator explained the tasks that needed to be done. This was done just before the test, so there could not be made any errors. The writer has performed the test, by making pictures with a microscope of the cutting edge of the cutting tool and measured the flank wear. For all tests, this is done by the writer, to make sure the test is performed in a constant way and human errors are minimal.

5.2.7 RESULTS TOOLING TEST

The first test is performed on the Makino D500 M186. In this test, there were some startup issues. After two tests, the lifetime of the cutting tool was 17 minutes for both tests. This indicates that the lifetime was too short to make a good flank wear graph. The cutting tool parameters are changed to the following settings, using old programs from NTS Norma:

Old parameters	New parameters
Ap = 18mm.	Ap = 18mm.
AE = 10% of diameter.	AE = 10% of diameter.
Vc = 160 m/min.	Vc = 90 m/min.
Fz = 0.223 mm / teeth.	Fz = 0.12 mm / teeth.

5.2.7.1 TEST GROUP

With these new parameters, the test at Makino D500 M186 is performed. The test could not be finished, because time ran out. The used machine could only be used one day, to prevent lagging behind on production. Nevertheless, the graph can be used to compare with the next test, that is performed on the Makino D500 M184. Both M186 and M184 are technically the same, so these result should be the same to have a repletable test setup. As can be seen in Figure 29 and Figure 30, these graphs are indeed the same. The graphs represents the flank wear in mm per 18.5 minutes. There is a small change in the height of the flank wear. This is due to a small human error. The multiplication factor of the microscope was turned a small amount, that results in a changing flank wear width. In the next tests, this multiplication factor is the same and checked in front, during and after the test. What can be seen between the two graphs, is the shape of the graph. Both tools on different machines shows an initial wear zone, resulting in a large wear ratio. After that, the graph stabelise, and the steady state wear zone is reached. Unfortunately, in the test the accelerated wear zone could not be reached. Probleably, the new parameters for the test where too conservative, resulting in long lifetimes of the cutting tool and slow production speeds.

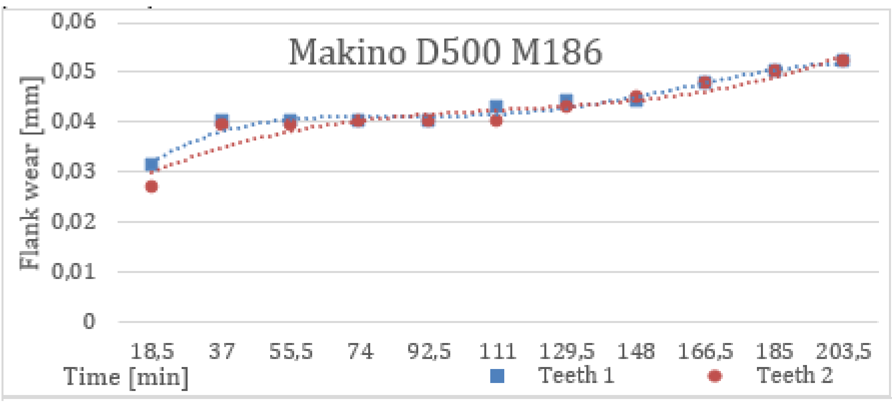

FIGURE 29: TOOL LIFETIME TEST MAKINO D500 M186

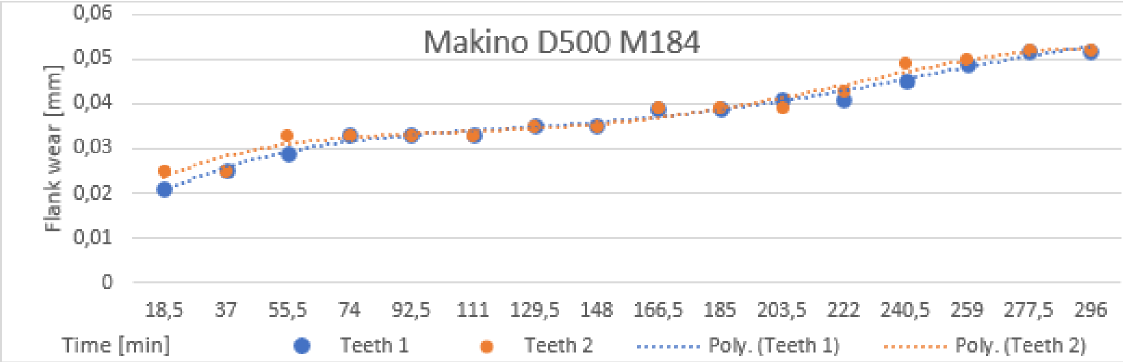

FIGURE 30: TOOL LIFETIME TEST MAKINO D500 M186

5.2.7.2 UNSTABLE VS STABLE MACHINE

In this test, the results of a unstable and stable machine are compared, the Makino D500 as stable and DMG DMU 50 evo as unstable machine. The result is rather unexpected, and can be seen in Figure 31 and Figure 32. From practical data was visual that the lifetimes on the Makino D500 are 3 times longer in comparison with DMG DMU 50 evo. The current test results are showing the opposite.

Makino D500

- Shows initial wear zone
- Shows steady state zone, with a wear ratio that is increasing over time.

DMG DMU 50 evo

- Does not show initial wear zone
- Shows steady state zone with a wear ratio of almost 0, so no wear at all.

From this data can be concluded that with the current cutting parameters, that are very conservative, the lifetime of a DMG DMU 50 evo shows a more constant, lower wear rate in comparison with the Makino D500. These results are in contradiction with the practical results, indicating that something odd is happening. After discussion with some specialists, an assumption is made that there is a possibility that due to the conservative cutting parameters, the machine will not need to use the machine stability, resulting in a different result that expected.

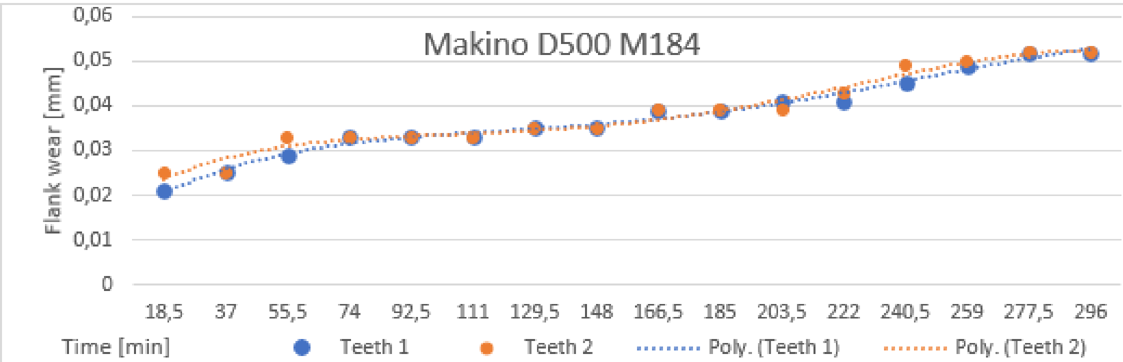

FIGURE 31: TOOL LIFETIME TEST MAKINO D500 M184

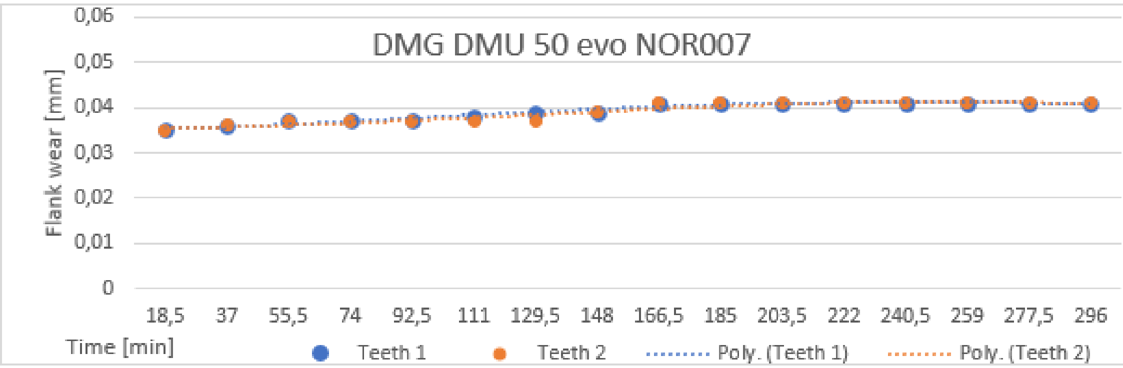

FIGURE 32: TOOL LIFETIME TEST DMG DMU 50 EVO

5.2.7.3 OLD VS NEW MACHINE

In this test, the results of a new and old machine are compared, the Makino D500 M184 as new and Makino D500 M180 as old machine. As told before, the Makino D500 M180 has a lot of spindle play. This reduction of stability can be seen in the results of the test, which is visualized in Figure 33 and Figure 34. The results of the Makino D500 M180 are reported for all teeth of the mill, to indicate if there is a change in flank wear between the teeth due to the spindle play. This can be seen, teeth 2 shows slightly higher flank wear in comparison with the other teeth. The shape of all teeth is the same, but teeth 2 with higher initial wear stabilizes in the same shape as the other teeth with less initial wear. From the results can be concluded that spindle play will result in a difference of flank wear per teeth. What is unknown, is if this change will result in a shorter lifetime of the tool. This is unclear, because the tool did not fail during the test.

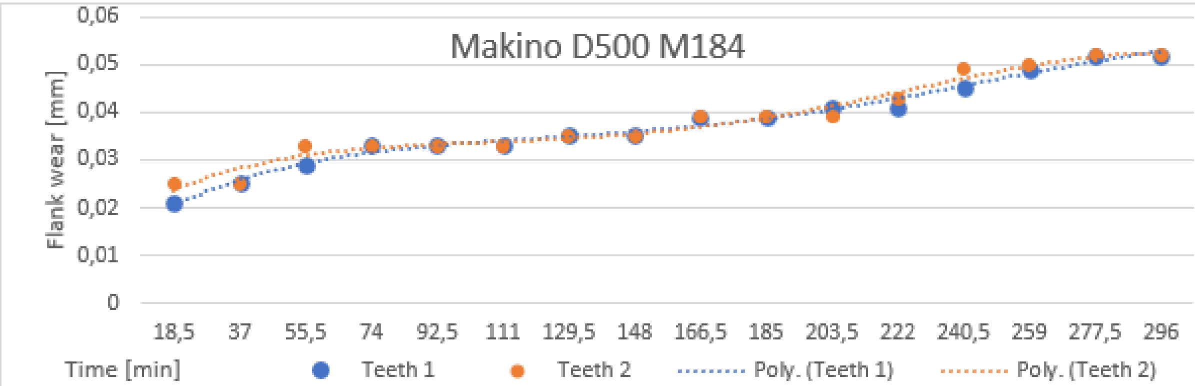

FIGURE 33: TOOL LIFETIME TEST MAKINO D500 M164

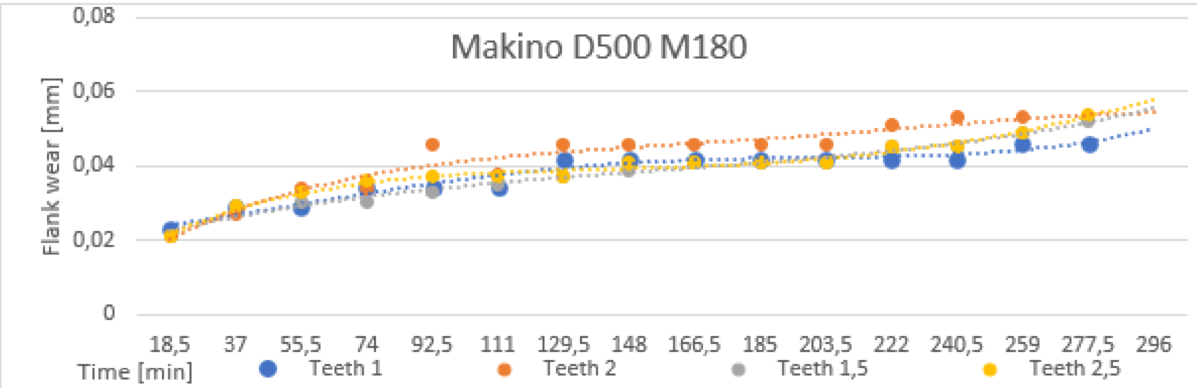

FIGURE 34: TOOL LIFETIME TEST MAKINO D500 M180

5.2.7.4 RECOMMENDATIONS

Due to conservative cutting speeds, the test took 6 hours to perform with 5 hours of production. Normally, the lifetime of this cutting tool in RVS is around 100 – 120 min, indicating that the test is conservative. Expected is that these conservative cutting speeds have influenced the results for the stability test. The machine does not require a lot of stability due to very low cutting forces, which can be the reason of the unexpected results for the test.

For the next test, the following improvements should be used to make sure that the current result represents a real representation of the production process, and that this test can be used as an indication of the stability of the machine.

- Use a larger mill with a diameter of 12mm. This mill will increase the cutting forces and will force the machine to use the stability to get good cutting results.
- Search for cutting parameters in which the cutting tool breaks in around 100-120 min.
- Make sure that one person measures the flank wear. This will reduce human errors, because the measure points are measured in the same way.

5.2.8 LABOR COSTS

Labor costs are the costs for al wages within the company. Labor costs can be divided into two categories, direct and indirect laborers. Direct labor costs are the wages from the people who are directly working on the product being manufactured. Indirect labor costs are all wages from people who are not directly involved to the products being manufactured, for instance maintenance engineers or cleaners.

To determine the labor costs per machine, direct labor will be used. In this case, direct labor costs are defined as the required operator hours to operate the machine multiplied with the machine hourly costs. This includes setup times and machine adjustment. All other actions like measuring products or cleaning is not included. In this way, the writer tries to find the workload per machine. This workload can then be compared to other machines and can be used for the economic life.

NTS Norma records a small amount of data about the downtime of machine. This data is based on the booking hours of NTS Norma, discussed in paragraph 5.1.3. These booking hours are calculated by the calculators, who divide the booking hours into manned and unmanned hours. Manned hours are the expected hours needed for the operator to setup the process and start producing the product. These manned hours are excluded from the data and made visual in Table 14. All assumptions from paragraph 5.2.1 still hold.

As described above, the manned hours include the setup time and starting to produce the product. In some cases, these are the only human costs, but in most cases, the operator should be available to fill the machine will staff material, remove finished products, change broken or worn cutting tools and other tasks to keep the machine up and running. All those human hours are not calculated, but are extra human costs that are not visual. For these reasons, this data is not reliable and cannot be used in the repair / replace model.

2021	Week 01	Week 02	Week 03	Week 04	Week 05	Week 06	Week 07	Week 08	Week 09	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19		Average
M181	1	6	1	5	5	4	7	3	2	10	5	3	8	1	5	7	2	2	0		4
M182	1	6	5	9	8	6	9	2	6	7	6	8	7	5	5	5	6	5	3		6
M161	3	16	5	8	9	16	10	3	18	16	4	15	6	8	6	5	15	7	8		9
M162	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
DMU/DMG 50	6	9	8	10	10	5	6	3	2	4	7	4	6	1	6	5	3	4	2		5
DMU/DMG 70	2	0	0	2	2	0	0	2	2	1	2	1	2	2	0	2	2	0	1		1

TABLE 14: LABOR COSTS

Conclusion data gathering approach

After multiple conversations with multiple operators and colleagues, it can be concluded that there is no usable data available for the labor costs, nor is another solution possible to gain information. Specialists give as feedback that the labor costs cannot be estimated, due to the following reasons:

The workload of the machine is product dependent. Some products require long human handlings, resulting in long setup times. Other products can be very simplified and easily to produce with short setup times. Due to these differences, it is hard to estimate the average workload. For some machines, the workload can be very high due to labor intensive products. This does not mean that the machine is expensive. It means that the work made on these machines is expensive. When a easy to handle product is manufactured on this same machine, it can be possible that the labor costs are lower. So this parameter is not machine dependent but product dependent.

In order to gain information about the labor costs per machine, all labor actions of the operator should be recorded, including the product that is made. This information can be used to understand the labor costs per product. When a product is changed from machine x to machine y, this data can be used to compare the labor costs per product on machine x and machine y. The difference in labor costs per product is the result of this switch between machines. This way of measuring the labor costs is very labor expensive and not feasible for NTS Norma. The required work does not fit the benefits of knowing a little bit more about the labor costs per machine.

New approach
After some discussions with colleagues, the following method is made that will give a deviation in labor costs between machines. Within NTS Norma, different machines with different automated systems are used. Some machines work fully automated in a 24/7 working environment and a low labor intensity. In these situations, the operator has time to perform side tasks in his working shifts aside of his normal work. Other machines work in a dayshift or dual shift and are not automated. This means that on these machines, the whole day an operator is needed to operate the machine. When the operator is not available, the machine will operate for a small amount of time and if the program is ended, the machine will endure downtime. This means that the machine cannot operate without the operator. To summarize, operator costs can be divided into three categories:

1. Setup time.
2. Manned work.
3. Unmanned work.

Setup time
Setup time is the time the operator needs to setup the machine, so making sure all tools are in place, the right program is uploaded or the material is mounted in the machine.

Manned work
Manned work is work where the operator is needed to operate the machine. Without the operator, the machine will not operate and suffer downtime. For automated machines, manned work is the time the machine needs to stabilized and adjusted to the right dimensions to work within a certain range of accuracy. For an un-automated machine, only manned work is performed, because the machine needs the operator to operate.

Unmanned work
Unmanned work is a category that is only usable for automated machines. Unmanned work is the time where the machine can operate without an operator and the operator has “spare time” to perform side tasks that are not directly needed to operate the machine.

In the current situation, a few assumptions can be made to compare labor costs between machines.
Un-automated machine

- Only two categories, setup time and manned work.
- The maximum time a machine can operate is automatically the labor time needed.
    - For a dayshift, a machine produces theoretically 8 hours a day, 8 labor hours are needed.
    - For a dual shift, a machine produces theoretically 16 hours a day, 16 labor hours are needed.

Automated machine

- Three categories, setup time, manned work and unmanned work.
- The labor time and operation time is different.
    - Due to incomplete data, unmanned work cannot be measured in a convenient way.
    - Assumed is for automated machines, the labor time is the time the operator is available, so 8 labor hours a day for theoretically 24 hours of production.
    - Unmanned work is neglected, due to incomplete data.

5.2.9 AVAILABLE DATA REPRESENTATION

In Figure 35 and Figure 36 is, all data from the previous paragraphs is visualized in two graphs, one for the benefits and one for the costs. Figure 35 is zoomed in to have a better visualization of all the different costs.

In Figure 35 can be seen that the benefits of the machine is available for the DMG DMU 50 evo since 2014. Before that, no data is found that can help to visualize the benefits.

In Figure 36, all different costs can be seen. Two data sets are incomplete, the tooling costs and the downtime. The tooling costs are calculated since 2015 and are based on the booking hours of the machine. Downtime costs are only measured in 2017 and 2018, but due to the high workload, this process is stopped.

Conclusion

Due to the missing data, the economic life cannot be determined. This is due to the unknown cumulative cash flow from the beginning of the lifetime till 2014. No benefits are reported, which result in very high negative cash flows, which add up in the cumulative cash flow. After 2014, the benefits are known, but due to the high negative cash flow, the result of the cumulative cash flow is unreliable and the economic life is not visual. It is tried to calculate the average benefits from 2014 till now, but due to the missing initial investment, the average benefits shows unreliable results, indicating that this calculation cannot be made with the current data sets. The average benefits are needed to determine the economic life of the system. In the current situation with the current data sets, the economic life cannot be determined.

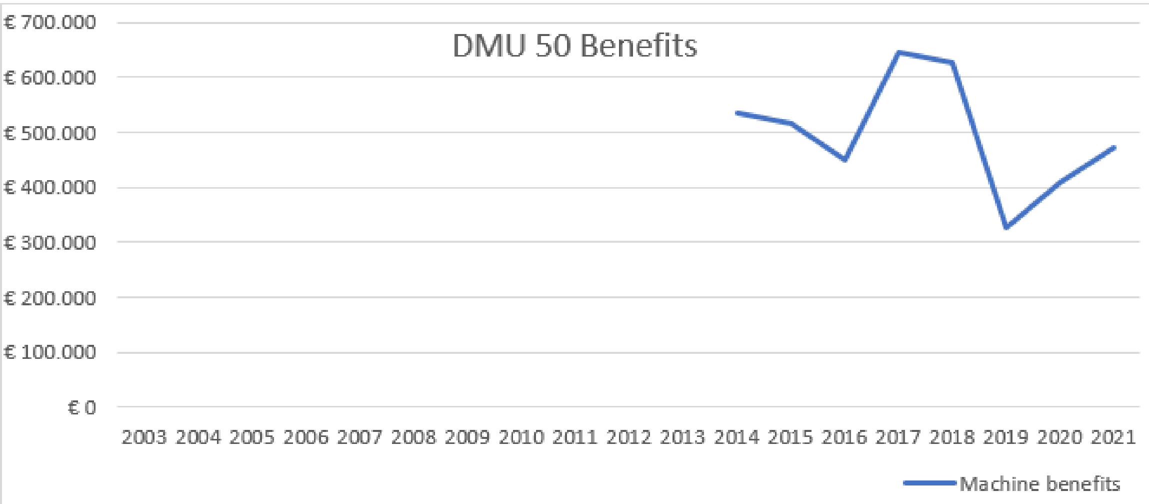

FIGURE 35: DMG DMU 50 BENEFITS

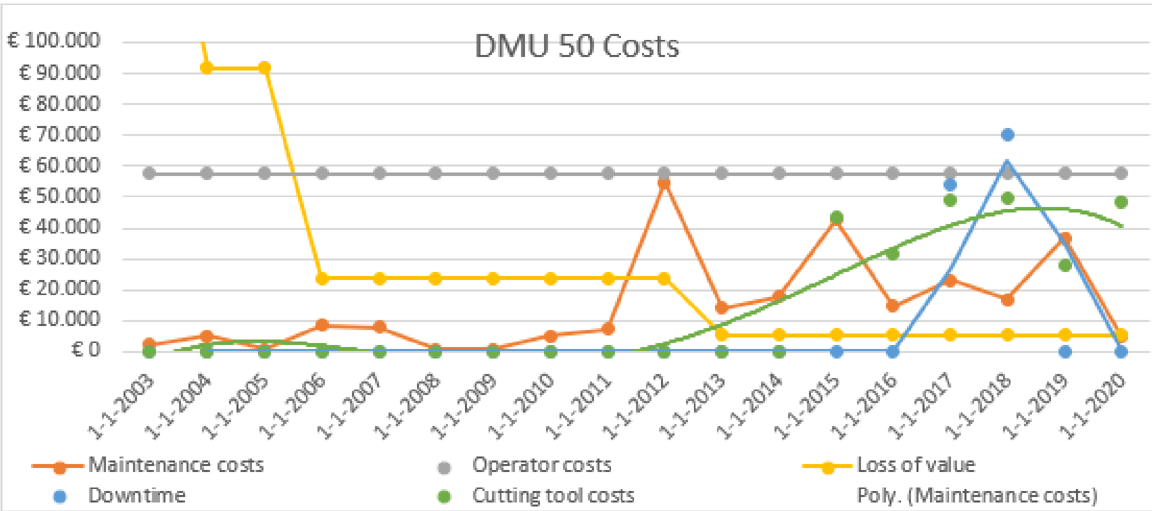

FIGURE 36: DMG DMU 50 COSTS

6 ROADMAP REPAIR / REPLACE DECISION

In the previous paragraphs is learned that a lot of data and information is not available or too unreliable to base certain conclusions or choices on. To improve the data gathering, a roadmap is made to give guidelines on which data is needed for the repair / replace model and how to measure these data. Without trustful and specific data, the repair / replace model cannot be used.

Historically, manufacturing businesses have collected data manually, through many hands and be manually processed or at best, processed with a spreadsheet to produce valuable conclusions [20]. It's also error-prone and subject to human bias because accurate reporting is sometimes at odd with internal incentives. Due to this reason, data should be gathered automatic when possible using data from signals. In this process, human actions should be prevented as much as possible, to reduce human errors.

In Figure 37, a timeline is made with all data that should be optimized. The timeline is divided into two phases, phase 1 represents the steps required to use the economic life model in the future. Phase 2 represents improvements of data, but is not required to use the economic life model. As can be seen in Figure 37 is that the uptime, downtime and tooling costs require a new strategy to gather this information, to gain usable information that can be used in the economic life model. The maintenance costs and depreciation costs can use some improvement to gain more information from the data, but is not required for the economic life model to use.

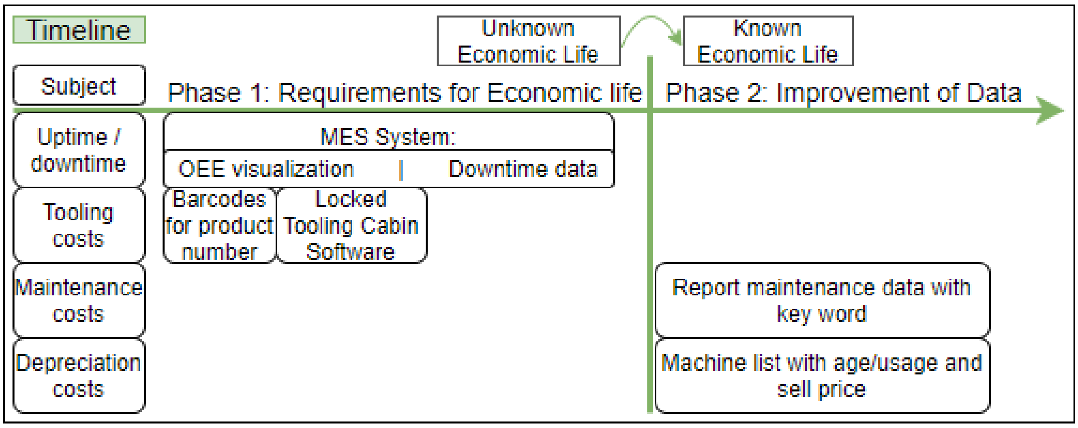

FIGURE 37: TIMELINE DATA IMPROVEMENT

6.1 Phase 1: Uptime machine

After analyzing the data can be concluded that the data for the uptime of the machine includes a lot of assumptions. These assumptions decrease the reliability and usability of the gathered data. The biggest problems are:

- The data is based on calculated hours, so nobody knows exactly how accurate the data is (only valid for the 24/7 plein).
- The data is reported at the end of a series of products. The result is variating benefits per week and thus uncertainty in the data.
- The data is reported at the calculated machine, so there is no traceability whether the data is from machine x or machine y.
- Additional human errors, made during the report of data.

An additional problem is that the current data represents the production hours per week. Production hours do not give a clear overview of the benefits of a system, because it is based on produced hours and not on produced products. In general, the company earns money by producing products instead of making production hours. The faster a process can be made, the more products can be made in the same amount of time, resulting in higher benefits. In the current situation, it is not visual what the actual benefits are. This is explained with an example.

Two machines make the exact same product. Machine x uses an outdated process and machine y an optimized process. Machine x will need 30 min of production time to produce 1 product. Machine y will need 10 min to produce 1 product. If both machines produce 20 products, machine x will need 10 hours and machine y 3.3 hours. With the current calculation, machine x will be more beneficial than machine y because the higher the production hours, the higher the benefits, but in reality, machine y is preferred because this machine can produce for the same costs 3 times more products. Another method is needed to visualize the benefits, taking in account the production speed.

To determine how effective machines are used it is possible to have an analysis that is used to determine the level of overall equipment effectiveness also known as OEE. An additional system monitors all the work planned and made during a certain timeframe, by using sensors and reading the machine software. OEE uses three different sets of data: production hours; cycles times; scrap. Every data set will indicate a potential loss of production. Production hours is the difference between possible production hours minus actual production hours. Cycles times are the fastest cycles times minus the current cycles times. The cycle times will give an indication of the speed of the machine in comparison with other machines. Scrap is the produced products minus scrapped products. With all this data combined, the OEE can be calculated. The OEE represents a effectiveness, as a percentage of the real production hours, so the total production hours minus all production losses. The OEE solves the problem when machines produces faster or slower, because the OEE decreases when the machine is producing slower in comparison to the optimal situation. With the OEE, a better representation of the benefits is made.

From a previous study within NTS Norma, research is done in a manufacturing executing system (MES) [21]. A MES system is a system that can be installed on a manufacturing machine, for instance the Makino D500. The system is coupled to all sensors available in the machine and can read / gather the information from the machine. This data / information will be documented into a data system. This whole process is automated and the data is directly available for usage.

This MES system can be perfectly used to gather the OEE of the machine. The MES system can read and gather data of all products that are made including cycle times or production times. This information can be used to calculate the OEE, overall equipment efficiency. The MES system cannot measure scrap, because this is measured in a later stage on different machines. To measure the scrap, every product that is indicated as scrap should be reported into a data system, coupled to the right machine and right product number, so it can be coupled to the right moment in time.

6.2 Phase 1: Downtime

In the current situation, the downtime costs are not visual. In 2017 and 2018, a test is done to gather the downtime costs, but due to the high workload to report this data, this process was stopped after two years. This means that another method is required to report the downtime costs.

For downtime registration, the MES system discussed in the previous paragraph can be used in the same way as for the uptime. As said in the previous paragraph, the MES system gathers and reports all available data in the machine. This includes sudden errors or warm-up programs. In the most optimal situation, the errors are categorized into different categories, resulting in an overview of possible errors and how much downtime this has caused.

6.3 Phase 1: Tooling costs

As said before, the tooling costs are since 2019 reported using a locked tooling cabin. The cabin can be accessed using a badge that will store the operator number and report the booked tools on this number. To gain more information from the data, the way of getting access to the system should be changed.

After some conversations with the tool data management specialist (TDM), a solution is found for the current problem. The first question is what data must be available to gain information about the tooling costs. Two factors are the most important, machine number and product number. The machine number will make sure that the tooling costs are divided over the used machines, so the costs per machine becomes visual. The second factor is the product number. This number is used to divide all tooling costs over the different products. When a product changes from one machine to another, the difference in tooling cost per product per machine is visual. These two numbers must be inserted into the tool cabin system in order to get access to the software. This process is sensitive for human errors, two long number combinations should be typed into the system, which can result in typing errors and thus human errors.

To solve this problem, the number combinations of the machine and product number should be visualized using a bar-code. This bar code represents the number of either the machine number or the product number, so both bar-codes should be scanned and after that, the operator will gain access to the system. All booked cutting tools will be reported on the used machine and product number, so with this process, the tooling costs can be seen for all individual machines and all products.
Every product uses its own unique set of tools, so every product will have different tooling costs. It is possible that one machine produces products that have a very expensive set of tools, resulting in high tooling costs for that machine. When the tooling costs are coupled to the product number and a product switches from one machine to another machine, the difference in tooling costs can be found. This difference is an indication that the costs on machine x are higher than on machine y.

From practical information, this change in tooling costs between machines can be big, for instance that the tooling costs are cut in halve. NTS Norma thinks this is a result of a difference in machine stability. Unfortunately, products do not change very often between machines, so information from the same product and different machines is small. To cover this problem, an test setup is in development to measure the tooling life on different machines with different stabilities. This test as described in paragraph 5.2.5 should help to give an indication of the difference in tooling costs between different machines.

6.4 Phase 2: Maintenance costs

The maintenance costs provided by HTM was quite clean and usable. The data is reported including date, action description, action, costs. With this information, the maintenance costs per year can be gathered. The data cannot be gathered automatic, because mechanics are performing the maintenance actions. This is not a problem, because the mechanics are used to report all taken actions into the data system, which results in good quality data.
Nevertheless, there is always room for improvement. The current data is stored at a database of HTM. To get access to this data, NTS Norma should ask the maintenance manager to send the actual data of HTM, which results in a delay of information. This delay and additional effort to gain maintenance data can withhold people using this data, resulting in a waist of information. A more optimal solution is that data is stored directly in the data system of NTS Norma, or that the data system of HTM is coupled to NTS Norma, resulting in live data.
Recently, NTS Norma started to gather the maintenance data by themselves. Currently, NTS Norma uses there own data system for the maintenance management, named Ultimo. In this data system, all data from the maintenance engineers are going to be stored, machine errors and possible solutions are saved.
The maintenance data is currently still stored with an action description. In this action description, the taken action are described and how this solves the found problem. This way of reporting prevent the decision maker to use this information, because it will take a lot of time to find the right action description and the possible solution. So in other words, effort is taken to make data but the information is lost. To optimize this, it is better to store data per machine part. This can for instance be done by using different levels. The top level can be the machine group, one level lower the different machine assemblies, such as spindle unit, table unit, chip removal unit. After that, one level lower, the broken parts can be described. Important is that every part is described by standardized and specific key words, so the maintenance manager can get more information about the historic maintenance data. This information can then be used to tackle “new” problems that already happened in the past. In other words, the maintenance manager can learn from the historic data and use this in his advantage. Another advantage is that with this same information, the mean time between failure can be gathered from different parts. This can be very useful for NTS Norma, because the vision of NTS Norma is to create machine groups with duplicate machines. This means that a lot of data can be gathered from the same type of machine, resulting in a lot of information about mean time between failure that can be used to improve the maintenance plan.

6.5 Phase 2: Depreciation costs

The marked value of equipment changes over time, resulting in different depreciation costs over time. Due to corona, all prices of equipment are increased due to shortage of parts. This change in market value can have influence on the repair / replace decision, because a machine can have a higher marked value than expected. Based on this fluctuating marked value, more information should be gathered about the actual value of the machine. Important to know is that in this master thesis, with depreciation costs is referred to the loss of market value of the asset. It is not based on for instance administrative models like linear, annuities or % of the booking value.

The writer has proposed a method to gain more information about this changing market value. Different websites sells second hand machines. These websites reveal a lot of information about the actual value of a machine, by showing the sell price, lifetime and spindle hours of the machine. This information can be used to gain a better overview of the depreciation costs. The tactical purchaser can gather this information from different websites and use this to understand the current market value and how this can change over the years. With this information, a better depreciation model can be made that represents the true value of the machines over its lifetime.

7 FINAL MODEL VISUALIZATION

For the final repair / replace model, two different models need to be used side by side, both equally important. The first model is the model of technical life, showed in Figure 39. This model will help the decision maker to get an overview of the technical situation of a machine.

The model is made using success factors, which can be seen in Figure 38. The success factors are made using the safety cube and divided into three main topics, environment, technical and human. These success factors must cover all important information about the technical life of the machine. Important is that the technical life is defined as all topics that are maintenance independent. This means that with infinite money, the problems occurring with the current machine cannot or partly be solved. With the technical life, the difference between the technological development of the current machine and machines on the marked is measured. When this gap becomes too big, it can be chosen to replace a machine for a machine with the new, better technologies, which can result for instance in better quality or faster production speeds.

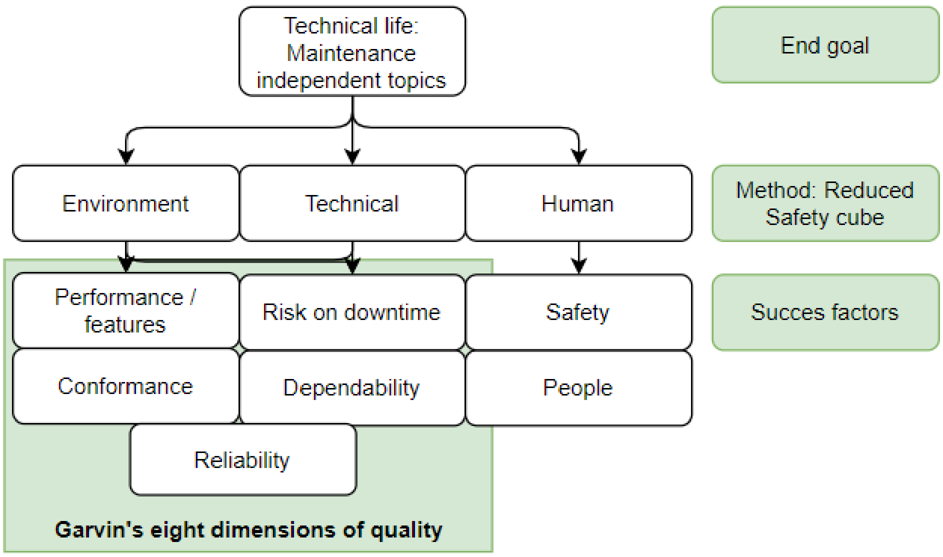

FIGURE 38: SUCCES FACTORS

The success factors are spread into different fields, from safety and knowledge of the people, to reliability of the system, and the difference between technology from the current machine and new machines from the market. For safety, the vision of the company is used to determine when a machine is considered as safe. NTS Norma has achieved multiple certifications in order to be able to produce these high tech products. In these certifications, safety measures and regulations are covered to ensure that the working conditions of the machine is safe. From the vision is learned that a lot of factors will influence the goal of NTS Norma to produce products at low costs with a fast throughput time, while still remain a reliable system. All these factors are used to get a starting point for conversations with colleagues. It also provided a bird view of the problem, which helped the researcher to keep an clear overview of the problem and possible solutions or important topics.

The specific information from the colleagues and literature together with the bird view of the vision helped the researcher to fill in the technical life model.

The technical life model is checked by several stakeholders, for instance the operators, the decision maker, maintenance manager and milling specialist. In this process, the model was explained and feedback or remarks could be given. After this process could be concluded that all topics that are important for NTS Norma are covered. The stakeholders did not know any other important points or aspects that required some work, so the apparent truth is reached.

Technical Life Model. Maintenance independent topics.

Safety	**Description**	**Dimension**
ISO 14001	The machine can fit in the ISO 14001 laws and regulations related to environmental impacts.	Yes / No
AS9100	The machine can fit in the AS9100 laws and regulations to ensure that the company is permitted to manufacture products for the aviation, space and defense.	Yes / No
NEN 3140	Electrical system is conform the rules of NEN 3140, which gives guidlines and rules about the electrical system.	Yes / No
CE certified	The machine is conform the rules of the CE certification.	Yes / No

Performance / features	**Description**	**Dimension**
Overall equipment efficiency (OEE)	Efficienty of the machine. Gives insight in the downtime, cycles time and scrap of the machine	[%]
Posibility to increase production yield	What is the expected increase in process speed in case a new machine is bought.	[%]
Cooperation features or systems Step to Industry 4.0.	**Machine can cooperate in a reliable way with all systems:** These systems are required for the data management of NTS Norma and will be a step towards industry 4.0.	Yes / No
	Manufacturing execution system (MES)	Yes / No
	Enterprse resource planning (ERP)	Yes / No
	Zoller tool measuring system	Yes / No
	Chips cutting tools	Yes / No
	Tool Data management (TDM)	Yes / No
	BLUM lazer measuring system	Yes / No
	Zero point clamping system	Yes / No
	Cad/cam system	Yes / No
	Post processor	Yes / No
Thermal drift	Is the cooling system of the machine conform the norm of NTS Norma to controll the termal drift	[pressure] [Temperture difference] [Internal machine cooling]
Chip removal	Chip removal of the machine. The reliability of the chip removal system, without human actions.	[bad - perfect]
Machine software	The reliability, calculating speed and precision of the machine software.	Calculation speed Precision [# numbers behind the comma] Memory capacity
Automation	Indication of the automation of the machine. There are two levels possible within NTS Norma: Dayshift, 24/7 production.	[Dayshift, 24/7 production] Upgrade to 24/7 possible?

Risk on downtime - Reliability	**Description**	**Dimension**
Machine software	The reliability, calculating speed and precision of the machine software.	Reliability
Singular machine	Singular machine, so one available in the entire production hal. In case of downtime, no backup available for this machine.	Yes / No
Product group	Can the machine's product group be transferred to another machine, with only making small adjustments.	Yes / No
Strategy	Are there products produced that have a strategical position that cannot be transfered to another machine or outsourced to another company?	Yes / No
Marked product capacity	Is the marked demand high enough to fill the full capacity of the machine.	Capacity per year
Competitor	Can we compete with the current machine to the competitor	Yes / No
Failure mode, effects, and criticality analysis (FMECA)	Perform and keep track of the FMECA. With the FMECA, the risk of downtime can be made visual.	[Days]

Conformance	**Description**	**Dimension**
Maintenance machine status	Get information about the status of the machine from the maintenance department. This will give an indication about the defects of the machine. Defects could be translated into maintenance actions and costs.	[Slecht - perfect]

Dependability	Description	Dimension
Spare part delivery	Spare parts must be delivered for at leasts 10 years after the investment. After this 10 year, more risk on long downtime.	[Year]
Delivery time spare parts	List with critical parts and expected delivery time and stock. Are there spare parts on the list that are longer than NTS Norma can accept?	[delivery time in days]
Stability test Cutting tools	Test setup that can be executed to test stability of the machine, using the expected lifetime of cutting tools.	[%]
People	**Description**	**Dimension**
Machine knowledge	How many operators have the knowledge to operate or programm the machine.	[#]
Maintenance knowledge	How many mechanics are available with enough knowledge to maintain the machine.	[#]
Maintenance reaction time	Time between identivication of the problem and the arrival of mechanics.	[hours]

FIGURE 39: TECHNICAL LIFE MODEL

For the final model representation of the economical life, fictional data is used to check whether the model visualizes the expected outcome. The end goal for the model is to visualize the economic life of the machine, as is showed in Figure 40. To visualize the economic life, the data described in the previous chapter is needed. Important is that the used data is reliable and usable.

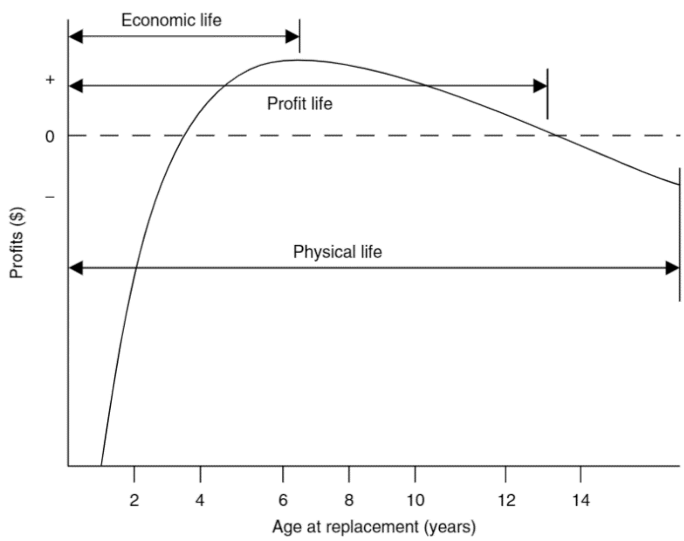

FIGURE 40: THEORETICAL ECONOMIC LIFE [7]

Due to all missing data, a fictional data set is made based on experience of the operators and specialists within NTS Norma.

This fictional data set can be found in Figure 41 and Figure 42. The benefits are increasing the first years due to the learning curve for a new machine. After that, the benefits are fluctuating between 360.000 and 450.000 euro. After around 10 years, the benefits are reducing because more downtime is expected.

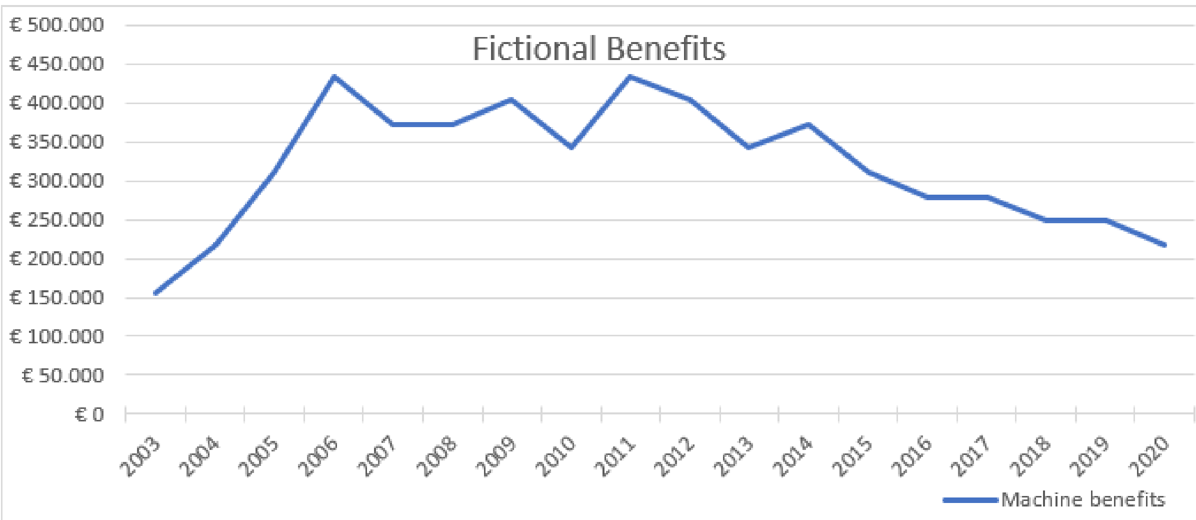

FIGURE 41: FICTIONAL BENEFITS

The fictional costs is partly based on experience from the found data and knowledge from the craftmanship of NTS Norma. The loss of value is based on the case study of the DMG DMU 50 EVO.

These costs where known, so can be re-used in the fictional costs. Maintenance costs are based on the data from DMG DMU 50 / 70 EVO. In this data set was observed that the first years of operating, the maintenance costs where low. After a certain moment in time, the maintenance costs where raising with sudden peaks, as can be seen indicated with the orange line. The tooling costs are filled in based on experience from the operators, where old machines can endure shorter tooling lifetimes in comparison with new machines. This means that after a certain moment in time, the tooling costs can raise, indicated with the green line. The downtime can raise due to for instance small errors, corrective maintenance or unavailable spare parts.

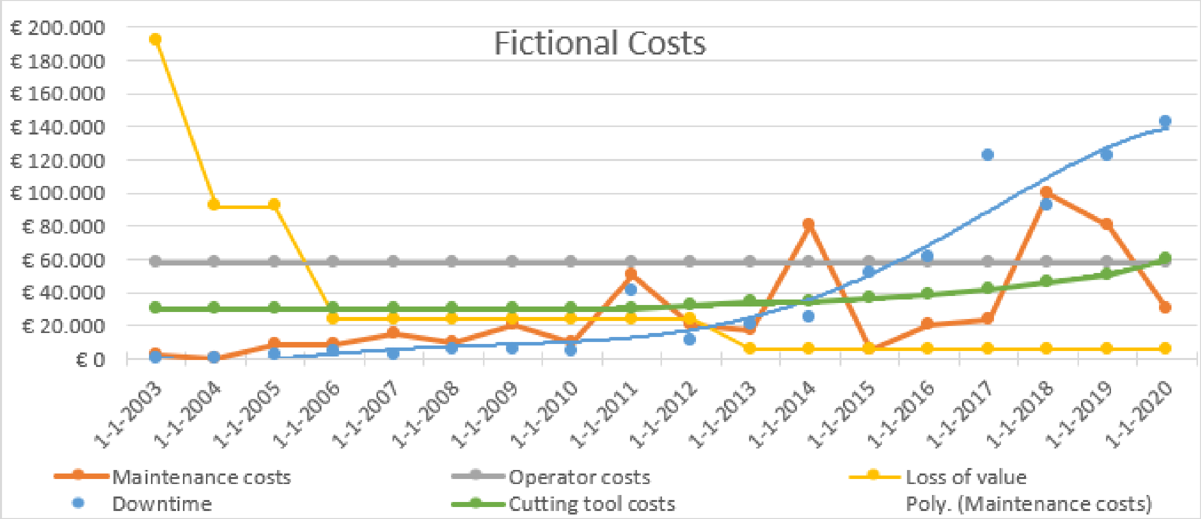

FIGURE 42: FICTIONAL COSTS

With this data, the economical life can be calculated. The economical life is determined, using the average benefits per year. The point where the average benefits per year is maximized is called the economical life, because at this point, the benefits are the highest. To make the average benefits per year, the cumulative benefits are required. This is made by adding all benefits and costs for every year, resulting in the total benefits, which can be transformed into the average benefits per year. This is done by dividing the cumulative cash flow by the lifetime of the machine. So if a machine is 3 years old, the cumulative cash flow will be divided by 3. This graph is visualized in Figure 43.
In this graph can be seen that the economic life is reached in 2017, so 14 years of lifetime. After 2017, the average benefits will reduce slightly over time, indicating that the total benefits will become lower.

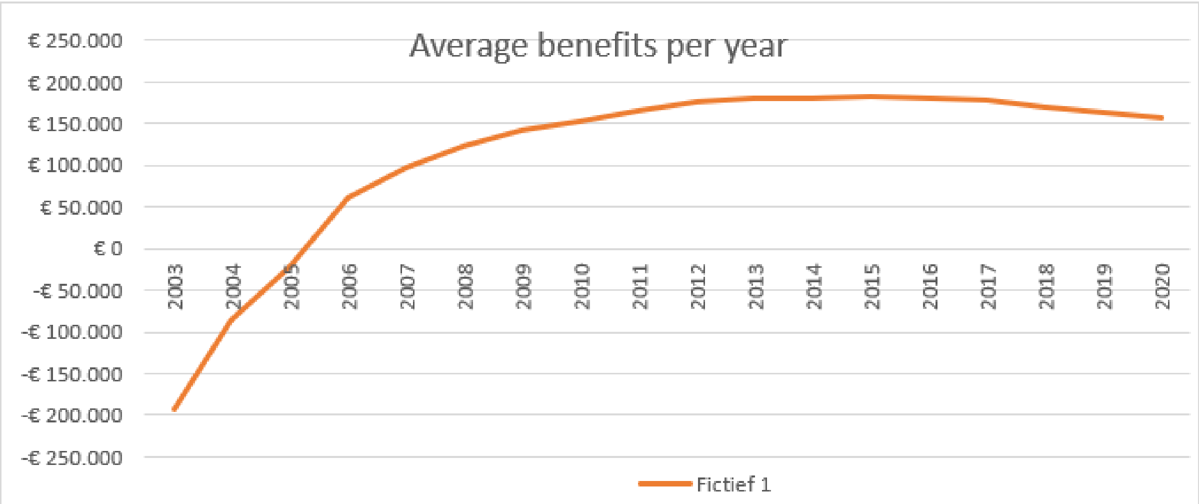

FIGURE 43: FICTIONAL AVERAGE BENEFITS PER YEAR

This graph can be used to indicate the economic life of the machine. There is only one minor downside in the graph, it is based on historic data, so data from the past. This means that the economic life is passed before this can be seen in the graph, resulting in an sub-optimal solution.

For this reason, multiple approaches are made to use this model in the best way. The company can decide the best method of use, depending on the strategy and risks.

1. The machine will be replaced when the economic life is exceeded. This means that the decision maker will wait until the economic life is reached and the average benefits are slightly reducing. At this point, the decision maker did not reach the economic life, but will gain an better result in comparison with the current situation.
2. The economic life is predicted based on the average benefits per year, using a combination between trend lines and experience. With the historic data, the future data can sometimes be predicted if it follows a certain trendline. This is for instance possible for the tooling costs, where is expected that the tooling costs are raising after a certain lifetime and probably will follow a trendline. This trendline can be derived from the historic data, as can be seen in Figure 42 with the green line. Expected is that this green will follow to grow exponentially, resulting in more grow every year. For maintenance costs, it is usual that the first years, the costs are low. After a point in life, the maintenance costs will have peak costs, due to worn out parts. After that, the machine can operator for a few years, and another peak can happen, depending on the situation. When the machine gets older, the peaks will become higher and the maintenance costs in between the peaks will raise. With this knowledge from the historic data, an expectation can be made for the future. Unknown is if this expectation is right.
3. The expected average benefits from a new machine will be compared with the average benefits of an existing machine. The goal of this method is to look if old machines that do not have reached the economical life yet can be replaced by a newer machine with higher average benefits. An estimation is done whether a machine can be replaced early to gain the higher benefits of a new machine, taking into account that an initial investment is done early.

In the first method, it is excepted that the economic life of the machine will be exceeded and after that time, the machine will be replaced. With this method, the economic life is never reached, less profit will be made. On the other side, this method is a very safe method, because the decision maker knows that the economic life is passed so this is a very clear indication that the machine must be replaced.

The second method relies on predicted data, using trend lines and experience from the decision maker. This method is based on more risks, because it is not known if the predicted data is right or wrong. In the worst case scenario, the machine is replaced too early, resulting in a lower average benefits and less profit. The advantage of this method is that when the prediction is right, the economic life is reached and the maximum profit is made.

A third method is to compare two average benefit graphs from two different machines. The goal of this method is to determine if a machine that not reached the economic life yet can be replaced early by a newer, more profitable machine. To perform this calculation, an estimation should be done on the expected benefits and costs of the new machine. The calculation works in the following way:

Situation 1:
In situation 1, the benefits in the normal situation are calculated. This is done by estimating the optimal average benefits per year, so in case of Figure 44, this will be around 2015 with a height of 182.000 euro. In 2015, the machine has produced for 12 years, so 12 X 182.000 = 2.184.000 euro.

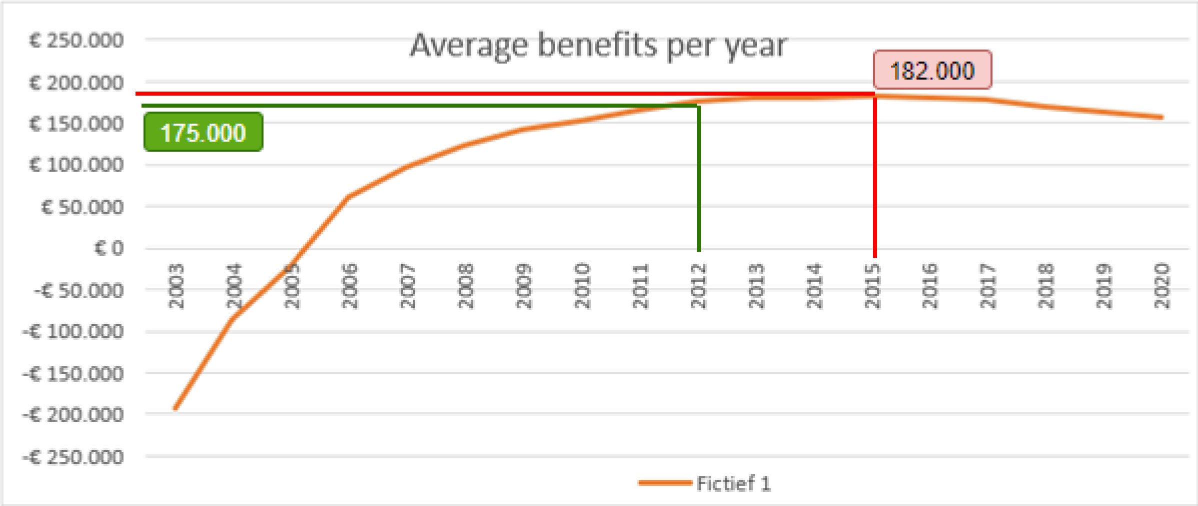

FIGURE 44: FICTINAL AVERAGE BENEFITS PER YEAR, SITUATION 1

Situation 2:
A new machine came to the marked. A test is performed and expected is that every year, 40.000 euro can be saved. That will mean that the average benefits per year will raise with 40.000 euro, resulting in a total of 222.000 euro, assuming that all other costs will remain the same. The company wants to know if the machine can be replaced 3 years earlier, by this newer machine. The benefits are calculated in the following way:
The current average benefits are used, so in year 2012, this is 175.000 euro. With this average benefits, 9 years is produced, so 9 X 175.000 = 1.575.000 euro.
The new benefits of 222.000 euro will be used 3 years early, so this will result in a benefits of 3 X 222.000 = 666.000. The total benefits are 2.241.000 euro with an early replacement of 3 years.

Situation 1 and 2 are compared. As can be seen, in situation 1, the benefits are lower in comparison with situation 2. This will mean that it is beneficial to replace the old machine before the economic life is reached by a newer machine, because the new machine will have higher average benefits per year. This early replacement will cause an early investment, but over the years, this investment will increase the average benefits per year and will result in more profit. In Table 15, the calculation can be seen.

	Years	Average benefits per year	Total benefits
Situation 1, total	12	182.000	2.184.000
Situation 2, part 1	9	175.000	1.575.000
Situation 2, part 2	3	222.000	666.000
Situation 2, total	12	-	2.241.000

TABLE 15: EARLY REPLACEMENT CALCULATION

Assumptions method 3
Important to know is the assumption of this calculation. In a real life situation, the optimum average benefits are not known exactly, so a prediction must be made. Nobody knows exactly if this prediction is right or wrong, the only thing that is known is the average benefits line from historic data and the general savings of a new machine. With this data, the curve of the graph is visual and an expectation can be made if the economic life will be reached soon. If this is the case, an estimation can be made over the maximum height of the curve. Both the current average benefits per year and the future average benefits per year are needed to perform this calculation.

The average benefits per year graph shows the economical life of the asset. This graph is calculated by adding all benefits and costs and divide these benefits and costs by the asset life. Due to the long lifetime of around 10 – 20 years, the graph has a slow reaction speed on big costs. For this reason, an extra graph is added to get additional overview of the situation. This graph is shown in Figure 45, and shows the cumulative benefits per year. The benefits of Figure 45 in combination with Figure 43, is that the economical life can be determined in more detail. From Figure 43 can be seen that the economical life is around 2013 and 2016, but this is not very clear. In Figure 45 can be seen that in 2016, the cumulative benefits are lower in comparison with 2014 – 2015. This is a good indication that the machine must be replaced.

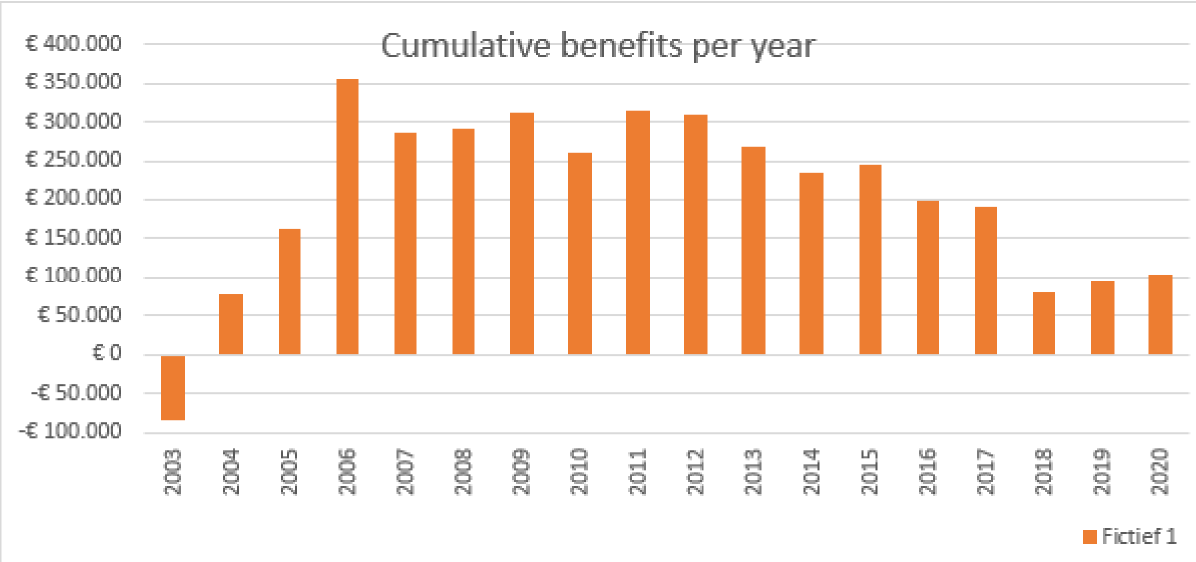

FIGURE 45: CUMULATIVE BENEFITS PER YEAR

Important for the economic life is that all four graphs are used to gain an good overview of the situation. Figure 43 and Figure 45 are used to gain an overview of the situation and determine the general economic life. Figure 41 and Figure 42 are used to gain detailed information about the situation. This information is needed when the company expects that the economic life is going to be reached. The decision maker can look into these details and search for answers why the costs are rising or benefits are degrading. This information can be used to develop an expectation of the future benefits and costs. All this information will lead to a well-founded repair / replace decision.

8 VALIDATION OF THE MODEL

From asset management is learned that in order to gain insight in the repair / replace decision, multiple topics should be investigated: Organizational strategic plan, Asset knowledge, Risk and review and organization and people. Within NTS Norma, there is a lot of knowledge from the organization and people. The repair / replace model gives guidelines to gain more information about the other topics.

8.1 Technical model

As described in paragraph 5.1, the technical model is made using success factors, literature and knowledge from the company. At the startup of the technical model, a lot of literature is found about key performance indicators. All these key performance indicators where listed in different categories, using the safety cube method. After that, practical information is gathered and used to make a new list. Important to know is that the search for this practical information is guided with the made success factors. Every success factor needs measure points to indicate if a success factor is satisfied. With multiple iterations and revisions, all important measure points are found for every success factor. This is validated using the method investigator triangulation. This method indicates that if multiple investigators come to the same conclusion, this is the apparent truth. This method is used in the company to verify the technical model. The model is revised multiple times due to new discussions with different departments. In the end, all departments agreed that the technical model was complete and no further questions or remarks could be made. At this stage, the technical model can be seen as the apparent truth, because all colleagues agree with the points and verified that the technical life model is complete and clear, resulting in a reliable model that can be used to determine the technical state of the machine.

An important fact about the technical life model is that it is a dynamical model, meaning that it will change over time. In other words, without continuous improvements to the model, it will be outdated over time, resulting in a model that is no longer useable. To keep the technical life model up to date, it should be revised in a regular bases, depending on the technological improvement of the company. The faster the company improves the technology, the faster this technological model should be revised.

8.2 Economical model

The economical model cannot be validated into detail. This is because for the economical model, a lot of reliable data is needed. This data is not available, resulting in a theoretical model with incomplete information. To validate the model, a fictional set of data is made to see if for a full set of data, the result is expected and desired. This fictional set of data is made using experience from the company and seen results of the current incomplete data sets. From this fictional set of data can be concluded that it is plausible that the model will work with a complete, reliable set of data, because it shows the economical life as expected. In the theory was shown that the economical life is reached if the average benefits per year are maximized. The current model with the fictional data set shows this curve, indicating that it is plausible that the model will work with a complete reliable set of data. A full validation of the economical model cannot be given due to unknown information. In a later stage, where this data is made visual and reliable, the validation of the model can be done in more extend.

What is known about the economical model is that it is based on the biggest cost factors within NTS Norma. These cost factors are determined by questioning specialists and discussions about the gained information. Important fact is that these costs factors are stated as the biggest costs factors from NTS Norma, so the costs factors that have the most impact on the economical life of the asset. It is possible that there are more costs factors available, for instance the electronical costs, but these costs are significantly smaller or with smaller fluctuations than the used costs in the economical model. This indicated that these smaller costs with smaller fluctuations will have a small contribution in the final decision whether the machine has reached the economical life. Adding these small costs can be seen as fine tuning of the economical model which is not included in this thesis due to time considerations. In a later stage, these smaller costs can be added. Important is to take into account the general overview of the model. Too many costs can result in a unclear image where the minor costs take too much attention and mayor costs are overlooked.

9 CONCLUSION

In this thesis, the following main questions are answered:
How can NTS Norma gain within 28 weeks overview and a well-founded repair / replace decision regarding milling machines?
Which input is needed to get an overview and a well-founded repair / replace decision and how can this data be gathered in the future?

The main questions are answered using asset management as a guideline for the process. Asset management can be divided into different topics: Strategic plan, organization and people, Asset knowledge, Risk and review. In the beginning of the project is concluded that the knowledge about the organization and people is very high. Other topics such as asset knowledge and risk and review are rather unknown, due to data with a lot of assumptions, missing data and lost information. The strategical plan (Vision / strategy) was not clear due to a missing visualization and an incomplete overview. If all key elements of asset management are improved, this information can be used to make a repair / replace model that gives overview and a well-founded repair / replace decision regarding milling machines.

In the preliminary investigation, the researcher looked at the current situation of NTS Norma and possible approaches to get an answer to the main questions. From this preliminary investigation could be concluded that the repair / replace decision of NTS Norma is mostly based on the knowledge and craftsmanship of the people. A small portion of information is based on data, but this data is usage independent and does not provide information about the actual state of the machine. From asset management is learned that NTS Norma does not use enough information from data or risk management, resulting in an incomplete set of information to make a well-founded repair / replace decision.

After the preliminary investigation, the vision of NTS Norma is visualized. At the beginning of the project, the vision of the company was not clear nor transparent. Colleagues have told the researcher halve sets of information, and sometimes, contradictions to other stories. After multiple conversations with decision makers, the vision became clear and is visualized. This vision is used in the process to give guidelines to the repair / replace model.

In order to design a repair / replace decision model for NTS Norma, the key factors of the repair / replace model must be determined. This is done using a repair / replace decision chart from asset management. From this chart could be concluded that a proper repair / replace decision model consist out of two key factors, Technical life and Economical life, both equally important. Due to the big difference between technical and economical life, two models are made that indicate if a machine must be repaired or replaced. The combination between these models gives the overview and well-founded decision NTS Norma needs.

In the technical life, the machine will be tested on the requirements of NTS Norma. This model will give insight in the difference between the current machines technological performance and the technological development available at the market. A changing technological development can result in a changing vision and strategy, due to new inventions or optimizations of the current machines. This changing vision and strategy affects the technological life of the machine. The “old” machine cannot for instance cooperate with new systems. To indicate these technical issues and give overview and foundation to the technical life, all important technical, maintenance independent topics are listed. To ensure that all important topics are found, success factors are made. This is done using the safety method in combination with Garvin’s eight dimensions of quality. For every success factor, multiple measures are found which will help the decision maker to get an overview of all success factors and thus the technical life. The measures in combination of the vision of the company will decide if the machine has reached the technical life. Important for the use of this model is to update it regularly, to make sure it is conform the current vision and strategy of NTS Norma. This model can only be used by NTS Norma and is not suitable for other companies, because it is based on the vision and strategy of NTS Norma. The progress to gain this model can be used by other companies.

For the economic life, a lot of data is gathered within NTS Norma. The goal of the economic life model is to determine the optimal economic life, this is the point where the average benefits per year are maximized. To determine this point, all cash flows must be gathered. For this thesis, the biggest costs of NTS Norma are depreciation cost, downtime cost, maintenance costs, tooling costs and human costs. This list is designed using the knowledge of specialists from NTS Norma. All these cash flows are gathered using different methods and systems, some data was already partly available, some data was unknown. All data is checked for human errors. After that, the time between data points is made equal using extrapolation. When the data was made clean and usable, the assumptions within the data are determined. All this information is used to determine if the gathered data is usable and which aspects from the data must be improved.

At the end of the data gathering process is concluded that the following data set is unavailable or from poor quality: Downtime costs, tooling costs, and uptime benefits. For this reason, the data is deemed as unusable. As a result, the economic life model cannot be used in the current situation and improvements must be made to gain a better, more reliable set of data in the future.

Due to this conclusion, a roadmap is made to indicate the important steps to gain a usable model that can be used to gain an overview and a well-founded repair / replace decision. The data set “uptime, downtime and tooling costs” need to be improved in order to determine the economic life of a system. This data was unavailable or from poor quality.

From a previous study within NTS Norma, research is done in a manufacturing executing system (MES). A MES system is a system that can be installed on a manufacturing machine and is coupled to all sensors available in the machine. The system can read / gather the information from the machine and store this data / information into a data system. This whole process is automated and the data is directly available for usage.

To improve the up- and downtime data gathering, the overall equipment efficiency (OEE) can be used. The OEE describes the efficiency of the asset, using the downtime, production speed and scrap. This information is needed to gain a reliable set of data of the uptime and downtime costs.

The total amount of tooling costs are visual for NTS Norma. Unknown is which machine used these tooling costs, so the traceability of the tooling costs is unknown. In the current situation, tooling costs are booked out using a tool cabinet combined with a tool data system. Tooling costs are booked out with a personal number. To improve this process, tools need to be booked out using machine numbers and product numbers. This can for instance be done with the use of barcodes, to reduce human errors and improve the speed of this process. In this way, the traceability of the tools is made visual, resulting in reliable data.

To conclude, the main questions are answered by making a model for the repair / replace decision, by dividing the problem into two different models, the technical life and economical life, both methods equally important. For the economical model, new improved data is required in order to use the model in the future. The technical model must be adjusted according to the changing vision of the company and technical improvements of the market. If the information of both models is available, a well-founded repair / replace decision can be made that is understandable for non-experts.

In comparison with the old repair / replace model, this new model uses reliable data to calculate the economical life, instead of looking at usage independent parameters. On top of that, the technical life model will show the difference between the expectation of a machine in comparison with the actual machine. In the old situation, this comparison was partly done by the experienced decision maker, but could not be made visual for the rest of the company, resulting in an unclear story. This new model should give guidelines and overview to the repair / replace decision that is user friendly for the decision maker and clear for the rest of the company.

10 DISCUSSIONS

This master thesis is performed during the covid_19 pandemic. At the start of this thesis, most of the company was working from home when possible and meetings where taken online using teams. The startup of the project was more complex than normal, because the researcher could not just walk over to somebody to ask questions or gather information, but arrangements had to be made in order to speak to colleagues. The researcher was allowed to work at the office with the colleagues directly involved to the machines, for instance maintenance manager, operations manager or work preparation. Due to these strange working conditions, the startup of the project took longer than expected. The time it took to gain contact to new, unknown colleagues is longer than in a normal situation, without covid_19. In the end, this delay cannot be seen in the end result of the master thesis, due to a good planning that is adjusted during the project.

At the start of the master thesis, the company did not know exactly what kind of model was required or needed to calculate the repair / replace model. To gain this understanding, extra time is scheduled for a lot of conversations with different decision makers. A new model is designed using this information together with the found literature. This model is unique due to the combination between the technical and economical model. Most models use a process to predict the most optimal time to replace the asset, depending on assumptions that may not be true or applicable in all situation. This method is not suited for NTS Norma. Therefore, a new, totally different approach is designed. In this design, specific measures from NTS Norma are used. Due to this long approach at the beginning of the project, the designed model is properly designed according to the needs and knowledge of NTS Norma, resulting in a repair / replace decision model that can be used into the future.

The technical life model is a dynamical model, meaning it will change over time. If NTS Norma has interest in keep using the technical life model, it should be adjusted at a regular basis. The model describes the gap between the technical development from the market and the constant technical machines from the company. The technical development from the market is constantly changing. Due to these new developments, the technical life model will change, because the technological gap is growing and old machines cannot compete to the new vision of the company.

Finding useful papers for the technical life model was hard. There is a little bit of information available on the internet, but most of the times this information was unimportant for NTS Norma and did not fit in the vision of the company. Most companies hold these specific information classified, because this information strengthens the competition position. Therefor, the researcher has searched for KPI's that could be used to determine the technical state of the machine. This information is then used to gather information within NTS Norma to design the technical life model. Looking back at the process, the researcher thinks this was the best choice. The internet is used to gather a general overview of possible measures. This in combination with the broad experience of the company, a good technical life model is designed.

The economical model cannot be validated, because a lot of reliable data is needed. This data is currently not available or from unreliable quality. To gain more insight if the model can work, a fictional set of data is made. This is done using experience from the company and seen results from the current incomplete dataset. From this fictional set of data can be concluded that it is plausible that the model will work as designed, resulting in a visualization of the economical life. In the future, reliable data should be used to verify the economical life model in detail.

During the data gathering is concluded that the uptime data is incomplete and does not describe the yield of the machine. To gather and process the data of the uptime from NTS Norma and HTM took some time, but at that time was not known that this information did not describe the yield of the machine. If this was known in advance, less time could have been spend to the current data set and more time was available to look at the product data. Maybe this data could have helped to gain more information about the benefits of the machine. The end result of the economical model will not change. As said in the road map, the OEE fits perfect to measure the benefits of the machine. This means that in the future, the OEE should be measured, instead of using the current data sets.

The workload of the machine is still unknown. The current data within NTS Norma could not give reliable information about the workload of the machine. Furthermore, the researcher has not found an alternative way to measure the workload accurately, taken into account that the workload is product dependent. To let the model work, an assumption is made that in a 24/7 production environment, the operator is working 8 hours a day at the machine. In this time, the operator has no spare time to do other side tasks, besides operating the machine. In reality, this is not true. To gain information about this ratio between main operating tasks and side tasks, an alternative approach is needed. Important is that this approach should not increase the workload of the operator. The most optimal situation is that this ratio is measured without human actions.

In this master thesis, a tooling test is done to determine if machine stability influences the cutting tool life. At the start of the tests, the cutting parameters are used from previous tests, but due to an excessive wear rate, the cutting parameters are adjusted. The cutting speeds are now based on found production programs, but these cutting speeds are too conservative. The test took 6 hours to perform with 5 hours of production. Normally, the lifetime of the used cutting tool in RVS is around 100 – 120 min, indicating that the test is too conservative.

After some discussions with the specialists, expected is that the stability of the machine is not used during these conservative cutting speeds. The forces acting on the mill and machine are too low. The test should be redone in the future to gain trustful results

11 RECOMMENDATIONS

To improve the dataset of the up- and downtime, a new system is needed for the machines. This system is called the MES system, and measures all sensors from the machine. MES systems are available from different brands with different features. To gain more insight into the MES system, research can be done to compare different MES systems. After that, the system that fits best into the requirements should be chosen and installed on the machines.

For the tooling costs, locked cabins in combination with a TDM system are used to gather data. Right now, this data is divided between the operators and tool setters. Unknown is which tooling costs are used at which machine and for which product. To increase the quality of this data, the way of processing data should be changed. Right now, only the operator code is used to look out cutting tools. In the future, the tooling costs should be gathered using the machine code and product code. These codes can then be used to divide the costs into the category machine and product, which are needed to gain information about the machine costs.

The data of maintenance costs where clear and reliable for the economical life. Nevertheless, improvements can be made to improve the information from the data, usable for the maintenance plan. To implement data into the system, different fields must be filled in. These fields are: Data, machine, working order, working company, taken actions, action category, price, remark. The big improvement that can be implemented is the field: “taken actions”. This field is now filled in using a description of the work. At the moment when the actions are taken, this way of reporting data is good. The big disadvantage is that in the future, the company cannot learn from their mistakes. It is unknown what machines have endured which problems and solutions, because this cannot be found using key words. To gain more information, the description should be divided into multiple topics. The first topic is a predefined category, so in which category does the problem fit? This can be done very detailed, but also more in general, depending on the vision of the company. For instance, which part of the machine endured a problem and under what problem can this be reported? Important is to use clear key words that is commonly understandable by the maintenance engineers and managers. After that, the problem and solutions should be described. In this way, the maintenance engineer can find problems of the past together with a possible solution.

The depreciation costs are now based on literature and experience. From this, an estimation of the market value of a machine is made. This estimation can be improved, by making and updating a list with current selling prices from machines. The list can be used to get an practical understanding of the marked value of a machine over the years. Important is that this list is updated regularly, because the marked value can change over the years.

The tooling test is done to find out if machine stability influence the lifetime of cutting tools. Due to conservative cutting speeds, the results of the test did not match with the practical data. To gain better results that are plausible, the test should be redone with other cutting parameters. These cutting parameters should be more representative to NTS Norma’s standard. A first indication is made for improvements of the test setup. The milling specialist should determine the exact changes to gain a good result.

- Use a larger mill with a diameter of 12mm. This mill will increase the cutting forces and will force the machine to use the stability to get good cutting results.
- Search for cutting parameters in which the cutting tool breaks in around 100-120 min.
- Make sure that one person measures the flank wear. This will reduce human errors, because the measure points are measured in the same way.

The last topic of the recommendations is the data system. Right now, a lot of data is stored at different locations and are not coupled to each other. To derive graphs from the data automatically, all the data from all topics should be stored at a central location. Important is that the data is stored within short intervals, to ensure that the data is always up to date. This data storage system can be used to derive graphs, that are needed for the economical life model.

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APPENDIX LIST

A: MACHINING PARK

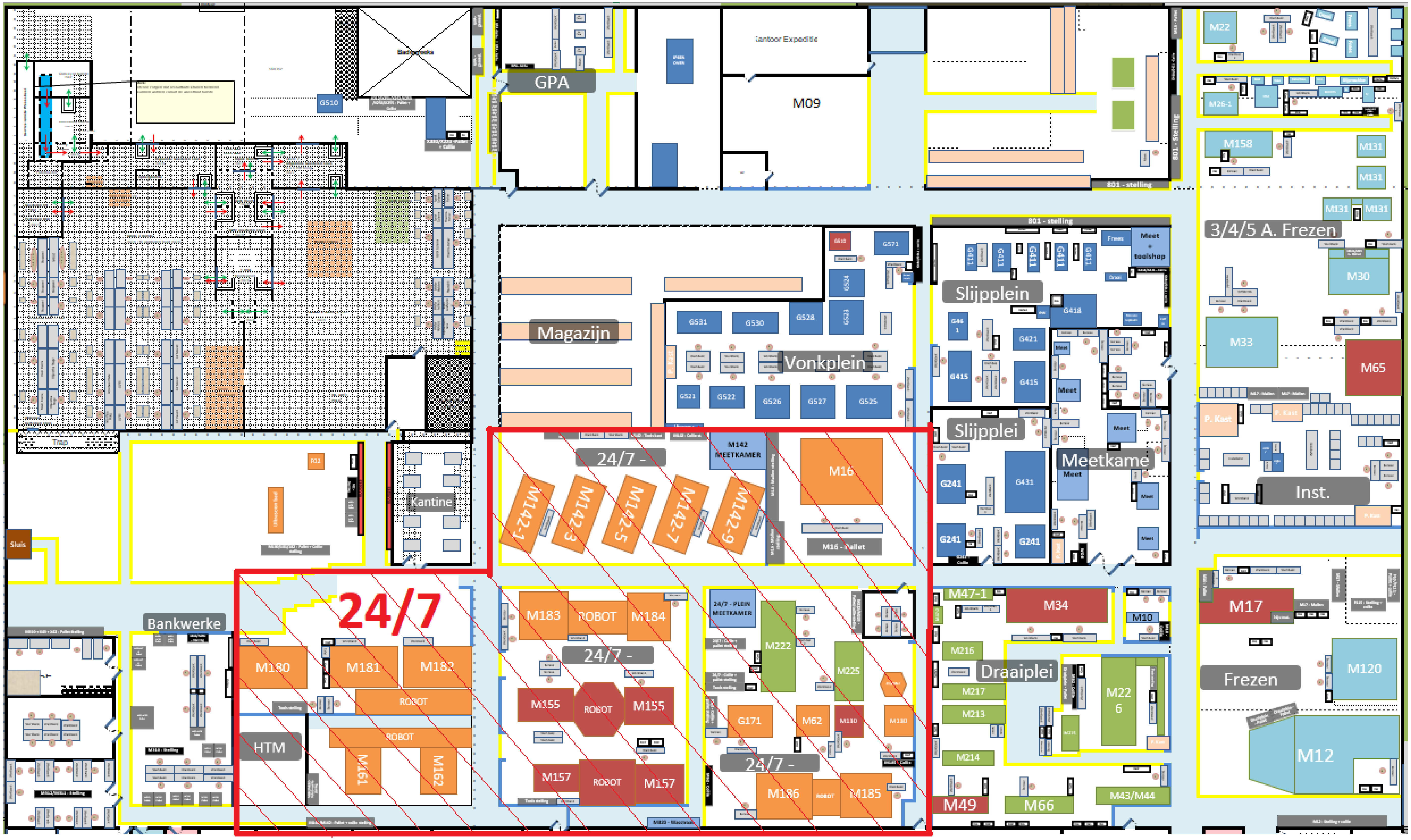


FIGURE 46: MANUFACTURING MAP

B: STAKEHOLDER ANALYSIS

In this paragraph, a stakeholder analysis is performed. In this stakeholder analysis, different people from different perspective are asked some questions to gain information about the repair / replace decision. This is done to get an wide view of the problem and gain information about all important topics. An overview is made to indicate the most important stakeholders. This can be found in Figure 47. A short summary of every conversation is made to give more insight in the process. Some summaries are put together, because the told information was almost the same.

Interest of stakeholder			
	High	**Keep informed**	**Know expectation and keep closly informed.**
		Project manager imrovements Production manager	Maintenance engineer
	Low	**Regular contact**	**Know expectation**
		Software engineer Work preperation Operator Planner Marketing department Quality Operator Master planner Planner	Director
		Low	High
		Influence of stakeholder	

FIGURE 47: STAKEHOLDER ANALYSIS

PROJECT MANAGER TOOLING IMPROVEMENTS

The project manager tooling improvements is busy optimizing the process of tooling. There is made a plan to upgrade the production process from a product dependent process to an process dependent process. The big difference between these two processes is that production dependent process optimizes the process looking at specific products and production depended process optimizes the process looking at the whole process. The advantage of production depended process is higher logistical flexibility, minimal programming time, less spare parts, lower chance on errors and the most important, predictability.

What are important topics for machine replacement?

Important topics are: Costs vs profit; Performance/tolerances of replacement machine; reprogramming time; tooling; release FAI.

The costs versus the profit is very important. This information can give you insight at what time, the machine can make the most profit and at what time the machine is too expensive.

When a new machine is bought, it is important that it is functioning in the same or better conditions than the current machine, so the performance and tolerances should be the same or higher than the current machine.

Reprogramming time is a non-visual cost that can cost a lot of money. That’s why this topic should be covered in the repair/replace decision.

The last topic is the release of a FAI, first article inspection. This is sometimes needed or requested from the customer.

What is the influence of a better repair/replace decision on your work?

The project manager tooling improvements has not a direct influence in the repair/replace decision. The progress after the replacement of a machine is more important, because a new machine will be chosen and a plan must be made to get this machine into the plan for tooling.

What is the optimal situation for a good repair/replace decision?

The machine is replaced when it is not producing profits, except when this machine has an strategic function to keep the customer satisfied.

The machine is chosen such that a group of these machines can produce specific product groups (big, small, precise, rough). Within these machine groups, different product are interchangeable.

MAINTENANCE ENGINEER

The maintenance engineer is responsible for the preventive and corrective maintenance and tries to keep the uptime of the machines as high as possible. The maintenance engineer is closely related in the repair/replace decision, because he/she knows the current state of the machines.

What are important topics for machine replacement?

Important topics are: Performance machine; Safety; Age / spindle running hours ;Visual and nonvisual costs; Chance on waste; Tooling costs.

What is the influence of a better repair/replace decision on your work?

Huge, when a plan/model is available, the maintenance engineer can use this to determine which machine must be replaced. These machines are not repaired or maintained anymore. The model can also be used to convince the financial engineer to invest in new machines.

What is the optimal situation for a good repair/replace decision?

Put some parameters from different machines into the model and give me advise on which machine must be replaced. Model must be compatible for different machines and can be used to compare different machines.

Interest in this project.

Yes, when performed properly, model will provide insight in the process of machine replacement. This can be used to make better decisions in when and why machines should be replaced.

MARKETING DEPARTMENT

The marketing department is responsible of buying machines, equipment, spare parts, making contracts with the supplier, etc.

What are important topics for machine replacement?

Technical and financial aspect need to work together. Right now, engineers choose the machine, marketing department will buy the machine. More optimal approach is to use knowledge of both technical and financial. This can lower the total cost of ownership, because cheapest or most reliable supplier can be chosen. Supplier is responsible for machine, critical parts, after sales service, etc.

What is the influence of a better repair/replace decision on your work?

Choice to replace a machine can be addressed earlier and with a better understanding. Model will use information from different perspectives, resulting in more insight and influence from different perspectives. The marketing department can get better deals due to better understanding and influence of the machine, resulting in bigger supplier selection and negotiation.

What is the optimal situation for a good repair/replace decision?

Choice to replace is addressed early, marketing department and engineers look together for an alternative machine and compare this with the current machine. This can result in a wider range of suppliers, negotiation can take place and costs can be reduced.

Interest in this project.

Relatively high, because a good model can result in more influence of multiple perspectives, better negotiation position, better understanding in choices and lower total cost of ownership.

SOFTWARE ENGINEER

The software engineer is responsible for making the cnc milling program. This program can be uploaded to the machine, after that, the machine is able to read this program and make the product.

What are important topics for machine replacement?

Important is the geometric quality of the machine. The geometric quality is the range of accuracy where the machine can work in. For the operator, this parameter is important, because this indicates how accurate the machine is in comparison with the required product. If the machine is very accurate and a product must be made that has less accurate tolerances, the product can be made easily. In the past, these accuracies where measured with a milling block. This milling block was measured and could tell something about the accuracy of the machine. Right now, this is done ones a year with an other measure, called the ballbar measure. This measure is performed in the yearly preventive maintenance action, to measure the accuracy of the machine in x-,y-,z-axis.

Another important topic is the safety of the operators. When a machine degrades over time, the safety of the machine can become lower. In the replacement policy, this will always result in replacement or expensive repairs.
In a repair/replace decision, it is important to look at the product group that is made on the machines. This product group can be very specific and only suitable for a small range of machines or even one machine. This particular machine can be degraded a lot and maintenance costs can be very high, but there can be a good reason to keep that machine. If you are the only one that can produce this product, this product can deliver a lot of side products, that you can loose if you stop producing that one product. That means that this unprofitable product can indirectly produce money with alternative products.

What is the influence of a better repair/replace decision on your work?

If a new machine is bought, the software engineer must make new programs, new simulation of this particular machine and new tooling software is made.

What is the optimal situation for a good repair/replace decision?

Standardization is very important. If standardized machines are bought, the software engineer can reduce the programming time.

DIRECTOR

What are important topics for machine replacement?

For a good repair / replace decision, a financial analysis should be performed, to indicate all cash flows of a system. Important cash flows could be residential value, investment, maintenance costs, tooling costs. The director thinks that there are a few topics that can be changed: Spare parts costs, Maintenance labor costs, residential value and tooling costs. Other costs are assumed to be fixed costs that have to be made but cannot changed in value or height.

What is the influence of a better repair/replace decision on your work?

If the repair / replace decision gets a better foundation, the director can more easily decide if an investment must be made to replace a machine. Also, there is possibly more insight in the future data, that can help to make other decisions as well.

What is the optimal situation for a good repair/replace decision?

Due to the director, the optimal situation is to determine the residential value and replace the machine when it has a high residential value. He thinks that a high residential value results in a low total cost of ownership.

Interest in this project.

Designing a cash flow diagram to get insight in the measured data and convert this data into information.

PRODUCTION MANAGER

What are important topics for machine replacement?

The production manager thinks that the difference between costs and quality is important. For NTS Norma, the goal is to guarantee 99.85% quality products. To achieve this goal, certain costs must be made to keep the machines in a certain quality. In the best situation, the costs are as low as possible while remaining the 99.85% quality products.

What is the influence of a better repair/replace decision on your work?

The model will reduce the workload of the employees. Right now, a lot of conversations and work must be done to indicate if a machine is ready to replace. Due to the poor foundation of the current repair / replace decision, this will take a lot of time to understand.

What is the optimal situation for a good repair/replace decision?

A model that predicts the repair / replace decision. The delivery time of machines is currently almost a year. If a model can predict when a machine should be replaced, the initial investment can be done in advance.

Interest in this project.

Improved market position, because costs can be reduced due to predictability and foundation in the repair / replace decision.

WORK PREPARATION 1,2

What are important topics for machine replacement?

Important is to look closely to the product group of the machine. Some product groups are not suitable to change from one machine to another, due to specific tolerances, working area or stability. When machines are replaced, this should be known or available information.

There are a lot of invisible costs in the repair / replace decision, such are new software program, new tools, new fixating tools, unknown childhood deceases or release of the first article inspection.

What problems can be expected with new machines?

For every machine, a post processor is made. This post processor is the chain between computer software and machine software, and makes sure that the motions of the program in the computer convert exactly the same as on the machine software. To make this post processer cost a lot of money and time.

What is the influence of a better repair/replace decision on your work?

Due to a better foundation and prediction, the work preparation can think better and more in advanced when and where the current products must be produced.

What is the optimal situation for a good repair/replace decision?

An situation where all machines are standardized, to get a flexible logistic situation where products can easily change between machines.

Interest in this project.

If the repair / replace decision is made in advance, a better planning can be made for the current products and where to produce them.

WORK PREPARATION 3

What is the optimal working situation for work preparation

For work preparation, it is important to have machines with high performance, low costs that work in a 24/7 process. The machines must have high quality, even if only low quality products must be made. These high quality machine ensures a higher reliability and thus predictability, resulting in more uptime and more benefits. High quality machines also improve logistic flexibility, because a larger range of products can be made on the same machines.

Which machines can be replaced?

The whole 3 4 5 plein, due to the old, product dependent machines that can only produce a small product group. These machines are working without a backup machine, resulting in higher risks when one machine endures downtime. All products cannot be produced anymore, till the machine is repaired. This can result in long throughput times.

Which costs can be expected when a new machine is bought?

Tool sockets; foundation; isolation; training; post processor; product clamping system; robot; maintenance contract; lease VS Buy; first pass product.

QUALITY

What are the differences between old and new machines?

Old machines have a high error rate, resulting in more downtimes and uncertainty in the system.

How can you ensure quality?

During production, periodic measures are done on the products and machines. This is a indication of the quality of the machine. On top of that, a good maintenance plan can result in well maintained machines that are more reliable. This reduces the risk on quality issues.

OPERATORS

What are important topics for machine replacement?

Operator 1 tells that it is important what products are made on which machine. Is it possible to change this product to an alternative machine or should a new machine be bought that is able to produce the current products? When a machine is phased out, NTS Norma not always buys a new machine. The other possible solution is to use an over capacity of the current production hall.

Which machine from the current machine park can be replaced and why?

A few machines can be replaced, these machines are old, have a lot of wear in the tool slide mechanism and the relays are sticky, resulting in a lot of downtime.

Which problems have old machines?

The electronics are old and become sticky, resulting in a lot of unexpected downtime. Fluid and electric cables are hardening, resulting in surface cuts and in the end, leakage and dangerous situations.

In addition, there are more problems to produce in a predictable way. Chips control is harder for old machines, scratches can be made on the products or spare parts are not available.

MASTER PLANNER

What are important topics for machine replacement?

The machine must be in a technical good shape. Products can be exchanged between different machines, so the machines should be identical to each other. The machine can produce in a human-free production environment. This means that most of the work can be done without human actions. The last important factor is the time to change between different products. The faster this process is, the better.

Which problems have old machines?

Products cannot be exchanged between machines from different lifetimes, due to differences in features that changed over time.

PLANNER

What are important topics for machine replacement?

Important are the dimensions, geometry and product interchangeability of the machine. These parameters determine which products can be made on which product and if there is a machine that can be used as backup for the other machine.

Which problems have new machines?

For new machines, a new first release must be done for a couple of products, depending on the product group of the new machine.

Which problems do have deteriorated machines?

Due to the deterioration, the geometry of the machine reduces, resulting in less accurate and predictable machine. After a certain amount of years, the maintenance costs will raise due to deteriorated parts that need to be replaced. Wear and errors are also problems for deteriorated machines resulting in more downtime. Due to this increased downtime and reduced uptime, the capacity of the machine is reducing.

C: VISION EXTENDED

COMPANY VISION

The vision of the company is made using the information of the stakeholder analyses. This stakeholder analyses can be found in appendix C. The paper of Rajabalinejad, Dongen and Ramtahalsing is used as a guideline to sort all topics that are included into the vision [6]. In that paper, the vision is divided into different levels from small to large. The lowest level starts with the technical system integration. In that paper, they have chosen a train system, rails subsystem and catenary subsystem. One level higher is the human system, so how is the technical system used by the human system. After that, they choose a system of system integration, sociotechnical system integration, political system integration and global integration. This process can be used to look at the vision from a high point of view and the goal is to gain a wide overview of the vision of the company. For the vision of Norma, the following levels are used: Output; Machine; Machine system; Market; Company; Government. Every step will be discussed. The visualization of the vision can be found in Figure 54.

GOVERNMENT

This is the highest level at NTS Norma. At this level, all norms that the company has gained are stated. These are: NEN 3140, ISO 14001 and AS9100.
The NEN 3140 describes the safety of the electrical systems. This norm can be gained if regular predefined checks and regulations are performed, regarding to the electrical system [22]. These regulations and checks are made to make sure that the electrical system is safe to use and performing accordance to standards.
ISO 14001 give guidelines for the environment. This norm will make sure that the company reduces the environmental impact [23]. Also, the norm will force the company to compete with all laws and regulations related to environmental impact. This is done by following a management system based on a plan-do-check-act model of Deming [24].
The last norm is the AS 9100 norm. This norm gives an indication of the quality Norma can achieve. This norm is a certification that the company is able to design, develop or manufacture aviation, space and defense products. Without this norm, the company is not permitted to manufacture products for the markets they work for right now. To gain this norm, the processes to make the products must be stable and controlled in the right way [25].

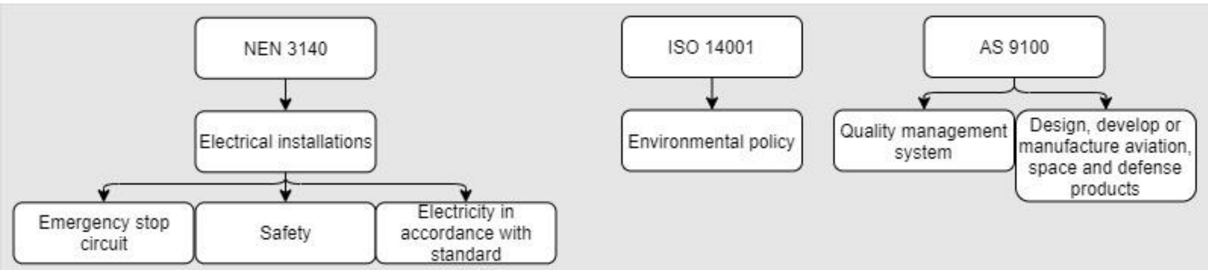


FIGURE 48: GOVERNMENT

COMPANY

The company has a clear vision. The most important topics in the company are safety and 24/7 production. At all costs, all people should have a safe working environment. Accidents must be prevented at all costs. If there is a safety related problem, Norma search for the root cause immediately and solves this root cause either with maintenance or replacement.
24/7 productions is important for the competition between other countries. In the Netherlands, the salary of people are high compared to other countries like china [26]. To compete with these countries, NTS must have other savings to lower the prices. The best way of reducing the salary costs is to reduce the amount of work done by humans. To achieve this goal, Norma seeks for a 24/7 production where human work is reduced to its maximum. The result is competitive product prices and a lower risk due to a reduction in human errors, which is the highest risk in a production process [27].
Other topics that are important for Norma are deliver reliability, logistic flexibility, predictability and standardization. A high deliver reliability is expected from the customers of Norma. When Norma gives an expected deliver date, the goal is to deliver the products within this expected deliver date. If this is

always the case, the deliver reliability will raise. This will result in high trust between Norma and the customer. To raise the deliver reliability, logistic flexibility is crucial. Logistic flexibility means that the product can be made in multiple ways, without facing big challenges or delays. In other words, the product is not depended on one or a set of predefined machines, but can be produced on a series of identical machines. For example, in case of a low logistic flexibility, the product must be made on machine x. An error is occurred on machine x, resulting in a long downtime of the machine. The product that was made on machine x cannot be made anymore, because this specific machine is broken. The delivery times will get longer and the deliver reliability will be reduced. In case of a high logistic flexibility, the product will not be depended of one machine but can be made on multiple machines. When one machine will break down and cannot produce, the product can be switched easily without facing big challenges. The product can still be made and the effect of the brake down of one machine is minor.
A key element of logistic flexibility is access to universal machine groups. Universal machine groups are multiple machines that are identical replicas to each other. If a product can be made on one of the machines in a machine group, all machines of this group can make this product, without having big adjustments in programming, tooling and production strategy, resulting in a low risks. Due to these reduced risks, the deliver reliability is raised.

To achieve the AS9100 norm, a high predictability is required. Predictability means that the system always behaves or occurs in a way that is expected [28]. This is very important for the customer, because Norma makes products for aviation, space and defense products. Without a high predictability of the process, Norma cannot guarantee that the products are always from the same high quality. To increase the predictability of the system, standardization is a key element. In a standardized process, the engineer has access to a list of predefined actions or processes. All those actions or processes are tested and proved to work. The great benefit of standardization is the reduction of engineering time, reduction of different machining parts and a raise of the predictability. The engineer can choose between proven concepts and use those to make the product. If all engineers choose between those proven concepts, the deviation between processes is reduced because every engineer works in the same way. Also, all concepts are proven and thus predictable.

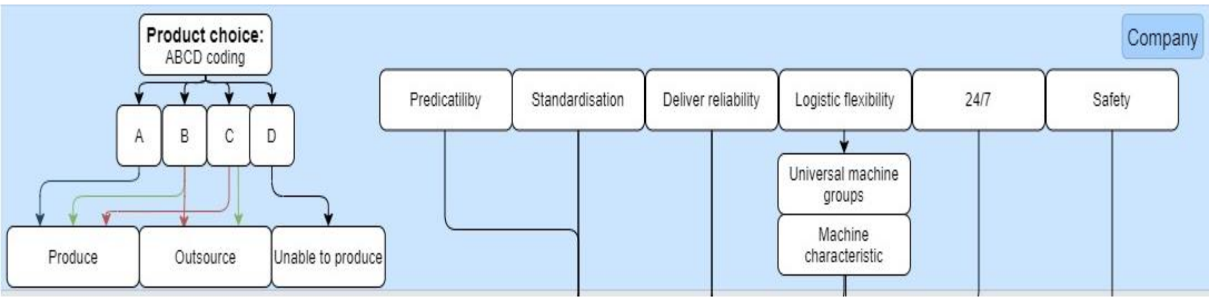


FIGURE 49: COMPANY

MARKET

As said before, Norma makes products for aviation, space and defense products. These products can require tolerances within 5 mu accuracy. Norma is specialized to produce these ultra-precision products. 80% of the products have a length, width and high below 300mm. They produce products with small series and have an high mix of products. This is called a high mix, low volume. The products of aviation, space and defense require complex operations and the products can be made out of materials that have a complex material behavior. These complex products are made with a lot of different steps, resulting in a long chain of operations
The production demand deviates according to customer demand. This customer demand can fluctuate a lot, resulting in a constant changing production demand. To cooperate with these fluctuating demands, logistic flexibility is very important. Due to the logistic flexibility, the capacity of different machines can be used to either increase the production output, or reduce the production output and produce different products on this machine.
Fast throughput time is also important for Norma. This will decrease the costs, improve quality (process problems can be found more quickly), and increase flexibility [29].

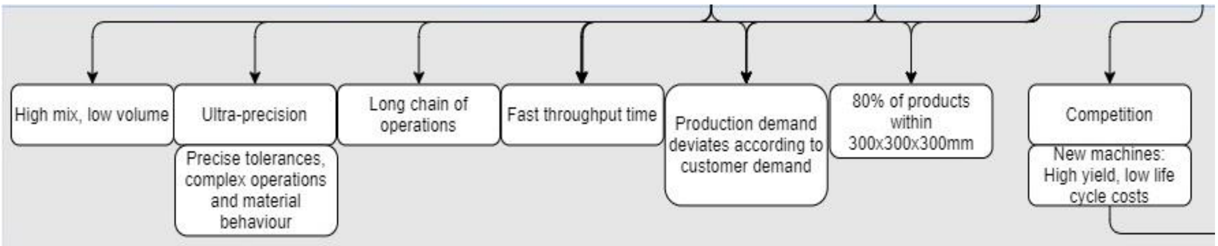


FIGURE 50: MARKET

MACHINE SYSTEM

To produce for the market, a machine system is required. This machine system must be capable of producing 24/7. All-important systems are: Machine; MES; Chips for tools; Zoller; Chip removal management; Zero point clamping system; Robot; TDM; Blum laser measuring system; Renishaw system; Gravity belt filter; Human. In appendix 0, a short explanation can be found of each system.

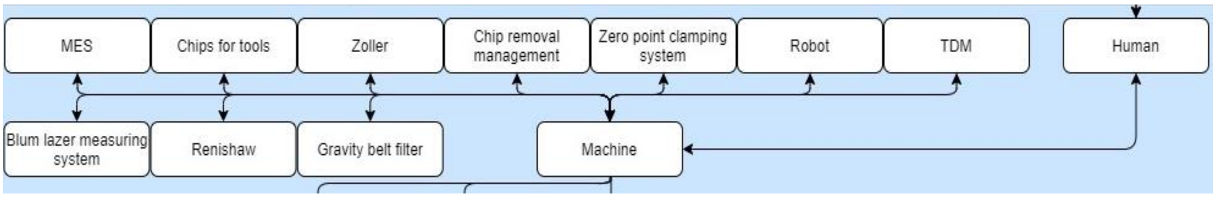


FIGURE 51: MACHINE SYSTEM

MACHINE

The machine is a crucial system in order to produce all ultra-precision parts. Three important factors within Norma around machines are: Machine is suitable for different product groups; Machine is high end; Machine is predictable.

The machine should be suitable for different product groups. This factor is important to increase the logistic flexibility. If the machine can produce a lot of different products, for instance, the machine can work with aluminum, messing and titanium, this gives a great flexibility for the planner. A lot of different products can be produced by this same machine.

Norma seeks for high end machines. The term “high end” means that the machines are from really high quality and are mostly the most expensive machines. These high end machines are required to produce ultra-precision products. Also, it increases the logistic flexibility even more, because a very precise machine can produce precise and less precise products. For the less precise products, the reliability is increased. This is because the machine is more precise than the product requires, so it is easy for the machine to get between the right tolerances.

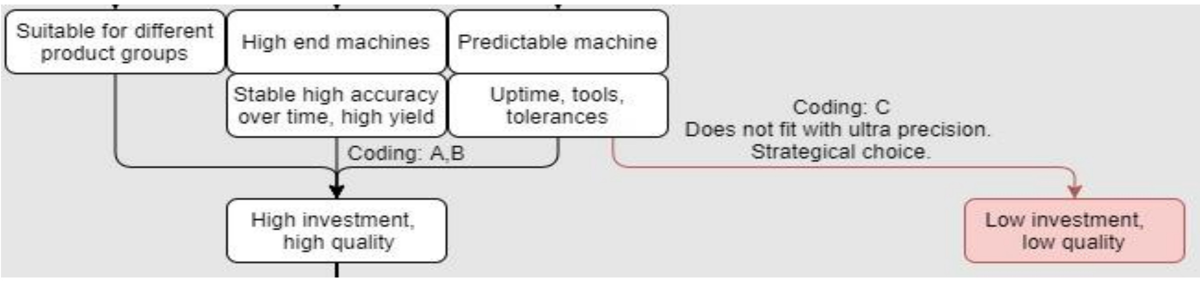


FIGURE 52: MACHINE

OUTPUT

In the output, all the benefits are described. These benefits are only gained when all elements of the vision are successful integrated within Norma. Due to identical machine clustered in groups, more knowledge is gathered for these specific machines. This will result in a reduction of maintenance costs, because preventive maintenance can be performed better due to more knowledge of the failure life. This knowledge can be higher, because other machines can be used as an example for the other, identical

machines. The first time an maintenance operation is performed, this action can take a long time because the operator has to find the problem first, and after that, an solution has to be found. A second time, the same problem can occur, but now, the operator has a better understanding of the problem and has an possible solution.
Machine groups also reduce the spare parts costs per machine. Spare parts are bought to reduce the waiting times and thus the time to maintenance. If all the machines are different, a lot of different spare parts are available. Every machine needs different parts, resulting in either very high spare parts costs, or longer waiting times. In the case when machine groups are made, identical spare parts are needed. The range of spare parts is reduced, so this smaller range of spare parts can be bought for less money and for a higher reward, because a range of machine can provide from these spare parts when a failure occurs.
High end machines are bought. Expected is that these high end machines remain at a more accurate, precise geometry over the lifetime. This means that the machine can be used for a longer time at the same precise geometry as when it was bought.
Automation is required to ensure 24/7 production. Also, automation reduces the labor costs of the operators, because multiple machines can be operated by one operator. At night, the machine can produce products without the help of operators. To gain this automated process, high reliabilities are required. When the machine is in its stable working range, it must remain in this range in order to be stable and reliable. The longer the machine can keep working in this range, the higher the reliability of the machine is. For 24/7 production, reliability is very important. The goal is to work 24 hours a day, but with only 8 hours a day of operators working. So that means that the machine must work for 16 hours without supervision of operators. This is only possible with really high reliabilities.
Stability is another important factor within Norma. It is expected that stability of the machine increases the tooling lifetime. From practical knowledge, it is known that there is a difference in tooling lifetime between machines. In a later stage of this research, a test is performed to find out if the stability of a machine increases the lifetime of tooling.
Standardization of the process increases the reliability and predictability of the system. Under standardization, three topics are important within Norma: Material cluster; Same working process; Machine tool uniformity. Material cluster is as it is called, cluster of material. That means that certain machines only produce products with a certain material. This will increase the predictability, because there is a lot of data and experience available to improve this specific machine with specific material. The downside is that the logistic flexibility reduces. Not all products can be made on all the machines in a machine group, so there is a lower flexibility. The same working process will increase predictability and logistic flexibility. Same working process means that all tooling parameters for tools is fixed and stored in a data system. So for a tool, the tooling parameters are predefined and must be used if possible by the engineer. The benefit of this working process is that programming time is reduced, because all parameters are predefined. Predictability is higher because of every tool, it is known that it produces high quality result at certain parameters for certain material. The last topic is machine tool uniformity. That means that for certain operations, certain tools are predefined. It will reduce programming time, because the engineer does not have to search for the best tool. Also, it increases the logistic flexibility because a wide range of tools are used for a lot of products. This will decrease the variety of tools over different products. Also, it increases the tooling capacity of the machine, because tools are used for different products, resulting in more variety of products in the same tooling set.

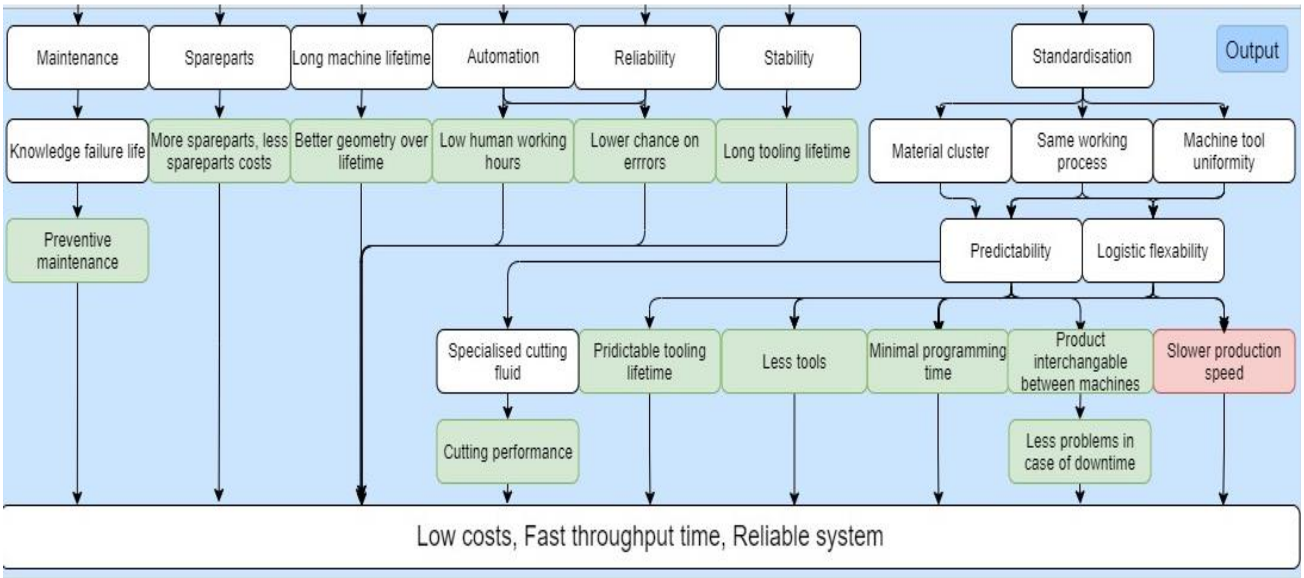


FIGURE 53: OUTPUT

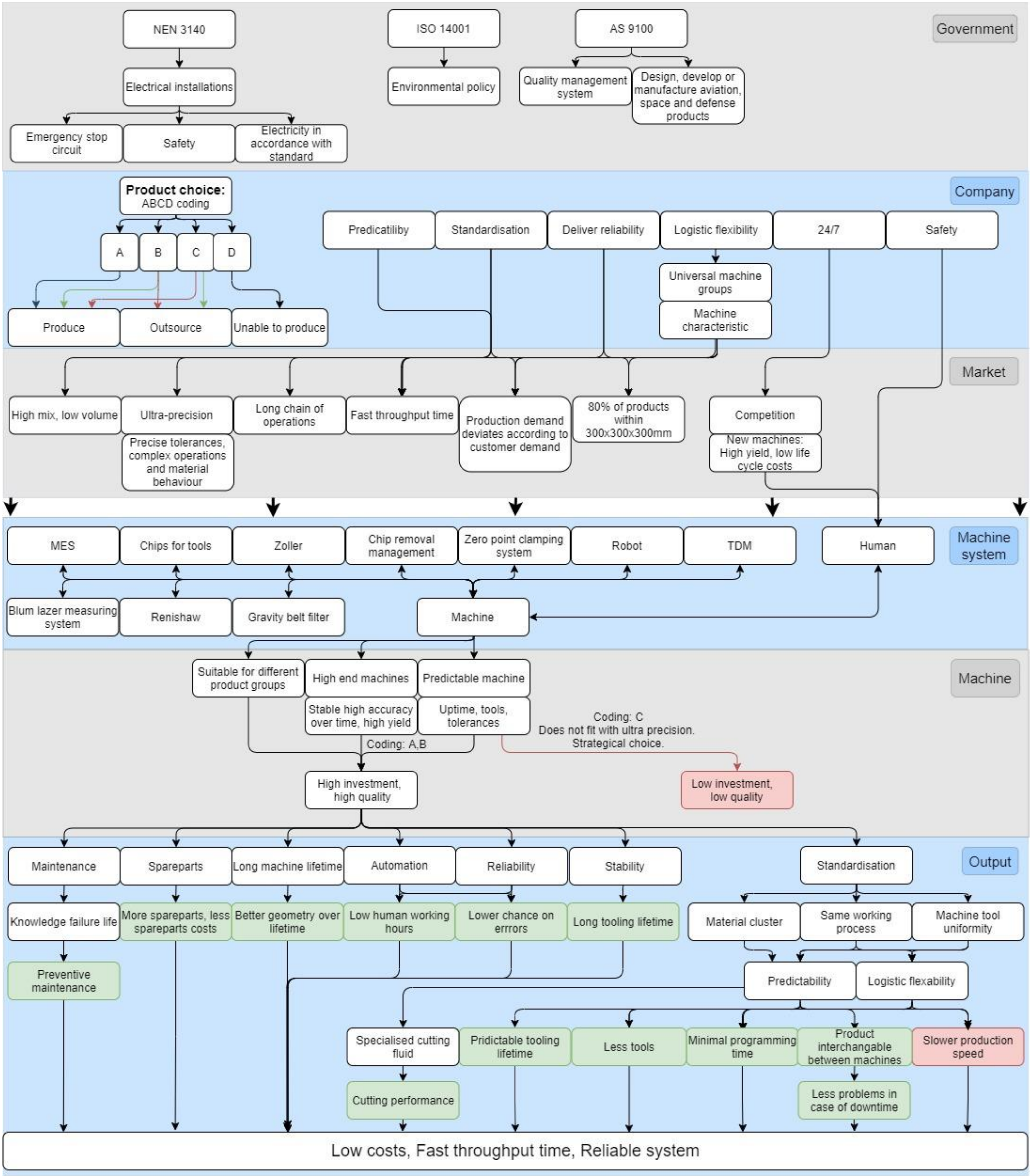


FIGURE 54: COMPLETE VISION NTS NORMA

D: METHODS

In this paragraph, multiple methods are described. All these methods are used as an inspiration in this research.

ASSET MANAGEMENT

Asset management is a method that search for possible direct and indirect costs of the whole lifetime of an asset [3]. The definition of asset management is [2]: ‘asset management involves the balancing of costs, opportunities and risks against the desired performance of assets, to achieve the organizational objectives.’ Asset management is performed over the whole lifetime of an asset, beginning in the phase where the asset is designed or bought and ends when an asset is disposed. To get insight in the lifetime from begin to end, asset management looks from different perspectives to an asset and gives guidelines to keep a high performance and low costs of an asset. In Figure 55, a visualization of asset management can be seen. In this picture, the different perspectives are shown, together with the relations between the perspectives. Asset management uses input from the organization and people, Asset knowledge and risk and review. These three topics, together with the organizational strategic plan will give input in the asset management strategy and planning, which will affect the lifecycle of the asset. Important for asset management is to have proper information and feedback from all topics, because all topics are related to each other and generates input and response.

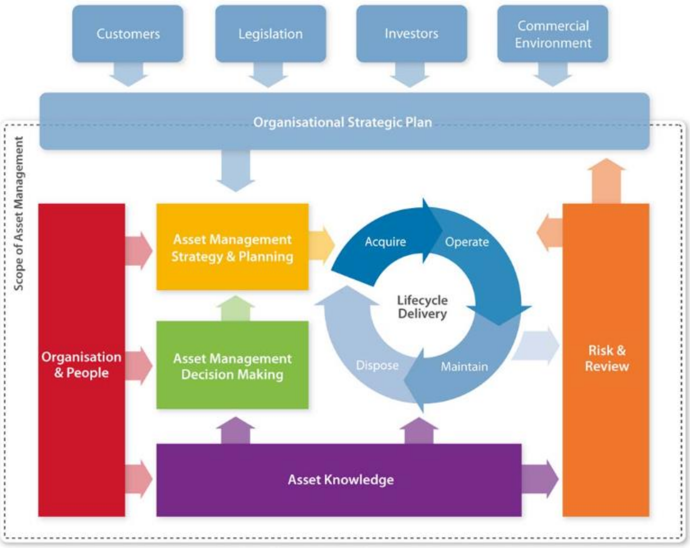


FIGURE 55: ASSET MANAGEMENT [6]

ASSET PERFORMANCE ASSESSMENT

A side step from asset management is asset performance assessment. Asset performance assessment is a method to measure the performance of an asset. This method uses a multi-disciplinary approach to indicate the safety and performance of the asset [2]. Asset management assessment is a key function in sustaining long-term profitability and sustainability of an organization and its assets. To gain overall success, it is essential to plan and monitor assets throughout their entire life cycle, from development, procurement stage till eventual disposal. Asset management assessment can be divided into different topics, as can be seen in Figure 56: Asset performance assessment [2]. Important is the strategy of the company and the translation from company strategy to asset performance objectives. When the asset performance objectives are clear, critical success factors are determined and chosen. To measure these critical success factors, key performance indicators (KPI’S) are needed. These KPI’s translate the objective into a measurable value, resulting in a list of measurables that need to be filled in and regular updated. This list can be challenged to the asset performance objectives and strategy, to measure the performance in comparison with the expected performance.

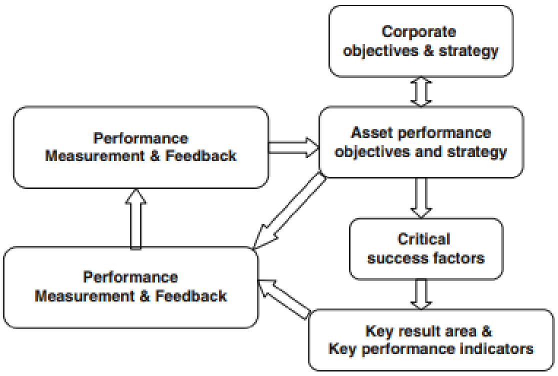


FIGURE 56: ASSET PERFORMANCE ASSESSMENT [2]

GARVIN’S EIGHT DIMENSIONS OF QUALITY

While most authors contend that product quality is complex and hard to define, they tend to agree that quality is based on product attributes that are largely defined by the customer [11]. Garvin advocates a

deeper understanding of the customers' perspective as a necessary first step in defining product quality. According to Garvin, "quality is not a single recognizable characteristic, rather it is multifaceted and appears in many different forms [11]." For this reason, Garvin proposed eight factors or dimensions that describe quality: Performance; Features; Reliability; Conformance; Durability; Serviceability; Aesthetics; Perceived quality. A short explanation is given for every dimension.
Performance is the primary operating characteristics. This is for example the speed of a car, which can be one of the performance indicators. The features are the bells and whistles of the product. The features represents the performance of an product that are not directly necessarily primary or important characteristics. The line between performance and features is rather small, so in a lot of situations, these two topics can interfere with each other. Reliability is the degree to which a product can be counted on to perform or the expected chance to failure. The conformance of a product is the degree a products design and operating characteristics match the preestablished standards. Does the product work as expected and do wat it is supposed to do. Durability reflects to the physical life of a product. How long can the product work without any problems and in case of problems, how long does it take to repair the product and what level of skill is needed to perform this repair. Serviceability is concerned with the ease with which the product can be serviced, so the accessibility of maintenance, time to repair. Aesthetics refers to the looks of a product and are most of the times subjectively evaluated. The last dimension is perceived quality. Perceived quality looks into the quality of the brand and previous experiences.
In a paper of Sinclair et all, the eight dimensions of quality are tested and revised, resulting in slightly changed dimensions: Performance/features; Reliability; Conformance; Durability; Service/perceived quality; Aesthetics; Economics. In this paper, some dimensions are taken together because of the large similarities between these topics. The study did confirm that Garvin's eight dimensions of quality is a good approach to determine the quality of a product.

SAFETY CUBE

The safety cube is a visualization of the building blocks of safe integration and the relation between the building blocks. The building blocks of integration are system, human and environment [6]. The visualization of the safety cube can be seen in Figure 57. As can be seen, the other three faces of the cube are the relations between the main building blocks, so the relation between human and system, system and environment, human and environment. The safety cube can be used in many different situations and forces the user to think not only about the main building blocks of safe integration, but look at the safety problem from multiple perspectives and indicate all safety issues included the safety issues in the relations between the building blocks.

The system is defined as "a set of elements which interact according to a design, where an element of a system can be another system, called a subsystem and may include hardware, software and human interaction". Important to know is that the human interaction is included in the definition of a system of interest, but the human is not an integral part of it.
The human may refer to an individual group of individuals or organizations which have connections to the system. They may cooperate or compete with the system of interest.
The environment consists of all of the relevant parameters that can influence or be influenced by the system of interest in any lifecycle phase. This can for instance be the temperature of the production hall, vibrations.
The relation between system and environment may be a physical or non-physical relationship. A physical relationship can for instance be the cooperation with other features or systems in the environment of the machine. Non-physical factors that are related to the system can be regulations or laws.
The relation between human and system can be physical, logical or emotional. In most cases, this relation refers to the communication between human and machine. This can be in multiple ways, for instance the interface of a machine, manuals or checklists.
The human environment relation involves the relationship between the human and both the internal and external workplace or system environments. The internal workplace includes physical elements such as temperature or noise, where the external environment includes operational aspects, such as the weather.

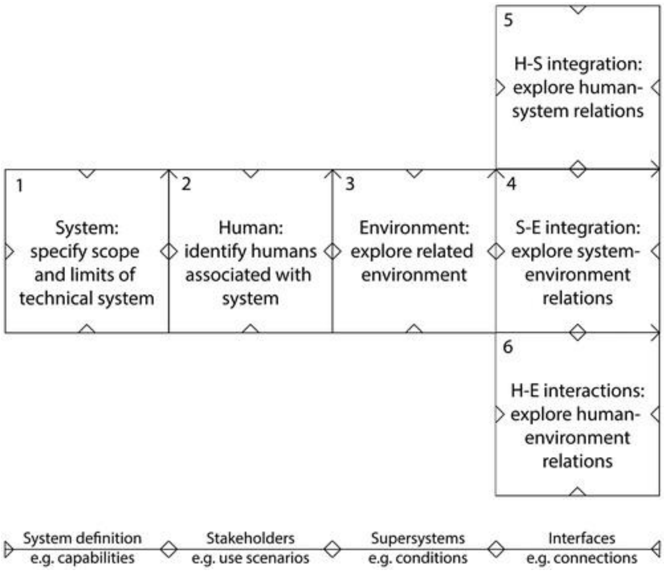


FIGURE 57: SAFETY CUBE [6]

INDUSTRY 4.0

The first industrial revolution, the first change is made to work with steam and water power instead of hand production. This implementation of new technologies took a long time from around 1760 till 1840. The second industrial revolution made it able to use installations of extensive railroad and telegraph networks, which allowed for faster transfer of people and electricity. Due to the electrification, factories could develop modern production lines.

The third industrial revolution is known as the digital revolution, occurred in the late 20th century. In this revolution, the technological advancement is slowed down in comparison with the other revolutions. The industry starts to use computers and advanced digital developments.

Right now, the goal is to work to the fourth industrial revolution, also called industry 4.0, which is originated in 2011 from a project in the high-tech strategy of the German government, which promotes the computerization of manufacturing. Industry 4.0 is divided into 9 main pillars [30]. Those pillars are: Big data; Autonomous robots; Simulation; Horizontal and vertical system integration; internet of things; cloud computing; additive manufacturing. In Table 16, the definition and example can be found of every main pillar.

Big data

The concept of big data applies to large, diverse and complex datasets that affect the organizational decision making of a company. The increase of data sets and improve these data sets to gain more information from the data will improve the productivity, innovation and competition. The data can also be used by decision makers to solve challenges at the organizational level by monitoring, measuring and managing in a better way.

Autonomous robots

Robots are used to perform tasks that in the old situation, a human would do. Robots are also used to solve complex tasks that are not easily solved by humans. In industry 3.0, robots are programmed to perform the tasks that are programmed, but cannot cooperate together with humans. In industry 4.0, autonomous robots are used that can cooperate with humans with the help of human-robot interfaces.

Simulation

Simulation tools play a supportive role in production related activities by promoting sustainable manufacturing environment. Simulations can offer the adjustments into complex systems by planning the operators, having the knowledge and information and accurate estimations about the system.

Horizontal and vertical system integration

Vertical integration refers to the flexible and reconfigurable systems inside the factory and the extent to which they are fully integrated with each other for achieving agility. Horizontal integration deals with the integration of partners within the SCs.

The industrial internet of things (IoT)

IoT refers to the next technological revolution by giving solutions for computations, analytics by relying on cloud based systems. IoT connects several systems to the internet, making it able to communicate to each other. Data is collected from several systems and higher level devices make decisions using this data.

The cloud

Cloud computing will help to gain access to all gathered data by multiple systems from different locations.

Additive manufacturing

Additive manufacturing, in other words 3d printing, refers to producing customized goods for the requirements of the customer. The most common way is to prototype and make small batches with 3d printing, to gain advantages of having less stock and produce to the changing requirements of the customer.

Augmented reality (AR)

Augmented reality is defined as the interactive technology that enables harmony between the virtual world and the real world. AR can be used in very different applications, from guidelines in the worksite to concept design discussions. AR can visualize virtual models into the real world, resulting in a combination between real life and virtual world.

Cyber security

Cyber security is the negative impact of industry 4.0. Due to the digitalization, the company is exposed to cyber-attacks. To prevent this from happening, the cyber security should be high enough to keep the company same.

THE CONCEPTS	THE DEFINITIONS OF THE CONCEPTS	THE EXAMPLES OF THE CONCEPTS
BIG DATA	Large,complex datasets that affect the decision making of companies	Big data analytics, algorithms, software programs
AUTONOMOUS ROBOTS	Solve complex tasks which cannot be solved by human	Kuka Iwaa has the learning ability to achieve some certain tasks
SIMULATION	Mathematical modelling, algorithms that optimize the process	Software programs
HORIZONTAL&VERTICAL SYSTEM INTEGRATION	Integration of inside of the factory and SCs	Smart factories, cloud systems
INTERNET OF THINGS	Connection of the physical objects and systems	Smart network
CLOUD COMPUTING	Shared platforms that serve to the multiple users	Google Drive, BlueCloud, Windows Azur
ADDITIVE MANUFACTURING	3D printing technology, producing in mass customization	3D printers to produce smart phones
AUGMENTED REALITY	Human-machine interaction on maintanence tasks	Google Glass
CYBER SECURITY	Cyber attacks to business environment	National defense systems in order to prevent attacks

TABLE 16: MAIN PILLARS INDUSTRY 4.0 [30]

ICEBERG MODEL

The iceberg model is a visualization of the visual and non-visual costs, as can be seen in Figure 58 [31][32]. The visual costs are the costs that are generally reported, like maintenance costs, scrap or initial investment. In a manufacturing environment, more unknown costs are affecting the benefits and profit of a system, for instance reprogramming time, longer setup times, rescheduled products, adjusting documentation. The iceberg model is made to indicate the unexpected losses in a system. The model forces the user to think about all losses of value in an asset. When all value losses are visual, improvements can be considered to eliminate or reduce the costs. The goal of the iceberg model is to visualize all non-visual cash flows and give overview of all value losses in the process.

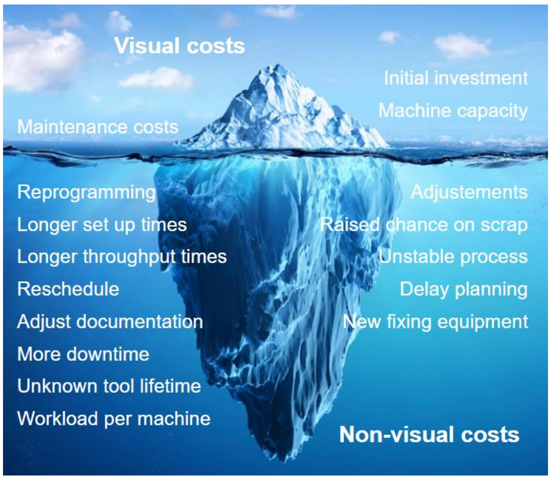


FIGURE 58: ICEBERG MODEL

E: DESCRIPTION / VISUALIZATION MACHINES

MAKINO D500

Specifications:

Axis range:	550 x 1000 x 500 mm
Max. product dimensions:	rd 650 x 500 mm
Swivel angle:	30 / -120 º
Spindle direction:	Vertical
Build type:	Portal
Machine weight:	17.5 ton
Spindle power:	30000 rpm / 13 KW / 16.9 Nm
	20000 rpm / 15 KW / 63.6 Nm
	14000 rpm / 18.5 KW / 96 Nm
Spindle swing:	<4 mu / 400mm

FIGURE 59: MAKINO D500, LEFT MACHINE HOUSING INCLUDED, RIGHT EXCLUDED

The Makino D500's are the newest machines and the biggest group within NTS Norma. Right now, there are 7 machines of this type with different ages, from 2011 till 2018. In the future, more Makino D500 will be bought, because of the accuracy and reliability of these machines. The Makino D500 has the highest accuracy within NTS Norma, and is made for a low force production process. The working range is 550 x 1000 x 500 mm, and can be used in a 5 axis situation. The machine is designed with a portal table, this means that the table moves in the x, a and c axis, and the spindle in the y and z axis. This design prevents high moments around the spindle, because the spindle is closely positioned at the stable main frame.

GROB G550

Specifications:

Axis range:	800 x 1020 x 970 mm
Max. product dimensions:	rd 900 x 610 mm
Swivel angle:	45 / -185 º
Spindle direction:	Horizontal
Build type:	Portal
Machine weight:	20.9 ton
Spindle power:	30000 rpm / 40 KW / 47 Nm
	18000 rpm / 28 KW / 35 Nm
	16000 rpm / 25 KW / 160 Nm

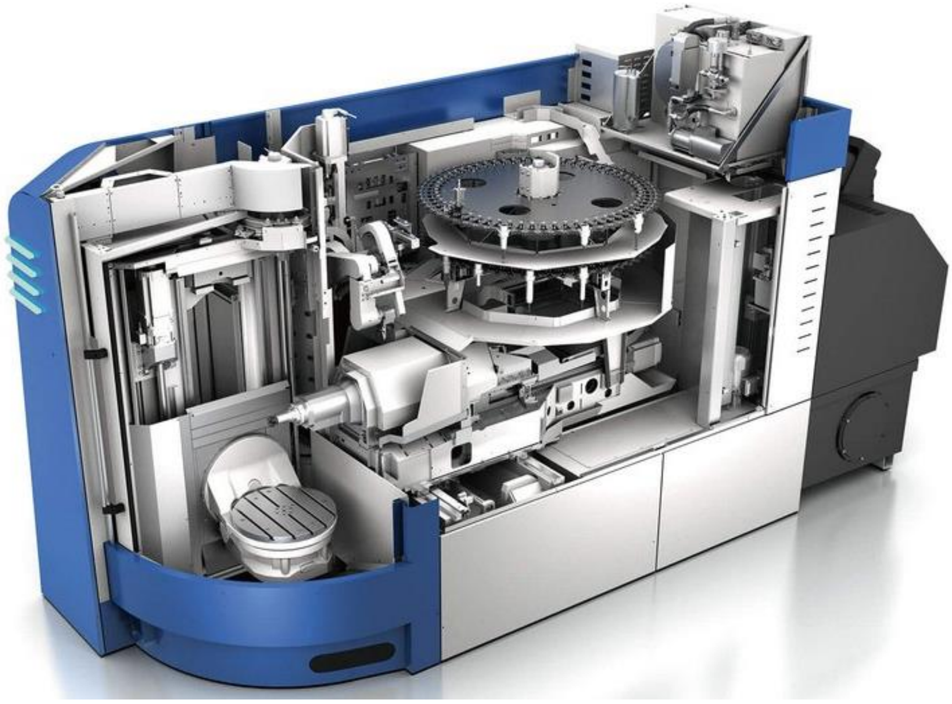


FIGURE 60: GROB G550, MACHINE HOUSING EXCLUDED

The Grob G550 is a smaller group of machines, consisting out of two identical machines, bought in 2013. The Grob G550 has high spindle power and coupling, but is less accurate in comparison with the Makino D500. For this reason, the Grob G550 makes products with larger tolerances, compared to the Makino D500. The Grob G550 is used in situations with high spindle forces or torques. It is also included with a portal, in this case is the portal located at the spindle instead of the table. The spindle moves in the x and y axis, where the table can move in the z axis and can rotate around the a and c axis.

DMG DMU 50 EVO

Axis range:	800 x 1020 x 970 mm
Max. product dimensions:	rd 900 x 610 mm
Swivel angle:	45 / -185 º
Spindle direction:	Horizontal
Build type:	Portal
Machine weight:	20.9 ton
Spindle power:	30000 rpm / 40 KW / 47 Nm
	18000 rpm / 28 KW / 35 Nm
	16000 rpm / 25 KW / 160 Nm

FIGURE 61: DMG DMU 50 EVO

The DMG/DMU 50/70 are the oldest machines, and will be replaced by the company soon. The DMG/DMU 50 is bought in 2003 and the DMG/DMU 70 in 2006. In comparison with the Makino D500, the DMG/DMU 50/70 are less stable and accurate. An indication of this stability and accuracy can be seen in the weight of the machine. Both machines have roughly the same working area, but the DMG/DMU 50 weights roughly 9 ton and the Makino D500 roughly 17.5 ton [10]. Assumed is that this extra gain of weight is due to for instance bigger linear bearings, more robust frame or larger spindle guide. The DMG DMU 50/70 is also installed with a portal table. The table can move in the x, a, and c axis. The spindle moves in the y and z direction.

F: SHORT EXPLANATION IMPORTANT SYSTEMS

In order to work in a 24/7 production, a lot of different systems need to work together. All systems can be seen in Figure 62. Every system will be discussed shortly.

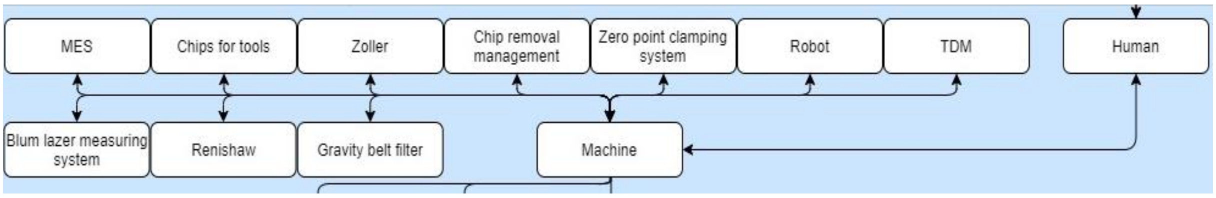


FIGURE 62: MACHINE SYSTEM

MANUFACTURING EXECUTION SYSTEM (MES)

The manufacturing execution system (MES) is a system that provides information between production and office [33]. MES measures all important information and data from the machine and sensors that are installed. This information is then stored at the system that is used at the office. It works also the other way around. When someone from the office changes for instance the planning, the operator can see this directly. Using this system gives a good insight of the performance of the production process.

CHIPS FOR TOOLS

In the current situation, machines cannot store tooling data such as rotation hours, length diameter. To work effectively in a 24/7 environment, this information is required to raise the predictability of the system. Right now, the rotation hours, length and diameter are written down by the operator and re-used when needed. The chips for tools will eliminate these human tasks, to reduce the human error in the system. Also, the information of the tools can be stored in the cloud, providing useful data for improvement of the system.

FIGURE 63: ZOLLER SMARTCHECK

ZOLLER SMARTCHECK

Zoller smartcheck is a system that presets and measures cutting tools, Figure 63. These cutting tools are then used in the production machine. All cutting tools are preset on a specified height. This height can be very important, and must be preset within a few mu meters. The Zoller system can preset and measure these cutting tools fully automatically using predefined programs.

FIGURE 64: CHIP REMOVAL MANAGEMENT

CHIP REMOVAL MANAGEMENT

In the process of making products, a lot of chips are generated. All these chips must be removed from the system. This is done with a chip removal management system, Figure 64. This system moves the chips from the machine to a storage container, placed close to the machine. This is done using a belt.

ZERO POINT CLAMPING SYSTEM

The zero point clamping system increases the die exchange of the machine, Figure 65 [34]. The system guarantees fast, precise fixation and reference of the clamping tool. It can be used for pallets, clamping towers and clamping stations. The system guarantees a high repeatability. This system is required to decrease the die changing time to less than a minute.

FIGURE 65: ZERO POIENT CLAMPING SYSTEM

ROBOT

A robot is a key element in 24/7 production. The robot takes the place of the operator and makes sure that the products are placed into the machine, Figure 66. Two different approaches are available for the product placement. The first one is using bulk material and a fixated clamping device on the machine. The robot places the bulk material on the clamping device. In this situation, a few clamping devices are needed and a lot of bulk material. The second approach is using clamping devices that are already filled with bulk material. The operator makes sure that the material is fixated in the clamp and the robot makes sure that the clamping device is positioned in the machine. This last approach is mostly used within Norma, because the variety of products is large and different clamping devices are needed to produce different products without standstill.

FIGURE 66: ROBOT

TOOL DATA MANAGEMENT (TDM)

In a modern production factory, tools are used to produce the required products. Tools are designed to perform certain production steps, like face milling or shoulder milling. Multiple tools can be used for this same production step, some can perform better in some situations. TDM can help in the process of choosing the tooling and strategy. In TDM, all used tools can be added with all the important data included. The tools can be sorted into different classifications and preferences can be added, to gain overview of all the available tools. The TDM System can them be used to design the production strategy.

BLUM LASER MEASURING SYSTEM

Blum lase measuring system is a system that is used to measure the tools of the machine [35]. The system is a key element in 24/7 production. It is used to detect if tooling failure has occurred. In 24/7 production, operators are only available 8 hours of the day. The rest of the time, the machine is producing without human actions and inspection. If a tool will brake of wears out, it will be seen when the operator is back for its shift. All the production time will be lost and a lot of scrap can be produced. To prevent this, the Blum laser measuring system is installed. This system measures the tool wear or tool failure. When the measure parameters exceed the predefined parameters, the machine will not use this tool anymore. Two options can occur: Machine will go in error mode, because one tool is broken or worn out. The second option is that the machine will produce another product that is not using this particular tool. It depends on the machine and software capabilities if the second option is possible.

RENISHAW

Renishaw is the brand name for the measuring system used on the machines. This measuring system can measure the product while it is still on the machine [36]. It gives a quick indication if the performed work is between specifications. The Renishaw system is used to prevent high scrap rates. Products can be measured quick without a human action involved.

GRAVITY BELT FILTER

A gravity belt filter is used to filter all the chips and dirt from the cooling water, Figure 67. This is done with the use of a filter. The water will move through this filter and with the gravity force only, the chips and dirt are separated from the water. In this way, the cooling water can be re-used.

FIGURE 67: GRAVITY BELT FILTER

G: TOOL WEAR LITERATURE

FLANK WEAR

Wear on the flank face of the cutting tool is called flank wear, and is the most predictable wear condition. Flank wear is most commonly caused due to abrasive wear of the cutting edge against the machined surface. If no other wear type caused the end of life, flank wear will determine the tool life. Flank wear cannot be prevented, but can be controlled with the cutting parameters, as can be seen in Figure 68 [37]. This figure shows the relation between the Rotation speed (Vc), Feed per teeth (f) and cutting depth (ap). In this graph can be seen that a reduction in rotation speed has the biggest impact on flank wear and reduces flank wear exponentially. A reduction in feed per teeth will result in a smaller reduction of flank wear, and reduces in a linear way. Cutting depth has the smallest impact on flank wear, but is limited by the length of the tool that is used. Other ways to reduce flank wear are [18]:

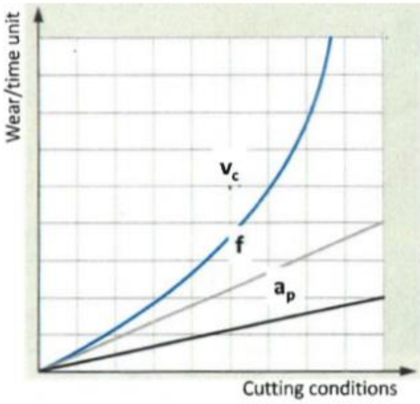


FIGURE 68: FLANK WEAR CUTTING PARAMETERS [18]

- Select a more wear resistant harder carbide grade.
- Apply coolant correctly.

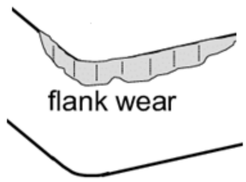


FIGURE 69: FLANK WEAR [18]

CHIPPING

Edge deterioration where parts of the edge break away is called chipping. Chipping is typically caused by excessive loads and shock-loading during operation. It can also be caused with high heat input. Chipping will only occur when the milling conditions are not fit for the operation. For instance, if the speeds or feeds are too high for the situation [38]. Chipping can be expected in non-rigid situations. Workpiece materials with hard particles also will cause chipping of the cutting edges. Ways to reduce notch wear are [18]:

- Ensure proper machine tool setup and minimize deflection.
- Select a tougher carbide grade and a stronger cutting edge geometry.
- Reduce the feed (especially at the entrance or exit of the cut).
- Increase the cutting speed.

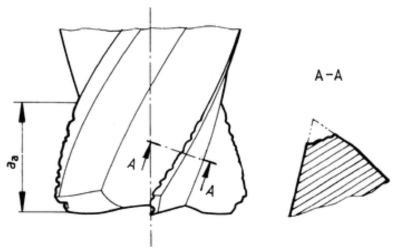


FIGURE 70: CHIPPING [18]

NOTCH WEAR

Notch wear is mainly caused when the surface of the workpiece is harder or more abrasive than the underlying material. This can be due to surface hardening during previous cuts or forged or cast surfaces with a surface scale. The tool will wear rapidly where it is in contact with this hard layer. Local stress concentrations can also be the cause of notch wear. Notch wear can be seen by an excessive local wear, as can be seen in figure xxx. Ways to reduce notch wear are [18]:

- Reduce the feed and vary the depth of cut when using multiple passes
- Increase cutting speed if machining a high temp alloy (this will give more flank wear).
- Select a tougher carbide grade and use a chipbreaker for high feeds.

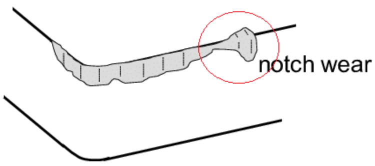


FIGURE 71: NOTCH WEAR [18]

BUILD UP EDGE

Build-up edges are caused by adhesion of workpiece material on the cutting edge. A build-up edge is a result of the workpiece material being pressure welded to the cutting edge. Build-up edges occurs when there is a chemical affinity, high pressure and sufficient temperature in the cutting zone. Eventually, the build-up edge breaks off and takes pieces of the cutting edge with it, leading to chipping and rapid flank wear. Ways to reduce notch wear are [18]:

- Increase the cutting speed and or feed.
- Select an insert with a sharper geometry and a smoother rake face.
- Apply coolant correctly, perhaps increase the concentration.

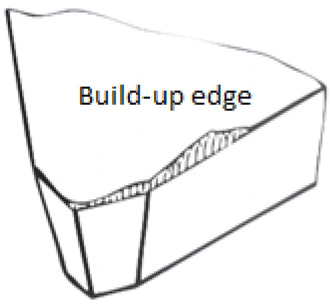


FIGURE 72: BUILD-UP EDGE [18]

CRATER WEAR

Crater wear is a combination of diffusion and decomposition (higher cutting speeds) and abrasive wear (lower cutting speeds). The heat from the workpiece chips decomposes the tungsten carbide grains in the substrate and carbon leeches into the chips (diffusion), wearing a ‘crater’ on the top of the insert. The crater will eventually grow large enough to cause the insert flank to chip, or ma cause rapid flank wear. Crater wear is formed in the form of a crater or pits on the rake face of inserts. Crater wear will be mainly observed when machining abrasive workpiece material or material with a hard surface. Ways to reduce crater wear [18]:

- Coatings containing thick layers of aluminum oxide are best.
- Apply coolant.
- Use a free cutting geometry to reduce heat.
- Reduce the cutting speed and feed.

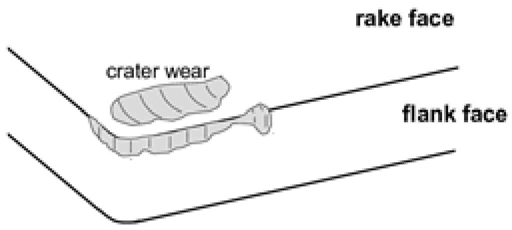


FIGURE 73: CRATER WEAR [18]

PLASTIC DEFORMATION

Plastic deformation is caused mainly by thermal overloading. Excessive heat causes the carbide binder (cobalt) to soften. Due to mechanical overloading, pressure on the cutting edge makes the cutting edge deform or sag at the tip, eventually breaking off or leading to rapid flank wear.
Plastic deformation looks like a deformation of the cutting edge. Careful observation is asked for, as plastic deformation can look very similar to flank wear on the cutting edge.
Plastic deformation can be expected when the cutting temperature is high (high cutting speeds and feeds) and when the workpiece material shows high strength (hard steels or strain hardened surfaces and superalloys).
Ways to reduce plastic deformation [18]:

- Apply coolant correctly.
- Reduce the cutting speed and feed.
- Select an insert with a larger nose radius.
- Use a harder, more wear resistant carbide grade.

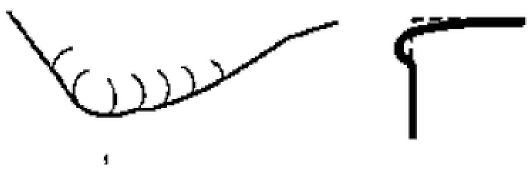


FIGURE 74: PLASTIC DEFORMATION [18]

H: DATA

UPTIME MACHINE NTS NORMA

In Figure 75 till Figure 80, the uptime of different machines can be seen. The uptime is represented as hours per day, calculated by dividing the hours per week by 7. All assumptions and observations are:

Estimated time to gather data

- Processing data into information.
  - 0.5 day.
- Data can be updated by hand (every month).
  - 0.5 hour for whole document.

Assumptions

- Pre-calculation is the same as recalculation (vc-nc = 100%).
  - Hours are based on calculated hours. So if calculated production hours are 12 and 8 hours are actual produced hours, 12 hours are booked.
  - Produced hours are not gathered.
- There is no traceability of used machine.
  - Hours of production are booked on the calculated machine.
  - There is deviation in calculated machine and actual used machine to produce the product.
- M162 is zero since 2019 Week 43.
  - Change in registration, all hours of M161 and M162 are booked on M161.
  - Traceability of used machine is gone.
- Hours / day are above 24 hours.
  - Hours are booked when a full batch is finished. All work of for instance one week can get finished on the next week. All hours are booked on that particular week, resulting in fluctuating results.
  - Calculated production hours are higher than the actual produced hours. This will raise the hours / day.
  - A portion of parallel human work hours is booked on the machine. These are not machine production hours but will raise the hours per day.

Observations

- Optimizations of production from 2018.
  - Result can be seen from 2019.
  - Production yield remains the same, but less hours are needed for production.
- Phase out of multiple machines 2020
  - Some machines are phased out.
- Production yield remains te same, production hours per machine are raising

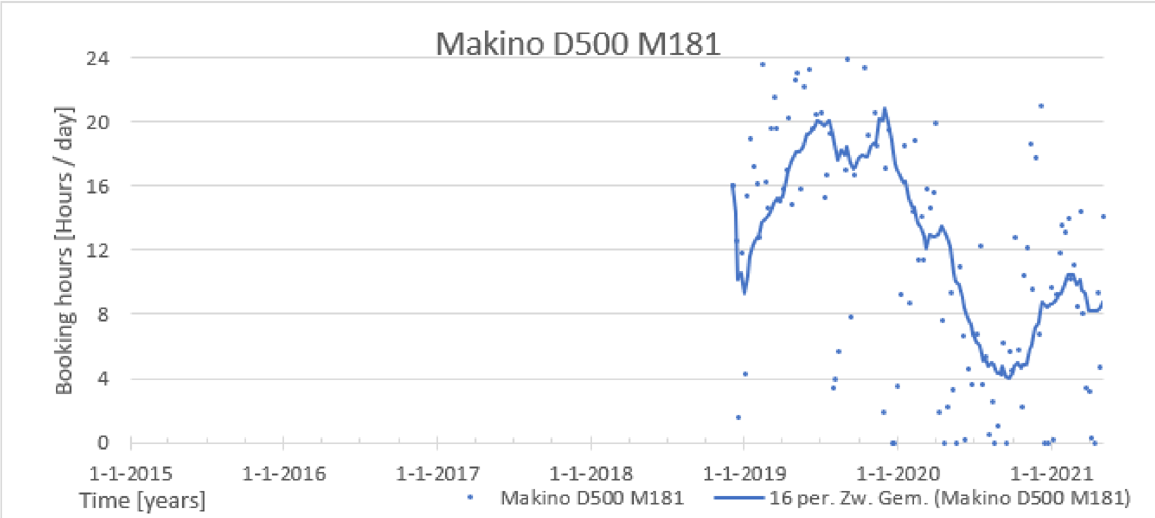


FIGURE 75: UPTIME MAKINO D500 M181

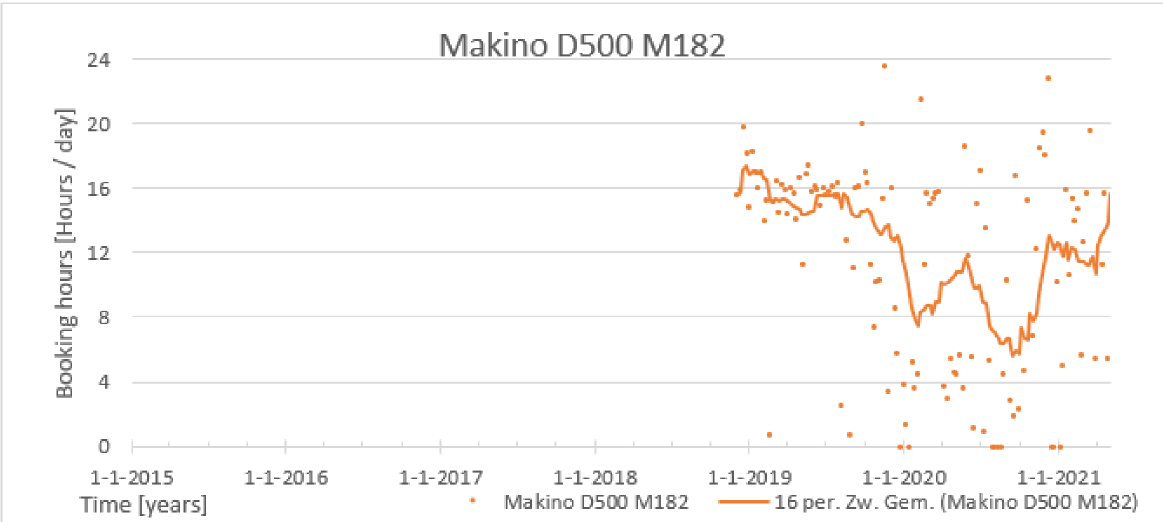


FIGURE 76: UPTIME MAKINO D500 M182

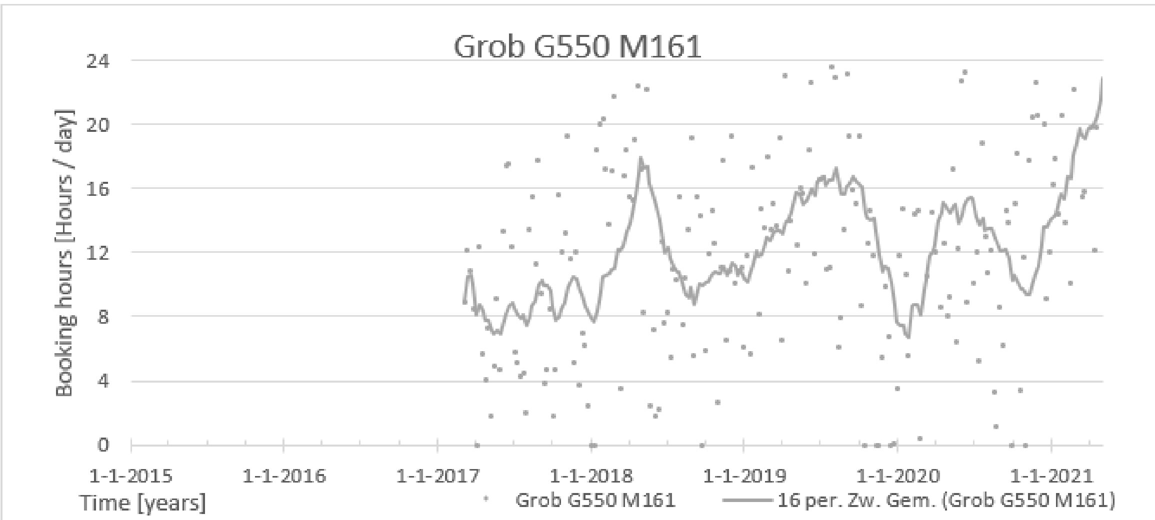


FIGURE 77: UPTIME GROB G550 M161

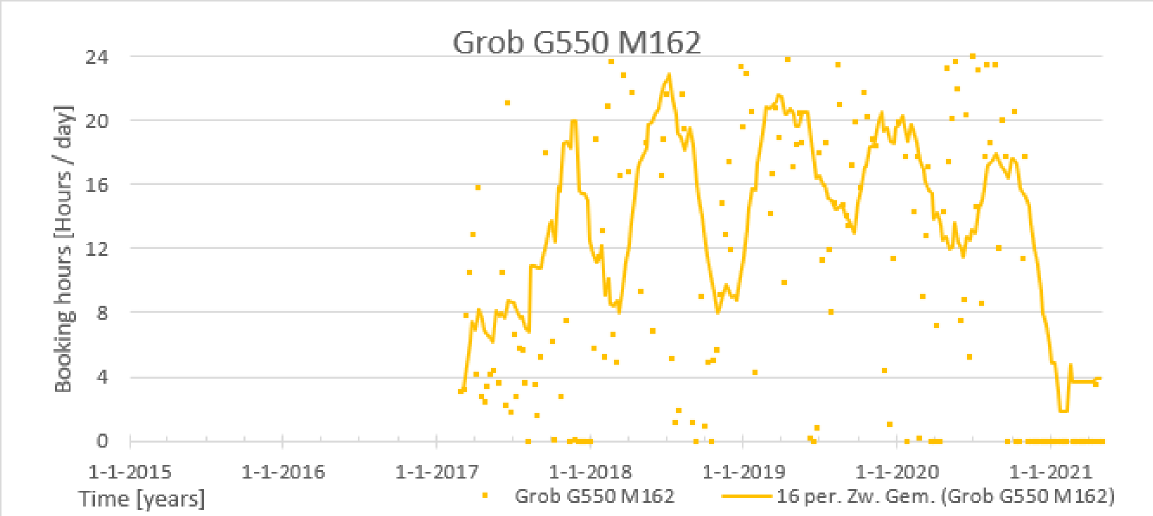


FIGURE 78: UPTIME GROB G550 M162

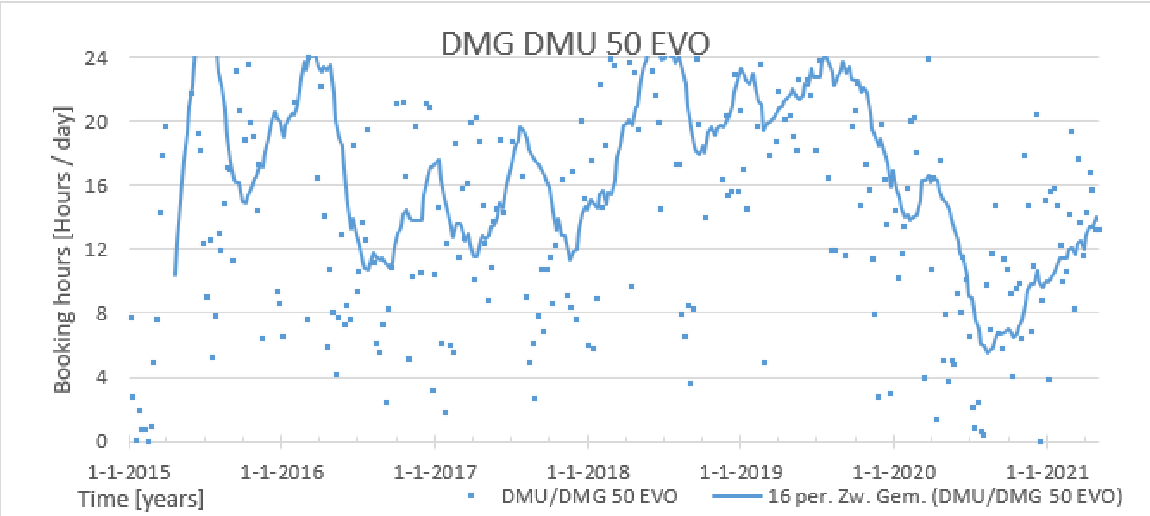


FIGURE 79: UPTIME DMG DMU 50 EVO

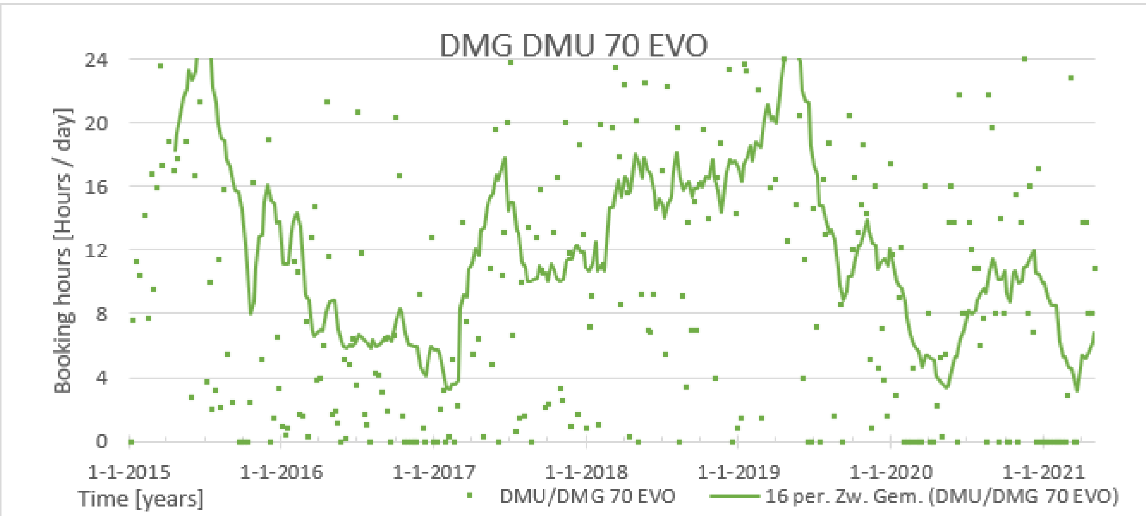


FIGURE 80: UPTIME DMG DMU 70 EVO

UPTIME MACHINE HTM

Estimated time to gather data.

- Waiting time for data.
    - Ca. One week.
- Processing data into information.
    - All missing data points must be filled by using extrapolation.
    - 1 – 2 day.
- Data can be updated by hand (every month).
    - Ca. 10 min per machine.

Assumptions

- Uptime machine.
    - Data is based on logged data from the machine, so including production hours and warm up hours.
    - Unknown what this ratio between production and warm up hours is. Can depend per day / month / year.
    - Time between data is not constant.
        - With extrapolation, time between data is made the same.
        - Inaccuracy in data due to big data gaps.
            - Goal was to measure data every week.
            - Reality is that measurement was between months or even years, depending of the situation.
    - Human error
        - Data is written and filled in by hand.
        - Chance or errors is mayor.
        - In some points in time, data was corrected due to made human errors.

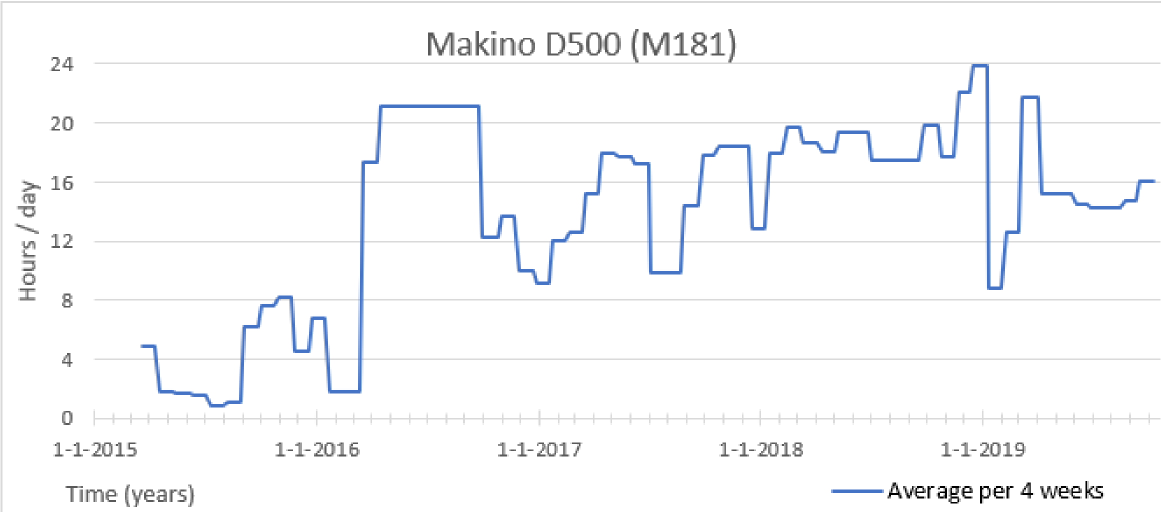


FIGURE 81: UPTIME HTM MAKINO D500 M181

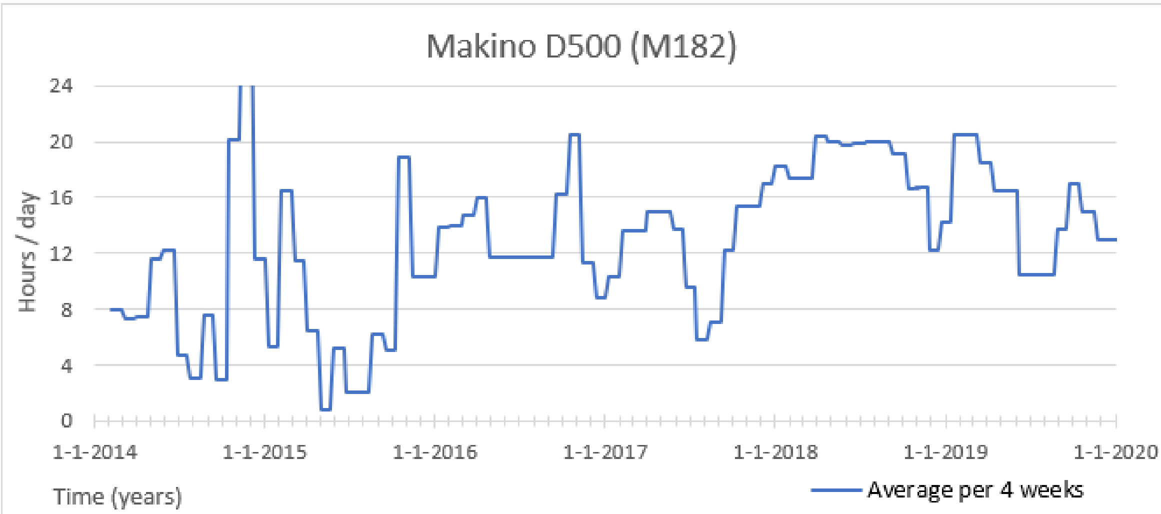


FIGURE 82: UPTIME HTM MAKINO D500 M182

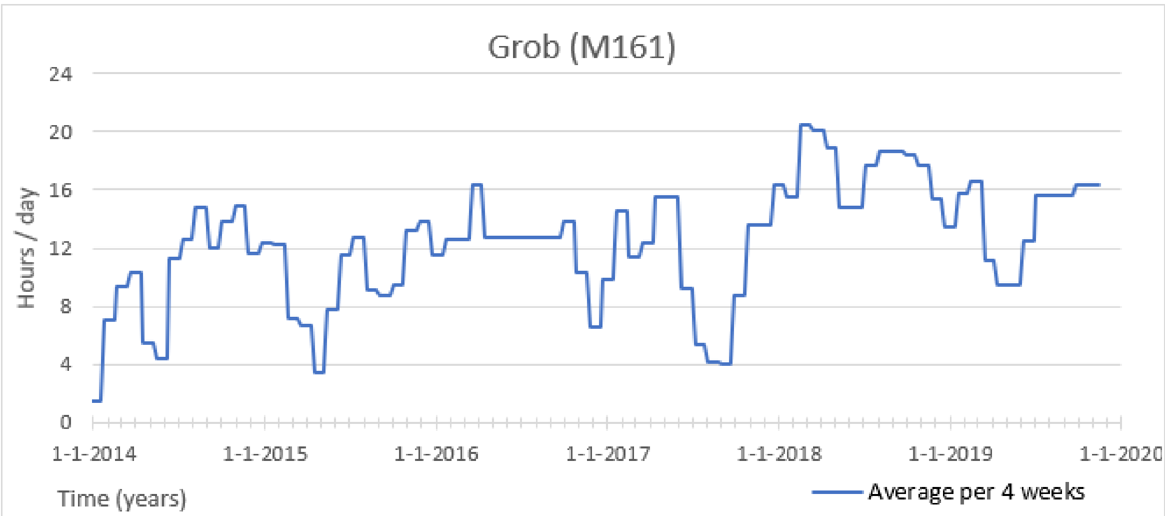


FIGURE 83: UPTIME HTM GROB G550 M161

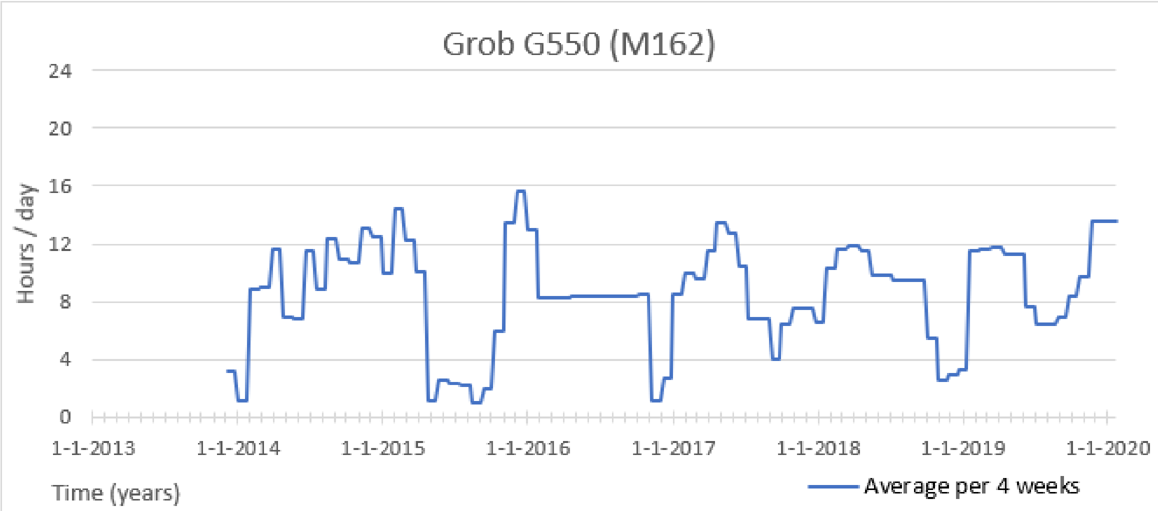


FIGURE 84: UPTIME HTM GROB G550 M162

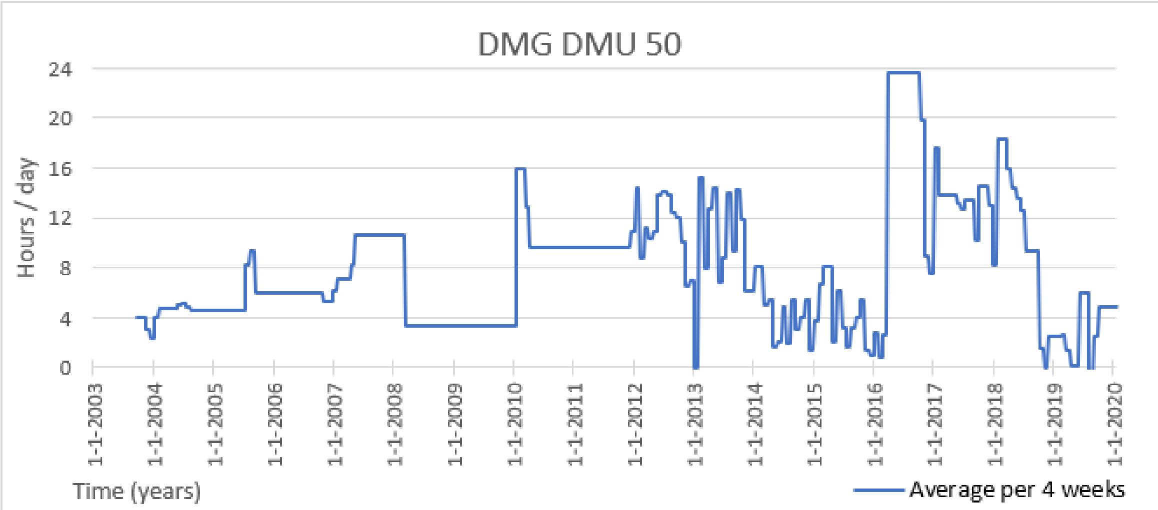


FIGURE 85: UPTIME HTM DMG DMU 50 EVO

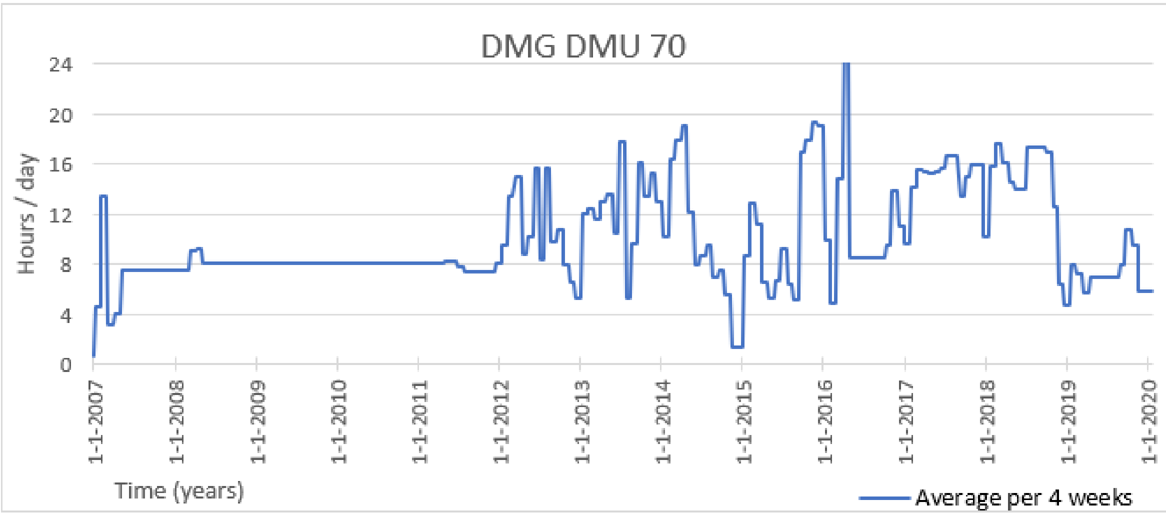


FIGURE 86: UPTIME HTM DMG DMU 70 EVO

COMBINING UPTIME NTS NORMA AND HTM.

When the two data sets of both NTS Norma and HTM are combined, some observations can be made. These observations are based on the errors and assumptions of both data sets, so when the data sets are improved, the observations can become different.
The data of NTS Norma shows the booked hours, so the calculated production hours of the machine. HTM shows the production hours and the warmup hours. When these two data sets are combined, an estimation can be made of the amount of warmup hours produced at NTS Norma. Figure 87 and Figure 88 are used to estimate the warmup hours. Figure 87 shows the uptime gathered by NTS Norma and Figure 88 shows the uptime gathered by HTM. In 2019 can be seen that NTS Norma produced roughly 12 – 18 hours in the beginning of 2019 and 0 – 12 at the end of 2019. From the data of HTM can be seen that the machine has rotated roughly 15 hours per day in 2019. The difference between the data of NTS Norma and HTM are warmup hours. On average of whole 2019, NTS Norma produced roughly 8 hours a day and kept the machine warm for another 7 hours a day. This means that in 2019, almost 50% of the total production hours where used to warmup the machine.

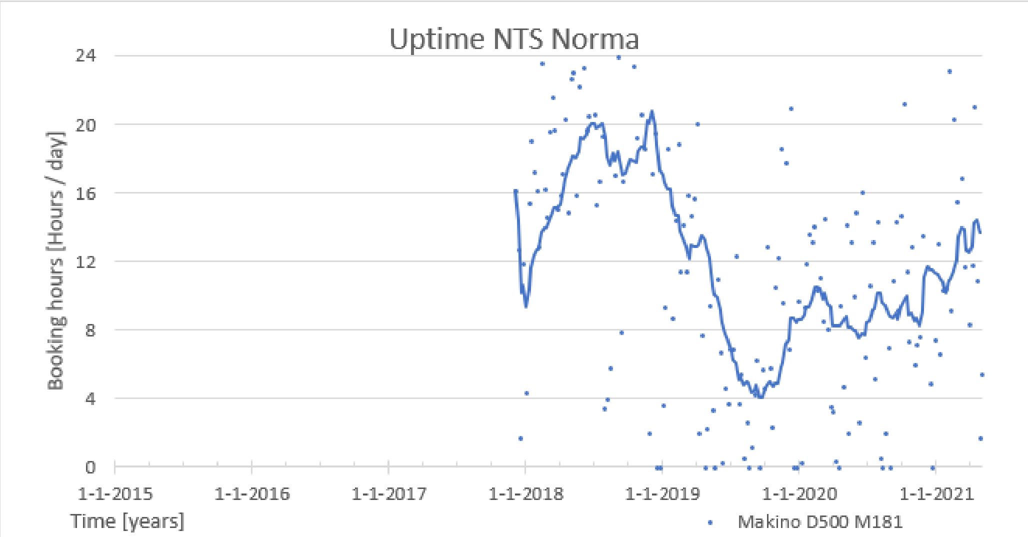


FIGURE 87: UPTIME NTS NORMA

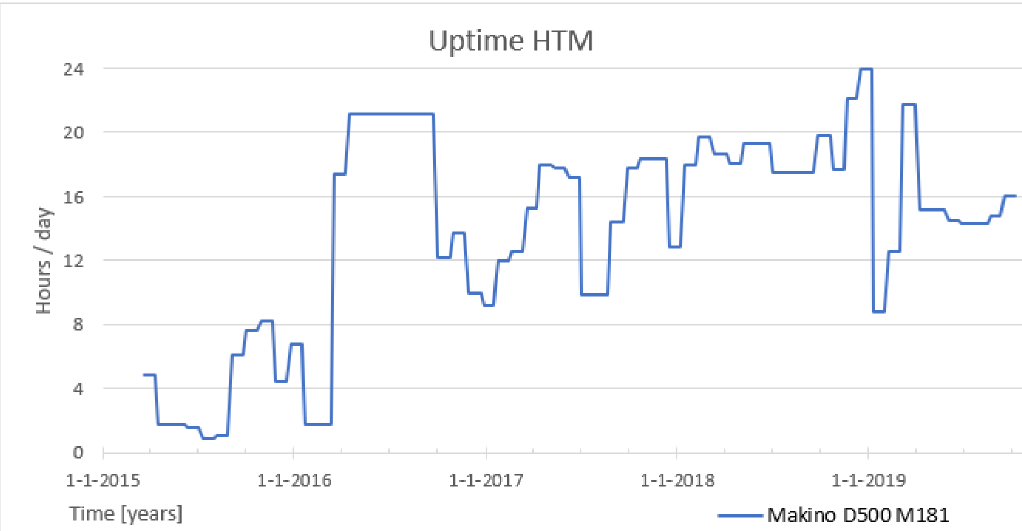


FIGURE 88: UPTIME HTM

MAINTENANCE COSTS

Estimated time to gather data

- Waiting time for data
    - Ca. One week

- Processing data into information
    - 0.5 - 1 day
- Data can be updated by hand (every month).
    - Ca. 10 min per machine.

Assumptions

- Maintenance costs
    - Distinction between corrective and preventive maintenance
        - Corrective maintenance is maintenance performed due to failure or inspection.
        - Preventive maintenance is maintenance that is planned. For HTM, this will include corrective maintenance that is planned at a certain date. So a part of corrective maintenance can be included into preventive maintenance.

Observations

- DMG DMU 50
    - First 9 years almost no preventive nor corrective costs.
    - After 9 years, a lot of corrective and preventive costs.
- DMG DMU 70
    - First 6 years almost no preventive nor corrective costs.
    - After 6 years, corrective and preventive costs high.
- From 2012, a change in maintenance strategy, resulting in higher maintenance costs, preventive and corrective.
    - Preventive maintenance costs are higher due to the change in maintenance strategy.
    - Corrective maintenance costs are higher because more critical failures are made visual in the preventive maintenance.
    - The benefits of this change in strategy is not visual, because downtime due to failure is not monitored.

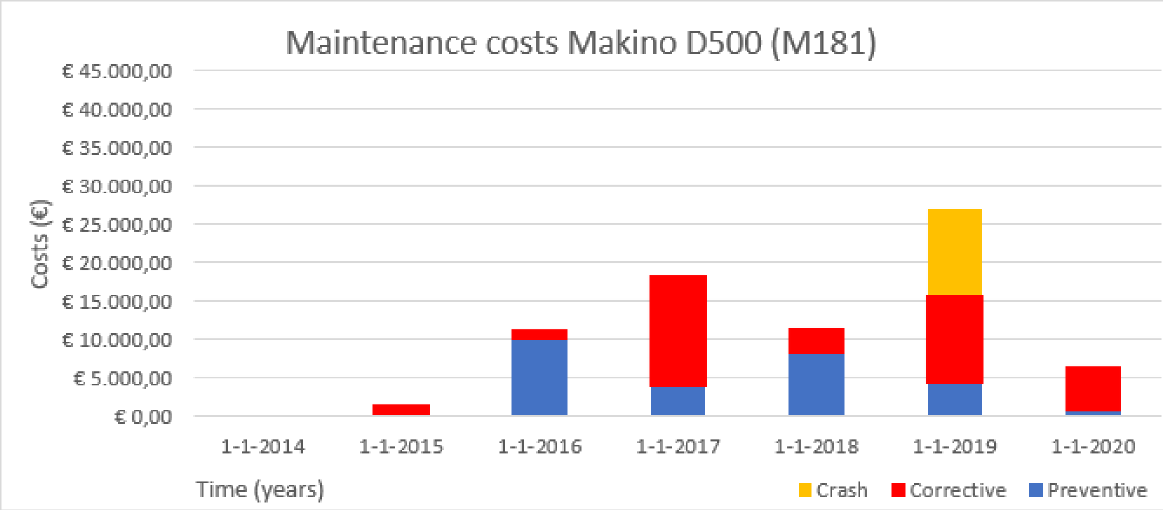


FIGURE 89: MAINTENANCE COSTS MAKINO D500 M181

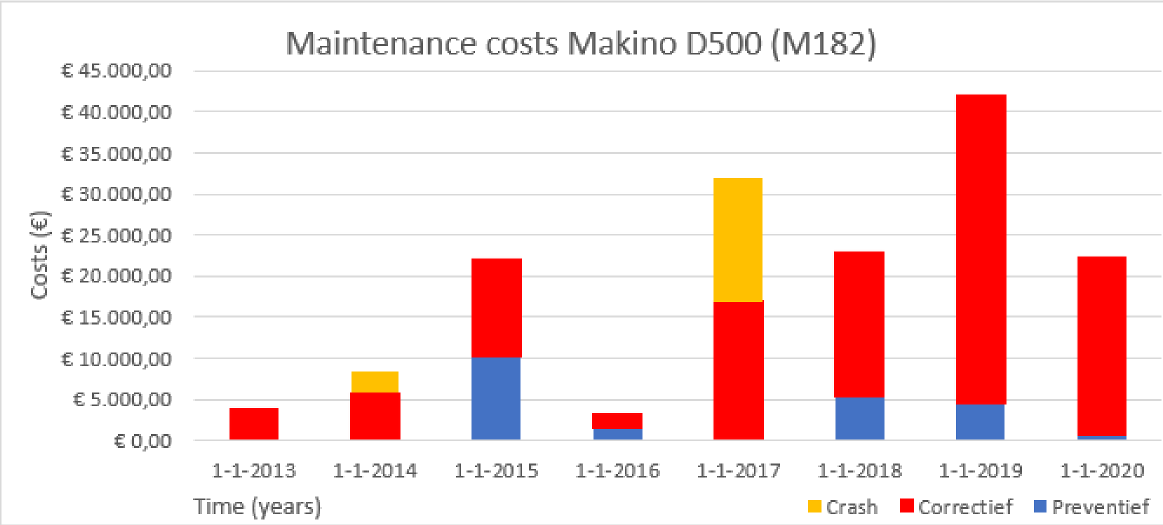


FIGURE 90: MAINTENANCE COSTS MAKINO D500 M182

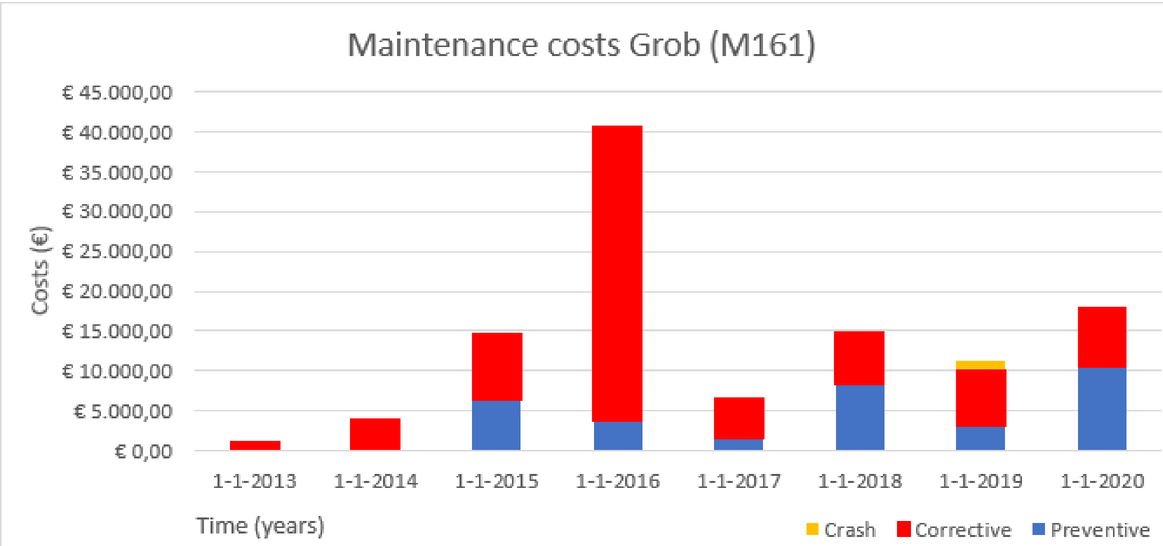


FIGURE 91: MAINTENANCE COSTS GROB G550 M161

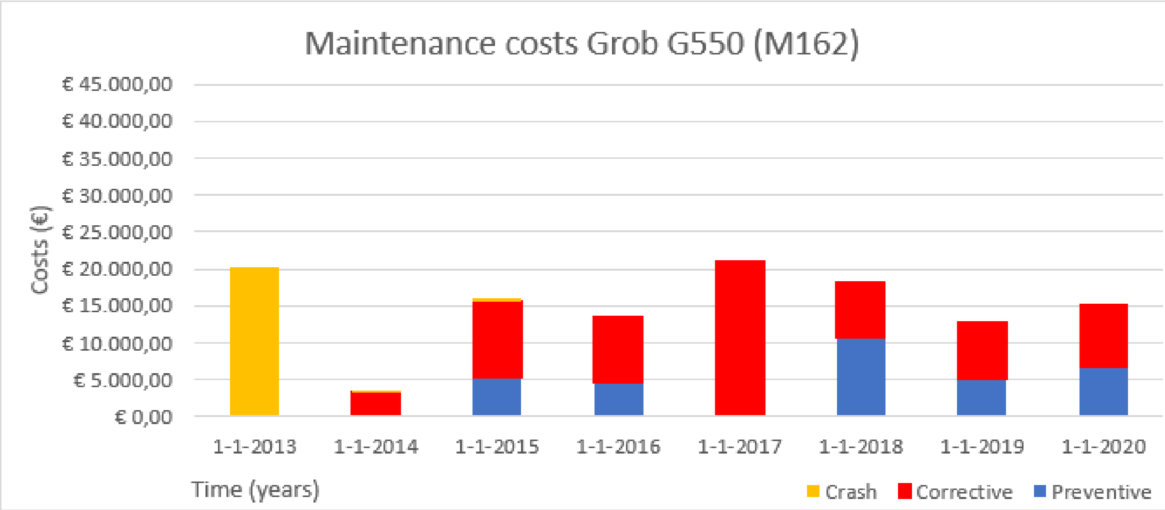


FIGURE 92: MAINTENANCE COSTS GROB G550 M162

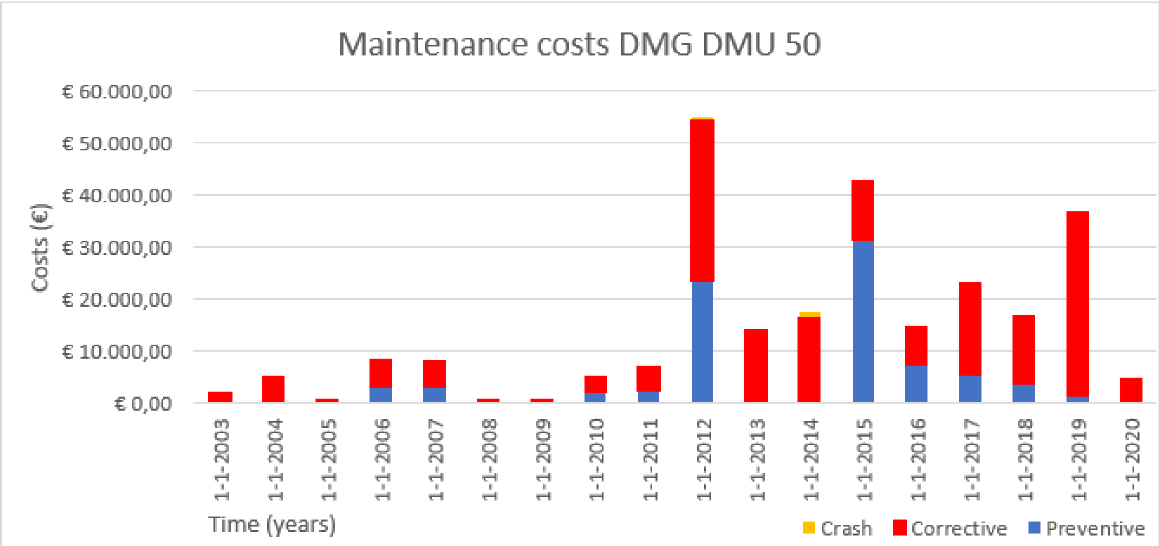


FIGURE 93: MAINTENANCE COSTS DMG DMU 50 EVO

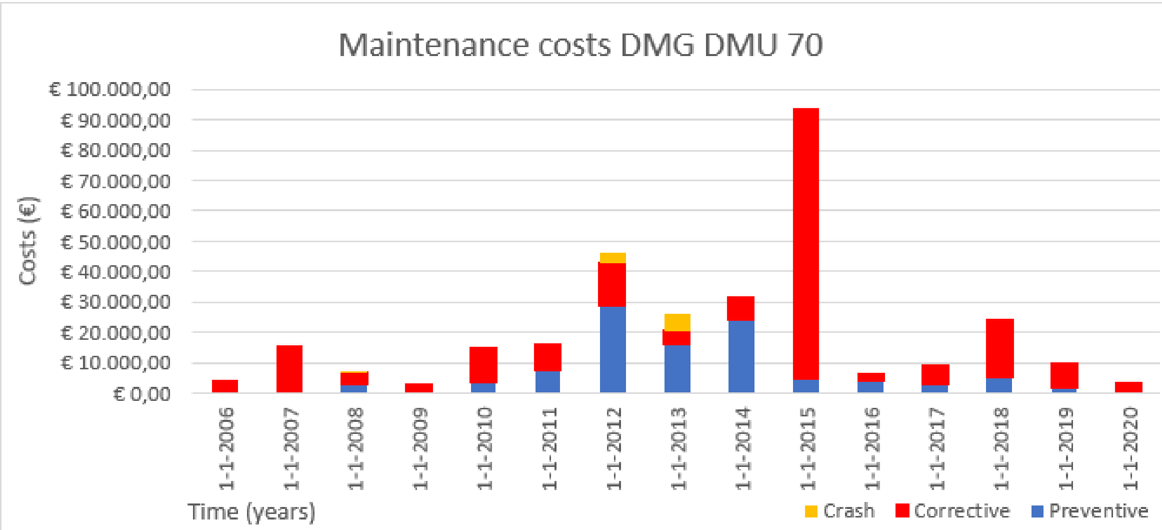


FIGURE 94: MAINTENANCE COSTS DMG DMU 70

HUMAN COSTS

Estimated time to gather data

- Processing data into information.
  - 0.5 day.
- Data can be updated by hand (every month).
  - 0.5 hour for whole document.

Assumptions

- Pre-calculation is the same as recalculation (vc-nc = 100%).
  - Hours are based on calculated hours. So if calculated human hours are 12 and 8 hours are actual used, 12 hours are booked.
- There is no traceability of used machine.
  - Human hours are booked on the calculated machine.
- M162 is zero since 2019 Week 43.
  - Change in registration, all hours of M161 and M162 are booked on M161.
  - Traceability of used machine is gone.
- Hours / day are multiple weeks zero.
  - A production process of NTS Norma needs human actions to keep the machines up and running. If after multiple weeks, for instance at the M181 in 2020 week 16 – 21, no human hours were needed for production, this is an indication that either the machine was not running in this time period, or the way of booking the human hours is wrong.

Human working hours per day

2014	Week 01	Week 02	Week 03	Week 04	Week 05	Week 06	Week 07	Week 08	Week 09	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25	Week 26	Week 27	Week 28	Week 29	Week 30	Week 31	Week 32	Week 33	Week 34	Week 35	Week 36	Week 37	Week 38	Week 39	Week 40	Week 41	Week 42	Week 43	Week 44	Week 45	Week 46	Week 47	Week 48	Week 49	Week 50	Week 51	Week 52		Average
M181																																																						
M182																																																						
M161																																																						
M162																																																						
DMU/DMG 50	4	3	0	2	1	0	0	1	4	2	8	10	12	16	14	16	15	16	14	11	13	11	17	8	12	11	9	6	5	7	11	9	8	10	16	11	11	9	13	15	11	9	11	8	8	6	6	12	8	9	6	6		9
DMU/DMG 70	0	0	4	4	1	0	0	1	2	0	0	0	5	3	2	0	2	2	0	6	5	3	1	6	1	1	4	10	2	3	0	1	0	5	1	2	2	0	0	0	0	2	4	2	3	3	1	0	0	0	3	3		2

2015	Week 01	Week 02	Week 03	Week 04	Week 05	Week 06	Week 07	Week 08	Week 09	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25	Week 26	Week 27	Week 28	Week 29	Week 30	Week 31	Week 32	Week 33	Week 34	Week 35	Week 36	Week 37	Week 38	Week 39	Week 40	Week 41	Week 42	Week 43	Week 44	Week 45	Week 46	Week 47	Week 48	Week 49	Week 50	Week 51	Week 52	Week 53		Average
M181																																																							
M182																																																							
M161																																																							
M162																																																							
DMU/DMG 50	4	9	12	10	9	11	13	8	6	9	10	9	8	9	7	3	4	5	3	3	7	3	5	6	5	4	6	4	7	7	6	4	3	3	4	2	2	6	9	8	14	9	7	4	6	8	13	6	8	10	8	3	2		7
DMU/DMG 70	1	0	1	4	5	6	2	2	1	0	0	3	4	4	6	9	5	2	2	1	0	5	0	0	0	4	8	5	2	1	0	0	4	4	3	0	2	0	0	8	10	2	0	0	0	0	0	3	1	0	1	0	0		2

2016	Week 01	Week 02	Week 03	Week 04	Week 05	Week 06	Week 07	Week 08	Week 09	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25	Week 26	Week 27	Week 28	Week 29	Week 30	Week 31	Week 32	Week 33	Week 34	Week 35	Week 36	Week 37	Week 38	Week 39	Week 40	Week 41	Week 42	Week 43	Week 44	Week 45	Week 46	Week 47	Week 48	Week 49	Week 50	Week 51	Week 52		Average
M181																																																						
M182																																																						
M161									9	5	6	4	0	1	1	2	13	0	2	5	2	5	7	10	9	6	2	0	4	2	6	4	6	8	4	1	3	4	2	5	11	10	6	4	12	5	12	3	7	6	2	0		5
M162								3	3	0	1	0	0	0	0	2	3	4	4	2	4	6	2	4	2	7	3	6	6	4	0	3	4	2	5	4	1	3	6	0	4	3	3	8	0	0	0	0	0	0	0	0		2
DMU/DMG 50	4	2	2	7	3	2	9	5	7	6	7	10	6	7	7	9	7	9	10	10	6	11	8	12	11	9	10	10	10	6	6	4	5	3	4	4	3	6	8	9	7	7	6	10	3	5	5	6	8	10	8	3		7
DMU/DMG 70	0	2	1	0	0	2	0	2	1	1	4	3	3	2	5	2	0	3	9	5	7	0	4	0	0	7	4	1	2	0	2	1	0	4	11	6	2	1	2	6	3	2	2	3	8	2	1	1	2	5	2	1		3

2017	Week 01	Week 02	Week 03	Week 04	Week 05	Week 06	Week 07	Week 08	Week 09	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25	Week 26	Week 27	Week 28	Week 29	Week 30	Week 31	Week 32	Week 33	Week 34	Week 35	Week 36	Week 37	Week 38	Week 39	Week 40	Week 41	Week 42	Week 43	Week 44	Week 45	Week 46	Week 47	Week 48	Week 49	Week 50	Week 51		Average
M181																																																2	1	0	0		1
M182																																																5	6	9	8		7
M161	4	12	13	14	17	14	10	13	14	0	8	7	6	4	5	10	6	1	7	1	4	1	2	7	8	8	2	7	4	10	6	10	8	8	6	5	3	0	2	5	5	8	3	11	11	7	8	6	10	11	6		7
M162	6	12	12	11	5	13	8	4	3	7	8	8	8	10	12	19	1	14	9	17	3	11	9	6	7	5	6	1	1	2	3	4	4	3	1	0	0	1	1	1	0	1	0	6	2	1	0	3	0	2	5		5
DMU/DMG 50	8	6	5	7	6	7	10	6	6	10	11	14	15	12	6	5	8	16	14	11	13	11	7	10	8	15	26	12	16	8	7	4	7	6	2	4	9	8	12	7	15	13	11	13	20	9	10	10	9	10	7		10
DMU/DMG 70	1	9	2	1	2	2	3	7	10	3	2	0	7	4	0	1	10	0	1	6	4	0	2	10	5	1	3	9	5	14	3	0	2	0	2	7	15	4	6	0	21	2	6	3	3	3	4	10	9	0	2		4

2018	Week 01	Week 02	Week 03	Week 04	Week 05	Week 06	Week 07	Week 08	Week 09	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25	Week 26	Week 27	Week 28	Week 29	Week 30	Week 31	Week 32	Week 33	Week 34	Week 35	Week 36	Week 37	Week 38	Week 39	Week 40	Week 41	Week 42	Week 43	Week 44	Week 45	Week 46	Week 47	Week 48	Week 49	Week 50	Week 51		Average
M181	0	3	2	4	4	0	3	2	2	0	2	2	0	3	4	2	3	2	3	2	1	7	5	2	5	5	4	7	1	2	1	0	0	2	5	6	0	1	3	4	6	3	0	3	1	1	0	0	1	8	0		2
M182	5	8	7	6	7	4	4	1	5	6	4	6	6	4	6	5	4	6	1	7	7	6	6	6	5	6	5	6	3	5	6	3	7	3	1	1	6	6	7	7	5	1	7	4	5	5	6	3	4	4	6		5
M161	6	6	2	9	4	7	9	4	5	4	7	5	7	2	8	6	2	9	5	9	6	5	8	8	12	9	5	7	7	7	14	4	6	8	13	23	19	5	5	9	4	0	4	10	12	0	0	6	10	2	0		7
M162	2	5	2	4	0	3	3	2	0	4	4	4	3	3	1	2	3	4	1	0	4	3	3	0	0	1	5	3	1	3	1	2	3	1	2	1	1	4	3	3	3	0	3	4	2	2	3	3	0	4	1		2
DMU/DMG 50	5	13	10	12	17	16	9	14	2	19	10	15	13	11	15	9	16	7	11	7	12	19	13	14	11	13	6	15	17	12	7	7	8	17	6	12	3	15	7	6	11	6	13	10	5	5	3	2	7	4	12		10
DMU/DMG 70	1	0	6	4	14	2	6	8	1	9	5	2	11	7	5	3	7	3	6	1	3	4	1	1	0	0	3	0	0	3	2	2	4	2	-1	0	0	3	4	2	1	3	1	2	2	2	0	2	5	4	4		3

2019	Week 01	Week 02	Week 03	Week 04	Week 05	Week 06	Week 07	Week 08	Week 09	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25	Week 26
M181	0	2	1	1	3	7	1	0	0	0	0	1	0	1	0	0	6	0	0	8	2	0	9	5	0	3
M182	0	4	1	0	5	4	4	1	1	5	5	5	5	6	4	1	3	6	5	4	6	4	19	12	6	1
M161	0	0	6	12	3	1	16	3	6	0	11	2	15	8	5	15	9	10	6	2	5	3	12	10	23	9
M162	0	2	3	5	3	0	3	0	6	0	0	4	0	0	0	0	0	0	9	3	4	2	1	3	0	3
DMU/DMG 50	3	15	6	3	6	6	3	6	5	6	10	14	2	6	5	5	0	5	2	2	1	1	2	2	3	3
DMU/DMG 70	2	8	5	3	1	2	0	0	0	1	0	0	0	2	1	0	0	2	5	0	5	2	4	2	0	3

2019	Week 27	Week 28	Week 29	Week 30	Week 31	Week 32	Week 33	Week 34	Week 35	Week 36	Week 37	Week 38	Week 39	Week 40	Week 41	Week 42	Week 43	Week 44	Week 45	Week 46	Week 47	Week 48	Week 49	Week 50	Week 51	Week 52		Average
M181	0	3	3	5	0	0	1	3	0	1	3	6	0	1	0	3	6	2	4	9	7	3	6	2	7	0		2
M182	5	7	1	4	5	0	0	0	0	4	4	3	2	6	2	7	5	5	5	7	2	8	7	8	10	0		4
M161	16	10	8	1	9	4	10	12	3	1	9	3	4	4	0	6	9	2	9	0	8	4	13	11	12	7		7
M162	1	3	2	2	0	3	3	1	2	3	3	0	3	0	2	3	0	0	0	3	0	0	0	0	0	0		2
DMU/DMG 50	2	2	1	0	1	0	0	6	5	3	4	3	3	8	5	4	3	3	6	4	8	6	2	5	8	0		4
DMU/DMG 70	1	1	2	4	3	3	0	2	0	3	3	1	0	5	1	0	0	3	3	0	2	3	1	2	0	0		2

2020	Week 01	Week 02	Week 03	Week 04	Week 05	Week 06	Week 07	Week 08	Week 09	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20	Week 21	Week 22	Week 23	Week 24	Week 25	Week 26
M181	0	1	0	2	3	3	5	5	5	6	3	6	6	3	3	0	0	0	0	0	0	1	1	1	1	2
M182	0	4	0	5	10	9	4	4	4	6	2	5	6	5	5	7	1	5	5	10	1	8	10	5	0	7
M161	2	2	4	18	5	11	5	17	7	8	19	24	11	16	22	3	5	13	16	25	30	13	14	20	11	4
M162	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	4	0	0	0	0	5	10	6	2
DMU/DMG 50	4	7	3	8	8	3	3	2	2	6	6	4	5	4	4	5	5	6	4	5	3	3	5	4	5	1
DMU/DMG 70	3	0	0	0	0	0	0	0	0	0	2	7	0	0	4	2	2	1	1	2	0	1	1	4	2	0

2020	Week 27	Week 28	Week 29	Week 30	Week 31	Week 32	Week 33	Week 34	Week 35	Week 36	Week 37	Week 38	Week 39	Week 40	Week 41	Week 42	Week 43	Week 44	Week 45	Week 46	Week 47	Week 48	Week 49	Week 50	Week 51	Week 52	Week 53		Average
M181	0	0	2	1	2	2	1	0	0	2	0	1	6	1	1	1	5	6	1	4	0	1	0	6	7	1	0		2
M182	7	2	5	4	5	5	5	1	1	1	5	3	5	2	1	0	5	5	5	3	2	5	5	6	5	7	0		4
M161	4	18	11	7	5	8	0	1	8	14	4	6	1	4	5	3	11	0	11	4	4	9	7	12	16	5	0		9
M162	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	4	0	0	0	0	0	0		1
DMU/DMG 50	1	9	4	3	0	4	3	4	5	2	2	3	1	6	4	8	2	4	6	6	7	3	8	3	8	3	2		4
DMU/DMG 70	2	1	0	1	0	1	2	5	1	0	2	2	2	1	2	1	0	0	0	0	0	0	1	1	2	0	1		1

2021	Week 01	Week 02	Week 03	Week 04	Week 05	Week 06	Week 07	Week 08	Week 09	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19		Average
M181	1	6	1	5	5	4	7	3	2	10	5	3	8	1	5	7	2	2	0		4
M182	1	6	5	9	8	6	9	2	6	7	6	8	7	5	5	5	6	5	3		6
M161	3	16	5	8	9	16	10	3	18	16	4	15	6	8	6	5	15	7	8		9
M162	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
DMU/DMG 50	6	9	8	10	10	5	6	3	2	4	7	4	6	1	6	5	3	4	2		5
DMU/DMG 70	2	0	0	2	2	0	0	2	2	1	2	1	2	2	0	2	2	0	1		1

TOOLING COSTS METHOD 1

Estimated time to gather data.

- 0,5 day

Assumptions

- No machine traceability.
  - Data based on total production hours and total buying costs.
    - Different machine groups are combined, all with a different cost per production hour ratio.
    - Cost per production hour represents the average of the whole manufacturing hall.
    - Calculated by dividing the buying cost by the production hours.

Inkoopoverzicht gereedschappen per maand + productie-uren + Euro/prod.uur

snijgereedscshappen - exclusief investering (6, 6A, 7, en 7A)

Mehmet Dönmez Ordered Amount	Jaar 2019	2020	2021
Januari	€ 117,453	€ 135,795	€ 196,648
Februari	€ 125,490	€ 168,674	€ 131,606
Maart	€ 126,572	€ 217,204	€ 190,679
April	€ 112,403	€ 223,523	€ 192,460
Mei	€ 145,098	€ 160,819	€ 171,690
Juni	€ 80,155	€ 213,011	
Juli	€ 130,440	€ 160,228	
Augustus	€ 94,099	€ 82,246	
September	€ 115,213	€ 181,237	
Oktober	€ 150,795	€ 129,961	
November	€ 139,892	€ 178,614	
December	€ 162,276	€ 144,782	
Totaal	€ 1,499,886	€ 1,996,094	€ 883,082

Productieuren per maand Repeat en non-repeat	2019	2020	2021
Januari	16568	14629	15709
Februari	17690	15907	16975
Maart	18083	17793	32684
April	14302	16353	17536
Mei	14973	17262	16975
Juni	14356	17468	
Juli	16408	15056	
Augustus	12946	12034	
September	14997	14223	
Oktober	17460	15309	
November	17876	16621	
December	14304	14738	
	189964	187393	99878

Excl. Slijpwerk	## ##	€ 10.65	€ 10.07
Kosten per productieuur			
	2019	2020	2021
Januari	€ 7.09	€ 9.28	€ 12.52
Februari	€ 7.09	€ 10.60	€ 7.75
Maart	€ 7.00	€ 12.21	€ 5.83
April	€ 7.86	€ 13.67	€ 10.98
Mei	€ 9.69	€ 9.32	€ 10.11
Juni	€ 5.58	€ 12.19	
Juli	€ 7.95	€ 10.64	
Augustus	€ 7.27	€ 6.83	
September	€ 7.68	€ 12.74	
Oktober	€ 8.64	€ 8.49	
November	€ 7.83	€ 10.75	
December	€ 11.34	€ 9.82	
	€ 7.90		

FIGURE 95: TOOLING COSTS METHOD 1

TOOLING COSTS METHOD 2

Estimated time to gather data.

- Operator data.
  - 1 day.
- Costs per item name.
  - 0.5 day.
- Data not updatable!

Assumptions

- No machine traceability.
  - Data based on checked out tools by operator.
    - Most operators work mainly at the same machine.
    - Operator can switch between machines.
    - Operator can get tooling for his college when the other operator is busy.
    - When one operator is sick, day off, etc., operators can switch between machine to keep all machines producing.
- Costs per machine group.
  - Data from all operators divided by all machines from that group.
    - Operators do not switch between machine groups.
    - Tool setters check out tools for all machine groups
      - There is no traceability.
      - Assumption that 33.33% from tooling costs are for 24/7 group.
      - Based on total costs, which are in 2019 33.33% of the total costs.
- Costs per machine
  - There are 15 machines in 24/7 production.
  - Costs of all machines are equal.

TimeStamp	Trans Type	Product Name	Part No.	User	Quantity	Amount			
2019-08-27 14:56:44	Take	BOOR D4.1 VHM IK SL29	NO-100213	Operator 1	1	79,8		1-1-2018	€ 0
2019-08-27 15:07:52	Take	4-SN BOLFREES D1 VHM	NO-200374	Operator 1	1	68,79		1-1-2019	€ 15.033
2019-08-28 09:03:08	Take	BOOR D4.1 VHM IK SL29	NO-100213	Operator 1	1	79,8		1-1-2020	€ 57.914
2019-08-28 16:01:24	Take	WP XOEX120408R-M07	NO-340017	Operator 1	4	39		1-1-2021	€ 10.239
2019-09-03 11:40:04	Take	4-SN FREES D8 VHM F0.	NO-200047	Operator 1	1	27,4		1-1-2022	
2019-09-03 11:40:49	Take	4-SN FREES D4 VHM F0.	NO-200044	Operator 1	1	20,03			
2019-09-03 11:41:51	Take	CENTERBOOR D6X120 V	NO-150003	Operator 1	1	16,28			
2019-09-03 11:43:21	Take	4-SN AFBRAAMFREES D	NO-280001	Operator 1	1	20,84			
2019-09-03 11:44:30	Take	3-SN DRAADFREES M3 S	NO-290002	Operator 1	1	61,72			
2019-09-03 11:48:33	Take	3-SN FREES D12 VHM R	NO-200112	Operator 1	1	71,55			
2019-09-03 11:48:46	Return	3-SN FREES D12 VHM R	NO-200112	Operator 1	-1	-71,55			

TABLE 17: DATA PER OPERATOR

	1-1-2019	1-1-2020
Operator 1	€ 15.033	€ 57.914
Operator 2	€ 5.791	€ 17.170
Operator 3	€ 9.321	€ 5.876
Operator 4	€ 14.574	€ 17.140
Operator 5	€ 1.233	€ 2.630
Operator 6	€ 12.589	€ 18.149
Operator 7	€ 3.250	€ 20.065
Operator 8	€ 121	€ 112
Operator 9	€ 56.721	€ 72.031
Operator 10	€ 9.316	€ 2.908
Operator 11	€ 24.369	€ 31.574
Operator 12	€ 16.299	€ 0
Operator 13	€ 2.435	€ 49.056
Operator 14	€ 11.665	€ 21.651
Operator 15	€ 1.346	€ 2.293
Operator 16	€ 53.059	€ 51.747
Operator 17	€ 27.649	€ 55.785
Operator 18	€ 11.112	€ 16.613
Operator 19	€ 2.869	€ 3.203
Operator 20	€ 777	€ 12.266
Operator 21	€ 30.751	€ 46.623
Operator 22	€ 14.158	€ 25.320
Operator 23	€ 57.938	€ 63.963
Tool setter 1	€ 11.391	€ 52.668
Tool setter 2	€ 16.944	€ 35.935
Tool setter 3	€ 32.492	€ 99.471
Total	€ 443.203	€ 782.166
Factor	3,4	2,55
Booking hours	60.915	77.878
Total machine park tooling costs	€ 1.499.886	€ 1.996.094
Averager costs per hour	€ 7,28	€ 10,04

TABLE 18: TOOLING COSTS PER YEAR

DOWNTIME COSTS

Estimated time to gather data.

- Unknown

Assumptions

- Downtime measurement
    - Downtime is measured during shift times, so the time the operator is at work.
    - The time the operator is not working is not included in the downtime.
        - Night unavailable.
        - Weekend unavailable.
    - Only downtime due to failures is measured.
    - Only 2 years of data available.

Machine	Downtime [hours] (2017)	Downtime [hours] (2018)
Makino D500 M181	129.7	32.0
Makino D500 M182	0.0	0.0
Grob G550 M161	35.4	30.0
Grob G550M162	254.1	517.0
DMG DMU 50 EVO	633.7	824.0
DMG DMU 70 EVO	31.0	283.0

TABLE 19: DOWNTIME COSTS 2017

DEPRECIATION

With advise of the tactical buyer, these expected depreciation percentages are made. These percentages are found using a site that trades used machines. On top of that, in an article of Makino is stated that for high-performance machines, the value retains about 50% after 3 years of production [15]. This is an indication that the found percentages are plausible.

Expected depreciation per year.			
Jaar 0	Jaar 3 [16]	Jaar 10	Jaar 20
100%	50%	20%	10%

TABLE 20: EXPECTED DEPRECIATION PER YEAR

	Makino D500	Grob G550	DMG DMU 50 evo	DMG DMU 70 evo
Machine	530.000	650.000	400.000	450.000
Robot	140.000	150.000	150.000	150.000
Setup	100.000	100.000	100.000	100.000
Total	770.000	900.000	650.000	700.000

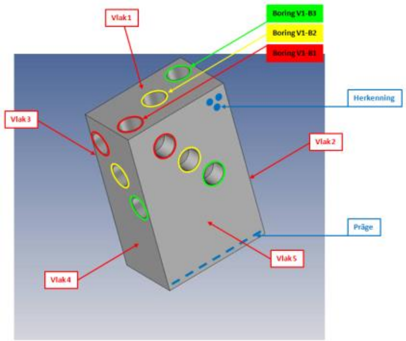
TABLE 21: INITIAL INVESTMENT

I: TECHNICAL LIFE INTERMEDIATE PROGRESS

The table below is a work in progress. In a later stage, this information is used to design a new technical life model, based on the information found here and new information that was available in a later stage of the thesis. For every success factor, different KPI's are found. These KPI's can be used to measure the quality of the machine. This list is not used as final product, but used as inspiration for the final technical life model.

SUCCESS FACTORS MACHINE

Success factor	Re	Method	Description
Overall equipment efficiency	[2] [39] [40] [41]	Performance	Efficiency of the machine
Potential production time	[2] [39]	OEE	Time that is available for production
Actual production time	[2] [39]	OEE	Actual time that is used for production
Theoretical output	[2] [39]	OEE	Theoretical fastest output time
Actual output	[2] [39]	OEE	Actual output time
Actual output	[2] [39]	OEE	Produced products
Good product	[2] [39]	OEE	Good products
Overall equipment efficiency costs	[42]	OEE costs	Downtime x hourly costs Hours to make up part deficit x hourly costs Cost of part x amount of scrap
Opportunity to increase production	[43]	Availability	Percentage of the possible increase of production
Maintenance and engineering costs	[43]	Maintenance → Economic	Total maintenance and engineering costs per machine per year
Net income	[43]	Performance → Economic	Neto income per machine per year
Maintenance costs / replacement asset value	[44] [45]	Maintenance → Economic	Total maintenance costs divided by the replacement value of the asset.
% of SOO (storing ongepland onderhoud)	[43]	Maintenance	Percentage of error maintenance that is unplanned. Error is unexpected and must be repaired directly.
% of planned maintenance	[2] [43] [41]	Maintenance	Percentage of maintenance that is planned
% maintenance overtime	[43]	Maintenance	Overtime of the scheduled maintenance
Mean time to repair	[46] [40] [47]	Maintenance	Sum of repair time (in hours) / Number of repairs
Mean time between maintenance	[46]	Maintenance	
Mean time between failure	[43] [47] [48] [41] [49]	Maintenance	Total run time / Number of failures
Mean time to failure	[47]	Maintenance	Average time between failures without possibility of repair.

Failure frequency	[47]	Reliability	Equipment failure frequency
Alarms	[43]	Reliability	Number of recorded alarms per machine per day
First pass	[50]	Reliability / conformance	Percentage of products that passes final inspection the first time.
Scrap and rework	[50]	Reliability	Scrap and rework as percentage of the shop sales.
SMED	[2]	Availability	Time to change from current product to another product
Current age of asset / technical service life	[45]	Durability	
Complaint ratio	[51]	Quality	Amount of complaints per time unit
Ball bar measure	[52]	Quality	Measures the geometry of the machine. Process takes 2-6 hours
Laser measure	[52]	Quality	Calibrates the machine. Process takes 3-4 days. Done when Ballbar measure is insufficient.
Test block measure	NTS	Quality	
Expected lifetime supplier		Durability	

SUCCESS FACTORS HUMAN

Success factor	Re	Method	Description
Training days / mechanic	[48]	Training	
Operator staff costs	[43]	Economic	Total operator cost per machine per year
Maintenance labor cost as a % of TMC	[48]	Economic	Percentage of the total maintenance costs

SUCCESS FACTORS ENVIRONMENT

Success factor	Re	Method	Description
Unplanned events	[43]		All unplanned events affecting production
Temperature change		Reliability	Temperature must remain stable within a certain range
Vibrations		Reliability	Vibrations must remain below a certain range
Foundation		Reliability	
Isolation		Reliability	

SUCCESS FACTORS MACHINE - HUMAN

Success factor	Re	Method	Description
Total recordable incident rate	[43]	Safety	
Consecutive injury-free days	[43]	Safety	
Total injury-free days	[43]	Safety	
Near misses	[43]	Safety	
Life-saving rules violation	[43]	Safety	Examples: using cell phone while driving, no fall protection, no seat belt, etc.

Decibel's		Regulations	
Amount of adjusting tasks per time unit	NTS	Reliability	

SUCCESS FACTORS MACHINE - ENVIRONMENT

Success factor	Re	Method	Description
Compatibility with features or equipment		Compatibility	Machine can work with new features or equipment

SUCCESS FACTORS HUMAN - ENVIRONMENT

Success factor	Re	Method	Description
none			

J: STABILITY TEST CLAMPING TOOL

TDM 2020

Gereedschappenblad

07.05.2021 13:15:27 / JVG

ID-nummer: MA63-N20713

Omschrijving 1: 4-SN FREES RVS VF D10 VHM R0.5

norma

T-nummer:

Gereedschapsklasse: M03 / FREES HOEKSCHACHT

Gereedschapsgroep: 07 / WALS-VOOR-GECENTR. V

Houd.: 1835 / HSK 63-A DIN69893 MST

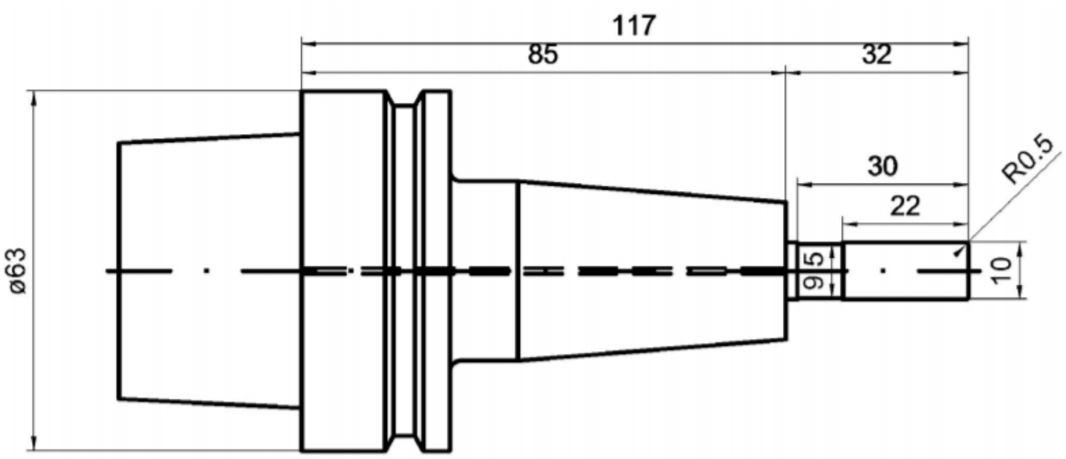
Gew.: 0.90

Schn.st.: 1000 / VHM

Z: 4

Tijdsch.:

Omschrijving 1	Waard	Eenh	Omschrijving 2
Dc	10.0000	mm	Snijdiameter
Xs	117.000	mm	Uitkragingslengte
Ls	22.0000	mm	Snijlengte
L4	30.0000	mm	max. werkdiepte
Lh	22.0000	mm	Freeshoogte
Ltot		mm	Totale lengte
DHB	9.50000	mm	Aansluitingsdiameter
RE1	0.50000	mm	Snijhoekradius1
F		mm	Snijhoekfase
KF		°	Snijhoekafschuining
Helix		-	Helix L /R / N
Alpha		°	Hoek invoeren Alpha



CAD-nr.: MA63-N20713

P.	Item-ID	Item-omschr.1	Standaard magazijnp	St.
1	NO-200424	4-SNFREESRVSVFD10VHMR0.5WEL1		1
2	NO-700231	HSK63AOPNAMEKRIMPD10KKLENGTE		1

Technologiedata:

Collisiegegevens:

FIGURE 96: STABILITY TEST CLAMPING TOOL