Designing a bottom-up Remanufacturing Process Control and Maturity Model for Airline MRO

A case study at KLM E&M

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by

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An electronic version of this thesis is available at `http://repository.tudelft.nl/`.

Preface

In this report is the result of my Master Thesis, which was carried out at KLM Engineering and Maintenance. The report you are about to read is the final report needed to complete my master studies Multi-Machine Engineering as a part of the Master Mechanical Engineering, and with that end my study career at the Delft University of Technology. This Thesis came to be in somewhat trying times, when most of the world was locked down. Fortunately I still got the opportunity to perform this thesis at KLM Engineering and Maintenance, being the first student back at the company after little while. At KLM I was given the chance to see the ins and outs of the Airline MRO world, which I am grateful for as this is a world often not shown to the general public. This thesis aimed to design a remanufacturing process control model, which aided in gaining control, sustaining it and if possible improve on it, as this is something currently missing in the Airline MRO, and remanufacturing field, in general.

During my internship I was active in the Process Excellence office. This is, in my opinion, the best place to be within KLM Engineering an Maintenance, as you can help at every different department or shop. This provides a great opportunity to really get to grips with all the different areas and intricacies of Airline MRO. Through Process Excellence I also got to visit other companies like EPCOR to see their way of working, which was very interesting as well.

The past months have been quite the journey. The COVID-19 pandemic did not make graduating any easier. Therefor I am grateful to those who helped me in these sometimes trying times. First of all I would like to express my gratitude to Guus Philips van Buren and Alex Gortenmulder. The days over the past months at the office were always fun and insightful, and without your guidance and advice this Thesis would have been even more difficult to complete. Furthermore I would like to thank Crispijn Huijts, Ronald Ellemijer and Joris Hampsink, for allowing me the chance to use their respective shops for my case studies. The knowledge about all the difficulties in controlling your shops shaped the remanufacturing process control model which is designed in this Thesis.

I would also like to express my gratitude towards my daily supervisor, Dr. Wouter. W.A Beelaerts van Blokland. Even though face to face communication was somewhat difficult at times, you always managed to provide me with new insights for interesting directions to take the Thesis, as well as provide me with new energy to keep on going whenever I was stuck on a certain problem. I would also like to thank Prof. Dr. R.R.Negenborn, The few times we had meetings you were always critical and asked the right questions, which lifted the level of this Thesis.

Lastly I would very much like to thank my family for giving me their full support over the past couple of months. My friends who I could always count on whenever i needed to complain about something, or needed help with a certain conundrum. And especially Gerard, Koen, Melle and Pim, my roommates, for all the help, support, guidance and enduring me when I was grumpy over the past months.
The layers of this onion have finally been peeled.

I hope you will enjoy reading this Thesis.

E.W.A. Tets
Delft, May 2022

Abstract

This research presents the design of a remanufacturing process control model, to be used in the Airline MRO sector, but with potential to be used for remanufacturing in general. Remanufacturing process control can be defined as a set of subsequent steps or actions which can be followed in order to control the set of activities in a production organization. The goal of implementing such a model is thus to get control over a process which is usually lacking it, not just improving already existing control. In order to get a model which can be widely applied this design was based on two different case studies at KLM Engineering and Maintenance, an Airline Maintenance Repair and Overhaul provider.

Through a literature study it became clear that there is a not yet a remanufacturing process control model designed especially for Airline Maintenance Repair and Overhaul, or remanufacturing in general. Different studies were analyzed, and through this, aspects which the model needed to contain were determined. This theoretical side of the model then had to be combined with problems from practice, which was done via the two case studies.

The two chosen case studies to base the design of the remanufacturing process control model on were chosen to be dissimilar, and each have different existing problems in control of the process. Identifying the problems and how to avoid them was the base for the model. This was then translated into a more general model which could be followed for achieving control. After the control is achieved the model also implements a strategy to sustain control, as improvement without sustainment is no improvement.

The presented remanufacturing process control model consists of six layers, which take place over three different intervals. The first interval is to be done ahead of the implementation. In this interval the Process Stream Analysis and Manpower plan of the process should be constructed. This provides the new ingredients of the process so to say. The next interval is focused more on real time control and can be carried out alongside the implementation of the model. Here the entrance and bottleneck control are of concern. These two aspects are linked together as the first bottleneck dictates the inflow of the process. If this is all determined the last interval of the model can be considered. First is the Target Control, which provides the opportunity to check if the model is performing as expected, and then the sustainment of control can finally happen to not lose any made progress. Even though the model consists of different stages all aspects should be evaluated and finished before the the first steps are implemented. Furthermore, a separate lean maturity model is presented, which can be used to check the progress towards being fully optimized as an organisation. These two models were combined in order to create production maturity model. Combining qualitative and quantitative aspects of both models to create an all encompassing model.

To test whether the model would actually help regain control and improve results for a process one of the two case studies has been simulated. This simulation resulted in twelve different future states on which the model was applied. These future states were then compared to the last year where the process took place without major disruptions. The future states were compared to the uncontrolled state on the basis of backlog, turnaround time, FTE utilization and service level.

When evaluating the results it showed that all of the twelve different future states outperformed the uncontrolled state on every aspect which was tested. This is in line with the hypothesis that the control model will improve the process performance. With this the need for such a remanufacturing process control model is thus emphasized. Lastly this thesis presents some pitfalls which were discovered for the implementation of such a remanufacturing process control model.

List of abbreviations

AFKLM Air France Koninklijke Luchtvaart Maatschappij.

AHA Automated Handling Area.

CS Component Services.

DMAIC Define Measure Analyse Improve Control .

E&M Engineering & Maintenance.

ES Engine Services.

JIT Just In Time.

LIFO Last In First Out.

LRU Line Replacement Unit.

MRO Maintenance Repair and Overhaul.

OCAP Out of Control Action Plan.

OEE Overall Equipment Effectiveness.

OEM Original Equipment Manufacturer.

OTP On Time Performance.

PSA Process Stream Analysis.

SL Service Level.

SLIM Sustainable Lean Iceberg Model.

TAT Turnaround Time.

ToC Theory of Constraints.

TPM Total Productive Maintenance.

TQM Total Quality Management.

VSM Value Stream Map.

WIP Work in Progress.

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1
Introduction

In the following chapter an introduction regarding the thesis will be presented. First of, some incentive for why the research is conducted is described in section 1.1. Next up in section 1.2 a little more light will be shed on the field in which the research was conducted. After this the knowledge gaps will be examined in the section Research problems, 1.3, this will be done in twofold, first looking at the problems arising from practical experience and then checking the existing literature on the matter to identify any gaps. Then the research objective will be shown, followed by the deliverables and the research questions. Lastly the methodology used will be examined in section 1.8, after which the chapter will get summarized.

1.1. Research context

In the current day and age sustainability is getting increasingly important. Even tough the airline business is not the first thing one thinks about when considering sustainability great efforts are in place in order to make the industry greener. One place where this is evident is in the airline Maintenance Repair and Overhaul (MRO). The airline MRO business is a remanufacturing business, which means it keeps extending the life of parts which are used up. This of course benefits the sustainability since new parts are needed less often, resulting in less production of said parts. Accompanying the environmental benefits remanufacturing also has economic benefits for a company [58].

It is clear that remanufacturing is an important business for any company, but for airlines it is paramount, since airlines lose huge amounts of money everyday their planes are unable to fly. In the airline MRO business there is thus a huge pressure to fix broken parts as fast as possible, while still retaining the quality needed to ensure safe flight. The pressures on European airline MRO businesses do not end there, with rising airline MRO companies in Asia, offering cheaper repairs due to low labour costs, along with high quality repairs and a low Turnaround Time (TAT) [54]. Combine this with the expected aircraft fleet growth over 40% [55] and it becomes abundantly clear that the European airline MRO market has to become more efficient in order to survive.

One such company which recognizes this need for improvement is KLM Engineering & Maintenance (E&M), a part of Air France Koninklijke Luchtvaart Maatschappij (AFKLM). KLM E&M is one of three subsidiaries of AFKLM, along with its passenger and cargo businesses, more on this will be said in the following section. KLM E&M has three main departments, which are Airframe, Engine Services (ES) and Component Services (CS). This research is conducted within the Component Services department.

1.2. Research field

This research is conducted at Delft University of Technology as a part of the master Mechanical Engineering with the Multi-Machine Engineering track. And at KLM E&M, specifically in combination with the Lean Six Sigma office. The research will be conducted in the component services department of KLM E&M. This department (and all of KLM E&M) provides maintenance to the internal KLM fleet, as well as external customers. As previously mentioned there are two other departments within KLM E&M next two Component Services, a simplified organizational chart is shown in figure 1.1. A more detailed chart can be found in Appendix A.

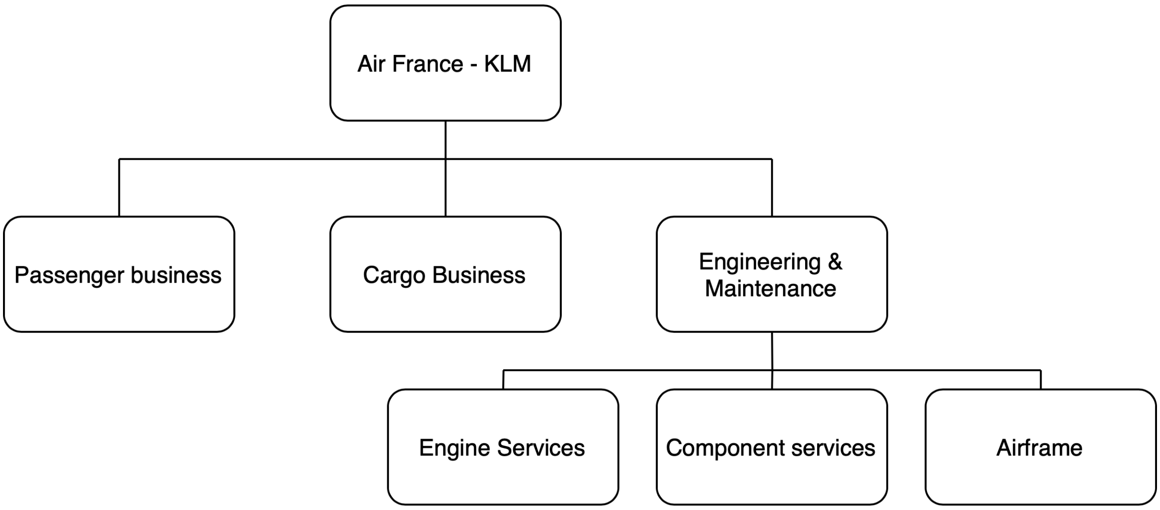

Figure 1.1: A simplified overview of KLM's organisation

At the time of conducting this research the world is still in the grips of a pandemic. Air traffic was one of the worst hit sectors of the pandemic, and thus also its accompanying MRO business. This has resulted in a lot of workers leaving the company due to a lack of work. When regular life is starting to begin again air traffic will slowly go back to normal as well, only now there is a shortage of employees, which is another reason to work more efficiently where possible. However, normal processes were somewhat disturbed due to the unusual circumstances, which made data gathering difficult.

Furthermore Component Services has a lot of different sub shops, the eventual improvements which come out of this research must be applicable to all of them. This means that the everything has to be made in a general way

1.3. Research problems

For any research to make a contribution to science or society in general it must solve a problem. The first step in this process is of course pinpointing what the problem is exactly. This can be done on numerous different fronts, one is based on practical experiences at the company in question, and another, more theoretical, is based on identifying missing gaps in the existing scientific literature. To start the practical experiences, and frequently occurring problems, of the KLM will be looked into, next, the more theoretical approach using missing gaps in the literature will be examined.

1.3.1. Practical experiences KLM

There are tons of different processes within KLM E&M, each with their own unique characteristics. Still the common denominator in the problems can be found in the Service Level (SL). The SL is basically another term for the On Time Performance (OTP), meaning which percentage of all repairs is back at the customer within the contractually agreed upon time. For some sub shops the SL is around the 90% which is not yet where KLM wants it to be, but certainly good enough for the time being. However, most shops, including internal logistic handling, have a service level of only around 50-60%. This is a huge problem. Further more when examining the problem using process excellence, it turns out that most of the time a repair order spends inside a process is waiting time. This is a problem which is relatively simple to solve. Of course it is not something that in reality is simple and easy to implement, simple in this sense implies that no complicated new systems are needed in order to solve the problem. The reasons for this large waiting time differs from shop to shop, some reasons mentioned are:

- Under staffed
- Poor planning
- No control of the process
- Dependent on external factors

At the moment it is very plausible that the different shops within CS are understaffed as a result of the many workers leaving due to the pandemic. However, the reason has been used since long before the pandemic was upon us. At that time it was most likely possible to complete the required workload within the agreed upon time, using just the workforce they had employed. The poor planning and no control of the process are two aspects which could greatly benefit from the use of a remanufacturing process control model which will elaborated on in section 2.1. The dependency on external factors is something which managers can only influence so much, however, learning how to deal with the uncertainty this brings along is something in their power.

1.3.2. Gaps in literature

The literature on production control models is quite large, but when the specification towards remanufacturing is made it quickly becomes a much smaller pool to choose from. Still there are some useful papers about this topic. The first is from Guide [14] and it lists common problems in the remanufacturing business. These problems will be dealt with more in depth in section 2.1.1. This paper has been backed by the work of Junior and Filho [23], which is twelve years older and filled in some of the missing gaps from Guide's work with newer literature. It pointed out missing area's in the literature which were mainly focused on the absence of well established predictive models. It also pointed out that there is a shortage of case studies, which are required to understand more about the complicated characteristics of Production Control.

There is thus a need for case studies like this one, which is why several master theses have been conducted at KLM E&M. Examining these theses shows multiple improvements were made to manage the current process better, which will be looked into in chapter 2, but few include ways to get control of a process, and sustain this control. A model which can fulfill both of these requirements, as well as improve process performance is thus missing in the existing literature.

Another important aspect to consider for any industry these days is the rise of industry 4.0, and how it could be implemented in the owned processes. A literature study shows that industry 4.0 for remanufacturing is gaining popularity but still has some ifs and buts about it. It is expected to be adopted by the remanufacturing industry as it will enable them to become more sustainable and efficient in their workings. [50] For processes it is for instance still not sure whether all the expected benefits will become reality, as the industry 4.0 in remanufacturing is still in its infancy, and a higher technology readiness level needs to be achieved [26][4]. For this research it will be looked into if KLM E&M is ready to implement industry 4.0 in some of its processes or if more technological advancement is necessary.

Combining the literature and the practical experience at KLM E&M the research problem can be defined as follows:

A model which aids in controlling production for remanufacturing processes in the present, as well as aiding in the sustainment for the future does not exist.

1.4. Research scope

Since KLM E&M is such a big company comprised of many different management tiers and organisational layers it is important to set up a clear research scope before conducting the research. Different levels of management can be defined within an organisation. Strategic decisions and policies are made by the top level managers, in the case of KLM E&M these would be at the top of the E&M unit. One level below that are the tactical decisions, which are made by the managers of the department, in this case the mangers of CS. Lastly there is the operational level. This level is most responsible for actually achieving all the goals set out by higher level management. Since this lowest level is also the production level, this will be the main area of focus in this research. One problem does arise when considering this management structure, as also defined by Thomson [49]. There usually is no clear link between the lowest level management and the two above.

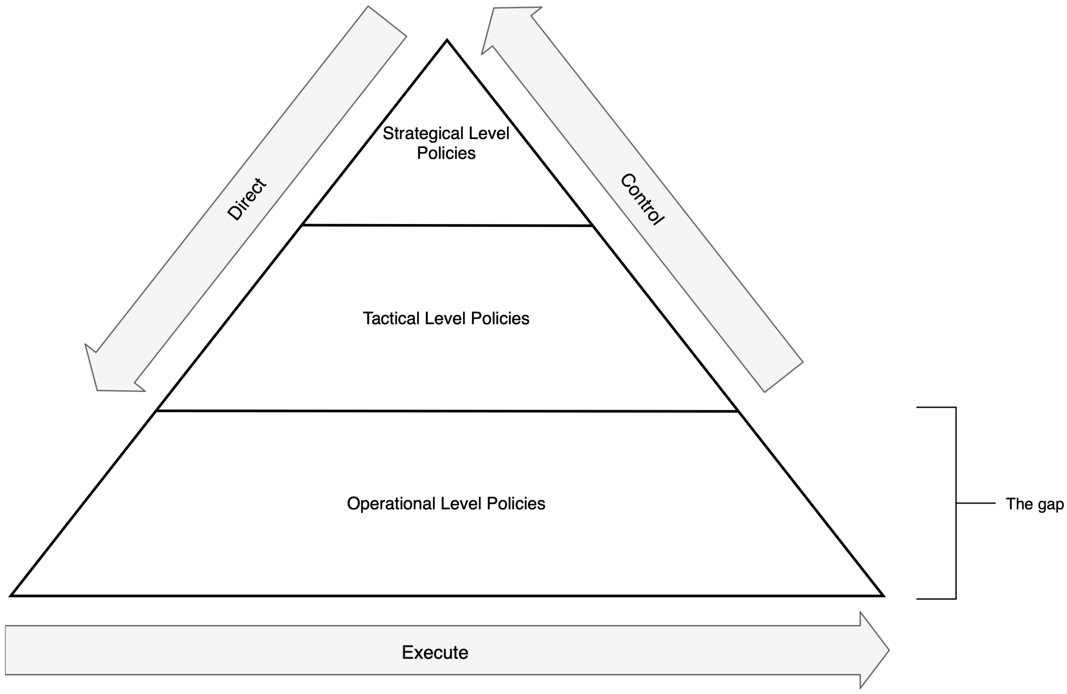

Figure 1.2: The three levels of management and the missing link by [49]

This missing link causes problems for operational level managers as the vision of the higher level management usually does not match that of the operational manager, who are much more aware of the potential and current performance of their respective shops. This can be a big problem since the operational level is where most of the gain of a process is hidden. Another problem faced using a top down approach is the missing knowledge of process intricacies. In some cases an adjustment looks good on paper, but is in reality impossible. Higher level management is in most cases unaware of these seemingly unimportant process details, which causes them to approve improvements which only hinder the process. This research thus focuses on this "lowest" operational level. This means that a bottom up approach will be used throughout the research, doing this leads to no process intricacies being unknown, so no impossible improvements will be started, furthermore the potential hidden away in a process can be uncovered in this level. At the moment bottom-up control strategies are rare in industry, as top-down is the most common manager style [37]

Throughout CS many different operations take place, many of which differ in their fundamentals from one another. This research should be applicable for most if not all of these processes. To accompany such a large scope some steps, such as the quoting process, will be left out of the initial design. The quoting process works as follows, when during a repair it turns out that a part is damaged beyond initial expectation the costs for that repair will rise. Before repairs are continued a go ahead should be received from the customer, this is called a quote. The quoting process for KLM E&M works both ways, meaning they send and receive quotes for repairs. Since the data from practice is collected solely from the CS department of KLM E&M it is important to note that the research is inherently bounded in it's scope by this department. Using known theories and literature there will be an attempt to broaden the scope somewhat, but these practices will naturally be limited.

1.5. Research objective

Now that the research problem and the scope of this research are known the objective can be defined. The focus of this research will be to create a remanufacturing process control model which allows for better management of the processes, which thanks to multiple remanufacturing specific issues are hard to manage. While still leaving room to have a bottom up approach to improve the processes for the future. Combining this the research objective becomes the following:

Create a remanufacturing process control model which helps get control over process performance on operational unit level and sustains this control

1.6. Research deliverables

Since this research is conducted for the Delft University of Technology, but at KLM E&M the deliverables will have to be of value for both parties. The main deliverable of this research will be a remanufacturing process control model which enables future improvements. Multiple aspects will be looked into for this model and as benefits from it, these will also be presented as a deliverable.

- A process stream analysis of the processes where the remanufacturing process control model will be piloted
- A method for entrance control for the process
- A method for bottleneck checks in the process
- A strategy for effective manpower planning
- A way for target control
- Financial benefits of implementing a remanufacturing process control model

1.7. Research questions

Based on the research objective defined in section 1.5 the research question can be formulated as such:

How to control, remanufacturing process performance on operational unit level using a remanufacturing process control model

This research question will be systematically answered through the use multiple sub-questions, formulated below:

1. How can a remanufacturing process control model be defined?
2. What requirements for design must the remanufacturing process control model include?
3. What are important underlying theories found in literature?
4. What is the current state of the pilot processes in CS?
5. What are the problems that these pilot processes face?
6. How can the remanufacturing process control model be designed?
7. How can a company check their progress regarding process optimization?
8. How can the proposed model be verified?
9. How can the proposed model be validated?

1.8. Methodology

Since this research is conducted in the form of a case study it is important to follow a clear methodology, in order to get the best results. Such a methodology has been created by Dul & Hak [10]. The first step indicated by Dul & Hak is to distinguish whether the research is practice-oriented or theory-oriented, in order t establish this both definitions, as devised by Dul & Hak are shown after which a choice is made which of the two matches this research the most.

Practice-oriented research: "Practice-oriented research is research where the objective is to contribute to the knowledge of one or more specified practitioners".

Theory-oriented research: "Theory-oriented research is research where the objective is to contribute to theory development. Ultimately, the theory may be useful for practice in general".

Judging from these two definitions, this research will be a theory-oriented research. This results in a sort of step-by-step guide for the research.
First of all it is important to define the research topic. Within defining the topic, the scope and other important aspects of the research should be highlighted as well, this is already done in the previous sections of this chapter.
When the topic is known and well defined the research objective can be established, as done in section 1.5. This is followed by defining the research type, which was done in this section, and resulted in the distinction that this research is a theory-research oriented research.
After the research objective and research type have been clearly defined it is important to pick the research strategy. For this research that was somewhat of a known fact already. Nevertheless it is defined as a case study. Since this research is in the form of a case study the instance at which the case study takes place must be well defined. This is done in section 1.2 and 1.4 respectively.
With these steps all the initial define practices are completed. Naturally the first step is to actually conduct the measurement. The measurement will be performed on the logistic handling area case only, where the results will be a combination of real life data and results of the simulation.
The results from this pilot case will be discussed next. This will be done according to the data which is collected in the measure phase. This data will have to be processed, validated and verified before it is of any use. When all of the results are in they can be discussed. Based on this a conclusion will be made and a recommendation to the company in question.
This described framework is presented in the chart in figure 1.3, on the next page.

One aspect of the theory oriented research is that it ends in a new proposition or hypothesis. The hypothesis of this research is that using an integral approach to production control will aid in getting control as well as sustaining it, all the while increasing performance. This hypothesis will be reflected in section 7.2.

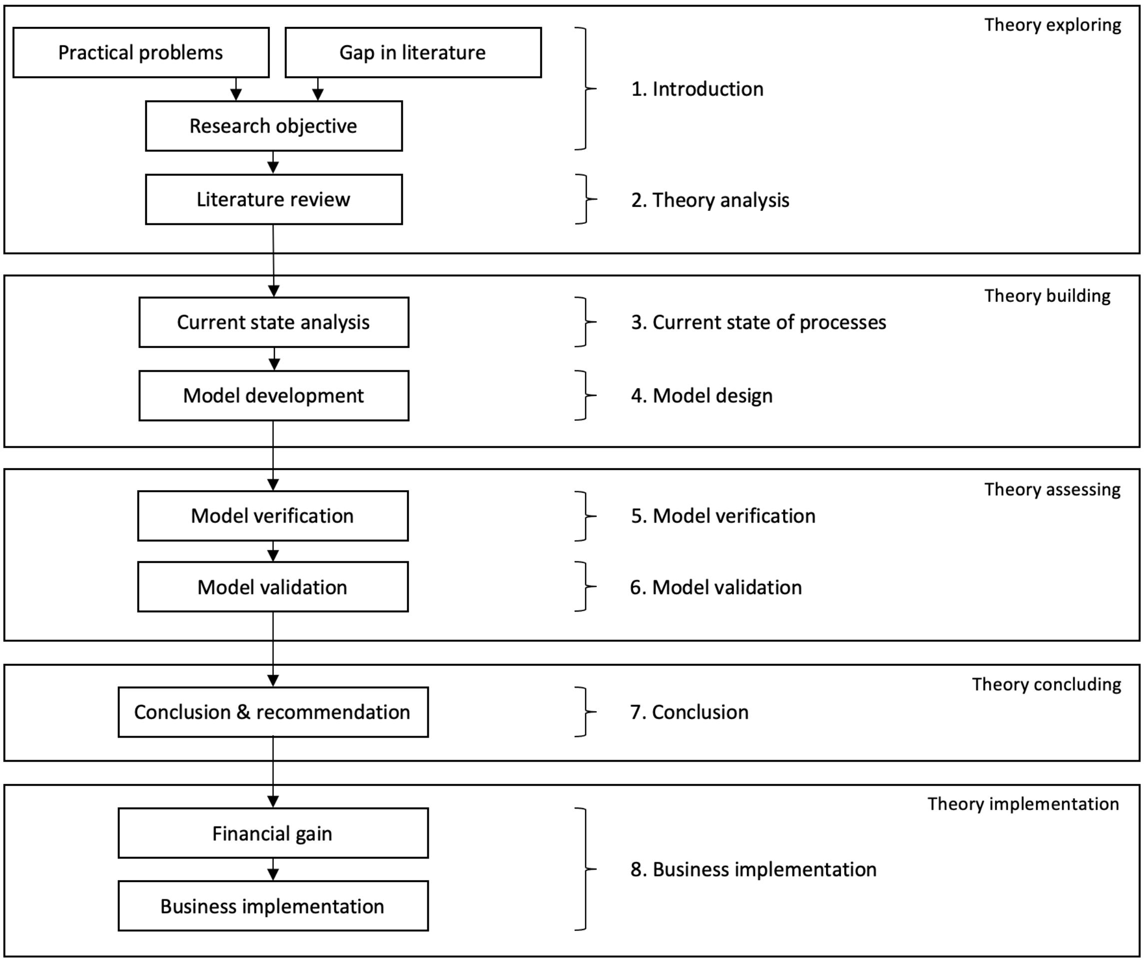

Figure 1.3: The research structure outline

1.9. Data gathering

Data gathering can be a difficult area since the research has to be conducted over a relatively short period of time. The first step is to use existing literature to form the base of the model. When a solid base of theories and insights is established previous research conducted at KLM E&M will be investigated. This will provide a clearer insight into how KLM E&M operates, and has operated over the past years. Since most of the processes within KLM E&M are to some extend digitised a considerable amount of data is spread out across numerous databases. These databases will be another way of collecting required data. Lastly interviews will be conducted with operational managers to get an understanding of the current issues at play, as well as a professional take on the process.

1.10. Conclusion

This chapter started out by explaining the research context, which specifically is the Airline MRO sector, and more broad can be seen as the remanufacturing industry. This research itself is performed at KLM E&M in the component services department. Within component services there are numerous sub shops, this research used the oxygen bottleshop and logistic handling area as case studies. With the research area examined the existing problems were evaluated next. The problems from literature will be examined further in chapter 2, and the specific problems for the two case studies will be examined further in chapter 3. But as a quick overview the main problem tormenting KLM E&M is a lack of control over the processes. In the literature this problem is found as well, through the missing link between the operational level of an organisation and the tactical and strategic level. This results in potential being lost, as well as not having a clear direction where the shop must steer into. With these aspects evaluated the research question can be evaluated, which in this research is:

How to control, remanufacturing process performance on operational unit level using a remanufacturing process control model

Lastly the methodology used in this research was evaluated and the methods used for data gathering were explained. With the methodology also came a new hypothesis, which stated that: *using an integral approach to production control will aid in getting control as well as sustaining it, all the while increasing performance.*

2
Theory analysis

In this chapter a deep dive into the relevant theories and literature will be presented. First of a clear definition of a remanufacturing process control model will be given in section 2.1, which will be followed by common problems. Next up will be in depth theory analyses in sections 2.2, 2.3 and 2.4. This will be followed by an examination of past research in sections 2.6 until section 2.10. Then literature on the final important points for the construction of the model will be presented in sections 2.11, 2.12, 2.13 and 2.14. Lastly, all findings will be concluded and the subquestions answered in section 2.16.

The coming chapter will also answer the following subquestions:

1. How can a remanufacturing process control model be defined?

2. What requirements for design must the remanufacturing process control model include?

3. What are important underlying theories found in literature?

2.1. Production control

One goal of this research is to design a remanufacturing process control model, which will aide in realising sustainment and implementation of lean production, as well as enable future growth. To do this it is important to first get a clear view of what a remanufacturing process control model is and does. Greene [13] referred to production control as :"the set of activities in a production organization that are directed at the control of the volume and types of products produced at specific places as a function of time". Which was then nuanced by Bertrand [3] saying:"In this scope, production control includes long-range planning, product development, manufacturing process development, customer service control, factory-layout planning, transportation and physical distribution, manpower planning, materials supply control and materials handling, capacity planning, scheduling, loading, dispatching and expediting, and inventory control." This scope for production control was aimed towards manufacturing companies and even though there are numerous fundamental points in which remanufacturing companies differ from standard manufacturing companies, the basic definition of a remanufacturing process control model translates very well.

Since there are differences between the standard manufacturing process and the remanufacturing process, as far as production control goes, it is important to define both processes well. A manufacturing process is defined by Kenton [25] as follows:" Manufacturing is the production of goods through the use of labor, machines, tools, and chemical or biological processing or formulation".
Remanufacturing is inherently different as it repairs parts, extending their life. It is formally defined by Levine [33] as:" Remanufacturing includes the disassembly, cleaning and inspection of an item. Parts are returned to Original Equipment Manufacturer (OEM) specifications, often through metal adding processes followed by machining. The parts are then reassembled, along with the installation of any engineering changes or improvements that have been released since the item's original manufacture. The assembled product and key subassemblies and components are tested, and the item receives a new warranty".

2.1.1. Common problems with production control

Production control in the remanufacturing business is tormented by some common problems. These problems have been uncovered in a survey from Guide [14]. He has narrowed the common remanufacturing problems down to these eight points, which have been indicated by managers from the industry.

- Uncertain timing and quantity of returns
- Need to balance returns with demands
- Disassembly of returned products
- Uncertainty in materials recovered from returned items
- Requirement for a reverse logistics network
- Complication of material matching restrictions
- Highly variable processing times
- Stochastic routings for materials for remanufacturing operations

First of, the uncertain timing and quantity of returns. It is impossible for remanufacturers to know exactly when they will receive which products. Some will fail without warning, in which case a shipment will suddenly arrive at the factory, how to deal with these unexpected deliveries is key in the remanufacturing business. Then there is the need to balance returns with demands. With it is meant here is having a matching inventory with market demand. If a certain part is very wanted at a certain time it is important to have everything needed for that part in stock, if not the service level would plummet. On the other hand if a lot of inventory is bought but not used it can be extremely expensive, which is why it is paramount to know when which parts will be needed.

Another important aspect is the disassembly of the returned products. Often times the exact fault of a part is unknown, so an investigation has to be started. This investigation always has to be thorough as finding one fault does not eliminate the chance of there being another. However, the disassembly of faulty parts can be a tedious task when certain parts have been damaged, this inconsistency in disassembly makes it difficult to plan for a certain number of parts per day. Next up there is the uncertainty in materials recovered from returned items. This point of interest is similar to the previous one. Just because two seemingly identical pieces come in does not mean the operations following will be identical, once disassembly starts it can become a whole different ball game. This again makes planning very difficult, as one part might take x hours to handle, but the other, seemingly identical part, will take y hours to handle.

There is also the requirement for a reverse logistical network. This basically boils down to being dependent of third party logistics providers to receive the parts which get send to you. Usually different customers use different logistic companies, all of them have different customs delivery times etc. It is up to the remanufacturer to work around all of these differences. Where it can take one day for a part to arrive after it has been announced by a customer, it can take a week coming from another customer. This makes planning ahead exceedingly difficult. Also there is sometimes the complication of material matching restrictions. This is a problem especially apparent in the airline MRO business. Regulation wise it is not allowed to just switch out certain components on a broken part, so if a component is broken that specific component has to be repaired and put back in the part, even if an identical component is in stock. Other times customers have a contract specifying they want the same components back on their part. These situations greatly increase a part's Turnaround Time (TAT). Which in turn can get expensive for both parties, as well as hinder work on other parts. Then there is the problem of highly variable processing times. Similar points have already been pointed out but where the distinction is made here is again with somewhat identical parts. If two identical parts come in, with the same fault it still does not mean that the process times will be the same, because it is not certain that the degree to which a certain part is malfunctioning or broken is the same. Both parts could have the same fault but one could be of way worse than the other, resulting in higher process times. Which is another aspect which makes planning increasingly difficult.

Lastly there is the problem which arises from the stochastic routings for materials for remanufacturing operations. With this is basically meant that the route through the entire process can be different for each part that comes in. Some parts have to be repaired internally while others have to be sent away, some require a machining operation one hangar next to the standard one. All of these aspects mean that it is very difficult to plan when a part is gonna be where, and thus when and where manpower is needed.

2.2. Value Stream Map/ Process Stream Analysis

As Zawadzki et al. [57] put it:"An effective production control can be realized only in the case of having the necessary knowledge regarding phenomena and interaction in the production flow". This is where the Value Stream Map (VSM) comes in. The VSM is a tool which was developed to analyze and improve a (re)manufacturing environment [46], it came forth from lean manufacturing, which will be handled in depth in section 2.3.1. In its core a VSM is thus a tool which' main purpose is clearly showing all the sub process steps in a complete process.

Within the process excellence method, currently used at some places at the KLM, a sort of VSM is already being constructed, called a Process Stream Analysis (PSA). This is a tool which is being used to map out a process. An example of such a PSA can be found in Appendix B. A PSA differs from a traditional VSM in a couple of ways. In Value Stream mapping the flow of both the material (or in the case of remanufacturing the part) and the flow of information is shown, where in a PSA only the flow of the part is shown. Furthermore in a PSA iterations are made. First the process time for each sub process can be added, this is defined simply as the total time a part spends at a specific sub process. After that a distinction can be made in this process time, dividing it in touch time and waiting time. Touch time is the time someone is actually handling the part, either for repair or moving it about. Waiting time is, as the name implies, the time spent by a part waiting for the next sub process to start. This waiting time is usually what makes processes take much longer than is originally planned and it can be resolved (in most cases) by managing the process better, rather than investing a lot of money into new equipment and a larger workforce, in order to improve the process.

The choice to use a PSA instead of a VSM makes sense when it is considered that it gets used in a remanufacturing environment. Because, as Forno et al. put it [7], problems using VSM can arise when a lot of different product types are assembled within the same infrastructure. Another problem which can arise from using VSM is that it is too detailed, since it contains more information per process step than a PSA does. This has the common pitfall of being to focuses on fixing every little detail rather than focusing on the process as a whole. For the two case studies a process stream analysis has been constructed. These are visible in sections 4.3.1 & 4.3.2 respectively.

2.3. Lean Six Sigma

Lean Six Sigma is a popular theory for managing processes. It combines practices of the two separate theories from which it is constructed, Lean Manufacturing and Six Sigma. In the coming section both will first be handled separately and then Lean Six Sigma will be discussed.

2.3.1. Lean Manufacturing

Lean manufacturing is a way of manufacturing pioneered by Toyota in the later half of the twentieth century. It is sometimes also referred to as Just In Time (JIT) manufacturing, Pull manufacturing or Total Quality Management (TQM) [20]. The main focus of lean manufacturing comes in threefold [5]: Improve the flow of the process, eliminate all waste from the process, only invest value adding steps in the process. Waste can be defined as:"Any operation in a process which does not add value to the customer is considered waste" [17]. Within Lean seven types of waste are defined which should be kept to a minimum as much as possible. They are [39]:

1. Over production
2. Waiting time
3. Transportation
4. Over processing

5. Inventory
6. Motion
7. Defects

When these wastes are kept to a minimum the process should reduce in time, decrease inventory, eliminate bottlenecks and become more stable overall. This all contributes to decreasing production costs and capital in the process, while increasing the eventual quality of the product.

2.3.2. Six Sigma

Six Sigma is another way of improving a process which originated at a company. Six Sigma finds its origins at Motorola in the nineteen seventies and eighties. The main focus of Six Sigma is establishing business performance benchmarks and providing organizational structures and road maps through which these can be achieved[51].

The main focus of Six Sigma is on the quality of the product or service, reducing variation and cost while still pushing continuous process improvement[9]. Six Sigma achieves these goals using a bunch of statistical tools, as well as management rules. An example of this is the low failure rate Six Sigma allows, which for most companies comes down to less than four faulty parts per million manufactured. It goes about achieving this in a quite statistical method using the Define Measure Analyse Improve Control (DMAIC) model. DMAIC works as follows: First the problem has to be defined properly in order to be able to fix it. Next the magnitude of the problem is measured and data is collected. Then the problems get analyzed in order to find out what causes each of them. When this is known it becomes possible to tackle each root cause by implementing improvements. Now the process should be improvement as a whole, it is important to control the process in order to ensure that the improvements are continuously being enforced.

2.3.3. Lean Six Sigma

Lean Six Sigma was formed out of the need for a specific action plan, when it turned out that Six Sigma was to theoretical for some, whilst lean was sometimes not theoretical enough. Hence a 'new' theory was created using the best parts of each. From Six Sigma for instance, concepts about reduced part variation are used, while from Lean the areas focusing on waste removal are prominent [48].

The two theories combine well because there already are many similarities between them. Both theories emphasize that the value of the product or service is determined by the customer, meaning that a process should be examined from a customers point of view. Both theories use flow maps to clearly illustrate processes and wastes and both use measurements to collect data for improvement and control. Of course there are also dissimilarities since the theories were not developed to tackle exactly the same problems. First of all there is the identification of a problem. Lean focuses problem identification around the seven wastes, whilst Six Sigma focuses more identifying the unnecessary sources of variation, in order to reduce inefficiency. The tools used within each theory also differ, Lean is more user friendly while Six Sigma uses more numerical and analytical based tools. This combination of similarities and differences is what makes Lean Six Sigma a powerful tool. On the one hand there are the similarities which mean both tools are applicable at the same time for the same process, and on the other the differences, which allow for the use of multiple different tools and strategies [47].

2.4. Theory of Constraints

Another important theory for process management is the Theory of Constraints (ToC). The ToC was first introduced by Eliyahu M. Goldratt in 1984. It focuses on five steps in order to improve a process. The argument made by Goldratt is as follows [6] :"If there was nothing preventing a system from achieving higher throughput (i.e., more goal units in a unit of time), its throughput would be infinite – which is impossible in a real-life system. Only by increasing flow through the constraint can overall throughput be increased". Hence there is always at least one constraint. The five steps which Goldratt focused on were:

1. Identify the systems constraints
2. Decide how to exploit the systems constraints
3. Subordinate everything else to the above decision
4. Alleviate the systems constraint
5. If in the Previous Steps a Constraint Has Been Broken, Go Back to Step 1

In order to follow these steps it is needed to know what classifies as a constraint. Very simply put, a constraint is anything that prevents the system from achieving its goal (increase throughput to make money). Such a constraint can show up in many shapes and forms, but a key take away is that there usually only are a couple in a system. If there is more demand for a certain product or service than the system can deliver it means that there is an internal constraint halting the process. There are also external constraints, these occur when the demand is lower than what the system can produce. Three common constraints are:

- Equipment
- Manpower
- Agreements

A constraint due to equipment means that a certain piece of equipment in the system is not able to produce at the rate required to meet demand. A constraint in Manpower indicates that there is a lack of (skilled) people in the system which again causes production rate to go down and be beneath demand. Lastly a constraint due to agreements means that there are certain rules and agreements which halt the process, for instance only producing 80% of what the system is capable of in order to keep the process clear[12]. It is important to note that a constraint does not necessarily mean that the process is not managed correctly. Even if everything in a process runs as smoothly as possible there will still be constraints.

2.5. Entrance control

As previously mentioned, the state a part is in when it arrives for remanufacturing is virtually always unknown. Not only does this make planning for the process difficult, but it also means there is a possibility that the part is damaged beyond repair capable at the facilities of the remanufacturer. This why there is the need for an entrance control. Such a control makes sure irreparable parts don't get admitted in to the process any further than necessary, and thus don't waste any time or resources. As Kurilova et al.[30] state, there is not yet a clear general approach which estimates when a part of most suitable for remanufacturing. At KLM E&M entrance control has to happen at the shops themselves, since all parts come in at the logistic centre, and it is nearly impossible for the employees to have enough knowledge about every incoming part to asses whether it is suitable for remanufacturing or not, let alone time to examine them all. At the shops there are inspectors of the incoming goods, who asses what the course of action for a part has to be.

Another important aspect linked to entrance control is controlling the input of a process. Thus far almost all research focuses on the output of a process and how to optimize this. With entrance control bottlenecks could be prevented by checking what the capabilities are down the line of the process. These capabilities are always limited, either by man, machine or materials. Controlling the input of a process could prevent piles of work forming at the places where capabilities are limited below the current input and so aiding in the flow of the process as a whole. This basically comes down to setting a potential max input for the process and not exceeding this even if more work came in.

2.6. Key Performance Indicators

A research conducted at Delft University of Technology looked into what KPI's gave relevant information to managers and which KPI's are relevant industry standards. This of course differs per industry. Hence a distinction has been made between different types of industry. The industry which is relevant for this research is: maintenance. The full list of KPI's and relevant theories as researched by van Stuyvesant Meyen [52] is shown in Appendix C. An important notion which has to be made about the research of van Stuyvesant Meyen is that all the industry essentials are set as ratio indicators. This gives them the benefit of being usable for benchmarking companies of any magnitude, and thus also compare small and larger corporations. Also, as van Stuyvesant Meyen put it:" The drawback of an industry essential or any KPI is that differences in outcome can be subject to strategic choices of operational management rather than the malfunction of a company and should always be kept in mind". One other aspect which came up in the research was the fact that having too many KPIs is undesirable, as they can make it easier to lose focus on what's important. This aspect is also used in the design of the remanufacturing process control model.

Having stated this there were three different KPI's which arose from the research as being essential for the maintenance industry. These were: Occupancy ratio personnel, work in progress and production cost per produced hour.

The occupancy ratio of the personnel was chosen over the occupancy ratio of machines and other equipment, since these varies heavily according to the running costs of the machine. If a lot of the personnel is doing nothing this is not necessarily a good or bad thing. If there is no work to be done it is not beneficial for the process to have workers run around and do unnecessary work, which will most likely clog the process down the line. If all personnel is constantly running around trying to finish their tasks this of course is also not a desired state for the process. Hence the occupancy ratio should be matched to the needs of the process.

Work in progress is a relevant KPI if used correctly, it can give relevant information about stacks of parts waiting to be serviced, which are often labelled as work in Progress, or WIP for short. The important notion here is that the term in process simply refers to the part having entered the process, not that the part is being processed. If huge piles of parts are building up, this shows there is a bottleneck in the process, hence a lot of work in process is a KPI showing the process is not running smoothly.

Production cost per produced hour is a KPI which is aimed mostly at managers, if the costs for remanufacturing a part become too high, for instance having to outsource repairs which could be done in house to meet the desired service level, this is not a sustainable solution for the process. Hence if the costs become too high the process is not running as it should.

2.7. Return Quality model

Furthermore at the TU Delft Daan Haak conducted a research examining the best method for proposing a sustainable initial repair process design from a return quality perspective. In this research[15] Haak establishes that it is paramount to not over stuff the process for it to run smoothly, switching the focus to the beginning of the process instead of the end. This adds on to the entrance control theory discussed in 2.5.

Haak in his research also stresses the importance of implementing innovation as a tool to allow sustainability. Stating that in a quick developing industry it is even more important to focus on innovation to prevent falling behind competitors. Not only is innovation a way to stay ahead of, or at least not fall behind, the competition. It is also an important tool to sustain improvements. Since it is impossible to innovate on a process which is not fully under control. If a process is innovating regularly that means the base of the process is completely under control. One other aspect highlighted in the research by Haak is that a process should not be filled over 80% of the capacity of the lowest bottleneck, since that makes the process too vulnerable. This is an important aspect for the validation of the model. Furthermore in the research of Haak there is no focus on integral level control, starting bottom up to uncover potential.

2.8. Business process redesign

Next there is the research by Erik Cornelisse [11] where the main research goal was modelling business process redesign strategies for improved reverse logistics in an aircraft component supply chain. In this research it is emphasized that at the start of any improvement track the goals must be made according to a pre-performed analysis. Based on this analysis realistic but ambitious goals can be set for the improvement track. This is also applicable for this research, as there has to be a goal to build the plans around, in order to uncover the hidden potential. In order to truly achieve this the plans have to be made bottom up, making for an integrated approach to the control of the process. This is not highlighted in the research by Cornelisse.

2.9. Service level focused control

Then there is the research conducted by Aïsha Lemsom[32], which focused on controlling the integrated component supply chain of aircraft MRO from a service level perspective. This research is very TAT driven, which matches this research very well. There are several findings from Lemsom her research which are also applicable for this research. Like:

- In order to get control over the supply chain (or an E2E process) a distinction must be made in the used components or steps to see what the main value driver is

- Service level (or; the on time performance) has to be established at the start of an improvement track

The first point is also important in this research since distinction is necessary to provide focus. Even the simplest processes consist of numerous steps and or components, and in a larger distinction there is always a regular, and a disrupted flow. In order to get the most out any improvement track it is important to improve upon the right things, and to first address the areas with the greatest potential.

As for the second point, the service level is in most cases a very clear incentive to start an improvement track, as well as a clear KPI of whether the track has yielded the desired results. The TAT is unmistakably connected to the service level, as a TAT greater than what has been established in the contract results in a lower service level. For this research the current service levels and average TATs will be taken into account at the start of the improvement track. One thing missing in the research of Lemsom is an integration of control over different levels, or having a more bottom up approach to control.

2.10. Scheduling process design

The final TU Delft research which is relatable to this research is the research by Hidde van Wezel[53], which unlike the others was not based on a case study of KLM E&M but a case study at DPD, a courier company. The focus of this study was on regaining balance between incoming work and available workers. This is also a very important step for the control model proposed in this research as a match between work and worker is one of the cornerstones of a well governed process.

Furthermore van Wezel discusses constraints at the entrance of the process. In the case of van Wezel these constraints were physical and could thus not be exceeded, however, the takeaway remains the same, a process should not be allowed to take on more work than it can handle or else it will clog up. This coincides with the research conducted by D. Haak and is an important aspect for this research as well. Again there was no distinction between levels of an organisation regarding control.

2.11. Bottleneck control

A difficult aspect of the remanufacturing process is the occurrence of bottlenecks. As Xue et al[56]. put it, spotting bottlenecks in a remanufacturing system is even more difficult than in normal manufacturing systems since the system is inherently unstable. The type of bottleneck in the system is also not set in stone. It can either be one dominant bottleneck or it can have multiple bottlenecks which arise instantaneously and keep shifting. Spotting and solving these bottlenecks is a crucial part of making sure the process runs smoothly, since a process will always be halted by bottlenecks, according to Goldratt.

A proven method to identify bottlenecks in a process has been made by Kuo et al. [29]. This method identifies bottlenecks by looking at two adjacent machines and whether there is a pile up or starvation between the two machines. By comparing either the starvation or pile up times at the respective machines it can be determined whether the bottleneck is upstream or downstream. This method has been referred to as the arrow method since when displayed graphically arrows are used between the machines to show either the starvation or build up. The process excellence method, used at KLM, uses a similar approach, showing a process graphically through a PSA, as described in 2.2, from this PSA conclusion can be drawn on where bottlenecks exist.

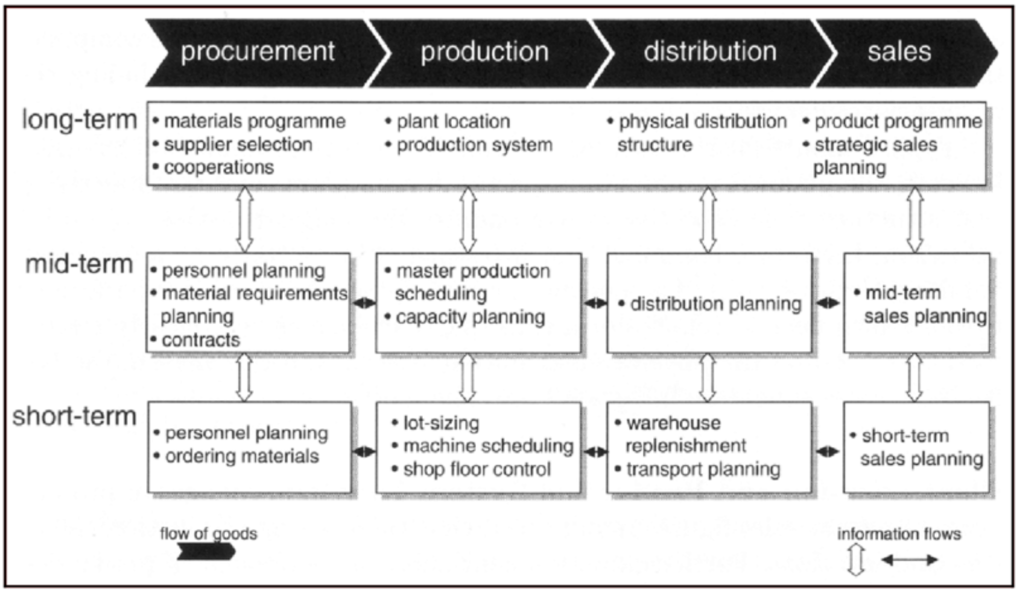

Figure 2.1: The supply chain planing matrix by Rohde et al. [44]

2.12. Assets and resource planning

When considering planning in a company like KLM E&M three distinctions can be made according to Stadtler et al. [16]. Stadtler makes a distinction between short, medium and long term planning.
First of there is long term planning, the long term planning decisions are also called strategic decisions. In these decisions the entire development of a company's future supply chain gets thought out. The decisions made are usually decisions which will not be implemented in the near future, but since long term planning focuses on the future state this is not a problem.

Next there is mid term planning, this level of planning looks ahead a couple of months to give a rough estimate of what is to be expected. If negotiations have already started with a new customer it can be expected that in the near future a spike in work will arise. This prediction is made by mid term planners.

Lastly there is short term planning. This is, as the name suggests, the shortest time span for the planning horizon. It only focuses on the coming few days, or weeks max. This is planning on the operational level, as it looks at what is needed right now, it will have an immediate effect on the flow through the supply chain. For this research only this short term planning is relevant. Long and mid term planning are outside of the scope. These different types of planning have also been illustrated by Rohde et al. [44] and are shown in figure 2.1

The biggest problem which arises in short term planning is the uncertainty of incoming parts. This problem is also called demand forecasting. Since there is uncertainty over what will arrive when and in what state planning which materials are needed, and how many FTE's are required is very difficult. Previous studies have identified numerous methods which can be used to estimate when parts are going to fail and thus need to be re manufactured. For airline MRO most of these methods provide insufficient insight since they assume a more normally distributed income of parts. One method which is capable of more random inputs is demand forecasting based on a time series analysis [38]. The problem here is that the error of these models is still up to 60%. This is why the decision is made not to focus as much on demand forecasting, but rather on planning appropriately. It is not necessary to know exactly how much parts will enter the system everyday as long as there are certainly going to be enough FTE's to handle them. The problem is that using to many FTE's will result in high labour expenses which are probably unnecessary. Balancing the FTE's with the not entirely known income of parts is thus the real problem which needs to be tackled by the remanufacturing process control model. This will be elaborated on in section 4.4

2.13. Sustainment of Improvements

A problem many companies deal with is the fact that a lot of the improvements made are often only temporary. The improvements which are meant here are of the management nature, if a new machine is bought this will of course be a steady improvement. However, as is shown in practice, when behavioural changes are made in order to improve, the improvements usually fade as soon as control of the process is loosened. One option would be to constantly actively monitor all FTE's in a process to check whether they abide by the new standard. This would however be extremely time consuming, create a bad work environment and be a very tedious and unrewarding job. It is thus needed to improve a method for sustaining improvements which does not rely on constant monitoring.

One theory about sustainment of improvements is created by Hines [19] about sustaining lean culture. He introduces the idea of the Sustainable Lean Iceberg Model (SLIM) as shown in figure 2.2. The SLIM divides lean into two sectors; the visible aspects of lean (above the waterline) and the invisible aspects which enable the visible aspects (below the waterline). As visible from figure 2.2 the enabling aspects of lean include: Strategy and alignment, Leadership and Behaviour and Engagement. These are also the most important aspects in order to sustain lean improvement, which is where most companies fail, since they focus mainly on the visible aspects.

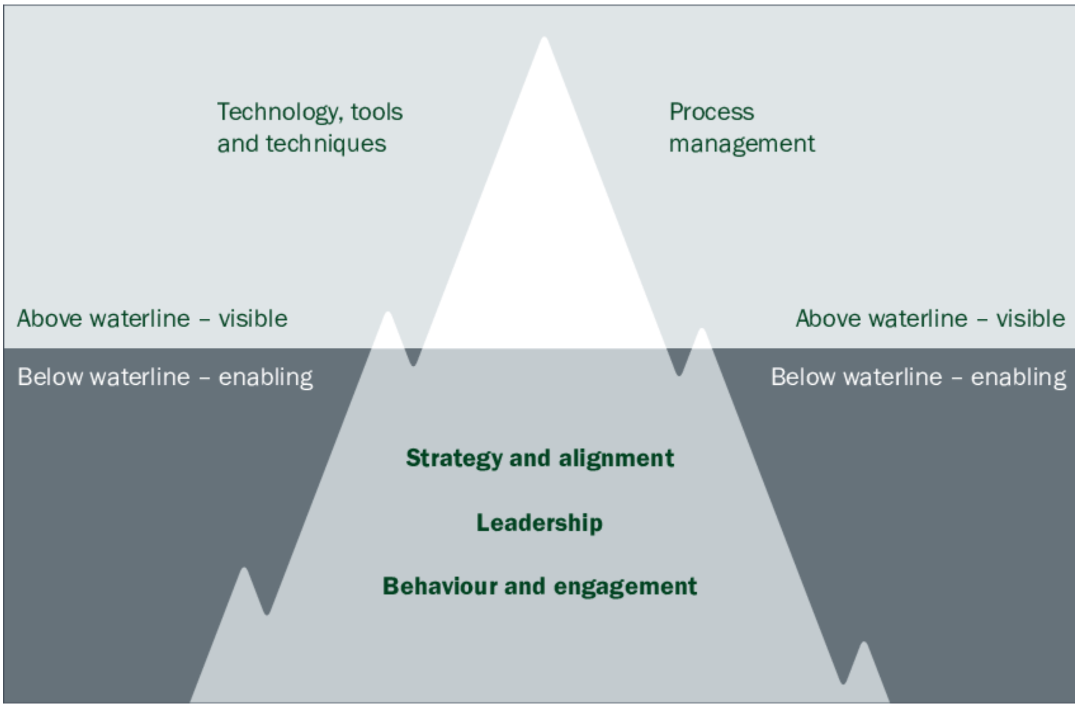

Figure 2.2: The Sustainable Lean Iceberg Model by Hines [19]

Adding on this is the work by George Roth who claims that in order for lean improvements to sustain two things are necessary. The first is agentic work behaviour, and the second is positive personal and interpersonal outcomes[45] . Agentic work behaviour means people are being self-organizing, proactive, self-reflecting and self-regulated. With positive personal and interpersonal outcomes Roth means being engaged and trying to improve on your work. Both of these aspects are linked to Hines' enabling aspect of Behaviour and engagement. Rentes et al. sum up the sustainment of lean improvements as follows:" Lean is not the implementation of a series of isolated production tools. The long term lean vision of the leadership must be shared continually trough all levels of the organization. The relationships through change agents must be built on mutual trust and commitment. Top management should not only demonstrate commitment and leadership, it must also work to create interest in the implementation and communicate the change to everyone within the organization" [43]. Even though these particular examples are based on lean, the highlighted aspects could be extrapolated as important aspects for the sustainment of improvements in general.

2.14. Enabling further Growth

One of the most important aspects of sustaining improvements is thus striving for continuous improvement. This can be helped by implementing a strategy which enables and stimulates further growth. Jager et al[8]. have created the framework visible in figure 2.3 for enabling continuous improvement.

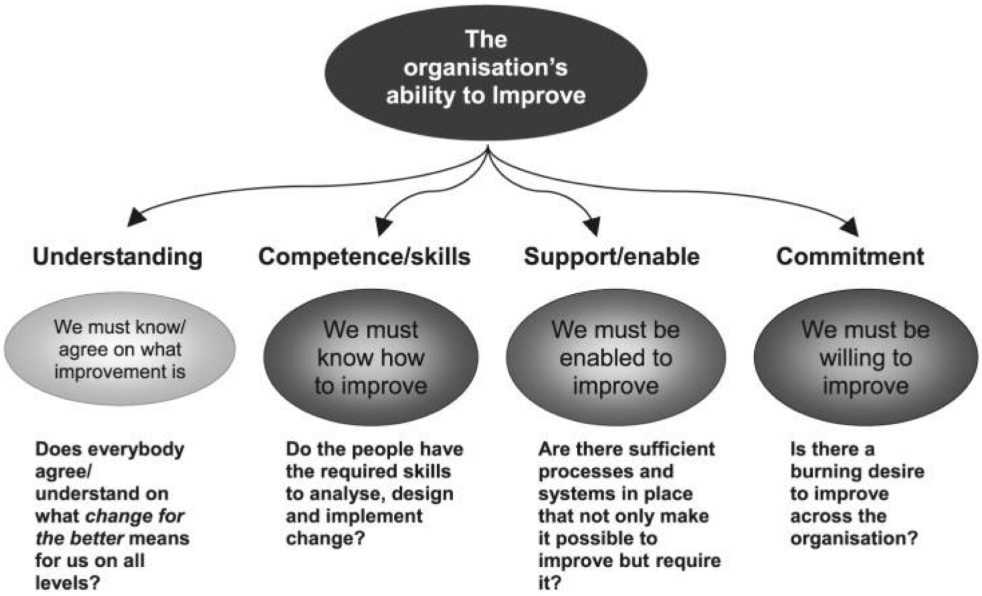

Figure 2.3: The continuous improvement model by Jager et al. [8]

The model starts out by highlighting the need for a real understanding of the process and the desired improvements. It stresses the importance of setting a clear goal in order to improve, simply stating that improvement is necessary does not suffice. Once this understanding is achieved one of the most important aspects of improvement can be tackled; how to achieve the desired improvement. If the goal is set to complete two times more work, it is crucial that all the assets and resources required for this improvement are in place. Once all the required assets and resources are in place it is important to make sure the process is set to accommodate the improvements and not still modelled after the possibilities offered by the old situation. Lastly, as mentioned before, it is paramount that there is a culture in which there is a desire to improve. This culture has to be enabled and encouraged by management.

Emily Lawson and Collin Price [31] pointed out changes in the mind-set and behaviour of employees as a deepest and most difficult level of change. They suggested four conditions for changing mind-set namely "A purpose to believe in", "Reinforcement systems", "The skills required for change", and "Consistent role models". John P. Kotter [28] also proposed a model for leading the major change. His model includes the following eight steps:

1. Establishing a Sense of Urgency
2. Creating the Guiding Coalition
3. Developing a Vision and a Strategy
4. Communicating the Change Vision
5. Empowering Broad-Based Action
6. Generating Short-term Wins
7. Never Letting Up
8. Incorporating Changes into the Culture

One last aspect to consider here is the absence of planning in operational levels of organisations. Since business plans are not constructed on operational levels of organisations it is difficult to measure the impact this would have. However, when looking at the research of Stephen Perry [41] it showed that for businesses below five hundred employees there was a significant correlation between businesses that did little to no planning and the failure rate. There could be other factors playing a role here as well, nevertheless as is the case for most strategies failing to plan is planning to fail.

2.15. Literature gap

As was mentioned in chapter 1 already there is a gap in the scientific literature regarding control models. The biggest gap is the absence of an integral control model for the remanufacturing industry in general. The remanufacturing industry has been topic for quite some research but no specific remanufacturing process control model has been designed, furthermore using a bottom up approach as a base for this design is also novel. To illustrate the gap further a literature matrix has been constructed as is visible in table 2.2. In this literature matrix the author and subject are shown in the first two columns, followed by nine different important aspects for production control in the remanufacturing environment. The aspects: Process mapping, Resource management, Bottleneck control, Entrance control, Target control and Control sustainment were chosen based on the preliminary model, as shown in 2.16. Integral control, or at least an operational level form of control is a novel idea, as is visible by the absence of literature. The only piece of literature which did go into integral control was by Thomson [49], and it denoted the absence of such a form of control. Then there were the existing control theories, aspects from these theories are used throughout the design of this model so these were an important foundation. Lastly was the aspect about the intricacies of remanufacturing. Especially when considering existing control theories these are very important as most control focused literature is based on traditional manufacturing, not remanufacturing. Keeping the intricacies of remanufacturing in mind during the design of the model should prevent this from happening.

One other aspect which should be noted is the Process Quality KPI. In this remanufacturing process control model KPIs will be used to check the performance. One new KPI is also introduced, which is the Process Quality KPI. A lot of research has been performed on the area of KPIs, and Process Quality is no new concept. However, the way it is utilized is new. Traditionally Process Quality is what is referred to as a resulting KPI, meaning it will score good as a result of other KPIs scoring good. Since it is traditionally seen as a resulting KPI it is not used to steer a process, as the KPIs used to asses Process Quality are used instead. This research however proposes to use Process Quality to steer a process. The way Process Quality can be defined and used is shown in section 4.7. This method of using Process Quality is also not found in literature.

Table 2.1: The Literature matrix showing the relevant parts of considered research

Author (year)	Subject	Process Mapping	Resource management	Bottleneck control	Entrance control	Target Control	Control Sustainment	Integral Control	Control Theories	Remanufacturing intricacies
Greene (1970)	Production and inventory control handbook									X
Bertrand & Wortmann (1981)	Production control and information systems for component manufacturing shops								X	
Cox & Goldratt (1986)	The goal: a process of ongoing improvement								X	
Goldratt (1990)	Theory of constraints								X	
Levine (1993)	Remanufacturing strategy									X
Kuo et al. (1996)	Bottlenecks in serial production lines			X						
Guide (2000)	Production planning and control for remanufacturing								X	X
Rohde et al. (2000)	Die supply chain planning matrix		X							
Rother & Shook (2003)	value stream mapping to add value and eliminate muda	X							X	
de Jager et al. (2004)	Enabling continuous improvement						X			
Dedhia (2005)	Total Quality Management & Business Excellence								X	
Melton (2005)	The benefits of lean manufacturing								X	
Chen & Taylor (2009)	Exploring the impact of lean management on innovation capability						X			
Hines (2010)	How to create and sustain a lean culture						X			
Salah et al. (2010)	The integration of six sigma and lean management								X	
Roth (2011)	Sustaining lean transformation through growth and positive organizational change						X			
Summers (2011)	Lean six sigma: Process improvement tools and techniques								X	

Table 2.2: The Literature matrix showing the relevant parts of considered research

Author (year)	**Subject**	**Process Mapping**	**Resource management**	**Bottleneck control**	**Entrance control**	**Target Control**	**Control Sustainment**	**Integral Control**	**Control Theories**	**Remanufacturing intricacies**
K.Thomson & M. Maninjwa (2011)	Information security governance control through comprehensive policy architectures							**X**		
Truscott (2012)	Six Sigma								**X**	
van Assen (2013)	Operational excellence								**X**	
Hassan (2013)	Applying lean six sigma for waste reduction in a manufacturing environment								**X**	
Hosseini et al. (2015)	Lean Manufacturing								**X**	
Matsumoto & Komatsu (2015)	Demand forecasting for production planning in remanufacturing		**X**	**X**	**X**					
Meyr et al. (2015)	Supply Chain Management and Advanced Planning		**X**				**X**			
van Stuyvesant Meyen (2016)	Behold in the industry essentials in different manufacturing industries					**X**				
Zawadzki & Zywicki (2016)	Smart product design and production control								**X**	
Zerhouni et al. (2016)	from prognostics and health systems management to predictive maintenance					**X**				
A. Lemsom (2017)	Controlling the integrated component supply chain	**X**							**X**	**X**
E.P.Cornelisse (2018)	Business process redesign strategies for improved reverse logistics					**X**			**X**	**X**
Palisaitiene et al. (2018)	Remanufacturing challenges and possible lean improvements								**X**	**X**
D. Haak (2019)	Return quality control model				**X**					
Kenton (2020)	Manufacturing									**X**
H.H.M. van Wezel (2021)	Design of a parcel hub scheduling process		**X**	**X**	**X**				**X**	
Xue et al. (2021)	A model to predict bottlenecks over time in a remanufacturing system under uncertainty			**X**						

2.16. Conclusion

In this chapter relevant theories have been shown to provide a foundation on which the model can be build. While doing so the first three subquestion have also been answered. The first subquestion was:
How can a remanufacturing process control model be defined?
A remanufacturing process control model can be defined as follows: a set of subsequent steps or actions which can be followed in order to control the set of activities in a production organization that are directed at the control of the volume and types of products produced at specific places as a function of time. With this definition in mind, as well as the common problems from the literature the design criteria which the model must include are chosen to be:

- The basic process through a Value Stream Map/ PSA
- A control at the entrance of the process
- A bottleneck check
- Assets and Resource planning
- Target control
- Sustainment of control

Which answers the second subquestion: *What requirements for design must the remanufacturing process control model include?*
These points will be implemented into the model using the following theories as a foundation:

- The basic process through a Value Stream Map/ PSA

  In this case there are multiple options to achieve roughly the same desired outcome; have a visual representation of the entire process. For the eventual model the choice can be made to either use a VSM or a PSA. The advantage of a VSM is that it shows more information, but to untrained managers this can also be overwhelming. An advantage of the PSA is that it is already being used throughout the KLM.

- A control at the entrance of the process

  A control at the entrance of the process has to be executed by the shops themselves, not already at the entrance of the logistical process. This has to be done at the shops to combat the lack of part specific knowledge required to asses whether a part is suitable for remanufacturing. For processes the control at the entrance should make sure that not more is entered than what can be handled further down the line.

- A bottleneck check

  In order to know which parts of the process are halting progress a bottleneck check is needed. This can be done from the already constructed PSA with only a small amount of data; the Touch time, process time and waiting time.

- Assets and Resource planning

  As mentioned remanufacturing knows a particularly difficult planning operation due to uncertain demand forecasting. Models trying to predict this uncertain flow of incoming parts have been developed, but are extremely complex and not yet very accurate. This is why the choice has been made to not try and predict the future as best as possible, but rather to try and be ready for it. Using average data and experiences from the past a regular process can be created, which on average will work out, even though the exact income of parts is still unknown.

- Target control

  Target control is a very important aspect to check whether the implemented model is working and showing improved results. The way to do this is by using a few tactically chosen KPIs. Using the wrong KPIs can make it seem as if the process is performing very well when it is in fact worse, and using too many KPIs leads to a loss of focus. Therefor, as suggested by van Stuyvesant Meyen [52] only a few KPIs will be used to perform target control

- Sustainment of control

  Sustainment of control is not only a necessary component of sustaining the improvements made, but also to enable the process to climb to new heights. The continuous improvement model of Jager et al. was shown to illustrate a way to achieve this. It starts out with a deep understanding of the process, followed by checking if all requirements are there for the improvement. Then the process has to be designed in the right way, lastly, an perhaps most important, there must be a commitment stimulated by management. Another way to enable sustainment of control is by implementing business plans constructed on the operational level, as this prevents failure of progress made by planning out the next actions according to Stephen Perry.

The third subquestion: *What are important underlying theories found in literature?* is already answered to some degree, but next to the theories which are directly linked to key points of the remanufacturing process control model there are still some other relevant theories which should be kept in mind when designing the model, such as:

- Lean/ Six Sigma
- Theory of Constraints

These theories won't be used on the forefront of the model but elements of them will be used for certain sub-steps, making them relevant nonetheless.

Combining these aspects the preliminary model is designed as shown in figure 2.4. This design will be elaborated on in chapter 4

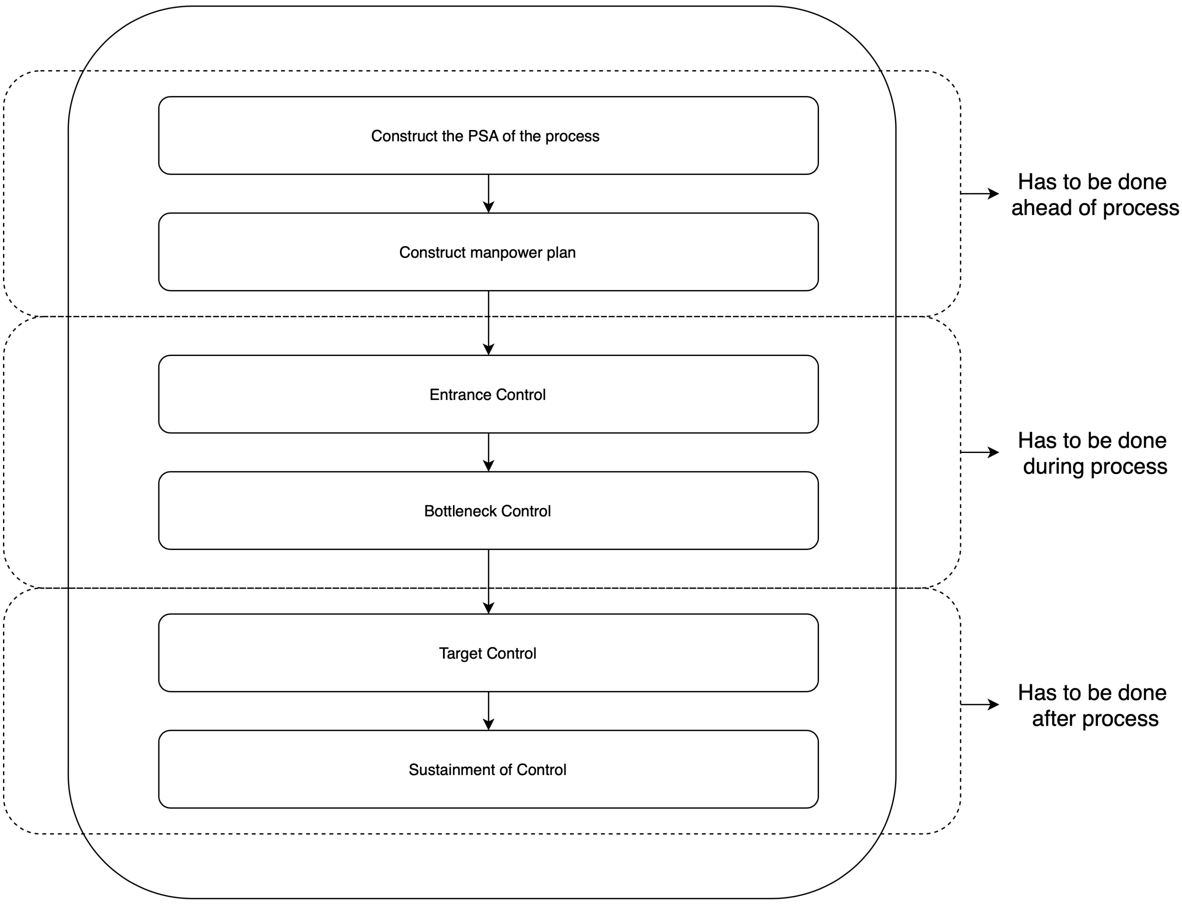

Figure 2.4: The basic structure of the remanufacturing process control model

In order for a process to be under control these aspects must thus be fulfilled. In the following chapter the case study processes will be evaluated and it will be checked if and up to what degree the processes follow the criteria for control.

3

Current state of processes at KLM E&M

In order to get a better understanding of the problems at hand two separate pilot cases will be examined. These cases will be at the oxygen bottle shop and at the logistic centre. The choice for these two shops will be elaborated on in sections 3.1 & 3.2 respectively. But one key point in the choice was the fact that these two shops, even though both part of CS, are very different in operations.

The following chapter will be constructed as follows: First the oxygen bottleshop and its problems will be explored in section 3.1, after which the logistic handling area will undergo the same exploration in section 3.2. Then the general problems faced throughout KLM E&M will be highlighted in 3.3. Lastly everything will be summarized in section 3.4

The subquestions which will be answered in the coming chapter are:

4. What is the current state of the pilot processes in CS?

5. What are the problems that these pilot processes face?

3.1. Oxygen bottle shop

The bottle shop is a small sub-shops of shop Electrics, Part of the component repair division of component services. The shop is relatively small, consisting of only 3.5 FTE's at the moment of writing this report. The main activities of the oxygen bottleshop consist of three operations:

1. Filling empty oxygen bottles

2. Overhauling oxygen bottles

3. Overhauling smoke hoods

These processes will be dealt with more in depth in Chapter 4 but a short description of each process is provided. First of all filling empty oxygen bottles, this is a relatively straightforward process consisting of only a few steps. Used up bottles arrive at the shop and must be filled again. In order to do this the bottles are filled in a special "explosion chamber". Since the bottles heat up during filling they have to cool down for a bit, during this cooling down the pressure inside the bottle drops a bit, which is why a secondary small fill is required. When the bottles are filled to the correct pressure they get tested, and if they pass this test they can be expedited.

Secondly there is the bottle overhaul, this is a more complicated process consisting of many steps. It starts with emptying the all bottles which arrive to ensure safe working conditions. After this disassembly can start. Depending on the fault with the bottle the overhaul process differs, sometimes a sub-assembly and sub-test are required before putting the entire bottle back together. When the bottle is fully assembled again the remainder of the process is the same as just filling the bottles.

Lastly there are the smoke hoods, which are masks that generate oxygen through a chemical reaction. When smoke hoods arrive in the bottleshop there are three possible processes. First of the smoke hoods need to be repaired, since smoke hoods are a one time use product these repairs are not drastic. Secondly, there might be an issue with the administration of the smoke hoods, in which case only some administrative tasks are required. The last possible process happens when the smoke hoods have exceeded their shelf life. Since smoke hoods use a chemical reaction to produce oxygen they are bound by the safe lifetime of the chemicals inside. When the smoke hoods exceed this lifetime they must be disassembled so they can be recycled, and deleted from the administrative files.

The choice to run one of the pilot cases in the bottleshop was made since it is one of the shops within KLM E&M which was performing quite well, but has somewhat lost its grip on the process. This is visible in figure 3.1. As can be seen, the OTP was rising from 2018 to 2019, but has since only declined. An OTP of above 80% might sound like it's quite good, but the aim set out by KLM is to be at around 95%. Before September of 2021 there were 4.5 FTE's employed in the bottleshop, this dropped down to 3.5 after. This means that with the same amount of workers employed and fewer orders to complete the service level still dropped from 2019 through the summer of 2021, indicating that something about the process is not running optimally.

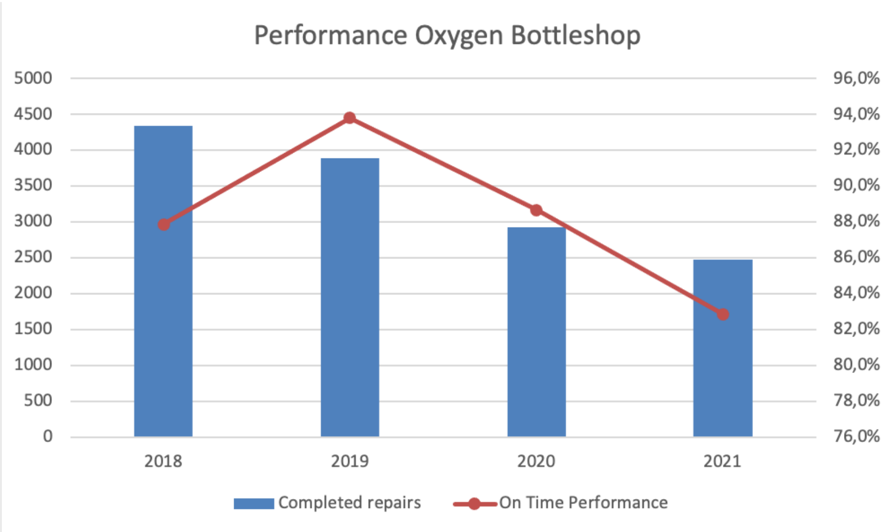

Figure 3.1: The finished repairs and On Time Performance for the oxygen bottleshop

It is important to note that the data for 2021 is data up until October 18th, this means that the total amount of orders completed will still rise somewhat, if the amount of orders is extrapolated over the remainder of the year the total amount of orders will be about the same as it was in 2020. This extrapolation is based on the notion that the orders are somewhat uniformly distributed over all weeks of the year, it could however very well be the case that some seasonality plays a role in the amount of orders received. Another aspect which is important to note is that for the last month of 2021 still included in the data the shop has been operating with one FTE less, which could have an impact on the OTP as it gets calculated as shown in eq. 3.1. It is namely not unreasonable to assume that with one employee less, less orders can be completed on time.

$$\text{OTP} = \frac{\textit{Amount of orders completed within contract TAT}}{\textit{Total amount of orders completed}} * 100 \quad (3.1)$$

Nevertheless, even if all the extrapolated orders for 2021 would be on time, the service level would only rise to about 86%. It is thus clear that there is room for improvement somewhere in the process. As was previously mentioned, at the moment of writing this report the bottleshop is not performing too bad. This is partly because the incoming flow of bottles is relatively low. Even though there are less and less people flying due to COVID and environmental issues the airline MRO market is still believed to be a growth market, it is thus necessary for the bottleshop to hone their process now, so they will be ready to deal with the increase in workload when it arrives.

Another reason why the oxygen bottle shop has been chosen to receive the pilot of this model is the fact that the eventual goal for the model is that it will be generally applicable, meaning that every sub-category of CS can implement this model on its own process. In CS there are shops and logistic centres. The best way to create a generally applicable model is thus to design it based on the pilot case of each one of these types of shops/ centres.

3.1.1. Current problems oxygen

As mentiond the current problems at the oxygen bottleshop are not dramatic, especially when it is considered that there were shops at KLM E&M in the past with an OTP of below 50%. Nevertheless they have recently downsized, combine this with an increase in workload expected in the future and it becomes clear that the bottleshop must take action to avoid being overrun with work in the future.

When looking at problems it helps to look at the 4M's, to see which of these areas is lacking. First of is the Manpower. A more detailed look into the manpower is provided in section 4.4.1 but looking at the current situation shows the manpower is pretty much all used up. Usually it is practice to have more employees on the payroll than are necessary, to combat people being absent due to sickness, vacations or other events. In the bottleshop however this is not the case. There are 3.6 FTE on the payroll at the moment of writing this report, and all of them are needed to complete everyday work. Meaning that if the shop would temporarily lose one worker they could complete the incoming work on time, and the delay would grow until a replacement worker is found, or the original worker is back. A weekly overview of the net amount of workers needed vs incoming work is presented in figure 3.2. One important note with this graph is that the incoming work in real life is not structured as one long task, but multiple shorter tasks. In practice this results in more hours needed to complete every task. So even though it seems like three FTE is enough to complete the work coming in it is highly likely that when there actually only are three FTE working the TAT targets can not be met.

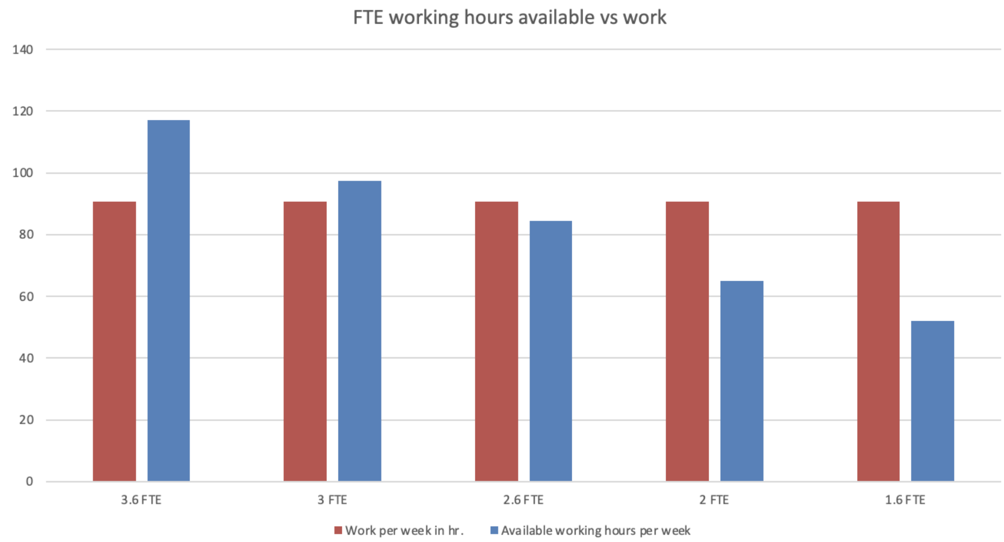

Figure 3.2: The relation between work and available FTE

Then there are the machines used. This is another aspect which could be a problem, as reaching a machine's full capacity could severely hinder production. A detailed analysis on machine capacity is provided in 4.6.1 but to quickly shine a light on the matter, the machines themselves still have plenty of capacity as to not hinder the process. What does play a small role is the availability of the machines, and the required certification to operate them. Some of the machines used are shared with other shops, and thus only available on certain days of the week. As work comes in every day it is important to anticipate on this fact and design the process in such a way that all the necessary work can be completed on these days. When designing the process it is also important to remember that not all employees are allowed to perform all steps in the process. To combat this they must either be assigned to only perform steps they are already certified for, or they must receive additional training.

Next the method is looked at. This is an area where the bottleshop has room for improvement. As was already mentioned, the shop is performing pretty well at the moment, but when more work will come in it is expected to fall behind. This is partly due to being short staffed but also partly because there is no method which is applied to the process. The absence of a clear working method does not seem like a huge problem to the employees involved, as they have a feeling of what to do when, but when they get overwhelmed a wrong decision is quickly made. Another benefit of using a clear method is that performance almost always goes up while workers feel like work is more relaxed. The proposed working method consists of multiple steps and is thoroughly explained in chapter 4.

Lastly there is the material aspect of a process. This basically ensures that all the parts needed for a repair are present, ranging from small cheap items like new O-rings all the way up to new valve heads. As was discussed previous the JIT principle is a very smart principle to use when considering material inventory. However, when considering the cheaper parts, which are the most numerous in the oxygen bottle overhaul process, it makes sense to stock more than would be advised by the JIT principle. This is based on the fact that it is highly undesirable to have an expensive component laying around waiting on a cheap part. At the moment of writing this report there isn't a huge material problem for the oxygen bottleshop, as there is also a different department which focuses specifically on supplying the shops with the required materials.

There is one other point to consider when looking at the problems a shops might be having, and that is the problems directly experienced by the workers. These will usually only reveal themselves when directly asked. These problems are usually not problems which will drastically improve performance, but they are experienced as annoying by the workers. Solving the problems creates a more pleasant working process, as well as creating goodwill from the team. So even though they should not necessarily be a priority they should be taken into account. Some problems/ irritations mentioned at the oxygen bottle shop are:

- The shop is more of an office than it is a workshop
- The party responsible for bringing new work in, and collecting finished work does not abide by the schedule
- The used IT systems are cumbersome

When considering the current state of the case study processes it is also important to see if any of the suggested preliminary model features already get performed, and if so, to which degree. First of mapping the processes through the use of a PSA. At the moment this does not happen at the oxygen bottleshop, meaning the standardized process exists only in the worker's heads. Since there is no set figure which mandates process length it comes as no surprise that there is also no manpower plan constructed. Again since there is no knowledge of manpower or process it is impossible to enforce entrance control, and after that bottleneck control. There is some form of target control, but one that simply focuses on whether the service level is at an acceptable percentage, this service level is however not used at the moment to asses process quality. Furthermore, the process quality is not used as a KPI to steer the process into certain directions. Since there is no control of the process there logically is no sustainment of control.

3.2. Logistic centre

The logistic centre is the facility of KLM E&M where all parts come in. This means the faulty parts which need repair, broken parts which need to be recycled and new parts needed for the remanufacturing process, or to be placed in the pools. It is clear that this is a critical department within KLM E&M, as having hold ups here effect every other shop or department in the organisation. The way this process works is as follows: An external logistic provider delivers a shipment to the logistical centre of KLM E&M, there every shipment goes through the expedition. In the expedition they divide the shipments in numerous categories which need specific handling later on, like dangerous goods, odd sized etc. The three different types of packages which occur most frequently, and which will be looked at in more detail in this report, are new buys, rotables and mutation parts.

New buys could be everything from new staplers which will be used in the offices, to bolts needed to fasten parts on the plane, to actual complete parts. Because of this new buys are considered the easiest too handle, and its the first type of package new employees learn to handle. Another characteristic of new buys is the fact that it is difficult to asses how long it will take too handle them. If the roster shows three hundred packages coming in it might seem like a lot of work, but there is a very real chance that fifty of those packages are new staplers, together in one box, which will only take fifteen minutes to process.

The next type of package is the mutation parts type. This type is scarce within the logistics handling area. A mutation part is basically also a new buy, which will end up on a plane, with characteristics of a rotable part. These characteristics shine through most in how the part has to be processed which is why the parts are a little more difficult to process than regular new buys, but still not as complex as rotable parts.

Lastly there are rotables. Rotables are for the most part components used on airplanes which have gotten repaired by third party vendors or which were sent to KLM E&M for repair and will either have to be sent back after repair, or they get replaced with an identical part from KLM's "pool". Such a pool ensures that customers don't have to wait too long for their repaired part, but it does mean that KLM E&M needs to stock more of such a part. Having a larger inventory is undesirable for companies as it gets expensive and consumes a lot of space. This is another reason why ensuring fast handling of parts throughout all process within KLM E&M is desired. As was already mentioned are rotable parts the most difficult for the employees to handle, as they require a lot of programming in CROCOS, an outdated IT tool which is still used at KLM by lack of a good enough replacement. Within the rotable parts there are two different types which can be distinguished: LRU easy and LRU complex. LRU stands for Line Replacement Unit, which is the technical term for a rotable. LRU easy parts are rotable parts without any special treatment necessary. LRU complex parts do need special treatment, in the form of additional CROCOS programming, because the parts either have a shelf life or have other special properties.

At the moment of writing this report the logistics handling area is having the most difficulties controlling the rotables of their incoming flow. New buys and mutation parts are bundled together, and handled by an experienced group of workers. The rotables make up for the most work within the logistic handling area, and they are experiencing the most problems in getting a grip on their process. Because of this the focus for of this case study within the logistic handling area will be specified further as being on the rotable flow of the logistic handling area. One important aspect to mention is that in the future there will not exist a separate team to handle the new buys and mutation parts, but all employees of the logistic handling area will be multi skilled. Which is why the results of this case study will have to be extrapolated to include the new buys and mutation parts in the future.

One other important aspect to mention is that at the moment of writing this report KLM E&M is testing its new Automated Handling Area (AHA), which needs to go live on July first 2022, as there old handling area is sold. This new AHA will provide an easier way to handle the incoming packages using conveyor belts and automated package delivery systems. The way this will work is as follows: Trucks can drive right up to the new handling area, to a covered area which is right next to the actual working stations, only separated by a thin wall. At the truck side of the wall there is a small indent where the conveyor belt perpetrates. Here logistic workers can place the packages in so called "totes" which are basically RFID tagged plastic containers. Then the tote will transport the package along the conveyor belt where it will automatically be weighed scanned an photographed. Next the system checks whether there is a worker with available space on his desk where the package can be sent towards. If not, the package will enter the mini load buffer, where is is stored until a place becomes available, where it will be sent too based on a priority system. This results in easier transporting of packages, as there will always be two packages waiting next to a worker's desk. As well as no picking of only easy package to handle, as the system assigns packages to the workers with appropriate skill levels. Nevertheless it is important not to stumble in the pitfall that automation immediately leads to improvement. The automated handling area will result in work being conducted faster only if the control of the work is properly managed. Without control there will not be any noticeable improvement. This needed control will be elaborated in chapter 4

3.2.1. Current problems Logistics

The immediate problem faced by the logistics handling area is the rising buffer, which is shown in figure 3.3. From this graph there are two main takeaways which are important to note. The first is the high number of packages in the backlog overall. The ambition set by KLM is to ensure a same day handling concept for packages which arrive before 9PM. As is clear from the graph this ambition is not being met at the moment, as same day handling would result in, either no backlog if backlog is measured as packages waiting for over a day, or a backlog which goes back to zero every day if it is measured as packages waiting to be handled. Another problem with the high number of packages in the backlog is the fact that it demotivates employees, as they are working to get rid of an ever growing mountain of packages. The second takeaway from the graph is the trend of the backlog, which is plotted as the blue dotted line. In this line it is clearly visible that overall trend in the backlog is rising, where it should be decreasing. If no action gets taken it is safe to assume that the backlog problem faced at the logistics handling area would get even worse over time.

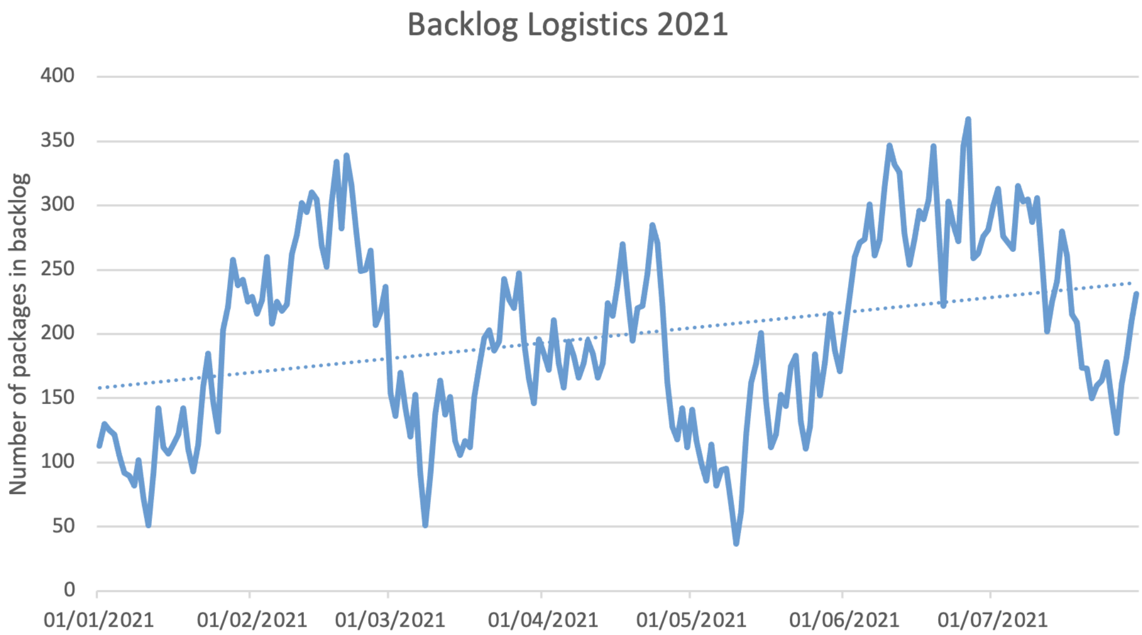

Figure 3.3: The amount of packages in the logistics backlog in 2021

In order to combat these problems the root cause of the problem must first be found, or is simple terms, the real problem. When interviewing managers of the logistics handling area about the problems of the logistic handling area they all point to the backlog, saying that without the backlog there would not be any problems. This however is not true, as the backlog arose from somewhere. Where this backlog comes from is the real problem. Another reason mentioned was the pandemic, and the outflow of experienced workers. This is a cause of some of the problems faced by the logistic handling area but if we look at the graph in figure 3.4 of the backlog from before the pandemic it is evident that there has always been a backlog.

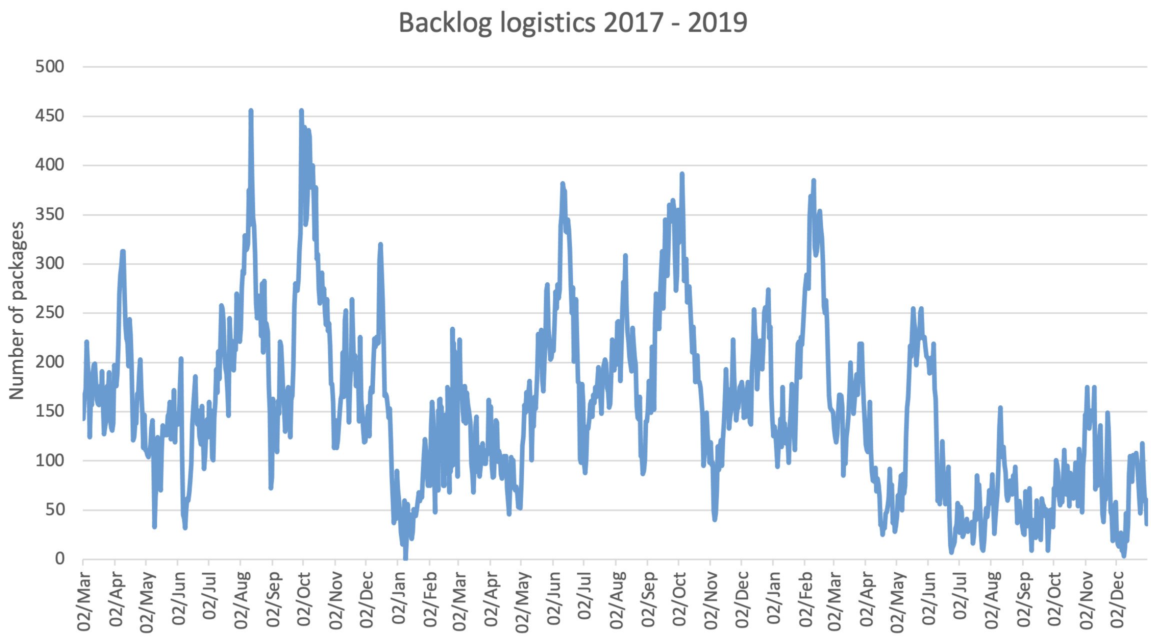

Figure 3.4: The amount of packages in the logistics backlog in from 2017 until 2019

It is thus clear that there is an underlying reason for the problems faced by the logistic handling area. In order to find the real reason for the problems the same methodology as used for the oxygen bottleshop will be used, checking the resources according to the 4Ms. Most of the elements which make up the 4Ms are easily checked for the logistics handling area, as it is not a value adding process. First of the machine resource, the only machines used are the computers where to administration is done. Every employee has their own laptop so a machine bottleneck is not present. The argument can be made that the desk where the employee performs his or her task should also be counted as part of the machine resource, as this is where the system sends the packages. At the moment there are thirty-five desks in the handling area, as there are only 29 employees on the payroll, who also work in two shifts per day, this can also not form a bottleneck. Then there is the material resource, as was already mentioned the logistic handling process is not a value adding process, furthermore, there are no external materials used in the process so this resource becomes obsolete. The method used is a little more complicated. The first skill new employees learn is new buys. This goes very much by the book, there is a predetermined way of working and all employees must pass a test in order to become an independent employee, meaning they are not allowed to sign off on parts until they have passed the test. After they have achieved this skill however things get a little less strict. There is no predetermined way of handling rotables, which leads to all different instructors explaining the process in the way they perform it, which is not necessarily the most efficient way. Once the new students have sufficient knowledge of how to handle the easy rotable parts there is no test to confirm this. The instructor has to judge whether the new employee is ready and from that point on the new employees get seen as fully capable of handling easy rotable parts. The step from easy rotable parts to complex rotable parts is done purely by gaining experience and learning as they go. This is why it is hard to gauge what the skill level of an employee is exactly. This whole learning process leads to there not being one sole method used in the logistic handling area, but rather a lot of personalized methods. In order to get more control over the process, this must change, with a set way of learning each new skill and a predetermined best way of working. Lastly there is the manpower, this is where the logistic handling area faces the biggest problems. As was already mentioned there has been quite a brain drain within the logistic handling area, resulting in a somewhat under skilled group of workers. However, if the current skill level of all employees get taken into account, the theoretical capacity should lay around 525 packages being handled per week, including training days for new employees. This theoretical capacity has been calculated as follows: First the average amount of packages handled by one FTE in one shift has been looked at over the past years, this was nine packages. If this average is known this is multiplied by the amount of FTE's working in a week to get a weekly average. To combat the fact that new employees still receive training there are only two shifts in a week where there is no training, and three where there is training. On these training days an instructor plus two new employees only counts as half an FTE. Adding this all up and multiplying by nine gives around 525 packages possible per week. The average amount of packages coming in per week for the past year was only 333, so it is clear there is a mismatch.

This mismatch is the real problem faced by the logistic handling area. When looking at the pattern of incoming work in figure 3.5 it is clear that the pattern is very capricious[1]. The way this gets handled at the moment is trying to predict how much packages will arrive in the future, but this method, as is visible from the backlog, does not yield much success. Instead of trying to predict the future a better alternative is to try and be ready for whatever it may bring. This will be explained in detail in section 4.4.2 but to quickly summarize: An acceptable target should be set by the management for how many days per year same day handling must be met. Then it must be determined how many packages must the team must be able to handle to ensure same day handling for the predetermined amount of days. This gives a base level for the amount of workers who must be present each day.

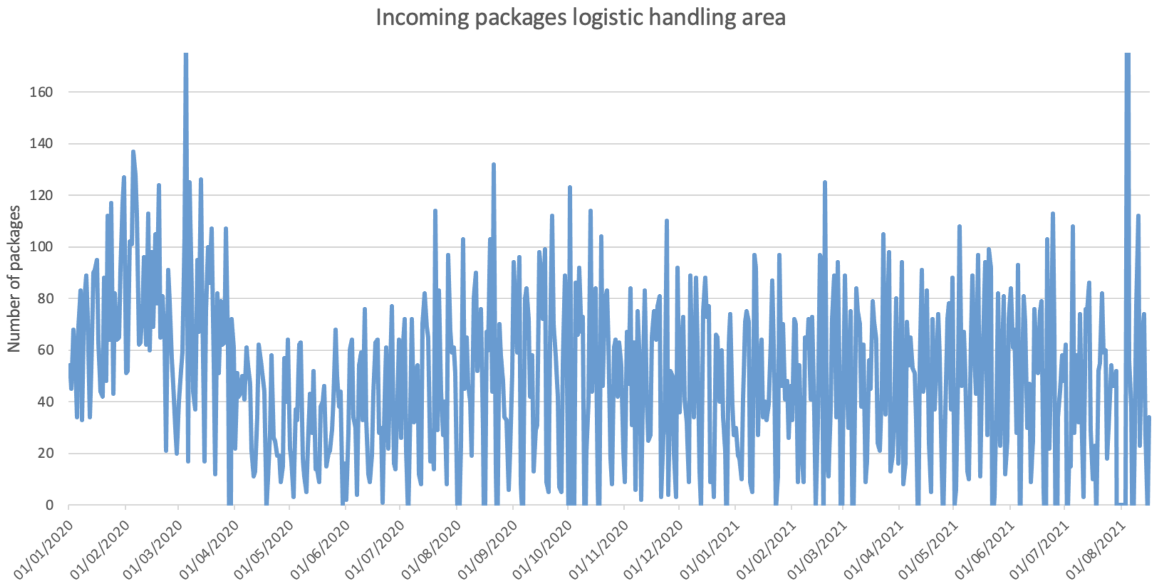

Figure 3.5: The amount of incoming packages per day for the logistic handling area over the last two years

Lastly, just as done for the bottleshop the problems directly experienced by the workers are also looked into. For the logistic handling area these include:

- Some workers feel that others don't put in enough effort
- When handling rare and difficult packages there is no reference book to check the handling procedure
- The administrative programming is cumbersome
- The IT help desk is only available during the day shift on weekdays, while the logistic handling area also works nights and weekends

Again, as was done for the oxygen bottleshop the suggested preliminary model aspects will be compared with the current state of the logistic handling process. As was the case with the oxygen bottleshop there was no overview of the process made through the use of a PSA, this resulted in not having a manpower plan, not having entrance control and not having bottleneck control. Target control is done primarily by the check of the backlog, which is a cumbersome job since it has to be counted manually everyday. Since no service level is being recorded neither that nor the process quality are being used to steer the process at the moment. And as was also the case for the oxygen bottleshop there is no sustainment of control as there is no control.

[1]One important note is that this data was collected by employees by hand, in some cases they forgot to log the incoming packages for that day, which is why the line sometimes goes back to zero. In real life it basically never happens that there are absolutely no incoming packages.

3.3. General problems faced by KLM E&M

Next to the problems faced specifically by the oxygen bottleshop and the logistic handling area there are also general problems faced by KLM E&M as a whole. Since most of these problems are most likely not unique to KLM E&M it is important to note them. These problems could possibly hinder the model from working as desired and must thus be eliminated to achieve the best possible outcome. Some of these problems include:

Too many improvement tracks or strategies being used simultaneously. One common problem faced by KLM E&M is the fact that there many different departments which aid in process improvement, most of which use their own unique method for improvement. This on it's own is an undesirable situation as it can lead to discrepancies between departments, but an even worse outcome of this is the fact that managers reach out for help to different departments. This leads to multiple improvement tracks being run at the same time, which inevitably interfere with each other. A company can choose to have different improvement departments and methods, since different approaches can improve different parts of the process. However, when this is chosen it is important to have a clear order which improvement track has to be done first etc. And to specify that new improvement tracks can only be started when the one prior has finished.

Another problem faced by KLM E&M is the rapid transition between positions of the managers. Since KLM E&M is a large corporation there are many different managing positions, in which employees can quickly climb through the ranks. This means that average time a manager spends at one department is only around two years. After two years a new manager comes who has to start from scratch and so on. This results in an environment where it is very difficult to improve, as it takes quite some time to get accustomed to the new department, and improvement tracks also take a long time. Another aspect which increases the difficulty for managers to actually improve their process is the fact that a real E2E understanding of the process is usually missing, as they spend their entire day "putting out fires" leaving no time to really get grips with their process or to think about possible improvements.

Then there is the problem often faced by higher management of making the fallacy that automation leads to improvement. Which, as R. Jelinek [21] showed, is a popular misconception in organisations. In KLM E&M this shows in the new logistic handling area, where packages will get transported using a conveyor belt and weighed and scanned automatically. This however won't solve any of the problems faced by the logistics team, which as described earlier were caused by a mismatch between employees and work. Higher management however feels like it should, as it was a large investment. This fallacy is an easy one to fall into, which is why it is important to note that automation without control will not improve the process.

Furthermore there is the problem concerning the plans made at KLM E&M. All departments have to make a sort of business plan ones per year, presenting their budget and ambition for the coming year. This in itself is not a problem, in fact it is very beneficial for the departments. However, the plans which get made don't include a plan for achieving the ambitions, but solely the ambitions. next to this, the ambitions are not based on a proper analysis, but rather on playing it safe. Still a lot of time goes in to constructing this plan, and after it's presented and approved it is almost never looked at again. Not following the constructed business plan is a problem faced by many companies according to [24]. This means that a lot of time and effort is wasted creating a plan which is then not used, while it has the potential to be a very powerful tool. The only place where business plans get used or on the strategic and tactical level of the company, which does not translate to the operational level.

3.4. Conclusion

In this chapter the two case studies have been looked at in more detail. Describing their current state and the problems they each faced. Furthermore the general problems faced by KLM E&M as a whole have been described. In describing these aspects multiple subquestions have been answered. The first of which is *What is the current state of the pilot processes in CS?* For the bottleshop this is answered quite easily as it relates directly to their service level, which now stands at 83%, which is not low but also not great. Furthermore, when investigating it showed that this service level will most likely drop off further when the incoming flow gets back to the levels it was at before the pandemic. Lastly it was shown that of the six aspects denoted in the preliminary model only one is being performed at the moment, and this one is not being performed to its full extend. For the logistic handling area the current state was more complicated as there is no direct service level connected to the department. There are however other ways to asses the performance for the logistic handling area. One of these methods is by looking at the backlog. In a well functioning logistic handling center the backlog should on average not contain the same packages for longer than a day. At the handling area of KLM E&M however packages were laying around for over a month. This combined with the fact that the backlog is growing over time indicates that this process is performing sub par. When looking at the six aspects from the preliminary model again only one is being performed, which is the target control. And as was just explained this is not being performed correctly.

The next subquestion which has been answered is *What are the problems that these pilot processes face?* Both pilot processes face multiple problems, but the most important one for each is the following: For the bottle shop the main problem is a lack of control over the process. Most employees are experienced and the performance is not distressing which is why the need for control was never experienced, but with one FTE fewer and more work expected to come in control has become paramount. For the logistic handling area the main problem was a mismatch between the incoming work and the available workers. This was caused by a brain drain in the logistic handling area as well as trying to predict future input.

4
Model Design

With a solid base of literature established, as well as the common problems from the previous chapter a preliminary model can now be constructed. The model will be build up of different layers, which arise from the different aspects which were noted as crucial for a remanufacturing process control model in the previous chapters. Adding in on this will be some aspects of a lean maturity model, which can be used to track the extent to which the lean, or other, improvements have worked.

The following chapter will be constructed as follows: First an overview of the model will be shown in section 4.1, then the different intervals will be explained in section 4.2. After this the separate steps of the model will be examined in more detail in sections 4.3 through 4.8. Then a way for checking optimization progress will be shown in 4.9. Lastly everything discussed in this chapter will be summarized in section 4.11.

The subquestion which will be answered in this chapter is:

6. How can the remanufacturing process control model be designed?

7. How can a company check their progress regarding process optimization?

4.1. Different model aspects

The remanufacturing process control model will consist of multiple steps, which should be executed next to the normal order of operations. These steps vary from checks, to see whether the process is coming along as it should, to pre-active steps which will aid the future states of the process. It is important to note that the aim of this model is that it can be applied everywhere within CS, so it has to be kept general. This means it is not tailored to the pilot processes, but constructed in such a way that it can be introduced all over CS. Hence no specified implementation plan is presented since these will differ for each department and shop. However, to aid in the understanding of each step it will first be explained in general, and then how it will be applied to the pilot cases. The sustainment of Control step will not be explained with its application to the pilot case since this is not applied yet, and the foundation of sustainment working is having the managers construct this plan (according to the laid out framework) themselves.

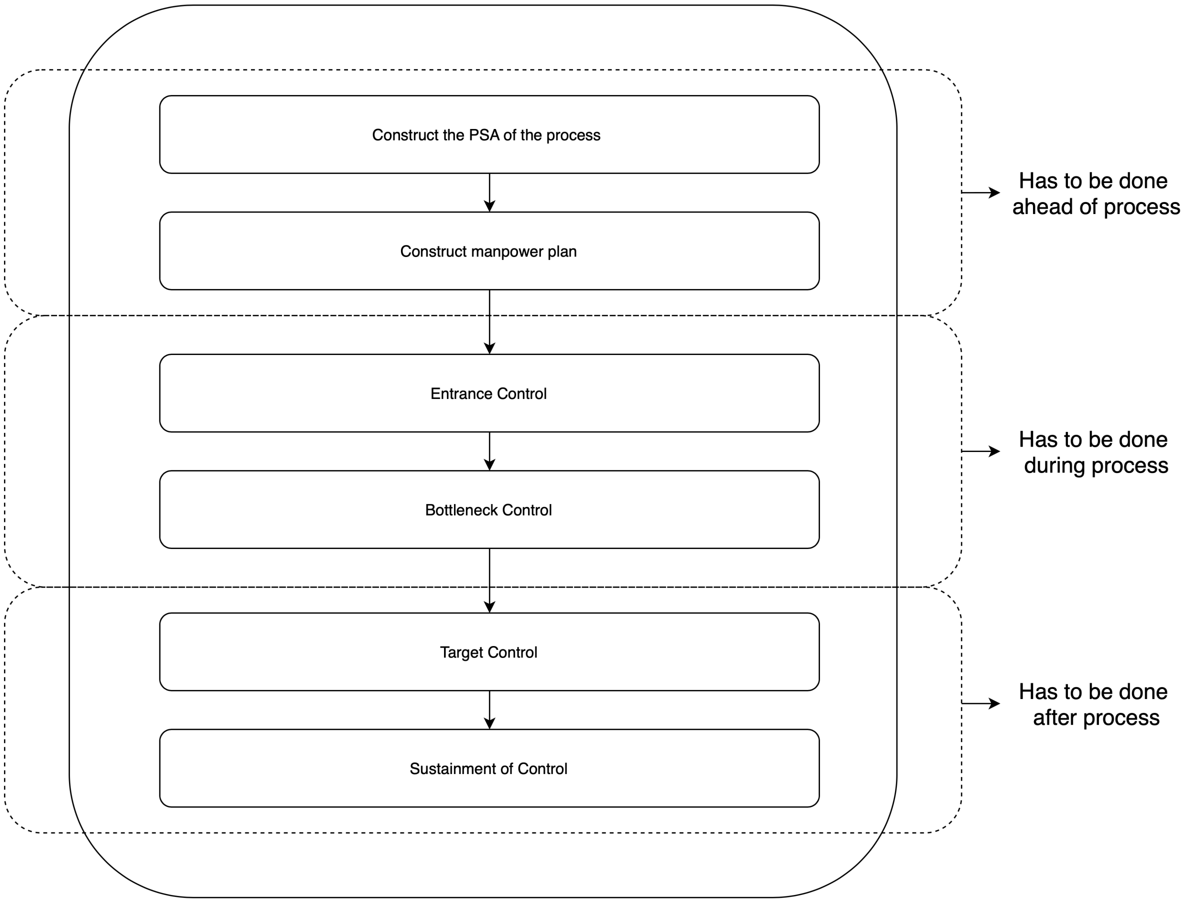

Figure 4.1: The basic structure of the remanufacturing process control model

As is visible in figure 4.1 the model consists of six different steps which have to be executed at three different intervals, first of the differences between these intervals will be discussed, after which the different steps will be examined.

4.2. Model intervals

As is visible from the model in figure 4.1 there are three different intervals in which steps take place. Ahead of the process, during the process and after the process. It is important to note that all of the processes on which the remanufacturing process control model can be subjected are already happening at the moment. Ahead of the process does thus not mean that the remanufacturing process control model nor the process can exist without the execution of the two steps within this interval. Ahead of the process in this sense means that these steps can already take place when the process is yet to begin. It is possible to argue that more steps could theoretically already start before the process takes place, like the bottleneck check. This might be true to some extend but in order to get the most accurate data and thus process it has been put in the next interval, during the process. Furthermore, the steps which appear later in the model can be based on the date which has already been acquired in the first two steps.

The interval 'During the process' is more true to its name, as it uses more real time data to complete its tasks. The entrance control, which will be further explained in section 4.5 needs the actual part to be executed, and can thus only be done during the process. The bottleneck check, elaborated in section 4.6, could in theory be done after the process as well as during, and should also be done during both intervals. The choice is made to put the task in during the process since the tasks which happen after the process are more to reflect back on the process, while the tasks which happen during the process are in place to steer the process.

Lastly there is the interval of 'After the process'. As was mentioned this interval consists of tasks which help reflect back on the process, and using this reflection create a better process in the future. The target control portion of this interval, further explained in section 4.7, needs results in order to give any relevant conclusions and thus has to happen after the process. The continuous improvement, is a bit harder to place as it needs to continuously happen, but using results from the process aids this step into getting feet on the ground, hence it was also placed at the end of the model.

4.3. PSA

To create a well designed process it is important to pinpoint the faults in the current process. After all, if there are no faults then improvement is most likely unnecessary. There are many different ways to locate fault in processes, but when the start of an improvement trajectory is considered a PSA is the chosen method. A PSA is basically a slimmed down version of the VSM created by Toyota and used in Lean practices throughout many areas of manufacturing. As was briefly mentioned in chapter 2 a PSA is constructed by taking the entire process and subdividing it into all the separate steps. It can be difficult to know what exactly counts as one step, after all, disassembly can be one step, but removing a screw in order to disassemble would be too small of a step to make sense in the PSA. A good rule of thumb when it is unclear what one step should encompass is the following: If it is undesirable to stop between steps (e.a. it would take a while to get back in to the task at hand if stopped) it makes more sense to view the actions as one step. In the disassembly example this shows, after the entire disassembly the worker could walk away from the process and pick up where he left of a day later. If he would have stopped mid disassembly he would have to spend some time figuring which parts he did and did not yet remove, making the step as a whole last longer than necessary. When all of the steps have been identified and put into the PSA it is time to enrich the PSA with data. The relevant data for the PSA exists of three different times: The Touch Time, The process time and the waiting time. The touch time is the time which a worker is actually busy with a the task at hand, and thus he can't do anything else. Process time is time which is required in the process, but not hands on. This could be paint drying, parts cooling down or any other step which does not require a worker to be present. Than lastly there is waiting time, this is the time in between adjacent steps, where the part is just laying around, even though it could be worked on. The goal of the PSA is uncovering waiting time and designing the future process in such a way that it will be reduced to a bare minimum. Completely eliminating waiting time is impossible in practice which is why the design is not based on zero waiting time.

Up until this point the PSA has mainly focused on the current, not optimized, state of the process. When all the required data has been collected though, the design of the future state can begin. For this more than just data is required. A real understanding of the process must be known. This means that not only the theoretical minimal TAT is used, but also important aspects like other bottlenecks in the process, which will be dealt with in detail in section 4.6. Since pushing more into the process than it can handle will lead to clogging in the process, this phenomenon will be explained further in section 4.5.

One last aspect which is important to mention here is that the PSA is build up with a regular flow in mind. This means that the parts go through the process as designed and nothing out of the ordinary happens to it. When a part does have something out of the ordinary it should be removed from the process and be placed in a separate holding spot. A dedicated team will then look into resolving the disruptions. The idea behind this is that workers don't waste time trying to fix problems, when the time could be better spent working on other parts which don't require special attention.

4.3.1. PSA - Bottleshop

To further explain the concept of a PSA the two pilot cases will be used, first up of these, the bottleshop. In the bottleshop three different processes happen simultaneously, filling oxygen bottles, overhauling oxygen bottles and overhauling smokehoods. Compared to overhauling oxygen bottles the other two processes are relatively simple, so for the example the overhauling oxygen bottles process will be used. First of the PSA of the current, unimproved, state of this process is shown in figure 4.2. The blue arrows represent the different steps in the process, the grey boxes are the touch times in hours, the green boxes are the process times in hours and the orange boxes contain the waiting time in days. As is visible some steps require only touch time, others only waiting time and some both. In the last case it is usually so that a small action is required before it's process time can start.

In the example of shown below the emptying step requires the bottle to be hooked up to a special machine which pumps out all the oxygen. Connecting the bottle to the machine takes only a couple of minutes, but it is time the worker needs to be actually handle the bottle, the pumping out all of the oxygen takes around 75 minutes, but during this time no worker needs to be present.

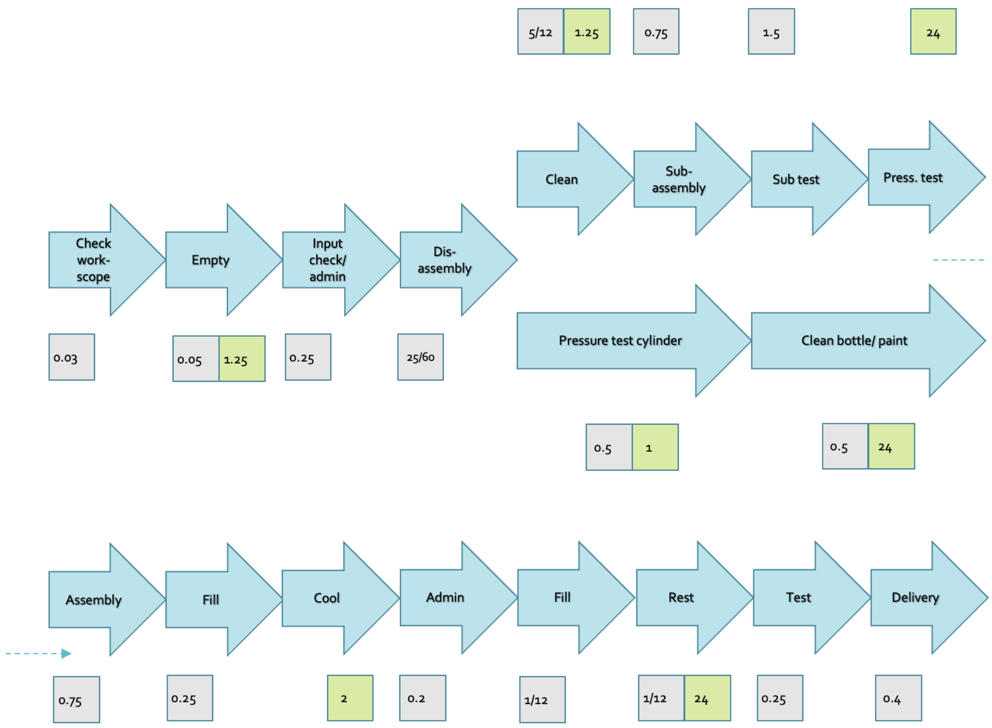

Figure 4.2: The PSA of the bottle overhauling process, in its current state

4.3.2. PSA - Logistics

The second pilot case is the one considering the logistic handling area. Here the PSA is a lot simpler, since there are very few steps required. In fact, in the new automated handling area the worker only really has to perform one step. The PSA does show more steps, like the shipment coming in and the expedition, but since these steps are not performed by the workers of the Logistic centre no touch-, process- or waiting times have been added, since the managers can't control these steps. In Processes as straightforward as logistics it might seem redundant to construct a PSA, however, it still shows whether a process, even if it only consists of one step, is performing sub par. In this example it is clear that the average waiting time of packages waiting to be handled is far too long. While some parts of the model can be very simple for certain processes others can be much more challenging to set up properly. As each process is different it is only logical that some parts of the model apply more to certain processes. This is why the model is built up using different steps.

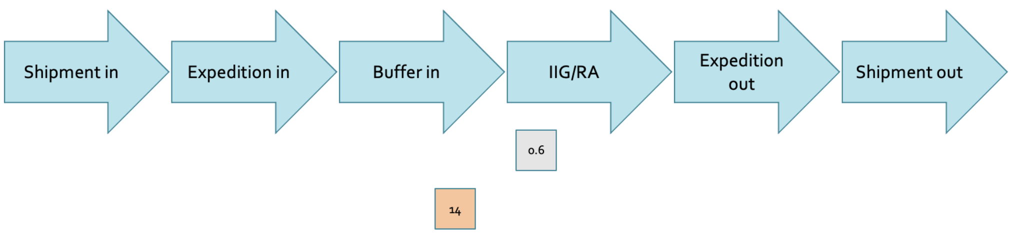

Figure 4.3: The PSA of the logistic process, in its current state

4.4. Manpower plan

When a PSA has been constructed the next part of the model can begin. There is a wrong consensus amongst managers that automation immediately fixes problems, this feeling is especially prominent in places where workers have to work side by side with robots. The fact is that if there are still workers necessary then so is control. For the worker part of the model a manpower plan is used. In this manpower plan part the main focus point is matching the work with the workers. What this means is creating different scenarios which are likely to take place in the foreseeable future. The first scenario should always be the regular process with regular inflow of work. This is the most important scenario as it, by definition, is the one which takes place most often. Having a good plan on how to deal with this scenario thus means that the majority of the time the process can be executed as planned.

Other scenarios can vary but it is advised to include a scenario where less workers are available and one where more work comes in. It might seem that these scenarios are pretty similar since in both there is too much work for the amount of workers, but except for workers there are others things which could be the bottleneck in a process, like the Machines, Method or Materials used. When different scenarios have been chosen they can be constructed. In a scenario a few things are important to know:

- The amount of work coming in
- The amount of workers available
- The skills of the available workers
- Out of control action plan

First of the amount of work coming in. To balance the amount of work coming in with workers it is required to know what the incoming amount of work is. Another required aspect is knowing how much work one worker can process in a shift, and what work should be completed in one shift, or by one worker. If a process spans more than one day these aspects becomes of importance, since it can make sense on paper to split certain parts of the process, but if this is a step which in practice should be performed in one go then splitting won't be beneficial.

Next up there is the amount of workers available. This figure is a lot easier to acquire but should not be copied from the employment form one to one. It is usually not the case that all of the employees on the payroll are actually available for work. There are vacations, sick days and other personal events which result in a lower actual employability. Most companies, or departments have a different percentage which is used as a rule of thumb to calculate the number of available workers from the total number of workers. This percentage is related to the work performed and the environment in which work gets performed.

When an overview of all available workers is constructed it must be enriched with the skills of each worker. Within one process multiple steps are usually required, these steps might require different authorisations. If three workers are planned in to perform a certain step in the process but none of them have the required authorisation the process can't continue. This is where the E2E understanding of the process becomes a big factor, it is impossible to correctly match work and workers if it is unknown which process steps must be performed by which worker.
Lastly there is the Out of Control Action Plan, or OCAP for short. This point might seem like it fell out of sky compared to the previous points, but it is in fact a very important tool. It is used in the event where the work is so gravely mismatched with workers that it has disastrous consequences for the process. In these scenarios it is good to have a plan to fall back on, like being able to make workers come in on the weekend, start working double shifts, or borrowing employees from other departments.

4.4.1. Manpower plan - Bottleshop

In the case of the bottleshop the manpower plan is not extremely difficult, as the shop only consists of four people, making up 3.6 FTE. Furthermore, for the bottleshop it is not the case that they often have to make do with less employees due to vacations or sick leaves. The skill sets of each worker do differ slightly, with one employee still being trained, and two employees waiting to renew their certificates, which did not happen the previous year due to COVID. The incoming work is of course never exactly as predicted, but when looking at a the graph in figure 4.4 it is clear that an average of about sixty orders comes in per week. The current prognosis is that this will stay pretty stable for the coming time. It is up to the manager to decide how to deal with this incoming workflow, designing the process to handle exactly sixty packages per week, or to built in a safety factor and design a process for seventy to eighty orders. Here the choice was made to design the process for sixty orders per week. When this decision is made a manpower plan can be constructed, an example of a manpower plan for the bottleshop is provided in Appendix E.

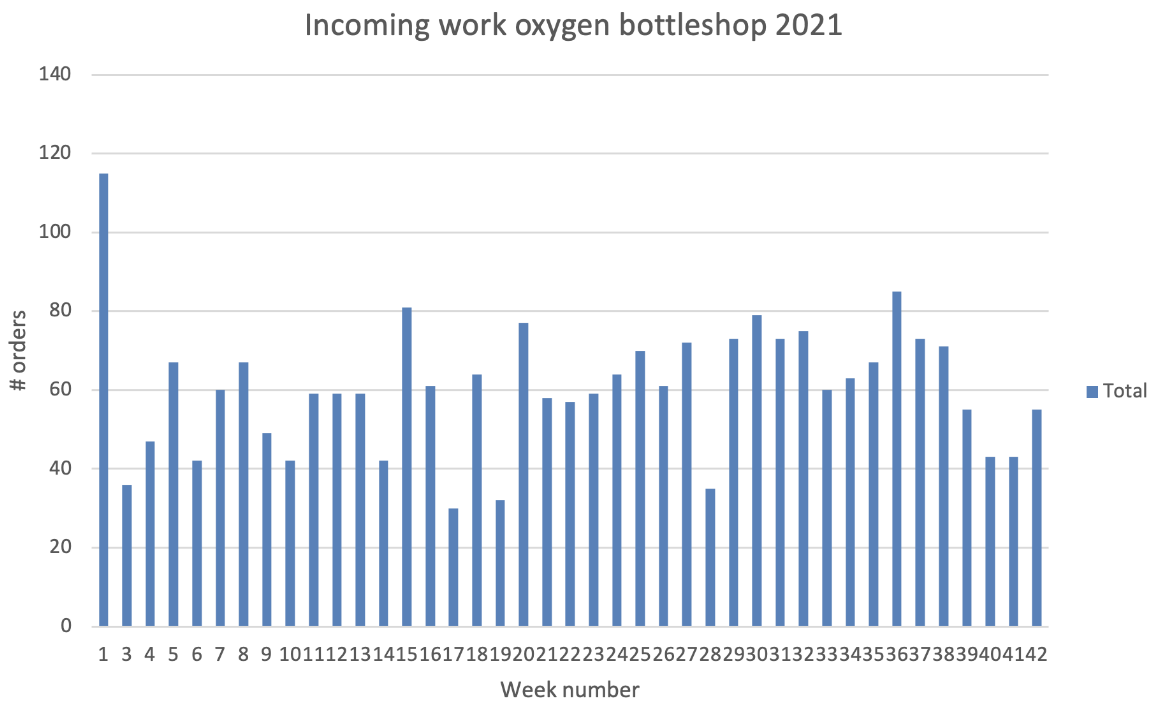

Figure 4.4: The incoming orders in the bottleshop in 2021

4.4.2. Manpower plan - Logistics

Contrary to the PSA, the manpower plan of logistics is somewhat complicated. First of the team is a lot bigger, consisting of 29 people. Furthermore there are three different skill levels, more packages coming in and people still being trained. First of the incoming work, this is as expected somewhat capricious. Due to COVID there has been a drop in work in general, but the forecast for 2022 is that working volumes will be on 77% of the 2019 volume. Since the 2019 incoming volumes are known a forecast can be made which is visible in 4.5

This estimation of incoming work is of course not something which should be used for control on a day to day bases, however, when it is combined with a goal set by higher management it can be a useful tool. The goal which is set for the logistic centre of KLM E&M is a same day handling concept. It is not profitable to try and ensure same day handling every day of the year, but it is also not necessary to. The first milestone is a same day handling of 80%, meaning that 80% of all days same day handling can be achieved. When looking at the forecast for 2022 this results in designing a control strategy which must be capable of handling 65 packages per day. This is because on 80% of all days there arrive 65 packages or less. One important aspect to note is that this does not mean that logistics will have a service level, based on one day, of 80%. Because even on the days that there are more packages coming in than the maximum of 65, there will still be 65 packages handled, with the remaining being handled the next day. When examining the service level it comes out to 96%, when

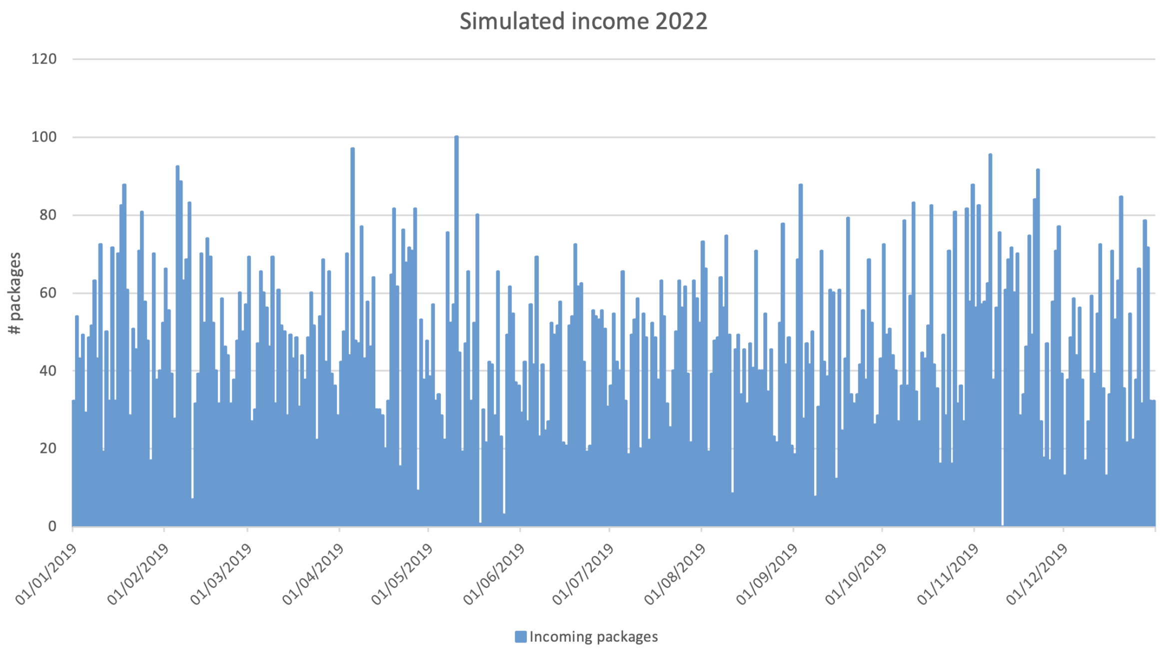

Figure 4.5: Simulated amount of work incoming

aiming at 80% same day handling. This is based on a Last In First Out (LIFO) way of working, since service level is defined as packages which get handled in the set time, earlier defined as same day, it does not matter for the service level whether the other packages have to wait one or ten days to get handled. It is up to the respective managers to decide if they want to handle packages this way, which ensures the highest service level, but some people will have to wait a long time on their package. If there is no rush for this package it might be beneficial to keep the LIFO principle in place. One other aspect of the incoming work which is beneficial to know is the distribution of the incoming work based on the skill level required to handle it. This skill distribution will be elaborated on later in the section.

Now that a general idea about the incoming work is formed the next point can be examined, which is the workers available. As was mentioned earlier there are 29 people on the payroll, however, it is almost never the case that 29 people can actually be used for work. Due to numerous reasons like vacations or sickness only about 70% of the total workforce is actually available, this results in about twenty workers available every week. It is important to match the amount of work and the workers properly, and one more aspect which increases the difficulty of this task for logistics is the fact that packages come in seven days a week, while people only work for five, furthermore packages arrive throughout the day, so there is a need for two different shifts during the day.

Then the skills of the workers coma in to play. The rotable parts of the incoming flow for logistics can be classified into four different skill levels, which from easiest to most difficult rank as the following:

- New buys
- D-orders
- LRU-easy
- LRU-complex

After this is known it can be expanded with the learning period per skill, in this case it's as follows, in around two months a completely new employee can learn to handle the new buys, even though he can now handle these by himself he is not allowed to sign off on parts until he has had a total of six months of experience so after the two months are done training continues with the next first skill being D-orders. These can be handled shortly after new buys as the process is very similar. The new buys do offer a good stepping stool into LRU-easy parts. The training to be able to handle these parts individually takes about nine months, and requires someone training the new employee three days a week. Lastly the training to handle LRU-complex is mostly based on getting more experience and takes around six months, but takes place very individual. When all of these aspects are know a planning can be made looking forward. Such a planning can focus on multiple aspects of the training period but in figure 4.6 one is shown for the available manpower on training days.

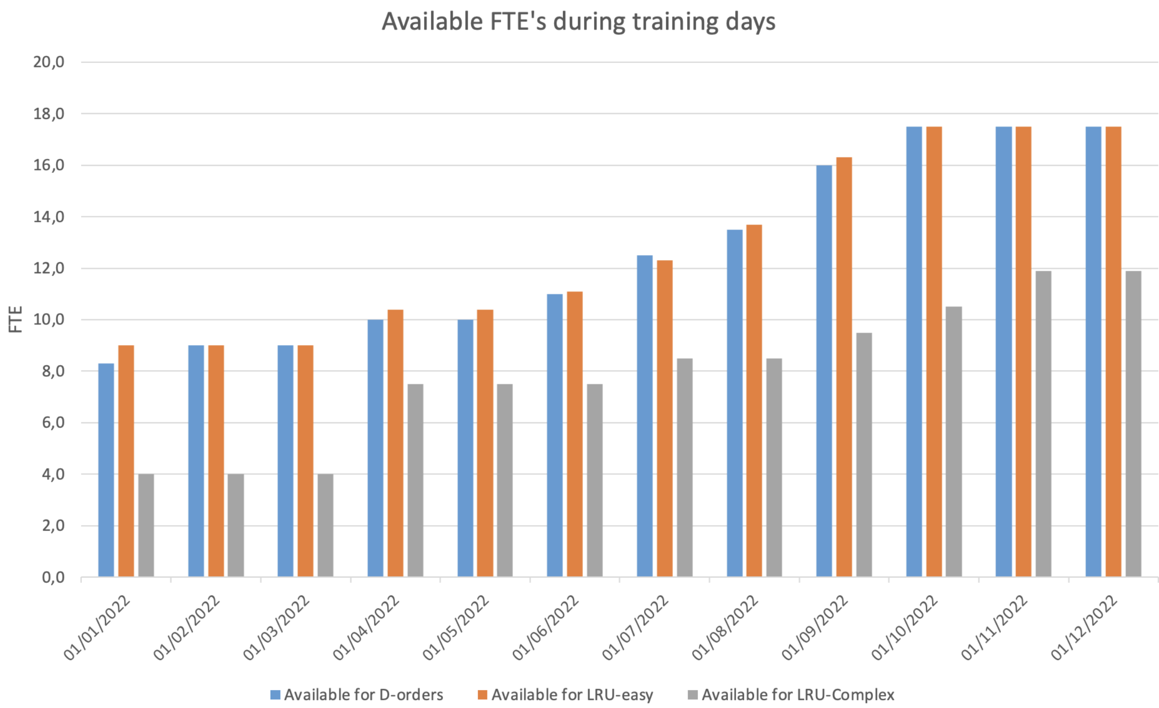

Figure 4.6: The available FTE's per skill on training days for 2022

One last piece of information which is required is the time it takes the worker to complete his task, this information should already be available from the PSA, so no extra effort is needed to figure it out.

When all of the above information is known the scenarios which might occur should be constructed. The first scenario, the one that should occur most of the time, should be the regular flow of operations. In this, and every other scenario it should be looked into how much work comes in per time period, how much workers are needed to complete this work and which skills have to be present. Next up are the out of the ordinary scenarios, which as mentioned can include, but are not limited to: More work coming then is able to be processed, too little workers available or the ratio between different skills incoming is mismatched with the ratio of those skills present. In the case that one of these scenarios occur OCAPs are necessary. In the case of logistics it is difficult to simply hire temporary workers, as they will not be skilled or have the proper licenses to perform the required work. An OCAP could be temporarily calling back workers which have moved to different positions within the company, or to simply work overtime when needed.

4.5. Entrance control

One important aspect of keeping control of the process is to make it run smoothly. If a process has many bottlenecks it will not perform well, nor will it be a nice working environment for the workers. One way to ensure a process will run smoothly, for production as well as for the workers is by using entrance control. Entrance control in this encompasses two different methods for controlling the smoothness with which the process will run. The first focuses on not allowing more into the process than it can handle, the second focuses on not allowing faulty parts to get further in the process than is necessary.

First the focus on not allowing more into the process than the process can handle. This sounds trivial but it is a point which very often gets overlooked, as it is custom to look only at the end of the process for results, and if the results are below expectations then the process itself gets an overview. However, the input of a process is a vital part of how it will perform. Input too much and people can't ever realistically keep up with the required work. Since different workers in a process often perform the same step of the process they are usually not aware of the bottlenecks forming behind them in the process, if more work than usual comes in, but they can still handle it since there process step takes less time they will process all incoming work, clogging the process behind them.

The second form of entrance control focuses on not letting faulty parts further in the system than is necessary. As is mentioned before, it is impossible to filter out all of the faulty parts entering the system without performing time consuming tests. The way faulty products are handled however can be made to better the flow of the process. A phenomenon which often occurs in practice is that workers spent too much time on trying to fix a problem. When a problem is encountered the process should not be halted to force one faulty product into the process, instead, the faulty product should be placed aside to be handled by a separate person or team, ensuring that the worker can continue his normal order of operations.

4.5.1. Entrance control - Bottleshop

For the bottleshop the incoming packages go through the local expedition, which handles the in- and outbound packages for all of the subshops located in the building. From there the packages get wheeled over to the oxygen bottleshop. Only when the packages arrive in the shop will it become clear what comes in, and what actions are required. Since the packages are left at the shop it is difficult not to admit more in to the process than it can handle. It is still important to, even if there are numerous packages waiting to be handled, not allow more into the process than was determined beforehand to be the max. The maximum machine capacity is calculated and shown in table 4.1. As far as the manpower goes it is always a bit less black and white. Based on the average incoming work over the past year the following distribution has been made on what to allow in the process per week: ten oxygen bottle overhauls, forty oxygen bottle fills and fifteen smokehood overhauls. Based purely upon the work in hours per week, about thirty hours worth of work can still be added per week, however in reality this will most likely be less due to processes not perfectly lining up. Since the bottleshop has three main processes it carries out the amount of extra work which can be handled per week differs based on the distribution of the three processes, hence the choice for hours instead of physical work.

Then there is the case of the faulty bottles. When bottles come in they are submitted to an input check to ensure that there is no excessive damage, and that all the necessary information is attached to the bottle. If this is not the case the bottle should be placed elsewhere and a separate team, or a dedicated worker should handle these faulty bottles. The same goes for faults which get found later on in the process, most likely during the overhaul.

4.5.2. Entrance control - Logistics

For the logistics handling area entrance control might seem difficult to enforce, since here all of the packages which get send out by KLM E&M will be handled. However, as was discussed in section 4.4.2 a target for the daily amount of packages to be handled can be set. This target is matched with the amount of workers available. If for a certain day only half of the workers are present, and there are is no OCAP then there should not be more entered into the process than the present workers can handle. This does not mean that if the workers work harder than they normally do they can't continue working on packages after their prescribed intake is finished. It does make sure the workers are not forced to run around all day. Since all packages coming in to the logistic handling area get placed in a buffer before being handled entrance control is somewhat less prevalent here, it is however still important to be aware of the limitations of the process.

Then there is the matter of not allowing faulty packages to get further in the process. Again it might seem that this is not really possible to enforce within the logistic handling area, since in section 4.3.1 it shows there only being one real process step involved in the logistic handling process. In reality however it often occurs that during this one step, which is mostly administration in the used software, there is an error. When this happens workers spend a long time trying to fix said error, when in fact there is a separate team to handle these disruptions, ensuring that the worker can continue working on regular flow.

4.6. Bottleneck Control

As was briefly mentioned in section 4.5 the reason why it is undesirable to push more in to the process than it can handle is because bottlenecks will clog up. Since the entrance control is based on these bottlenecks it is important to keep them up to date. Bottlenecks could take shape or form in any of the previously mentioned 4Ms. But mostly occur in the man or machine form. Since the man bottleneck should arise from the manpower plan the most prominent bottleneck which still has to be handled is the machine. The bottleneck basically encapsulates the capacity of the different machines used in the process combined with the amount of times they have to be used. Even though the material bottleneck occurs less frequently it is important to look into it. Delaying an expensive component because it is waiting for a bolt is undesirable. To combat this an upper limit to part prices should be put into place, all the parts which are below this limit should be readily available, for the parts above this limit the JIT principle should be used in order to avoid unnecessary storage costs. The height of this limit is dependent on the parts and components being repaired and is also a consideration which has to be made by the responsible managers. Lastly when considering the 4M's there is the bottleneck created by using the wrong method, however, since the method used is designed to eliminate bottlenecks this should not be an issue, nor should this create any additional bottlenecks.

4.6.1. Bottleneck check - Bottleshop

The bottleshop is a classic example of a remanufacturing shop in KLM E&M, where each of the 4M's is important to the success of the process. As has already been mentioned the bottleneck related to the available workers (man) has already been covered in the manpower plan, so that will not be handled again. That leaves the machine, material and method bottlenecks. First up the machine bottleneck. To check the machine bottleneck the incoming has to be known, as well as the machine capacity and the time the machine is in use per process step. At the moment the daily incoming products consist of: two bottles which require an overhaul, eight bottles which require to be filled and two or three smokehoods which need an overhaul. For the smokehood overhauling process no machines are used. The bottles which need to be filled require a connection to the oxygen supply, of which there are three. With an average of eight bottles coming in per day the oxygen supply connections are occupied for about an hour every day working on just the filling process. Lastly there is the overhaul process, this process starts with emptying the incoming bottles. The machine used for this process can handle two large bottles at the same time, and takes about an hour to empty completely. When the bottles are empty they get disassembled, and the valves undergo a different treatment than the cylinders. The valves have to get pressure tested, the machine used to do this has a max capacity of eight valves at a time and takes 24 hours to complete. The cylinders also need to get tested, using a hydrostatic pressure test. This machine can only test one cylinder at the time but the operation only takes half an hour, meaning in total fourteen bottles per day can get tested. When both parts have passed their respective test the bottle gets assembled again. The only machine required from this point onward is the oxygen connection, in order to fill the bottles, which as mentioned can handle three bottles at the time and takes fifteen minutes too fill. These results have been summarized in table 4.1. As is visible in the table the incoming work per day is far beneath the maximum capacity of each machine. So there won't be a machine bottleneck in the foreseeable future. The possibility remains that there is a material or method bottleneck, first the material bottleneck. A material bottleneck arises when a process step can't be performed since the required material is not present. As was mentioned in section 4.6 to combat this problem a limit should be put into place until which price parts should always be readily available and in stock. Everything above this limit should confine to the JIT principle. Lastly there is the method bottleneck, but as was also previously mentioned, this bottleneck can not arise when this model is abided, since the method is inherently present in the model.

Table 4.1: Machine occupation for the oxygen bottleshop

	Fill bottles	Empty bottles	Hydro. test	Press. test
Work per day (#)	10	2	2	2
Time consumed (hr)	1	1.25	1	24
Machine capacity (#)	3	2	1	8
Operation duration (hr)	0.25	1.25	0.5	24
Max capable per day* (#)	84	10	14	8

*=Based on 7 available working hours

4.6.2. Bottleneck check - Logistics

The logistic process at KLM E&M currently takes place in two locations, as they handling area is in the middle of moving to its new location. The new location will be in Hangar 14, where a lot of automation tools have been added. Since there is no (re)manufacturing taking place in the logistic process a machine bottleneck is unlikely to happen. All a worker needs in order to complete his work is a desk and a computer. In Hangar 14 there are more than enough desks, all outfitted with a computer, so this bottleneck is nearly impossible to happen. The man bottleneck is solved in the manpower plan part of the model, so this is also not a concern anymore. Then there are the material and method. Since there is no (re)manufacturing taking place the material bottleneck can't exist, so there is no need to further investigate this. That only leaves the method as a possible bottleneck. Since the way operations have to be carried out is regulated there is not much wiggle room in how to perform the task at hand. The biggest method issue arises in cases were there is a mismatch between work and the workers. In this case one of the earlier defined OCAPs must be called into action.

4.7. Target control

Any good control can not be just static, but should be dynamic instead. In order to be a proper dynamic model it is important to look back at the achieved results and compare these with the desired targets. This can be achieved using tactically chosen KPIs. As was already discussed in section 2.6 having too many KPIs is undesirable, plus only a handful were shown to actually be relevant in maintenance environment. Another argument in favor of reducing the amount of KPIs used is the fact that, even though a lot of the processes are automatized, meaning they automatically log every step they take, it still takes a long time to convert the relevant data into clear and useful KPIs. Building such a KPI dashboard showing a lot of different KPIs can easily take months, if not a full year. When processes have to be improved time is usually of the essence, since most managers still abide by the rule that they shouldn't fix what isn't broken, as this is the safe play. If an improvement track is started but no improvement is achieved it could backfire for the manager. It is thus beneficial to only use a small amount of KPIs, since there only are a few KPIs used it becomes increasingly important to choose which KPIs actually matter. The KPIs which were found to be useful by past research on KPIs in the maintenance environment were:

- Occupancy rate Personnel
- Work in Progress
- Production costs per produced hour

These KPIs are based on a regular maintenance environment, but in order to get the full potential out of the KPIs some small altercations must be made to tailor the indicators specifically to the remanufacturing environment. To start, the occupancy rate of the personnel. The occupancy rate is not as important as the amount of work finished per day or week. When a baseline has been set showing how much work one worker on average can complete in a certain time span it is important to check whether this complies with reality. If not, the baseline might be wrong, or there is a problem which impairs the workers in their day to day operations. The amount of completed (on time) work is one of the most important KPI to check whether the shop or department is running without problems. One important note with this is that it might implicit that employee productivity is an indirect important KPI, this however is not the case. Employee productivity should be a by-product of smoother operations. Forcing employees to work faster either results in lower quality work or a bad working environment. Then there is the work in progress. This KPI is very useful but to make it fit into the remanufacturing environment it has to be made a bit more specific. The amount of work in progress should specifically track the work which is waiting, or the backlog. By keeping control over the backlog it is possible to call OCAPs into action whenever necessary. The KPI which focuses on cost is less important in the remanufacturing environment, since most costs get translated to the customer. A third very important KPI is the Turnaround Time (TAT) of a process. The TAT should be the driving force behind the control for any process, so it goes without saying that there should also be a KPI to measure performance regarding this. Using the PSA a desired TAT should be created. This TAT should be designed in a such a way that there is still breathing room for the workers. Then using the KPI this TAT can be evaluated and if necessary adjusted.

Taking these adjustment into consideration the new KPIs are as follows:

- Amount of completed work
- Amount of work in backlog
- Turnaround Time of the process

A new KPI will also be introduced in this model. The Process Quality itself. When checking the literature Process Quality does not seem like it is new in any way, as there are many studies regarding it. However, in these studies the Process Quality is what is referred to as a result KPI, meaning it is the result of other KPIs. As a general rule of thumb, result KPIs don't need to be measured as they can be calculated using other KPIs. In this model it is proposed though to have the Process Quality play a more prominent role, bringing it to the forefront. By doing so the importance of the process quality is emphasized. Process Quality can be measured by looking at the TAT of a process, and how this TAT develops over time. A good quality process will have:

- A TAT close to the theoretical minimum
- A TAT which is very constant
- Nearly no need for OCAPs to achieve this

If these criteria are all matched it shows that the process is running smoothly, and thus that the process quality is high. As long as the resources are not exhausted more work coming in should not destabilize the process quality, if it does the process is not of as high a quality as desired. Even if contractual TAT obligations are being met it can thus still be the case that process quality is low, by having a fluctuating TAT for instance. This should be a trigger for process owners to revise the process, improving where necessary to create the desired lowest stable TAT. In a more general sense it is also important to find out how well a company is underway to creating the best operational environment, regardless of the desired strategy to do so (like lean, six sigma or Process excellence). This will be discussed in section 4.9.

4.7.1. Target control - Bottleshop

As the target control is based on only a few factors it may seem redundant to further explain it using the pilot cases, however, usually processes aren't as simple as they may seem. This is also the case for the target control of the oxygen bottleshop. The amount of completed work and the corresponding TAT is pretty straightforward and the data should easily be reciprocal from SAP, one of the administrative programs used by KLM E&M. The problem for the oxygen bottleshop however arises in the backlog. In the newly designed process, visible in E there is room for fifty bottles a week, if the shop is completely filled and there are another fifty bottles in the backlog this means the oxygen bottleshop will have to outsource repair in order to still meet their contractual TAT. When these bottles get outsourced they won't show in the backlog anymore, but outsourcing does mean the process is not running as intended, and thus needs to change. For the oxygen bottleshop this means that in addition to checking the backlog the amount of outsourced work must also be logged in order to have proper target control.

4.7.2. Target control - Logistics

Then there is the target control for logistics. In the old handling area this would be somewhat more intuitive as the backlog was placed next to the desks, meaning that it would be visible for the workers and the managers, making real time adjustment intuitive. In the new handling area however, the packages automatically get send to the miniload buffer, which is hidden away from the desks. This means that the system must actively be monitored constantly in order to have an idea what is in the backlog. To make matters even more complicated there is still a manual handling area for components which are too large to fit on the conveyor belt, this is located next to the desks and the corresponding backlog is also on the shop floor. However, the managers themselves are not located on the shop floor anymore, meaning they will have to go and check every now and then to get an update on the manual backlog. In order to have proper target control they will thus need a combination of checking in real time and monitoring the system.

4.8. Sustainment of control

An area which is still underrepresented in science is the sustainment of control. When a process is under control it is paramount to keep the newly created grip. If this can be achieved it will create breathing room in the process which gives the process managers room to improve upon their processes. There are two schools of thought regarding sustainment of progress, one which focuses on the short term and one for the long term. For the short term it is important to make sure everyone knows the new way of working by heart and carries it out. This is achieved by the use of check in and outs and shift support. A check in is used prior to the start of the shift, every employee's tasks will be told and if necessary the reasoning behind this will be explained. Especially in the beginning this might be difficult as it can feel intrusive for the employee and his work. Because of this some employees will be hesitant to give the newly designed way of working a try. This is where the support during the shift comes in. In the beginning stages it is important to check in on the employees during the shift, to see if they did not, fall back into habits, but are implementing the new way of working, and if they might have any questions. At the end of a shift it is important to have a check out to see if all the agreed upon work has been finished. If it hasn't the reason why should be documented so it can be acted on in the future. If there was any additional work left at the end of the day this should be incorporated in the next day's check in. In the beginning this process will take quite some time, but after a little while it will become second nature to all parties involved. Then the check in and out will take a few minutes, but it will ensure that everyone keeps working in the agreed upon way.

Then there is the more long term way of sustaining control. A way control over the long term can be supported is by making a clear plan for the future. The way this clear plan can be made is by making a future potential plan. A future potential plan is essentially a business plan which is made more in depth. Not just looking at what a subshop desires to achieve but also how to do so, and thus making a plan for the coming year evaluating different possible scenarios. Not only is the way this future potential plan gets build new in comparison to the traditional business plan, but also where in the organisation it gets created. Traditionally business plans get made at the strategic level of a company, there the new vision and company direction get thought up. The operational level of a company is then tasked with carrying out this new thought of vision, almost exclusively without any further guidance. This can create problems within a company as a misunderstanding is easily created here. Furthermore at the strategic level of a company employees often don't know the full potential hidden in a process. Using the shown model managers can easily find this hidden potential and drastically improve their processes. By having operational level managers create future potential plans for their own shops or departments much more hidden potential can be uncovered, and any mismatches regarding how to carry out the vision of the strategic level managers can be avoided.

When the choice gets made to employ the tactic of having future potential plans drawn up at the operational level of the company the next important question is what they should specifically contain. In general the following points should be included in a future potential plan to make sure all bases are covered:

1. Observation of the shops and insight in the current production that is being achieved, as well as the future goal of this production
2. If service level is not up to standard, how will it get it there?
3. What is used to achieve that production in terms of the 4M's
4. What is the potential of the process with current resources
5. What is the growth potential per resource
6. What is the financial gain of the governed process and the grown process

To explain further, the first point is used as a current state observation and to define the end goal. This is important because it basically encapsulates the start and end point of the improvement procedure. It is also important to denote what the first steps of action should be. If the current process runs at a high enough service level the first actions can immediately focus on improvements, whereas the first steps for a process which runs below the desired service level must focus on getting the process running up to par. The end goal of a process should not just be thought up, but rather follow from an analysis of the process, seeing the potential and then mapping out where in this potential the process should be at what point in time.

Then the second step. This step is only required if the process is performing below the set target. In this step the action plan for getting the process back on track is presented. It is important that the cause of the low service level is known in order to combat it. If the logistic handling area gets taken into account the low service level was explained by the large amount of unskilled workers. So a plan for schooling the new workers will have to be made. Once the workforce is educated and the service level is back above target the improvement procedure can start.

First step three will have to be examined, in this step the current used resources get examined. Most of this information has already been used earlier in the model, to construct a manpower plan and for bottleneck checks. It is necessary to have the used resources clearly visible in a quick overview to look at step four and five. The room still available in the used resources the first area of potential growth for the process. Only when this potential is filled up will new investments make any sense.

When looking at this potential with current resources it is also important to take ancillary matters into account. If growth is needed within two months because a new customer is announced, but this requires some employees to have a higher authorization it is important to check what time getting this authorization takes.

Then there is the growth potential per resource. With this is not meant how much a resource can still grow before it is used up, but rather how the resource can be expanded. If perhaps a new machine is required because the existing one alone is becoming the process bottleneck it is important to check what the delivery time on such a machine is, and what the educational period for the employees is going to be. In the future potential plan the necessities for growth must thus be evaluated very carefully, in order to make sure bottlenecks will not arise when the process is growing.

Lastly the financial gain of the process should be known. First the financial gain for improving the process using just the current resources can be calculated, as this is in a sense free extra profit. After this the financial gain with new resources has to be calculated. Often an operational level manager is not allowed to just buy every new piece of equipment he desires. If using a thorough analysis it is evident that buying the new equipment is the economical sensible thing to do the chance of getting the all clear is much larger, and if the all clear is not given then the manager is not to blame when the process stops growing. When all of these aspects get combined a clear plan for the coming year can be made, once such a plan is constructed it provides a clear and easy to follow direction for the manager to follow.

4.9. Lean maturity model

With the growing interest in different types of Lean manufacturing there is also a rise in ways to check whether a company is truly lean, or at least moving towards being more lean. A model which checks the amount of progress which is made towards being lean is called a lean maturity model. It is important to note that there is no one all encompassing lean maturity model, but it should be tailored more specifically towards the needs and desires of a company. A company can be immature in it's lean journey, or much further and thus mature. An immature company is characterized by unclear definitions of policies, standards and it's goals, which results in employees being unaware of them. Usually work is being done more by individuals than teams and standardization is uncommon. The problem these immature companies face is that the day to day management is busy fighting fires rather than improving the company's foundation.
A mature company on the other hand practices are well defined and acknowledged across all levels of the company. Day to day management is focused on improving practices and keeping everything running smoothly [35]. In such a company continuous improvements are much more realisable

There have been many efforts in order to create such lean maturity models, but one model which stands out since it is fairly applicable for this application is created by Mohammad Ali Maasouman [35]. The developed Lean Maturity model matches well because it is focused on operational level lean maturity. The study by Maasouman was however focused on manufacturing cells, instead of remanufacturing. This is why some changes will have to be made to the designed model. The eventual model gives a more qualitative view of maturity in an organisation.

The first step of creating the Lean Maturity Model is defining the maturity levels. The four levels of lean maturity are defined from least mature to most mature as: Understanding, Implementation, Improvement and Sustainability. These levels have different focus areas and expected results. These levels all have multiple indicators, which have to be met and control items to see if the indicators are met.

4.9.1. Understanding

First of the understanding. Understanding is the basis of lean maturity which is why it applies to the operations the most, this is after all where the improvements come through. The focus at this level is the capability of man, machine and the process in general.

The first indicator at this level is the movement towards a more standardized maintenance routine in the remanufacturing shops. there are three corresponding control items for this indicator which are:

- The amount of maintenance tasks which are already standardized, in relation to the total amount of maintenance tasks
- Standards are explicitly available for processes and remain updated.
- The prepared standards should be of quality, based on clarity, descriptions etc. This can be checked using a checklist shown in Appendix D

The next indicator is the progression of training. This progression of training is set to improve two different aspects of the remanufacturing process. Both the capabilities and skills of the employees and the stability of the used equipment. The stability of machines will be improved because the maintenance will be of a higher level through training of the corresponding mechanics. This indicator also comes with some control items, which are:

- Training on executing maintenance tasks 100% correctly, not just up till working order
- Operators should know maintenance tasks in and out. This includes, but is not limited to, safety points, maintenance points, safe operating limits and control limits.
- Operators should be aware of the types of losses in the process

Thirdly there is the indicator regarding set-up and shutdown procedures. As a part of improving the overall flow of the process it is beneficial to standardise these actions too. Having a routine which workers can follow as a start of their shift and also t end it helps them to start and get in to a flow.

- Which amount of all start-up and shutdown actions have been standardised, based on the total amount. The target is 100%
- The necessary standards for the start-up and shutdown are available, and up to date
- The quality of the standards is up to par, this can be checked by the checklist

Lastly there is the indicator again based on the training of the previous mentioned items. Here that translates to the training of the set-up and shutdown processes in the remanufacturing environment. This ensures the required skills stay sharp in the whole team and when improvements in the procedures get made, the whole team learns these improvements at the same time. Whether this is achieved can be checked by the following control items:

- Training on executing set-up and shutdown tasks 100% correctly, not just starting and shutting down
- Operators should know start-up and shutdown procedures in and out. Not just the order of the to be completed steps, but also what the consequences are of incorrectly performing (the order of) steps and how to fix these consequences

Throughout the past section a checklist has been mentioned numerous times. This checklist has been developed by Maasouman [35] and is available in appendix D.
If a company scores well enough on these indicators it is possible to classify that company as understanding, the next level it can aim for is Implementation.

4.9.2. Implementation

The second level of the Lean Maturity Model is implementation. Once an understanding of the Lean Maturity Model has been realised an implementation can start. Or if a company is evaluated, this is the state corresponding to an implementation of Lean. The implementation level is focused primarily on results and performance. Again there are numerous indicators with corresponding control items.

The first indicator of this second level is the correct execution of the maintenance tasks in the remanufacturing environment, according to all pre-defined standards. It is clear that this a level beyond understanding, where the progression towards a more standardised routine was desired. The control item to check this indicator is:

- The amount of compliance to the pre-defined standards. This is task and standard specific and should be measured accordingly

The second indicator is again focused on meeting the set commitments. But instead of the first indicator the second one emphasises on the scheduling aspect of the maintenance. In order to make sure that the process is not unnecessarily halted predictive maintenance is required. Predictive maintenance looks at the state of the equipment to asses whether maintenance is necessary. Based on the state a machine is in a schedule gets made for the required maintenance [42], since some parts will need maintenance sooner than others. The second indicator is about the fact that the maintenance tasks get completed according to this set schedule. This gets checked quite straightforward by the following control item:

- The amount of maintenance tasks completed on schedule compared to the total amount of completed maintenance tasks

Next up is the third indicator, which concerns itself with anything out of the ordinary, and the detection of these anomalies. At this level it is still the job of the supervisors, team leaders or operating managers to spot anything out of the ordinary in the process. Since it is fair to assume that the standard process is designed in such a way that it would yield the best outcome in the best way, anything out of the ordinary for the process will result in either a worse product or a worse process. Again the control item corresponding with this indicator is quite straightforward:

- The amount of anomalies detected by supervisors, team leaders or operating managers in relation to the total amount of detected anomalies

Lastly for the implementation is the fourth indicator, which is in place to make sure the correct standards will be used in the start-up and shutdown procedures. Here the focus lays specifically in who performed the task, which at this level is aimed at specific people in the team. In the remanufacturing environment there is usually a team leader, who does the same job as the team he leads (he is also a part of this team) but also some extra activities. One of these activities could be the start-up and shutdown of specific pieces of equipment. Once more the control item is as expected:

- The amount of set-up and shutdown actions performed by the team leader in relation to the total amount of start-up and shutdown actions performed

When these four indicators are all matched a company can classify itself as level two on the lean maturity model, or say that lean has been implemented.

4.9.3. Improvement

The improvement level of the Lean Maturity Model is again focused on the results and performance, and just like the previous two levels has its indicators in the same aspects of the remanufacturing environment. The expected result of the implementation level is Efficiency, where the understanding level focused more on achieving effectiveness. As the name suggests this third level of the Lean Maturity Model is focused on upgrading set standards and way of working. There are again four indicators with their own control items.

The first indicator follows in the footsteps of the levels below, and is thus focused on maintenance. In the previous levels standards for maintenance tasks have been established and checked. For the third level the indicator is a little simpler. Namely, whether the previous established maintenance tasks can be improved. When the standards are made up for the first time the environment is not lean nor is it used to having these types of standards, which is why the standards can't immediately be of the highest level. The employees and everyone else working with the standards have to be eased into them. When however, after a while the company is more lean and people are more used to having standards to work with it can be assumed that the standards themselves can become of a higher standard. So in the third level it is important to re-visit older standards and bring them up to the new level. The control item which goes along with this is the following:

- Shortening of maintenance tasks. The standard of the maintenance should always be 100%, but when a company becomes better at performing this task the time do complete it can go down. How much percent this time decreases is a good control for this indicator

After the time improvement of the maintenance task is reviewed the second indicator can be looked into. This indicator is focused on preventive maintenance, as it was in the previous level. As was explained in the previous section the equipment should be checked and according to this check a schedule can be made for when the preventive maintenance is required. If this all goes exactly as planned and predicted than the machine will only be down when scheduled. In the real world it will however sometimes happen that corrective maintenance will be required. Corrective maintenance is the least desired form of maintenance, as it fixes a problem after it occurs, so the machine will be down before the maintenance starts. In an ideal situation there would only be preventive maintenance and no corrective maintenance. This is not realistic though as problems always arise unexpectedly, therefor this indicator looks at the amount of preventive maintenance in relation to corrective maintenance, which is desired to be slanted in the direction of preventive maintenance. It is checked by the following control item:

- The amount of hours spent on maintenance which was scheduled, and thus preventive divided by the amount of hours spent on unscheduled or corrective maintenance, the higher the number, the better

Again, the trend established in the former levels is continued in this one, with the third indicator focusing on the set-up and shutdown procedures. This indicator is similar to the first indicator of this third, or improvement level. The standards for the start-up and shutdown of specific pieces of equipment have been first made when there were no standards about this matter. For that same reason it is very logical to assume that if a company is two levels further in their lean maturation that these standards will be old and outdated. When a company improves in each "leannes", but also its way of working the set standards should grow along with them. As before these standards have a base level of quality which has to be met. It is not an improvement of the standard if the set-up is completed twice as fast, but the machine is now incapable of doing halve the things it used to have no problem with. For that reason the control item for this indicator is:

- Shortening the time spent on set-up and shutdown activities, while keeping the quality of the end product the same. Every bit of time won is only actually an improvement if the quality can be assured

Then lastly there is another indicator focused on the predictive maintenance aspect of the equipment. It has already been discussed in this level that the predictive maintenance should be the main form of maintenance used, with corrective maintenance only being used when necessary, e.g. a machine suddenly breaks down. As mentioned corrective maintenance will always exist since sometimes machines breakdown without a former clue that this would happen. However it might be possible to spot trends in when the corrective maintenance is required. If the instruction manual of a specific piece of equipment states that a part of that machine can take 10000 uses, but it has broken multiple times after 3000 uses than a company should learn from this past data. Apparently the machine, in the way it gets used, goes through that part faster than the manufacturer calculated. Learning from this available past data and using it to improve the preventive maintenance schedule is thus the fourth indicator. This indicator can be checked using the control item:

- The time spent on a specific maintenance task. When a task is carries out for preventive maintenance it should be easier/ quicker than it is for corrective maintenance since nothing has broke yet and the part is in the state which it is expected to be in

As is visible the same aspect keep returning on different levels of the lean maturity model, with slight differences in expectations. When the aspects which have been visited are ready to be improved it is nothing short of logical that the corresponding level of lean maturity is improvement.

4.9.4. Sustainability

Lastly there is one final level in the Lean Maturity Model, which is sustainability. Since the previous level was all about improving to the best possible it only makes sense that the last level focuses on maintaining these improvements. The focus of this level aimed at autonomy and flexibility with the expected level of results being daily excellence, or the best it can be. The indicators for this last level are in the same categories as its predecessor but with a slight twist. However there still are four indicators with respective control items which will be explained below.

The first indicator is again looking at the maintenance side of operations, but this time with a slight twist. For the first time in the Lean Maturity Model the cost of the actions gets considered. In previous levels standards were set, after which it was explained that the quality can't vary much but the time needed to achieve this quality can. When the quality and time needed are already very low there is one important aspect which can possibly still improve, the costs of the operation. If it is very expensive to get the maintenance completed than it should be looked into and where possible made cheaper. This ensures that the operation can be executed even when there might be budget cuts or other financial setbacks. Furthermore it is always beneficial for a company of actions can be made cheaper, while ensuring the same output quality. There are multiple control items which give an insight to this indicator:

- The total amount of hours spent on maintenance work, if this amount could be lower it immediately saves money. It is important to note that this must not come at the cost of the quality
- The cost of remanufacturing not taking place due to a machine being down, when a machine is down it cuts into revenue not being generated
- The cost of the inspection of the equipment. If it is extremely expensive to inspect machines it might be smarter to d it less often. The opposite could also be happen, if it is not that expensive checking more frequently might be economical
- The cost of the used material and parts. This control item is more dependent on technical breakthroughs, however, when these breakthroughs happen they should be adopted as soon as possible.

Then the second indicator, which is again concerned with potential losses and anomalies in the process. However, in the past levels the indicator was focused on the spotting of losses by team members. For the sustainability level it becomes important that losses are not only spotted anymore, but prevented. In order to successfully achieve this there must be a deep understanding of the process and also of the consequences certain actions and events can have. Only when consequences can be predicted is it possible to prevent them. To achieve this there has to be an analysis of previous losses, what caused them and how they could have been prevented. When this analysis has been completed the whole team, or at least the responsible supervisors, team leaders and operating managers should learn from this, knowing how to prevent the same losses in the future. It is also desired to have the team solve problems themselves, in order to promote autonomy. Which is why team members should be encouraged to solve problems themselves. The control item which goes along with this indicator is:

- The amount of losses which the team prevented, or the amount of actions taken in order to prevent losses in relation to the amount of losses which still happened. The lower the number the better

After this there is the third indicator. Again focused on the set-up and shutdown procedures of the process. Once again there is a clear similarity between the third indicator and the first one. Since again the costs get taken up in the equation for this fourth level. The set-up and shutdown procedures are also quality bound, and should at this point be at (almost) the lowest possible time to be performed. Which is why again it is now possible to evaluate the costs associated with the operations. Cheaper options for set-up and shutdown procedures should be explored if it turns out that the current procedures are not economically feasible for a longer term. Since the set-up and shutdown procedures are a little less encompassing than the maintenance procedures there are fewer control items:

- The costs associated with set-up and shutdown procedures in the remanufacturing environment, which should be as low as possible without giving in on quality

Finally there is one last indicator for the sustainability level of the Lean Maturity Model. Which has to do with downtime. In the previous levels the preference for preventive maintenance has been explained. This preference arises from the notion that downtime should be as low as possible. A machine might never break if maintenance is scheduled after each day of it running, but this is not economically feasible, which is why a balance is needed. For sustainment it is important that the trend moves towards less and less downtime of machines, since less downtime leaves more time to earn revenue. This can be achieved in multiple ways. Outsourcing maintenance to a specialist might result in longer intervals between maintenance is required, which in the long term means less downtime. However, such decisions have to be calculated and checked for their possible economical gains or losses. There is one indicator associated with this indicator, which is:

- The time needed between maintenance is going up, or total downtime over a prolonged period of time is going down

Once these indicators are present in an organisation that organisation is well underway to sustaining the improvements made.

4.9.5. Maturity Axes

Next to the maturity levels there also exist somethings which are called the maturity axes. These axes can be thought of as pillars on which the organisation stands. in order for the organisation to be of the highest level of Lean maturity all of the pillars should be of the same length, and at the highest level. The maturity axes come forth from the four M's: Man Machine Method Material, with an additional fifth element being added, the Milieu (or environment). In the Lean Maturity Model this has been altered slightly and expanded, resulting in the following seven axes[35] :

1. People
2. Facilities management
3. Working condition
4. Production processes
5. Quality
6. Just In Time (JIT)
7. Leadership

These seven axes will be explained further in the following sections.

4.9.6. People axis

The first axis which is described in the Lean Maturity Model is the people axis. People are the driving force behind every organisation, so naturally they play an important role in a company's lean maturity. For people to be truly lean in the sense of the lean maturity model they should abide to multiple elements, which are: empowerment, involvement, motivation and team work [35].

Empowerment in this sense means equipping people with the skills and required know how to complete their daily activities in a manner according to the required level of lean. This can be achieved through adequate training of personnel, but this is not the main focus. The focus of such a training should be placed on changing mentality within the workforce by creating a deep understanding of changes which are being made. This means that combined with their respective technical skills people should also have competent social skills which in term aid in making the team work go smoother. Furthermore, it is convenient if some of the people in the team are multi-skilled, meaning they can do other jobs besides their own. Being multi-skilled also aids in personal development of employees, furthering their career.

After the empowerment of people the involvement is a big sub-pillar. As MacDuffie described it [36] operational employees have three different types of work they should be doing. There is the actual completing of your tasks, which is the "doing" work. There is the thinking of how to do and improve upon your work, denoted as the "thinking" work and lastly, there is the social aspect of supporting coworkers which is the "team" work. The involvement aspect of the people axis mainly concerns the "thinking' and "team" work aspects of working. Involved employees, according to MacDuffie, offer a larger number of problem-solving suggestions and actually implement the suggested solutions. They are only in a position to do so if the work enironment is lean enough to allow for such improvements.

Another important element of the people axis is motivation. Motivation sounds like a somewhat straightforward element which is desired for employees to have, but actually achieving employee motivation is one of the more difficult aspects faced in organisations. According to Beale [1] employee motivation is directly related to their attitude, their perceived ability and the social pressures existing in the work environment. A short term solution is to reward employees, but this is not a sustainable option for the long term. Instead companies look in to more enduring solutions, such as presenting the opportunity for further development through learning and training, which will increase a sense of autonomy as well as employee participation. If employees achieve their learning goals this will come with a sense of competence, which will encourage them and their colleagues to keep striving forward. Another aspect which can help employee motivation is praising good achievements. If circumstances were particularly difficult but through working hard and together the workforce finished its task then at least acknowledging this performance is beneficial for moral.

As is already somewhat mentioned in the motivation section team work is another very important element of the people axis. Almost all subsystems in remanufacturing cells are designed based on teamwork which is why it is of great importance that there is actual teamwork within the cells. There should be practices in place which promote teamwork. These practices include, but are not limited to: A check-in before, and a check-out after each shift. Actually discussing possible improvements with the entire team. And setting targets for the team to accomplish.

4.9.7. Facilities management axis

The second axis of interest is the facilities management axis. The term facilities management is somewhat all-encompassing for everything that is needed to maintain production. This includes, but is not limited to: Tools, materials, methods, standards, procedures and activities. To organize all of these aspects the framework of Total Productive Maintenance (TPM) is usually used. This framework was created by Seiichi Nakajima as a part of Toyota's Production system [40]. As a part of TPM Nakajima also came up with a specific KPI, the Overall Equipment Effectiveness (OEE). The reason this particular KPI is very useful is that it combines equipment availability, team performance and output quality, thus creating an all-in-one indicator. For TPM to succeed involvement all across the organisation is required. The operators on the remanufacturing, or operational level do play a more critical role, as they directly influence multiple aspects of the indicator. Nevertheless the organisation as a whole needs to transition towards TPM, and thus better managed facilities. The main idea in having better managed facilities is eliminating down time. There are numerous actions which can aid this process such as:

- Creating understanding of all equipment used throughout the entire team and honing the required knowledge and skills to spot potential failures early on, eliminate their origin and propose maintenance tasks to avoid having the same problems in the future.
- Encourage the whole team to participate in finding and eliminating the wastes in their equipment and promote the solving of these wastes.
- Create a set of daily maintenance activities, which can be easily performed by the operators, these could include, basic cleaning, a general inspection and where necessary fixing the found problems.
- Increasing the collaboration between the dedicated maintenance team and the operations team, to ultimately aid maintenance activities. This could include periodical training for the operational team hosted by the maintenance team.
- Giving the operational team hands-on practice opportunities to hone desired skills without having to stop production
- Documenting the findings and needed know-how for repairing machines so new operational employees can learn how to repair their machines easier and with less errors in the process.

4.9.8. Working condition axis

In the same category as facilities management there is also an axis for working condition. It is clear to anyone that good working conditions lead to better quality of delivered work, under more pleasurable circumstances for the employees, but there is more to it than that. To the most out of the working conditions axis it is split in to two categories, firstly, the working conditions as encountered by the operational team. And secondly the environmental conditions in which the work is executed.

The first aspect of importance is thus the working conditions as experienced by the operational team, henceforth referred to as the safety and ergonomics. Any organisation focuses on employee efficiency and productiveness, but any measures taken to achieve higher productivity must be carefully balanced as to not interfere with the safety and ergonomics experienced by the employee, as this could directly influence their health. So when designing a process it is important to keep the ergonomics an safety in mind. Ergonomics include the way necessary process steps are designed, evaluated and improved, the severeness of the work load, the setting in which the work is performed, the machines and other tools used by the worker and the methods they employ. All of these aspects must be designed in such a way that it is beneficial for the worker his safety and health [18]. To get the best results out of this an ergonomics expert should be brought in, but tools used throughout lean practices can also be of value [22]. Furthermore it is important to get input and feedback from the production team. A few ways to achieve this are:

- Include the design of proper ergonomics in to the lean measures taken
- Every "improvement" which gets applied to the process must be carefully evaluated on whether they hinder safety and/or ergonomics
- Safety and ergonomics should become a part of the basic training new employees receive, this training should also include possible risks which belong to improper safety and ergonomics
- The safety and ergonomics conditions should be actively monitored by the supervisor of a remanufacturing team
- Safety and ergonomics should be seen as crucial parts for an organisation's well being

Next to the safety and ergonomics the environmental conditions also play a big role for working conditions. Nowadays more than ever there is a big emphasis for companies to be "green" and focus on sustainability. One upside for organisations who focus on lean is that leaner companies also tend to be more green to start with. This is a result of, among other things, the elimination of waste [2]. Next to this, severely polluting events should be canceled and employee input for green initiatives should be taken seriously.

4.9.9. Production processes axis

The next axis of importance is the Production processes axis. This axis focuses most on the actual shops performing the remanufacturing. The production process axis calls for standardization of the most value adding component of the entire process, in the case of remanufacturing this means standardizing the repair process in the shop. The benefit of standardizing in the repair process of the shops is that it effects other processes as well, like the safety and ergonomics. The improvement of these aspects, it can be assumed, should be fairly standard, as they will be performed by an outside specialist. Furthermore it is shown that on the job training, as well as continuous improvement get increasingly more difficult when processes are not standardized [35].

Another important aspect which belongs to the production process axis is increasing the process capability through thorough analysis. Uncovering a process its hidden potential is one of the key takeaways from process excellence. It is thus important that supervisor are aware of this theory and its workings. Through the framework of process excellence the process can be analyzed and hidden potential will show in the form of unutilized time in the process, or waiting time. This waiting time gets evaluated to show potential bottlenecks or improvement possibilities, which if implemented will increase the capabilities of the production process, it will not be possible to immediately implement all the steps necessary to realize all the uncovered potential, so continuously evaluating and analyzing the process is necessary for continuous improvement.

4.9.10. Quality axis

After the production processes axis the Quality axis is next in the Lean Manufacturing Model. It is no argument that the quality of the eventual end product is paramount for an organisation, and even more so in the airline MRO business, as faulty parts could have disastrous consequences, which is why it is abundantly clear to anyone involved in the organisation there can be absolutely no skimping in this area. To ensure this quality two aspects are highlighted in the Lean Maturity Model. First of there is the quality control aspect and secondly there is a reactivity aspect. The quality control is a process which ensures the delivered product is up to the required standard. This gets checked by investigating both the key steps in the process and the established quality parameters. If it is observed that key steps of the process are not performed correctly this could lead to faults within the product. Furthermore if the product gets tested after the remanufacturing process and it fails certain criteria it is not "air-worthy" which means it may not be placed in an aircraft. Quality control can either be performed by the operational team, or by a separate quality control team. Furthermore, it is advisable to control quality at the beginning of the process, and with the first remanufactured parts. D. Haak recommends either Statistical Process Control or Entrance Control for this [15].

There is also the reactivity aspect of quality control. This happens when the actual quality control uncovered a fault. When this occurs it is important to, not only fix the uncovered fault, but also try and locate its root cause. If the root cause is human error it is a matter of personal opinion whether the employee needs additional training or whether the mistake was something which happened simply because men is fallible. If the root cause is not human error it means something in the process is inherently flawed, this can be either the method used, the material used or the machines used. It is important for the quality control manager to uncover where the fault lies, and if discovered, to fix this fault.

4.9.11. Just in Time axis

The second to last axis for the Lean Maturity Model is the Just in Time axis. JIT is a well known theory, which like most lean theories was developed by Toyota to avoid their ever growing inventory. Inventory can arise in multiple places of an organisation, for some cases inventory is not very expensive, space taking or a problem in general. However, in most areas of the organisation too much inventory leads to high expenses and when storage capabilities run out it can even clog the process. For successful implementation of JIT it is necessary to have a dedicated material ordering team, since it will be too much work to asses when new materials are needed for the operational manager. For the shops themselves it can be beneficial to focus on creating a continuous flow, as this will result in less inventory being stashed in the shops.

4.9.12. Leadership axis

Lastly for the Lean Maturity Model there is the Leadership axis. Successfully implementing any new company philosophy requires a great effort by the managers, and even from the CEO [27]. Again the axis is split in to two stages. First there is the leadership of the entire company or organisation, performed by the top level managers. Secondly there is the leadership on the operational level, as performed by the shop leaders and operational managers, or, the people actually communicating with the operational workers.

First of there is the top level management. Since these are the people who ultimately make the decision to implement a new way of working it is important that they are actively involved with the implementation of this new way of working. Simply telling the people lower in the organisation that they need to change will not yield good, if any, results. There role is thus expanded, from choosing the strategy needed to fulfill their long term vision, to actively participating and engaging in the implementation of this vision. This can be achieved by attending the training on the shop floor, reviewing activities together with the operational team and cooperating in monitoring progress. Their function thus shifts towards a sort of role model.

Then there are the operational managers. Their roles also significantly change during the implementation of a new way of working. Classically operational managers are very much managing in the moment, especially in an environment where the process is not running as smoothly as it could be. Managers are often busy fighting fires, explaining performance and handling last minute requests. When implementing a new way of working this needs to change. The daily tasks of operational managers shift more towards analyzing the past in order to prepare for the future. Doing this should form a base for their plan to implement the new way of working, and thus changing the culture in his shop. For this implementation to yield the best results it is important that mangers are skilled in both the technical aspects regarding the process as well as skilled as managers. Combining the two should result in a newly designed process, which from a technical point of view runs as smooth as possible, while still being in compliance with all the set visions of higher management. As for the direct leadership of the team it is important that operational managers possess the necessary skills to communicate what is going to change for the team, and what is expected of the team, as well as being able to train the team in the required skills for the new way of working. The operational manager must thus lead the team through the process all the while implementing the new vision.

4.10. Production maturity model

Now that both the remanufacturing process control model has been designed and the lean maturity model has been evaluated it becomes possible to combine the two, which results in a combination of qualitative and quantitative aspects. The two models will not be combined fully, but rather the levels of the maturity model will be coupled to the remanufacturing process control model. When doing this it is possible to see whether implementation is happening as desired, and to see at which level each element of the remanufacturing process control model is. An overview of this production maturity model is provided in figure 4.7. The way the model works is as follows. For each element of the remanufacturing process control model a checklist can be run. This checklist is available in appendix F. Using the checklist the maturity of each aspect can be determined and plotted into the model as shown in figure 4.8. For different stages of the implementation process different levels should be achieved in order not to run into problems. When it is chosen to run the improvement track the first level which should be achieved is of course understanding. Every party involved form the team should understand why the improvement track is being implemented, what every aspects means and how every aspect will be implemented. When understanding on every level is achieved implementation can start. The implementation level is a very important one, as it is absolutely necessary to fully implement the model before any next steps can be taken. This is an area in which many traditional (re)manufacturing organisation fail. They rush to keep improving, never securing past improvements. Before any new improvements should be attempted the old ones must have become the new standard. When implementation has been a success for all elements of the remanufacturing process control model sustainability is thus a natural next step. This is where the production maturity model strays away from the lean maturity model, where improvement is the next step. again with the philosophy being that the current improvement must be sustained before new improvements are attempted. If for all elements of the remanufacturing process control model it can be said to be the new norm only then can the last level, improvement, take place. In the improvement level it is about small tweaks to fully optimize the way of working. If the whole way of working gets changed then it is no longer the improvement level, but rather the understanding level of a whole new improvement track.

Control sustainment				
Target Control				
Bottleneck control				
Entrance control				
Manpower				
PSA				
LEVEL	Understanding	Implementation	Sustainability	Improvement

Figure 4.7: The production maturity model

To illustrate this model further it has been filled in for the current state of the oxygen bottleshop. The bottleshop has been chosen to illustrate the production maturity model since they have started the implementation track for the remanufacturing process control model. As the implementation track has only just begun it is expected that the model will reflect this in the form of low maturity levels. When considering the checklist as provided in appendix F the production maturity as shown in figure 4.8 can be created. In here it quickly becomes visible that not all aspects are on the level of understanding, which means the process is not ready for the implementation level. When all aspects are on the same level the journey towards the next level can be started. This is not to say that it will not happen that some aspects will have evolved faster, and are in levels two up from others. But this should be an exception and not a rule.

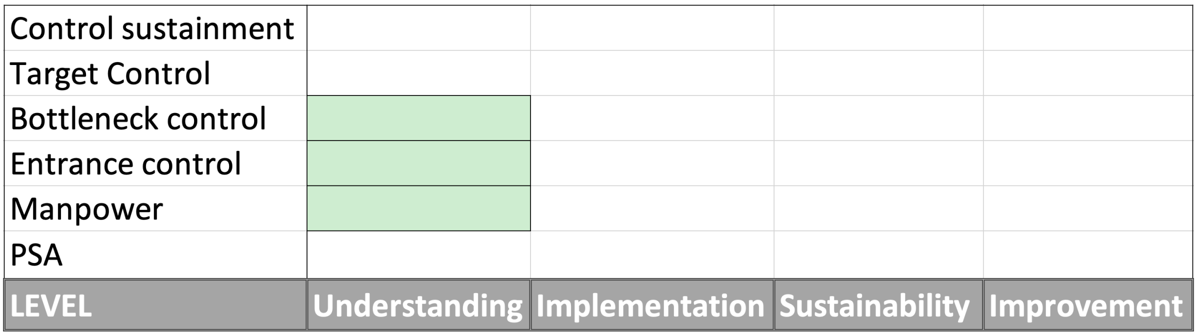

Figure 4.8: The production maturity model filled in for the current state of the oxygen bottleshop

4.11. Conclusion

In this chapter the proposed model has been presented and explained, using the two pilot cases to show an example of how to implement each step of the model. Furthermore this chapter also looked into maturity models, which can help an organisation check how they are faring on their optimisation journey. This was shown based on a lean maturity model, which is comprised of maturity levels and axes. Using the different levels and axes a company can check where they stand and where further improvement is necessary, looking at the next level to see what needs to be done to achieve said improvement. In describing this the chapter also answered two subquestions.

The first subquestion answered in this chapter is: *How can the remanufacturing process control model be designed?* Using the elements which were established in chapter 2 the framework as shown in figure 4.1 can be constructed. The design follows an approach which is based on first constructing the PSA of the process, which then gets used to construct the manpower plan. After this entrance and bottleneck control is used to guide the process. Lastly target control en control sustainment are used to not lose grip over the process. Tying in to this is the second subquestion, which was *How can a company check their progress regarding process optimization?* This can be achieved using the lean maturity model which was elaborated on in 4.9. A lean maturity model defines different levels of maturity, which from worst to best are: Understanding, Implementation, Improvement and Sustainment. The aspects which gets measured against these levels are called the axes, which are seven elements within an organisation which could separately mature. These axes are: People, facilities management, working condition, production processes, quality, just in time, leadership.

If these two separate elements are combined then a model can be formed which aids in getting control, improves a process and sustains control. Using qualitative and quantitative aspects of both models makes it very much all encompassing. When combining the models a framework like in figure 4.7 can be achieved. The way this framework is filled out is explained in appendix F, but it basically sets out to answer a list of questions which should all be answered with yes in order to advance to a new level.

5

Model verification

Now that the model is presented and explained it is time to see whether the model will actually work, and if the model is right. Since there is not enough time to have an actual trial the results will be simulated using Matlab and Simulink. For the verification part of this research both the model will need to be verified as well as the simulation.

This chapter will first go over the model requirements in section 5.1, then the expert verification will be discussed in section 5.2. Next the quantitative verification will be done for the simulation, which is shown in section 5.3. Lastly the chapter will be summarized in section 5.4. In verifying the model as well as the simulation is chapter will answer the following subquestion:

8. How can the proposed model be verified?

5.1. Model requirements

As stated the first step for verifying the model is listing the requirements, or what function the model should fulfill. This has already been touched on in chapter 2 when examining what aspects the model should contain, but as the requirements are concerned the analysis can go further. The following model requirements have been identified:

- **The objective of the model is to get control over a process, only when control is achieved can other benefits be reaped**
  Control over the process is the most important aspect, hence the name control model. The model is designed in such a way that if all steps are followed control over the process is guaranteed, if not the steps have not been performed correctly.
- **Next to gaining control over the process the model should aid in sustaining the control**
  Once control is achieved it is important to keep it, it is after all undesirable to go through the process every six months to regain control. In order to ensure this the last step of the model was added, constructing a plan on how to sustain control, or even, keep improving the process. Having something to work towards gives more purpose and effort to put into the process, making sure the gained control won't be lost, and will most likely improve even further.
- **The model should be general enough to be implemented everywhere, not tailored on the pilot cases**
  Since the model is designed with the idea of wide scale application in mind it must not be tailored to the pilot cases. This was prevented in three steps; first of the literature on which the model is based is taken from a wide range of industries, in order not to be biased towards just one type of process. Secondly the model was finished before applying it to the cases, making sure the general outlines of the model won't be made to fit a certain process. Lastly the two pilot cases were chosen to be very different operations, ensuring that if the same model works on both processes it has to be at least somewhat general.

- **The model must take process limitations in consideration**
A model which simply states buy more machines or hire more employees is not an optimized model. Using the proposed control model would ensure that current resources will be exhausted completely before new resources get added. Furthermore it plans for the future, keeping long delivery times and educational periods in mind. Meaning that when the current resources do get exhausted there won't be a delay in growth.

- **The model must identify the problems which hinder control in the current state**
In order for a process to grow beyond the current lacking state it is necessary to find the main fault in the current process. This is done by the model using the bottleneck check. Using the 4Ms the control model checks what aspect of the process is lacking. Furthermore the model offers support in the form of a framework which aids in gaining grip of the faulty parts of the process.

- **The model should prevent the future process from failing**
If the model works as desired it is imaginable that the process will keep on improving, growing beyond the confines of what the process was previously capable of. It is not unthinkable that in this scenario the control over the process can be lost due to a feeling of being overwhelmed in work. The model intents on fighting this using two strategies; first of, as was already mentioned, a plan will be constructed in which expected growth and the growth the process can handle will be outlined. Next t this there is an entrance control which may not be exceeded, meaning that if the resources including OCAPs are exhausted no new work can be accepted until resources have been expanded, making sure grip over the process is never lost.

5.2. Expert verification

In order to verify or validate the model en additional step is taken, the expert verification. In order to perform the expert verification as best as possible it was done in twofold, first an expert on the field of modelling was consulted and then experts regarding the modelled process were consulted. The first expert checked the model in general, whether no mistakes were made which happened to cancel each other out in other tests, and to check whether the model was not built overly complicated. In this first check the expert determined that the model was build up correctly, and that he could not find any mistakes based purely upon the model itself. This first test did not check whether the model represented reality as closely as possible, for this other experts were consulted who have more knowledge about the process. They checked whether no steps were missing in the simulation, whether no wrong assumptions were made, whether the used parameters were correct and lastly whether the results were realistic. They came to the conclusion that the simulation was accurate and that nor steps were missing. That the assumptions made and the parameters used were correct and most importantly that the results were entirely possible and within reason. Based upon this twofold expert verification the simulation can be said to represent reality closely.

5.3. Simulation verification

Now that the model is verified it is important to also verify the simulation. Verifying the simulation is basically checking if the cause and effect relationships which exist in real life also shine through in the model. This means identifying unmistakable scenarios and simulating them.

The amount of packages generated must coincide with the amount of incoming packages in 2019

Since the year 2019 is being used to verify and validate the model and simulation it is important that the programmed input actually gets generated. Is the sum of all incoming packages in 2019 gets taken it results in: 22736 packages over the whole year. Counting the entities which get generated results in a $22737x1$ matrix. This appears to be one package too much but the matrix starts it count with zero, meaning that the actual amount of packages generated is 22736. This gets supported by checking the number of the last entity created which is 22736.

Input must be equal to output

It is of course elementary that whichever amount of packages get generated at the beginning also have to go out of simulation at the end. This can be checked by plotting and logging the sum of all the entities which get generated at the beginning, and all of the entities which go in to the entity sink, which is the end of the simulation. Doing this results in the following two graphs visible in figures 5.1 & 5.2. In these figures the previous scenario gets proven once more, as is visible in both graphs the amount of points plotted, or packages logged, is 22736.

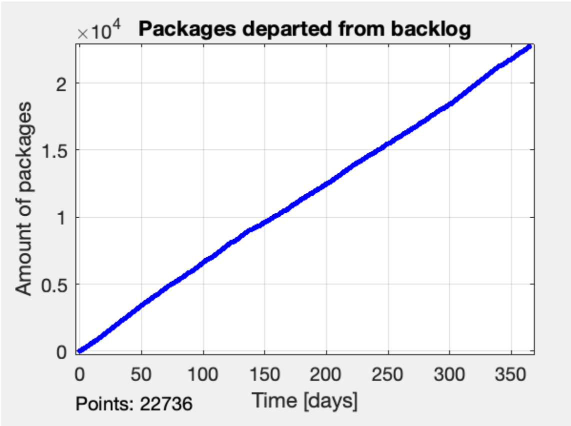

Figure 5.1: Packages at the start of the simulation

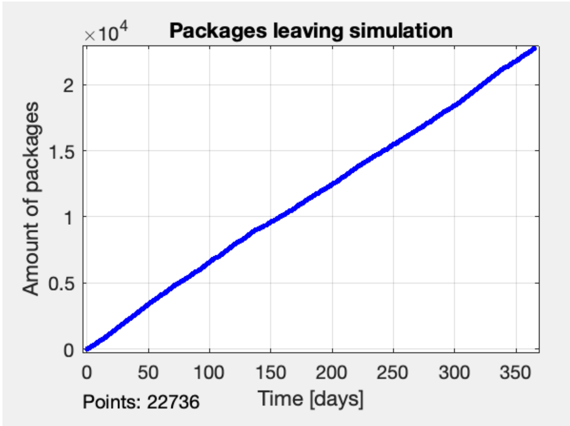

Figure 5.2: Packages leaving the simulation

Without employees the backlog will go up, and no packages can be handled

This might seem trivial, but it is important to check whether the serving blocks won't operate without a server. In order to check this the available FTEs get set to zero, leaving all other parameters the same. If the server blocks won't operate there can be no packages leaving the simulation, furthermore all the 22736 created packages must be waiting to be served. In figure 5.4 it is clearly visible that no packages have been processed, which confirms that without a server packages won't be handled. When looking at figure 5.3 it appears that something is of, since it registered 22744 points. This is however not the case. Since there are eight workstations modeled in the simulation the first eight packages get sent to a workstation to be handled, but since there are no workers present they get sent back until they can be processed. This means that eight of the packages get counted twice, resulting in a sum of all packages which is eight more than the modeled 22736. When checking the entity number of the last package in the backlog this is 22736, meaning that all packages are waiting in the backlog and no more or fewer packages have been generated.

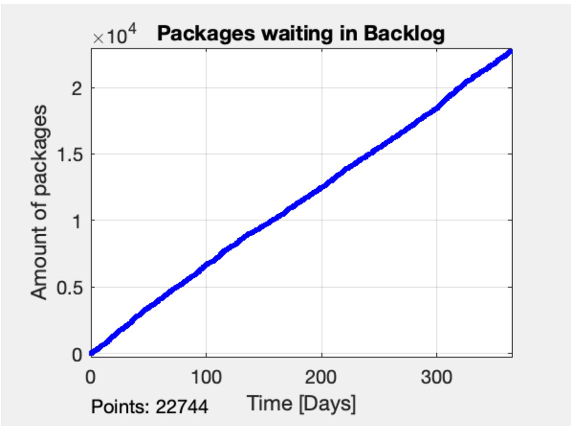

Figure 5.3: Packages in the backlog without employees

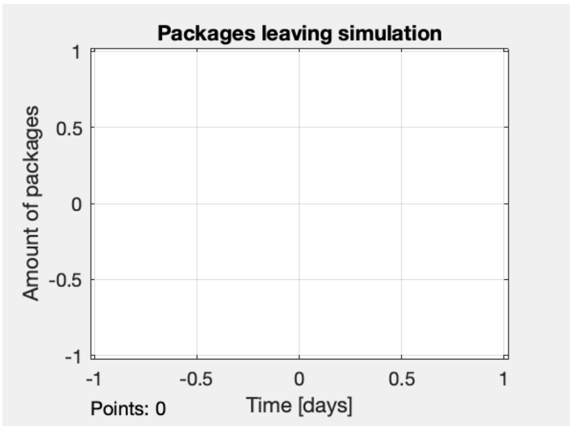

Figure 5.4: Packages leaving the simulation without employees

When there is an abundance of capacity there should be no backlog

In contrast to the previous point it should also be the case that when there is a lot of capacity there should be no backlog. Before this is evaluated it is important to note that the simulation is modelled after the real world scenario as closely as possible. This means that all packages which get generated immediately go into the backlog. In the real world scenario this is also the case. Incoming work gets placed in the backlog from where it gets processed. To check whether no backlog exists thus means to check whether no packages spend more than one day in the process. If there are packages which have a process time of over one day they must have been in the backlog longer than desired. To check this the backlog will be evaluated, since this must go back to zero everyday. Since there are 365 days in the simulation this won't easily show so in addition each package will be timed from the moment it's created until it's terminated. If there are no times above one then there won't have been a backlog. Lastly it is important to first check which capacity is required to not get a backlog. The highest amount of packages which have arrived on one day in 2019 was 130. The amount of packages which can be handled every day depends on the amount of workers and their processing speed, the product of the two should at least be equal to 130. Since the simulation was made with eight workstations, which was the average amount of workers present each day in 2019, the processing speed will be set to: 17 packages per day, since: 130/8= 16.25. Doing this results in the graphs shown in in figures 5.5 & 5.6. As is visible, the backlog goes back to zero everyday, since there are no uncoloured areas at the bottom of the graph. Furthermore as is visible from the timing no package spends more than one day in the simulation. Lastly, as is visible both graphs follow the same outline, which is to be expected. If there are more packages coming in then the last packages being handled will have to wait longer for processing. This results in graphs with similar shapes. All of these aspects mean that the simulation responds to the parameters as it should.

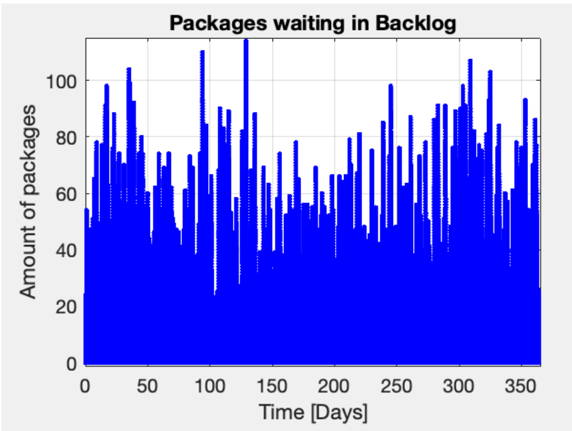

Figure 5.5: Packages in the backlog with abundant capacity

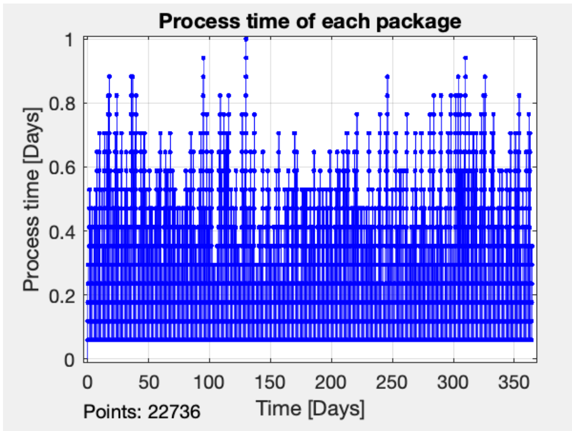

Figure 5.6: The time a package spends in the simulation

There can never be more than eight employees working at the same time

Lastly, since there are only eight working stations there can never be more than eight different employees working at the same time. If this would be the case it would mean that multiple workers would be working at the same station, giving a wrong process time. In order to combat this from happening the amount of available workers get set equal to the amount of available workstations. Nevertheless it is still important to verify whether the simulation can cope with a discrepancy between the two without giving wrong results. To evaluate this the amount of available FTEs gets set at sixteen, which is twice as many as needed, and the utilization of the FTE resource gets plotted. The other parameters get left the same as for the abundance of capacity scenario. Next to the utilization rate the process time will again get plotted, since this must be the same as for the previous scenario. Simulating this results in the graphs shown in figures 5.7 & 5.8. As is visible in the first graph the number of FTEs utilized does not exceed eight, even though there sixteen FTEs available. Furthermore as is visible from the next graph the process time is the same as it was for the previous scenario, where there were only eight FTEs available. This means that even if the amount of FTEs exceeds the amount of workstations it has no impact on the results of the simulation.

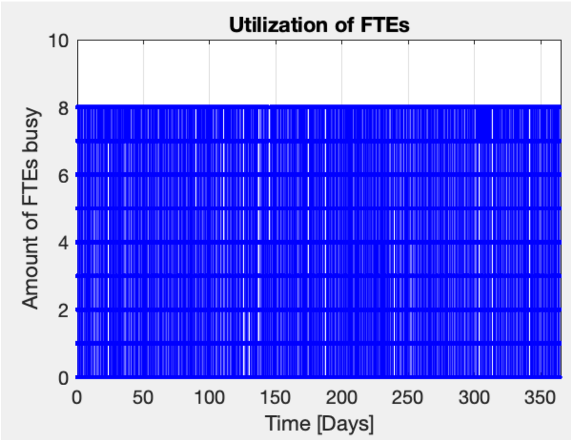

Figure 5.7: Amount of FTEs working

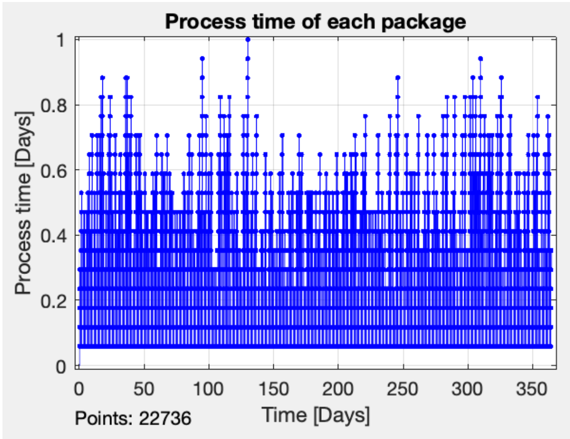

Figure 5.8: The time a package spends in the simulation

5.4. Conclusion

In this chapter the proposed model has been tested using numerous different criteria. First of all the requirements have been presented and checked. When it was determined if and how the model complies with the presented requirements the next step in verifying the model and simulation could be discussed, which was the expert verification. In this check two different groups of experts were consulted to check two things: First of it was checked whether the simulation was modelled correctly, looking purely at how the simulation was constructed. In this test it was concluded that the simulation was built up correctly and no errors are present in the simulation. The second part of the expert verification considered the realism of the simulation, and if it matched reality closely. This was done by checking whether any steps were missing, whether the correct parameters were used and whether results were realistic. It was concluded that for all of these aspects the model was correct. With this the twofold expert verification was complete. With this done the verification process could move on to simulation. Verifying the simulation is done by evaluating cause and effect relations. Five different scenarios were presented which were all individually evaluated. All five scenarios behaved as expected and therefor the simulation passed the verification.

In this chapter the following subquestion was answered: *How can the proposed model be verified?* As was discussed in the previous paragraph the verification process was handled extensively, by first checking the model requirements, then having a twofold expert verification and lastly verifying whether the simulation behaves as expected. Since the model and simulation passed all different aspects it is concluded that the model and simulation are the right ones.

6
Model validation

Now that the model is verified the validation is up next. Validating the model aims to answer the question is it the right model. Since in its most basic form this remanufacturing process control model aims to improve processes through newly found control it will be validated if it actually achieves this. This will be done by comparing future states via a simulation with results from the past. If the future states outperform the past results it can be stated that the model is right.

In this chapter the first thing that will be discussed is the simulation to asses future states, in section 6.1. After this the different possibilities for future states will be evaluated in section 6.2. Next the KPIs which will be used for the validation are discussed in section 6.3. Then the past results against which the futures states will be measured will be explained in section 6.4, after which the results of the simulations will be shown in section 6.5. Lastly the results of the comparison will be discussed in section 6.6 followed by a summary of the chapter and the answer to the following subquestion in section 6.7:

9. How can the proposed model be validated?

6.1. Simulation

Before the scenarios get evaluated the simulation will be explained in more detail. The model is based on the actual process of the logistic handling area, trying to model real life as closely as possible. As a quick recap, the logistic handling area goes as follows: Packages get delivered by an external logistic provider, these packages immediately go to the backlog. From the backlog the packages will be handled if there is a logistic worker who is not busy working on a different package. When the worker finished his task the package will be sent away, and the worker is ready to receive a new package. This in a nutshell encapsulates the logistic process. It is important to note that using this simulation only the quantitative aspects of the model can be tested, e.g. manpower plan and entrance control. The model also uses more qualitative aspects which help sustain control and could improve working rate. This sustainment of control is not measured in this simulation, but it was assumed that control would be in place for the entire duration of the simulation. Furthermore, the possible improvement in working rate has been accounted for in showing the results for a working rate of nine, which it is at now, as well as twelve, which the process is believed to be capable of.

To simulate this process the Simulink package in Matlab has been used. Simulink is a versatile tool which can be used to model an engine or an entire manufacturing facility. In this case Simulink has been used to recreate the logistic handling process. The overview of the simulation is presented in Appendix G. In Simulink for discrete event simulation entities are used. Entities can be used to simulate a wide range of applications. In this simulation the entities represent the physical packages which go through the process. The simulation spans a year, so each time step is defined as a full day, resulting in a simulation of 365 time steps. The incoming packages get generated on each new time step, using the actual amount of packages which arrived in 2019. Then the packages get send to the first in first out queue. This queue is basically the backlog. Packages always go through here, if they can immediately be processed they will, otherwise the packages wait in the queue. From the queue the packages get send to a workstation. In order to distribute the packages over the available workstations an output switch is added in front the workstations. A package of course can't be processed without a logistic worker. Workers are simulated as necessary resources for the server to operate. There is a set amount of workers available in the FTE resource pool. When the package arrives at a working station, modelled as a server block, it calls for a worker, if one as available it goes to the package, processes it, and then gets released again. The path of all packages gets combined again after this and then the packages leave the simulation completing the process and the simulation.

6.2. Future state scenarios

As a validation of the model different estimations for the future states will be presented, these states will all be handled as is dictated by the model. The the outcome of the simulation will be presented and compared to the 2019 results. There are multiple reasons why the year 2019 has been chosen as the base for comparison. First of all it was the last year which was not effected by COVID, showing the process in its purest form, as 2020 and 2021 both had extraordinary circumstances which resulted in unique results which show a distorted picture of the process. Furthermore 2019 is a year where a lot of data of the logistic handling process was recorded. Another important aspect of 2019 is that it was completely before the implementation of the Component Services 2.0 project, which is being implemented as of writing this report.

As a quick recap, the Component Services 2.0, or CS 2.0 project aimed to improve the logistic handling area, as well as move it from its original location in Hangar 10 to a state of the art facility in Hangar 14. This new facility differs from the previous one in the following ways: First of all the packages get send to the desk where an employee is working, eliminating the manual labor aspect of carrying packages to and from the desks where the administrative processes take place. This is achieved by having a conveyor belt running from the miniload buffer, which is where packages get stored, straight to the desks. This conveyor is also connected to the input for newly incoming packages, which get placed on the conveyor belt, automatically get weighed scanned and logged and if no employees are available to immediately handle the package, sent to the miniload buffer. Another benefit of the new handling area is that packages automatically get distributed to the available employees, which eliminates the past problem of favoritism. Favoritism in the previous handling area took the form of people picking only packages which were less intricate to handle, resulting in late shifts always being stuck with more difficult packages and hindering the education of the employees who skip these packages. It might not seem like a big problem that difficult packages get left for the end of the day, but with more difficult packages the risk of IT problems increases, the IT support team however only works day shifts, meaning that the package which are more likely to run into problems have to be handled when there is no support available. This results in these packages having to be placed back and handled the next day, basically meaning that all the work which was performed on the package the previous night was in vain. The miniload buffer could even be programmed to prioritize more difficult packages to prevent this phenomenon even further. Lastly the new location of the logistic handling area is more modern than the hangar the processed used to take place in, meaning working conditions are more comfortable, which also benefits the process.

All of these improvements do create a slightly new way of working, the administrative and controlling steps the employee takes are still the same but there is a little scanning and other small operations which are added to the process. This will result in a slight decline of productivity at first, but an improved productivity later on when all employees are used to the new environment and way of working, experts assume. The CS 2.0 project thus offers a new working environment with more automation than before. However, as already discussed automation without control is no improvement, as the conveyor belt only brings the package to an employee, who still has to complete manual labor and be at the right place at the right time. In 2019 no specific control model was used, as there were non readily available. In the following sections there will thus be a comparison on the projected performance of the logistic handling area in 2022 and the performance in 2019, if the model performs as desired than the performance should have improved. This will be evaluated by checking three different KPIs which will be examined in the next section.

6.3. Key Performance Indicators for evaluation

In the following section the chosen KPIs will be explained in more detail, the first KPI is the TAT of the process. The TAT of the process is one of the most important aspects of the real life process. KLM E&M has set out an ambition to have same day handling in the logistic handling area. This of course is more nuanced than just processing each and every package the same day, but it does boil down to TAT being used as an important ingredient for process evaluation. One problem using TAT is that it has never been measured in the past at the logistic handling area, so it is impossible to compare to real world data. Despite this there have been expert estimations regarding the average TAT for a package in the logistic handling area, this has been determined to be around twelve days.

It is however still a very important outcome of the simulation for the future state. Since it must be around one day. Having the TAT never exceed one is also not the desirable outcome of the model, since there is an optimal point between workers present and TAT. Always having an abundance of workers present just in case an abnormal amount of packages come in is obviously not the optimal state of the process, hence it is logical that sometimes there will be a backlog, resulting in a somewhat longer TAT.

TAT can't be compared to the real world case, however, in a scenario with constant occupation the TAT is closely related to the backlog, since a larger backlog will result in a longer TAT. Luckily the backlog has been tracked over the past years. Hence the second KPI which will be evaluated is the backlog. If the backlog rises beyond control it means that the model is not performing as desired. However, if there is no to little backlog formation this does not automatically mean the model is performing as it should, since there could very well be an abundance of workers present. To check if this is not the case the last KPI is used.

Lastly it is important to check the FTE utilization rate. If it shows that FTEs have nothing to do for half a day or are constantly working and still not able to handle all packages there is a mismatch between incoming work and workers, meaning the model did not produce the desired result. This is easily checked in the simulation as the FTEs are modelled as necessary resource for the process. If there are more than eight packages coming in all work stations will be occupied, and thus all workers who could be utilized at that moment will be utilized. This might give the distorted image that whichever number of workstations are present is also the number of workers which need to be present. This is however not the case. What needs to be checked is whether the backlog rises beyond control, and whether FTEs are busy the entire day, or only part of it. If the FTEs are only busy for half of the day then there are too many FTEs present. However, if the FTEs are busy all day and there is still a backlog originating then the number of FTEs is too low.

6.4. Base comparison 2019

Before the future states can be evaluated it is important to know what the baseline is, or in other terms, what the performance regarding the three chosen KPIs was in 2019. The first of the three KPIs is also the most difficult to evaluate, namely the TAT for the process. As was already mentioned, to this day there is no data available regarding the TAT of the packages in the logistic handling area. When CS 2.0 is fully implemented this data will finally be available, but until that time the best alternative is expert estimations. These estimations are based on the average TAT in a system which has to prioritize packages. This prioritisation happens due to the fact that same day handling can't be achieved, some parts need to be handled immediately since there is literally an airplane on the ground waiting for the part. Such a part will then be prioritized over a part which has to go to an external client, meaning that some parts wait a month to be shipped since priorities kept coming in. In a future state where same day handling can be achieved prioritization will have a gravely reduced impact on the process, as most days everything will be handled anyway. Since this is the case for the future states it would be unfair to compare the twelve days TAT with the future state, so the theoretical longest TAT will be determined by simulating the 2019 process if occupation were constant and FIFO would be used. When simulating this the graph shown in figure 6.1 is generated. In this graph the TAT of each package is plotted. As is visible the longest theoretical TAT in 2019 would have been just under five days for some packages. Again it is important to note that this is based on a FIFO system, which is why in real life some packages drastically exceed this theoretical nine day maximum due to priorities coming in.

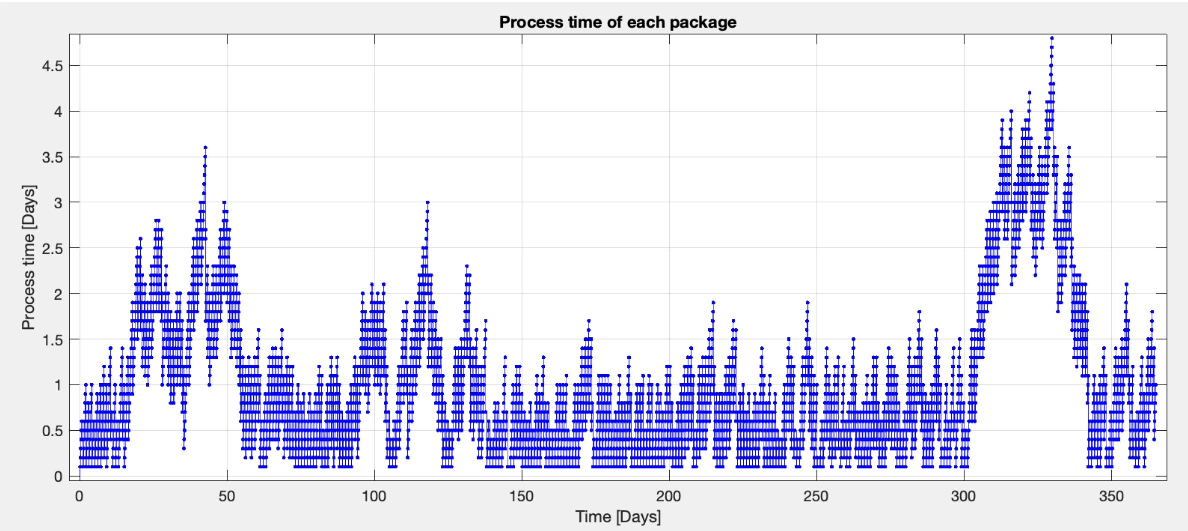

Figure 6.1: The theoretical longest TAT based on the averages in 2019

Next up is the backlog which formed over the course of the year. The backlog was counted everyday so this figure is more precise. One aspect to note is that the counting did not always take place at the same time during the day, so if the count happens just after a shipment comes in it will show a higher backlog figure than if the count happens at the end of a shift. One aspect which somewhat counterbalances this is the fact that packages do keep coming in throughout the day, dampening the error in the count. In figure 6.2 the graph showing the backlog throughout the year is shown. As is visible especially at the start of the year there were problems with getting the backlog under control. It is logical that once a backlog forms it much harder to get rid of it. This is because the packages which can not get processed have to be handled the next day, meaning some packages of that day have to wait longer to be handled and so on. The most important conclusion which can be drawn from this graph is that a backlog kept reoccurring, and when it did it usually took quite a long time to get the backlog under control again. Furthermore getting the backlog under control was more often than not a result of less new work coming in for a sustained period than it was due to efforts made in reducing the backlog. In a more ideal situation, where there is actual control over the process it is desired to not be reliable on external factors in order to get a grip of ones own process. This is why in the remanufacturing process control model OCAPs are defined. One figure which can be used to compare the past state with the future state is the backlog streak. With this is meant the longest streak of days where it is not possible the process all incoming packages. Since it was never kept track of which packages were in the backlog it is difficult to relate this to the actual data, but when looking at the simulated results of 2019 the longest backlog streak showed to be 46 days. This does not necessarily mean that the performance of the process is bad, but is does show that there is a mismatch between incoming work and available workers. One other figure which is known and can be compared to the simulations is the maximum amount of packages in the backlog. As is visible from the backlog graph in figure 6.2 this was 385 packages. It is of course unfair to compare the backlog formation with different input, as input automatically goes to the backlog. To combat this a backlog percentage is calculated which will be:

$$\text{Backlog percentage} = \frac{\textit{Highest amount of packages in backlog}}{\textit{Highest number of packages which came in}} * 100 \tag{6.1}$$

This figure can not be lower than one hundred percent. If the figure is closer to one hundred percent the process performs better, in the regard of the backlog. For the base comparison of 2019 the highest amount of packages which cam in on one day was 130. The highest amount of packages in the backlog was 385. This gives a backlog percent of 214%. These figures combined show the capacity of the process to deal with a possible backlog.

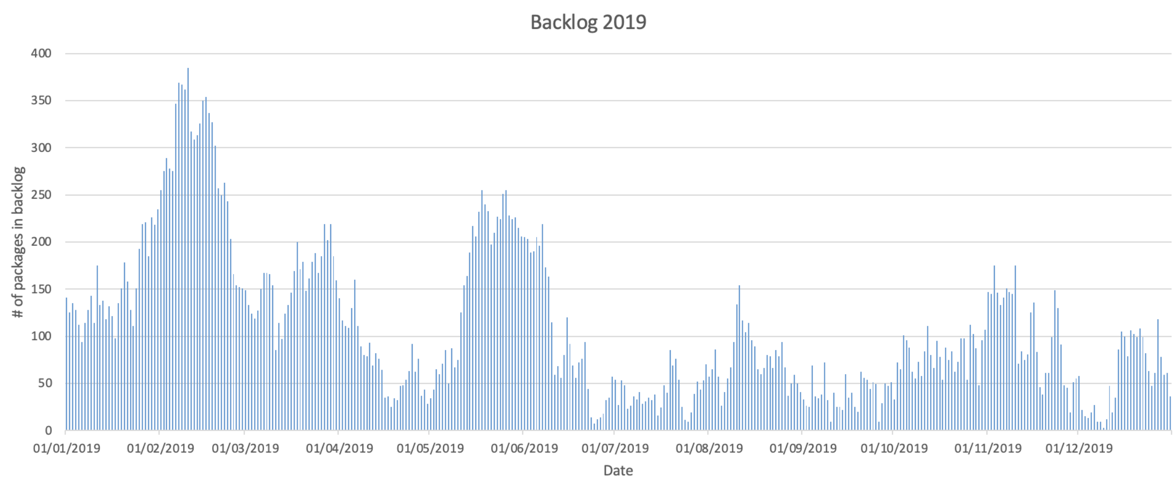

Figure 6.2: The true backlog in 2019

Last up there is the FTE utilization rate. As previously mentioned this is an important figure to check whether the amount of FTEs is somewhat coherent with the amount of work coming in. It is impossible to know exactly how much work is going to come in, so rather than try and plan based on predictions it is desired to have a set figure of workers who should always be available, this set figure is up to the managers to decide. For the logistic handling area it is desired to be around 80% or 90% same day handling capacity, meaning with that amount of workers 80% or 90% of all the days in a year all incoming work could be handled the same day. When looking at the graph of all FTEs present the figure in 6.3 can be constructed. The first thing noticeable is the capricious nature of the graph. In a more ideal situation as mentioned earlier it is desired to have a very constant amount of FTEs present. The only possible exception to this is if there is a so called "weekend-effect". A weekend-effect is used as a term to indicate less packages coming in because it is weekend. When looking at the data of the past years a weekend-effect is not as visible every year. In 2019 for instance there was little weekend-effect visible in the amount of incoming work. So even more so than in other years, the amount of FTEs present should be constant. One other thing which can be deducted from the graph is the average amount of workers present in 2019, which was 7.3 FTE. If the 80% same day handling concept gets taken for 2019 it is easy to calculate how many FTEs on average should have been present. In 2019 80% of all days 84 or less packages came in, taking the average amount of packages which one FTE handles in one shift as nine, which has been the average for the past years, the amount of FTEs which should have been present is actually 9.3. This means that on average in 2019 there two FTEs too little every day, which explains the difficulty faced in controlling the backlog. The utilization rate of the FTE's in real life is very close to 100% as people rarely get send home because there is no work for them. As was already explained however, a high or low utilization rate on its own does not say much, it has to be combined with the figures of the backlog and TAT. Both of these figures were high in 2019, combined with the high utilization rate this means that the process did not run smoothly, nor did it perform well. To be able to make a comparison the simulation is used in order to generate the FTE utilization rate. This showed to be 90%, which is in line with expectations of it being very high. When taking past research into account it was shown by [15] that ideally a process should not be filled over 80% of the capacity of its lowest bottleneck for production. In the case of the logistic handling area the bottleneck is the amount of FTEs, so ideally the utilization does not exceed 80%.

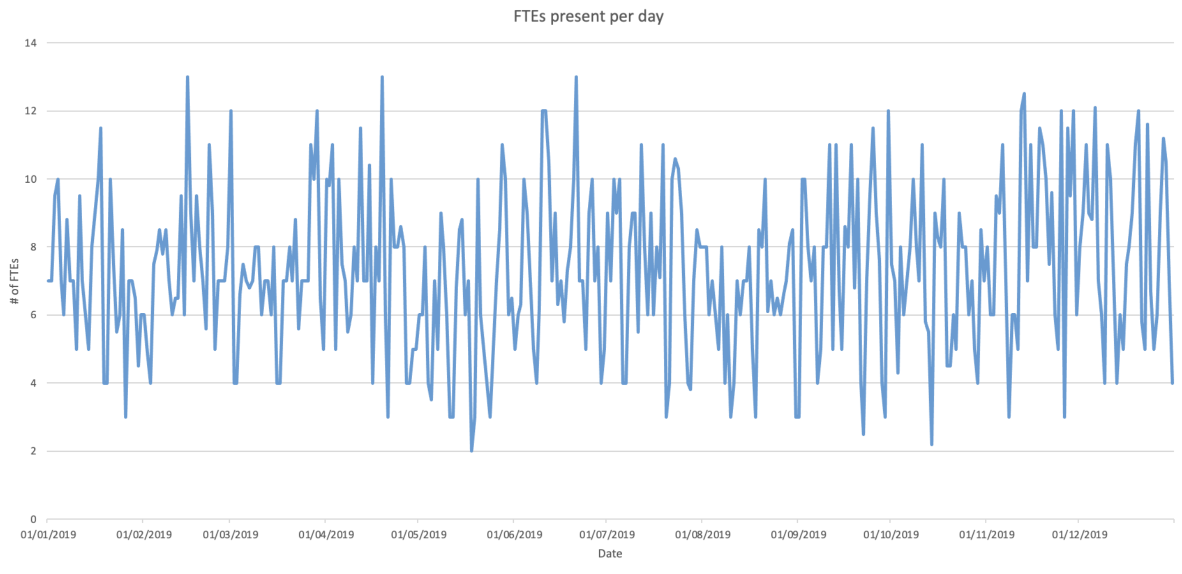

Figure 6.3: The number of FTEs present in 2019

One other aspect which will be evaluated is the achieved service level of the process over an entire year. This is is not evaluated as a KPI as such, since it follows from the performance of the backlog and TAT KPIs. Nevertheless it is one the most used figures within KLM E&M to asses the performance of a process. As there is no data available on the TAT of the past process the service level is also not known. Hence it will also be determined by using the simulation. The service level can simply be calculated by the following equation

$$\text{Service level} = \frac{\textit{Amount of packages with TAT =<1}}{\textit{Total amount of packages}} * 100 \tag{6.2}$$

Using the data of the simulation for the 2019 state it showed that of the 22737 packages handled that year, 13788 had a TAT equal to or lower than one, resulting in a service level of 60.6%. This is a realistic figure, as in practice most uncontrolled processes seem to converge to a service level between 50% and 60%.

To summarize, there are a few important takeaways necessary for the comparison of the uncontrolled state and the future, controlled state. First of is the TAT of the process. For the comparison of these figures the theoretical TAT of the process is taken, since no real world data on the TAT is available. To get to this figure all the real world parameters of the process have been used as the input for the simulation, since the parameters for the future state will be based on the designed remanufacturing process control model the comparison will show if there is improvement measurable. The longest theoretical TAT of 2019 was simulated to be just under five days. Secondly there was the formation of a backlog. In 2019 it was visible that there were problems controlling the formation of a backlog. It is expected that a backlog forms a couple of times per year, since this ensures that there is not an abundance of FTEs present. However, the duration of such a backlog, and thus the TAT of the process may not exceed a certain upper limit. The longest backlog streak for 2019 was simulated to be 46 days, with a max peak in the amount of packages of 385. lastly there is the FTE utilization rate. This figure is important to check whether the balance between incoming work and workers is as desired. One solution for preventing a backlog and ensuring same day handling is to just have more workers present, but this obviously is economically not a desired solution. It must thus be checked whether the amount of FTEs is right for the amount of work coming in, which is done by looking if the utilization does not exceed 80%, while also not getting too low. For the 2019 state the utilization rate showed to be 90%. These results have all been summarized in table 6.1.

Table 6.1: The figures for the 2019 uncontrolled process

The figures of the uncontrolled process in 2019	
Longest backlog streak	46 Days
Maximum packages in backlog	385
Longest TAT	4.8 Days
FTE utilization rate	90%

6.5. Future state evaluation

Now that the base comparison is evaluated the future state simulations can be run. Since it is a future state there are unknown parameters, such as the incoming work. This is why multiple different scenarios will be evaluated. There are expert estimations on the expected amount of incoming work for 2022. This has been set at 77% of the incoming work of 2019. This estimation, even though based on a thorough market analysis, is just that, an estimation. This is why multiple different states will be evaluated. First of the expected 77% of the incoming packages of 2019. Secondly, the exact amount of incoming work as came in in 2019 will be used. Lastly, 120% of the incoming work of 2019 will be taken. All of these different amounts of work will be evaluated for both 80% and 90% same day handling. Lastly, it is the hypothesis that the added control over the process combined with the new facility will increase the amount of packages which one worker can handle during one shift. The estimation is that the amount of packages handled will increase from an average of nine to an average of twelve. So for all scenarios both the old working rate and the expected new working rate will be used. All the other parameters follow from remanufacturing process control model.

6.5.1. Scenario 1 - 77% input

The first scenario to be evaluated is the expert estimated real input of 2022. This is taken to be 77% of the input of 2019. To evaluate the model first the required manpower is calculated. In this scenario 80% of the days 64 or less packages came in. Taking a working rate of nine packages gives an occupation of just over seven workers per day, if the working rate gets increased to twelve there are only a little over five workers required. For the 90% same day handling concept the amount of packages which need to be processed becomes 72. With a working rate of nine packages per worker per shift there are eight workers required every day, and with a working rate of twelve packages per worker per shift six workers are required. These parameters have been summarized in table 6.2. Lastly the highest amount of packages generated on one day in this scenario is one hundred.

Table 6.2: An overview of the input parameters for scenario 1 of the simulation

Percentage Same day Handling	Working rate per employee	Amount of packages necessary	Amount of workers necessary
80%	9	64	7
90%	9	72	8
80%	12	64	5
90%	12	72	6

The full results of the simulation will be shown in appendix G, but a summary of each scenario will be provided in the following sections. First up is the scenario evaluating a combination of workers for 80% same day handling with a working rate of nine packages per shift, the results of which are shown in table 6.3. As is visible all of the figures are very promising, showing an improvement on every KPI. When evaluating the data it shows a service level of 88.5% and a backlog percentage of 140%.

Table 6.3: The results of the simulation with 80% same day handling and a working rate of 9

80% same day handling with working rate 9	
Longest backlog streak	12 Days
Maximum packages in backlog	140
Longest TAT	2.3 Days
FTE utilization rate	78%

The next scenario to be evaluated is with the same working rate but with a desired same day handling of 90%. To achieve this eight workers are required everyday. It is to be expected that the longest backlog streak is lower than it was in the previous scenario, as well as the longest TAT. The utilization rate should also be lower, as there now are more FTEs present for the same amount of incoming work. These expectations are matched by the reality, as is visible in table 6.4. Since there is a perfect match between the required workers for 90% same day handling it is expected that this variation will perform as one of the best of scenario 1. In this case the service level is up to 96.9% and the backlog percentage is 103%.

Table 6.4: The results of the simulation with 90% same day handling and a working rate of 9

90% same day handling with working rate 9	
Longest backlog streak	5 Days
Maximum packages in backlog	103
Longest TAT	1.6 Days
FTE utilization rate	68%

Then the scenario which also takes the future state's improved work rate into account is looked at. First off again with a same day handling concept of 80%. This is expected to perform the worst, as actually there are 5.33 FTEs required. Missing that one third FTE will have the largest effect here since the working rate is highest. When looking at the results in table 6.5 this is also evident. Resulting in the longest backlog streak, the highest TAT and the highest utilization rate. One thing to note is that this scenario still well out performs the real life figures of 2019. The service level in this variation is still up to 82.3% and the backlog percentage is 157%.

Table 6.5: The results of the simulation with 80% same day handling and a working rate of 12

80% same day handling with working rate 12	
Longest backlog streak	21 Days
Maximum packages in backlog	157
Longest TAT	2.8 Days
FTE utilization rate	82%

The last scenario of the 77% input is based on 90% same day handling with an improved working rate. Since this scenario had a perfect match between the required workers for 90% same day handling it is expected that this scenario will perform the best of all, alongside the second variation of scenario 1, which also had a perfect match. Since it should not matter whether eight people handle nine packages per shift or six people handle twelve packages per shift it is expected that these results match those of the second variation. When looking at the results in table 6.6 this expectation is verified showing the same results for both simulations. As is to be expected the service level of the last variation matches that of the second variation, at 96.9% and the backlog percentage is 105%

Table 6.6: The results of the simulation with 90% same day handling and a working rate of 12

90% same day handling with working rate 12	
Longest backlog streak	5 Days
Maximum packages in backlog	105
Longest TAT	1.6 Days
FTE utilization rate	68%

6.5.2. Scenario 2 - 100% input

The next scenario for a possible future state is set to be the same amount of input as was handled in 2019. Again it is important to calculate the required manpower for all the variations of this scenario. First of calculating the amount of packages which needs be able to processed for the 80% and 90% same day handling principle. In the case of 80% same day handling the maximum amount of packages which need to be handled is 84. When considering a working rate of nine this amounts to 9.3 FTEs necessary every day. If the future state working rate of twelve is considered this amounts to seven FTEs. For 90% same day handling the amount of packages which need to be processed per day is 94. When looking at the old working rate this amounts to 10.4 FTEs. The future state working rate would boil down to 7.8 FTEs being necessary. These findings have been summarized in table 6.7 below. One important aspect which gets shown in this example is the imperfect nature of the real world. When considering the variation of scenario consisting of 90% same day handling and a working rate of nine the models shows 10.4 FTEs are required. In this case a manager has to decide how to act, either only use ten FTEs and have a service level which is a little lower, use eleven and be a little over staffed or have one FTE work half days resulting in 10.4 FTEs. For the simulation the worst case scenario gets taken, so 10.4 gets rounded down to ten. Lastly, the highest input is 130.

Table 6.7: An overview of the input parameters for scenario 2 of the simulation

Percentage Same day Handling	Working rate per employee	Amount of packages necessary	Amount of workers necessary
80%	9	84	9
90%	9	94	10
80%	12	84	7
90%	12	94	8

The first variation of the second scenario is again based on a same day handling concept of 80% and a working rate of nine. With only 9 FTEs present there is a slight deficit in to the actual 80% same day handling. Again though the expectation is that the results will still outperform any results of 2019. When looking at the results in table 6.8 this hypothesis proves true. Furthermore, since there are only nine FTEs in the simulation where there should be 9.3 according to the model the FTE utilization rate is expected to be higher than in other simulations. Again this expectation matches reality. If the data gets evaluated further this variation of the second scenario results in a service level of 88.1% and a backlog percentage of 138%.

Table 6.8: The results of the second simulation with 80% same day handling and a working rate of 9

80% same day handling with working rate 9	
Longest backlog streak	12 Days
Maximum packages in backlog	179
Longest TAT	2.44 Days
FTE utilization rate	78%

The second variation for the second scenario is again based on a working rate of nine, but now combined with a same day handling concept of 90%. Again this results in a little more FTEs required, 10.4, than there actually modelled, which are ten. However, since there are more FTEs working on the same amount of input the utilization rate should be lower than in the previous variation. If the results in table 6.9 are considered this confirms the expectation, as the utilization rate is 8% lower. Furthermore the Backlog streak and TAT have also decreased, again in line with what is to be expected. When looking at the service level of this variation it has increased to 95.6% and the backlog percentage is 111%.

Table 6.9: The results of the second simulation with 90% same day handling and a working rate of 9

90% same day handling with working rate 9	
Longest backlog streak	5 Days
Maximum packages in backlog	144
Longest TAT	1.78 Days
FTE utilization rate	70%

The next variation is the first one of the second scenario where the working rate is increased to the expected twelve packages per employee per shift, combined with a same day handling concept of 80%. This scenario perfectly matches the FTEs required by the model and the FTEs simulated, hence it is expected that the utilization rate is a little lower than in the first variation of the second scenario. When checking this in the results, presented in table 6.10 this expectation turns out to be true. The backlog streak and maximum TAT are also expected to be slightly lower than in the first variation. Again when checking the results this expectation turns out to be true for the TAT, but the longest backlog streak is the same in both variations, meaning that slightly being understaffed in the first variation does not result in any drastic effects regarding the backlog. Since the maximum TAT is shorter the service level is expected to have improved in this scenario. When evaluating this the expectation turns out to be correct, as the service level for this variation is 91.1%, with a backlog percentage of 132%

Table 6.10: The results of the second simulation with 80% same day handling and a working rate of 12

80% same day handling with working rate 12	
Longest backlog streak	12 Days
Maximum packages in backlog	171
Longest TAT	2.16 Days
FTE utilization rate	75%

The last variation considered in the second scenario is the combination of a working rate of twelve with a same day handling concept of 90%. In this variation the amount of necessary FTEs according to the model is 7.8, which gets modelled as eight. It is thus expected that the results for this scenario will be the best of all the variations. The longest backlog streak might not have shortened, as in previous variations it showed that this KPI is not incredibly responsive to relatively small changes in FTE amount. When looking at the results presented in table 6.11 These expectations appear true, with the shortest maximum TAT being the lowest of all variations and the backlog indeed being shortest along with the second variation. The utilization rate should be lowest since there is a slight over occupation. This shows in the lowest utilization rate of all variations. Because of all these figures the service level is expected to be highest in this variation. When evaluating the data this turns out to be true as the service level is 97.7% in the last variation. The backlog percentage is 100%.

Table 6.11: The results of the second simulation with 90% same day handling and a working rate of 12

90% same day handling with working rate 12	
Longest backlog streak	5 Days
Maximum packages in backlog	130
Longest TAT	1.5 Days
FTE utilization rate	66%

6.5.3. Scenario 3 - 125% input

The last scenario which is important as a possible future state is the possibility of a hugely increased input, which gets modelled as 125% of the input in 2019. This scenario acts as an extreme value test as well, since the expected input of 2025 is only a couple percent higher than it was in 2019. Nevertheless it is important to evaluate the model's behaviour for these larger inputs. The first step is calculating the required manpower. The input for this scenario will be much higher, resulting in more manpower required. When considering the packages which not be able to be processed for a same day handling concept of 80% this comes down to 105. For 90% same day handling it increases up to 117 packages. For the working rate nine packages this means there are 11.7 FTEs and thirteen FTEs required respectively. The 11.7 FTEs will be rounded up to twelve for the simulation, as a 0.7 FTE deficit would be too large in combination with the higher input. For the working rate of twelve the necessary FTEs come down to 8.75 and 9.75 respectively. Again these will be rounded up as the deficit would otherwise become too large. It is also to be expected that in a real world scenario a manager would opt to round up the FTEs as this would improve the service level. The maximum amount of packages which came in on one day was 162. The results of this manpower calculation are summarized in table 6.12.

Table 6.12: An overview of the input parameters for scenario 3 of the simulation

Percentage Same day Handling	Working rate per employee	Amount of packages necessary	Amount of workers necessary
80%	9	105	12
90%	9	117	13
80%	12	105	9
90%	12	117	10

With the required manpower known the first variation of the last scenario can be simulated. This, as was the case in the previous scenarios, is the variation consisting of a working rate of nine combined with a same day handling concept of 80%. Since the amount of necessary FTEs is rounded up the utilization rate is expected to be somewhat lower than in previous scenarios. When checking this in table 6.13 this turns out to be true. As in the previous scenarios the first variation has a utilization rate of 78% both times. With this it is also expected that the maximum TAT is shorter than it was in the previous first variations, which again turns out to be true. When evaluating the data this first variation of the last scenario also turns out to have a service level of 92.9%, again higher than the first variations of the previous scenarios. The corresponding backlog percentage was 125%.

Table 6.13: The results of the second simulation with 80% same day handling and a working rate of 9

80% same day handling with working rate 9	
Longest backlog streak	9 Days
Maximum packages in backlog	202
Longest TAT	2 Days
FTE utilization rate	73%

Secondly the variation with a 90% same day handling concept is looked into, keeping the working rate at nine. This is the only variation of the last scenario for which the simulation does not use a rounded figure. Since it does use more FTEs the utilization rate will be lower than in the previous variation. If the results in table 6.14 get checked this turns out to be true. Furthermore the backlog streak is among the lowest for this scenario. This combined with the maximum TAT of 1.56 days indicates a high service level. When evaluating the data this turns out to be true as the service level is 97%. In this variation the backlog percentage came down to 102%.

Table 6.14: The results of the second simulation with 90% same day handling and a working rate of 9

90% same day handling with working rate 9	
Longest backlog streak	5 Days
Maximum packages in backlog	165
Longest TAT	1.56 Days
FTE utilization rate	68%

Next up is the first variation of the last scenario which uses a working rate of twelve packages per employee per shift. As was the case with the first variation the amount necessary FTEs is rounded up. The expectation is that this variation will match the first variation, as the product of the number of FTEs times the working rate is the same. When looking at the results of the simulation in table 6.15 this expectation is true for the TAT and the FTE utilization rate, but not for the longest backlog streak. This seems like an odd and wrong result at first, as in both simulations the same input is handled and the daily capacity is 108 packages for both simulations. However, the result is not wrong. The problem lays in the way the simulation is made up. In the real life scenario the FTE handling the packages can have a package waiting for him while he is working on a package. This package which is waiting is of course released from the backlog by the system. Since the first variation uses more desks there can be more packages waiting to be processed outside of the backlog, meaning that the backlog drains quicker. This is what causes the difference in backlog, but this is also what happens in real life. This phenomenon does not effect the other results, since these are based mostly on capacity, which is the same. This is also shown by the service level, which just like the first variation is at 92.9%. It does show in the backlog percentage which is now at 127%, 2% higher than the first variation.

Table 6.15: The results of the second simulation with 80% same day handling and a working rate of 12

80% same day handling with working rate 12	
Longest backlog streak	11 Days
Maximum packages in backlog	205
Longest TAT	2 Days
FTE utilization rate	73%

Last up is the variation with 90% same day handling and a working rate of twelve packages. Based on previous scenarios the expectation is that the utilization rate for this variation will again be the lowest of all. Checking this with the results in table 6.16 shows the expectation is right. Furthermore the backlog streak should at least match the one from the second variation, which is does. The max TAT is the shortest of all variations which is in line with previous scenarios as well. Lastly, the service level is evaluated. This again is in line with previous results, as it is the highest of all variations at 97.6%, with a shared lowest backlog percentage of 102%.

Table 6.16: The results of the second simulation with 90% same day handling and a working rate of 12

90% same day handling with working rate 12	
Longest backlog streak	5 Days
Maximum packages in backlog	165
Longest TAT	1.5 Days
FTE utilization rate	66%

6.6. Results

Now that all simulations have been run and all results shown and explained the comparison can be made. To recap, the figures which get compared are those of the uncontrolled process in 2019, and the future state simulations. For the 2019 figures some had to have been simulated, as there was no record of this data. Other figures like the maximum amount of packages in the backlog at one time were known and can directly be compared. The baseline figures against which the simulations will be compared are:

Table 6.17: The figures for the 2019 uncontrolled process

The figures of the uncontrolled process in 2019	
Longest backlog streak	46 Days
Maximum packages in backlog	385
Longest TAT	4.8 Days
FTE utilization rate	90%
Service level	60.6%
Backlog percentage	214%

The first scenario which was run was based on an expected input of only 77% of the input which came in in 2019. Within this scenario there were four variations which were all evaluated on three KPIs and their respective service level. The worst performing variation in this scenario is based on an 80% same day handling concept with a working rate of twelve. In this scenario the longest backlog streak consisted of 21 days, with a maximum amount of packages in the backlog of 157, and a backlog percentage of 157%. The maximum TAT was 2.8 days and the utilization rate was 82%. All of these figures amounted to a service level of 82.3%. The best performing variation of the first scenario was the variation based on 90% same day handling with a working rate of nine. The variation had a longest backlog streak of just five days, a maximum TAT of only 1.6 days and a FTE utilization rate of 68%. The service level related to these figures was 96.9% and the backlog percentage was just 103%. Both scenarios outperform the uncontrolled process of 2019 for each aspect which is evaluated. It might seem that the higher utilization rate of 2019 is better, since it means employees fill their entire shift. In reality however this is undesirable, as was already explained in section 6.4, a process must not be filled beyond 80% of its lowest bottleneck. Furthermore it is also explained in the Theory of Constraints [12] that a somewhat lower utilization of employees gives a certain amount of calmness in the process, and leaves room for employees to perform extra tasks which might come up. Based on the findings at KLM E&M the ideal utilization rate is around 75%, which the future states are closer to than the uncontrolled process in 2019 was. For the first scenario tested, the future state thus outperforms the uncontrolled state.

The next scenario which was evaluated was based on the exact same input as came in in 2019. This scenario will provide the clearest view regarding the possible improvement brought by the remanufacturing process control model. The worst performing variation of this second scenario was the variation based on a 80% same day handling capacity with a working rate of nine. In this variation the longest backlog streak was twelve days, and the peak of the backlog was at 179 packages which gave a backlog percentage of 138%. The longest TAT associated with this was 2.44 days. This was achieved using an FTE utilization rate of 78% and resulted in a service level of 88.1%. On the contrary the best performing variation was the one based on a 90% same day handling concept with a working rate of twelve. In this variation the longest backlog streak was only five days, with a maximum amount of packages in the backlog of only 130, which gave the lowest backlog percentage of all scenarios and variations, at 100%. The longest TAT was just a day and a half. This was all achieved with an FTE utilization rate of 66% and resulted in a service level of 97.7%. This scenario had the exact same input as the 2019 scenario which everything is compared against so it paints a clear picture of how the remanufacturing process control model can outperform the uncontrolled process. In the best performing variation the longest backlog over nine times shorter than it was in 2019, the peak in the backlog was 250 packages lower, the longest TAT was over three days shorter and the service level was almost 40% higher.

The last scenario which was looked at was based on a much higher input than has ever been faced, or will most likely be faced in the coming years, at 125% of the input of 2019. Within this scenario the worst performing variation was based on an 80% same day handling principle with a working rate of twelve. This scenario still performed very well as the necessary amount of FTEs has been rounded up. The longest backlog streak in this scenario was eleven days, with a backlog peak of 205 packages, corresponding to a backlog percentage of 127%. The fact that this peak is higher than the other scenarios makes sense since there are more packages coming in, hence the introduction of the backlog percentage. The longest TAT was two days. This was achieved with an FTE utilization rate of 73% and resulted in a service level of 92.9%. The best performing variation of the last scenario was the variation based on a 90% same day handling concept with a working rate of twelve. In this variation the longest backlog streak was only five days, with a maximum amount of packages in the backlog of 165, which gives a backlog percentage of 102%. The longest TAT was just a day and a half. This was achieved using an FTE utilization rate of 66% and resulted in a service level of 97.6%. This shows that even when the input gets much larger than it was in 2019, with control the process can still perform extremely well.

6.7. Conclusion

In this chapter the model was validated, by evaluating if the remanufacturing process control model would outperform the uncontrolled process. First the simulation used for the future state determination was explained. Explaining how the simulation works and is built up to match reality as closely as possible. Then the future state of the process was discussed, recapping the Component Services 2.0 project. Next the KPIs used for the comparison were discussed, and why they were chosen. These KPIs were: The backlog, The TAT and the FTE utilization. With all the aspects necessary for comparison explained the states were discussed, starting with the base for the comparison, the uncontrolled process of 2019. This year was chosen since it had a complete data set of the available data, it was pre-COVID meaning it shows the process without extreme external disruptions, With the 2019 process evaluated the future state simulations could begin. The three scenarios were all based on the input of 2019. The first being the scenario which is expected by KLM E&M of 77% of the input of 2019. The second scenario is simply the same input as came in in 2019. The last scenario is based on a much higher input than has ever been experienced, or is expected in the coming years. This input was based on 125% of the input of 2019. All scenarios were split up in four different variations. Which were: a same day handling concept of 80% or 90% combined with a working rate of nine or twelve. The results of the simulations were summarized per variation, and the corresponding service level was determined. When all results were in the comparison between the uncontrolled state of 2019 and the controlled future states could begin. In this comparison it turned out that the controlled state outperformed the uncontrolled state in every scenario and every variation.

This coincides with the hypothesis, as controlling an uncontrolled process should lead to an improved process in almost all cases. Furthermore, the results from the future state simulations can be used by KLM E&M to build a business case if more FTEs are necessary to achieve the 80% or 90% same day handling concept. The highest amount of FTEs required by the model was thirteen, for the 125% input scenario. If this gets translated to the amount of people needed on the payroll it comes down to about twenty-four net employees, which at the moment there are.

This chapter also aimed to answer the subquestion: *How can the proposed model be validated?* This validation came down to checking if the model is the right model. The remanufacturing process control model aims to improve process performance, to check if the model was the right model it was checked if applying the remanufacturing process control model to a process indeed does improve performance. Through the comparison between the uncontrolled past state and the simulated controlled future states it showed that in all cases the performance improved. Based on this it is safe to say that the model is the right model, and is thus validated.

7
Conclusion

Now that all the scientific subquestion have been answered the results can be summarized in the following chapter. First the researched will be summarized in section 7.1, after which the contribution to the academic literature is presented in section 7.2. Lastly the limitations of this research and the recommendations for further research are described in 7.3.

7.1. Research conclusion

This research aimed to create a remanufacturing process control model which helps get control over production performance on production unit level and sustains this control. Specifically in the airline MRO field, but with the possibility to be extended into other fields. The main goal of this research was thus to create such a remanufacturing process control model, which is why the main research question was formulated as:

How to control production performance on operational unit level using a remanufacturing process control model

This research question was formulated by examining literature first and identifying a gap in this. Next to the gap the common problems in the remanufacturing environment were also looked at, as in the literature no solutions were offered to these problems. Then two case studies at KLM E&M were evaluated. These case studies were the oxygen bottleshop and the logistic handling area. When examining these two case studies the problems they faced were analyzed in order to find the root cause. If the root cause was known the problems should be able to be solved by the remanufacturing process control model, otherwise the model would not be correct. With the combination of literature and practice the remanufacturing process control model could be designed. The remanufacturing process control model was designed as a model consisting of six steps, each focusing on a different part necessary for gaining control over a process, improving the performance or sustaining control. The steps were: Creating a PSA of the process. Followed by creating a manpower plan. Doing this gives a lot of insight over the capabilities of the process. Next entrance and bottleneck control are performed. This is necessary to make sure the process keeps performing at an improved rate. The last two steps are target control and sustainment of control. Target control is necessary to check if the new process design is correct, or if it is performing above or below target, and if necessary adjustments can be made. Sustainment of control works in twofold, short term sustainment is achieved by consistently having a check in and out before and after every shift. This ensures all involved parties keep up with the new way of working. Furthermore the long term sustainment comes from constructing a future potential plan to have a road map for the coming year. Next to the remanufacturing process control model a maturity model was introduced. This maturity model tested how far along a company is in its improvement track. It does this by distinguishing four different levels of maturity, which from worst to best are Understanding, Implementation, Improvement and Sustainability. The model tests different aspects of an organisation for maturity, these aspects are the axes. The axes defined in the model are: People, Facilities management, Working condition, Production processes, Quality, Just In Time and Leadership. lastly the two separate models were combined to get a completely novel all in one model, which gains, improves and sustains control while checking overall progress towards a superlative organisation. With the model designed it had to be tested, this was firstly by verifying the model. Verification was done in twofold first with experts from KLM E&M and then quantitative of the simulation. After this the model was validated. This was done by testing controlled future states against uncontrolled past states. In total twelve different future states were evaluated, all of these outperformed the uncontrolled past state. With this the remanufacturing process control model was said to be correct.

7.2. Contribution to academic literature

This research contributes to the academic literature in multiple ways. First of all, as was determined by [49], there is a missing link in plans made by higher levels of organisations, and the translation to the operational level. This missing link has the effect that a lot of potential is lost since plans made higher up don't account for this, and the plans which do get made often won't get performed correctly. To combat this the control is based on a more integral approach, starting with a bottom up structure. The operational level has the best idea of what potential is hidden away in the process, and how to carry out plans made. Higher level management can check whether performance is as it should, as well as the maturity of the process if it so desires. This however is not a requirement as the well governed process is very independent. How the model fits the gap is shown in figure 7.1. Then there is the the fact that a control model for the Airline MRO business did not exist, and even for general remanufacturing systems there is no clear remanufacturing process control model. As [14] determined remanufacturing is an industry which differs much from regular manufacturing. With this come many different aspects which make controlling remanufacturing systems much more intricate than regular manufacturing. The remanufacturing process control model presented in this research aimed to overcome these difficulties, and offer a clear framework which can be followed for achieving control. In doing so the model contributes to the academic literature, offering a clear remanufacturing process control model aimed at the Airline MRO sector, but easily applicable to any remanufacturing system.

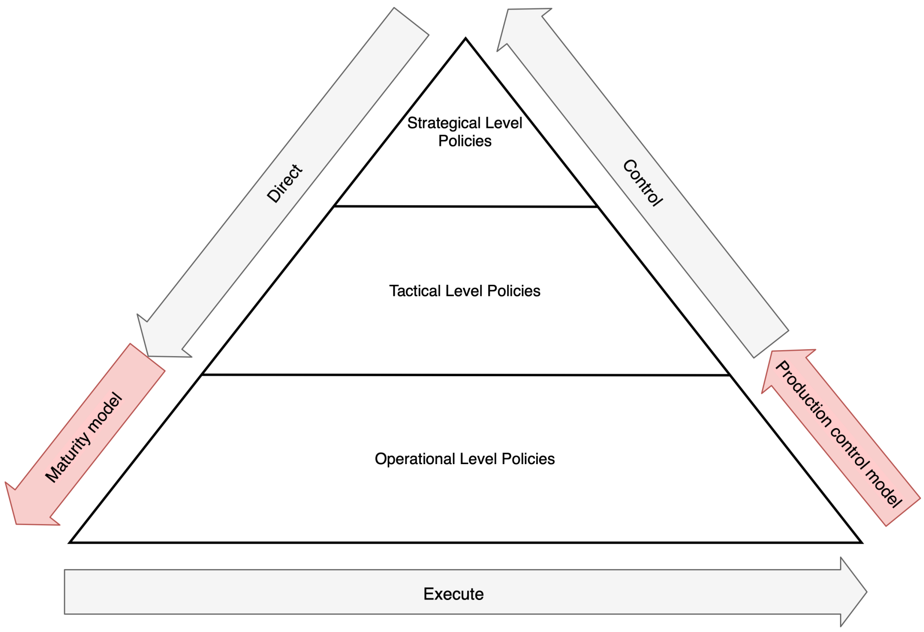

Figure 7.1: The filled literature gap

Furthermore the model emphasizes that automation does not automatically lead to improvement as was also determined by R. Jelinek [21], which is a misconception a lot of organisations make. Especially with the rise of Industry 4.0 it is paramount to avoid this misconception. Automation tracks are usually very expensive improvement tracks, which if controlled can be beneficial, but if not, become a wasted investment. With this model control over the process can be gained also when a high level of automation is achieved. Which will ensure the automation is utilized to it's full potential. Lastly this research introduces process quality as a separate KPI, instead of a resulting KPI. Traditionally process quality is considered as the result of other KPIs being up to standard. However, in this research it is suggested to lift it to the forefront and use process quality as a main driver for checking the performance of a process. In combination with these aspects a hypothesis was made in section 1.8. This stated that using an integral approach to production control will aid in getting control as well as sustaining it, all the while increasing performance. As was shown throughout this report, as far as this hypothesis could be tested it was correct.

7.3. Limitations and recommendations for further research

During the research some limitations did arise. The most obvious ones were the limitations which rose due to the COVID-19 pandemic. There was a lot of working from home which brought the necessary complications. When this is left unconsidered there were still other limitations. First of all in simulating the the future states only the regular flow has been taken into account, in real life of course this is not the case, and the disrupted flow can shake up a process of not handled correctly. Analysis shows that the disrupted flow for the logistic handling area accounts for about 8% of all flow. When handling a disrupted flow package the process starts of normally, but then can't be finished. This results in the package being placed in a special disrupted flow gantry. When the problem has been fixed the process has to start of from the beginning again basically in the end thus taking up twice as much time. Taking this flow into account as well would give more realistic results of the future states. Another aspect which would make the simulation more realistic is adding the prioritisation of certain parts. This is difficult to achieve since there is no log of the amount of prioritised parts, and there is some disagreement about the different levels of prioritisation. Adding this prioritisation would again increase the realism of the results, which would most likely effect the backlog size and duration. Implementing disrupted flow as well as prioritisation into the simulation is something which further research could focus on. Furthermore the simulation which got used for the evaluation of the model was only made for the logistic handling process, further research could test the model on different shops at KLM E&M. Further research could also enlarge the scope entirely and test the model outside of the Airline MRO sector for other remanufacturing industries, where the model should be applicable with little to no altercations. Testing this would show the models robustness. Another aspect which could not be tested was the sustainment of the newly found control, testing this without a simulation yields the best results, but would require a longer time span. If a longer time has elapsed since this research it is also interesting to check the production maturity levels of the oxygen bottleshop, since they have just started the implementation of the remanufacturing process control model it currently is still in its infancy, however in some months the levels should be higher. Then there was the software used for the simulations. In this research Simulink has been used, but this software does have its limitations. if more simulations will be made it is worth looking into more specialized discrete event software. Lastly trying to combine the model with industry 4.0 concepts could provide interesting new opportunities regarding planning and information flows. This is also an area which could be explored further in future research.

8

Business Implementation

In this chapter the implementation problems and benefits of the remanufacturing process control model will be discussed. In doing so two additional subquestion are formulated which will be answered. These additional subquestions are:

10. What are the (financial) benefits of the remanufacturing process control model?
11. How should the remanufacturing process control model be implemented?

8.1. remanufacturing process control model benefits

The benefits of using the remanufacturing process control model can be split into two different categories, first the benefits of this production control control model versus classic improvement methods will be discussed, after which the financial benefits of implementing the remanufacturing process control model can be discussed.

8.1.1. Specific model benefits

First off, the benefits of using the presented remanufacturing process control model instead of classic improvement methods, such as Lean or Six Sigma. The first and most important reason for using a remanufacturing process control model instead of more well known methods is the fact that these methods can only achieve good results when there is already some level of control over the process, whereas the remanufacturing process control model can be used to first gain control. In a lot of cases processes don't run optimally because they are simply not controlled. Trying to then implement an improvement track on this process will bare little to no results. This can be compared driving a car from the passenger seat, it is possible to change the seat cover and make yourself more comfortable, but until you get in the drivers seat you won't be able to control the car. Using the remanufacturing process control model does not only enable the possibility to gain control of an uncontrolled process, but it also sustains it. As Liker et al. [34] showed, only about 2% of all companies which implement a Lean improvement track eventually see the anticipated results, often because companies fail in sustaining the quickly made improvements. The remanufacturing process control model on the other hand forces the sustainment of improvements, and the focus on continuous improvement through the use of Check in and outs as well as the future potential plan. One other important benefit of the remanufacturing process control model is that it is easy to use. There have been deliberate choices to construct the model in a simple way, so that the rigorous training needed for for example Lean won't be necessary. As long as there is a real end to end understanding of the process, the remanufacturing process control model can be applied. Lastly, the remanufacturing process control model as presented in this paper has the benefit that it involves not only the managers, but also their employees, for example in constructing the PSA. Doing this increases the likely hood of everyone in the team being on board with the decisions made regarding process optimization, as well as provide people with a sense of pertinence.

8.1.2. Financial benefits

Next to the benefits of the remanufacturing process control model compared to other improvement tracks there are also financial benefits to the remanufacturing process control model. The financial benefits come in twofold, first of there is the unlocking of free expansion and capital, and secondly there is the possibility of extra income. To start off with the unlocking of capital and investment free expansion. As was described, one of the staring points of the remanufacturing process control model was to use up the current resources. Since there is much waiting time in most uncontrolled processes eliminating this shortens the TAT of the process. As waiting time in uncontrolled processes at KLM E&M accounts for more than half of the TAT of the process, eliminating this would result in twice as much work being possible in a time period without doing any additional investments. Furthermore the impact of TAT reduction for the entire process of KLM E&M has been calculated. This is of course based on averages since many different parts come in for repair at Component Services. However, all parts coming in and going out take the same route, it is only in the different shops that different TATs arise. Having said this the calculations of KLM E&M showed that every day this entire process could be shortened would result in €6 million and €4 million respectively, for the two most frequently repaired airplane types. It is not the case that €10 million extra would be earned, but shortening the TAT would result in less spare parts needing to be stored in the pool. All of the parts stored in the pool amount to the total capital of KLM E&M, shrinking this pool would thus free up a lot of capital.

Then there is the financial benefit associated with the possibility of handling more input. This of course varies greatly between all different shops. The first piece of this extra income comes from using up the current resources. In most cases the current resources are not used up, but still have a lot of room to handle more work. Filling the process until the limit, or at least 80% of this limit, will provide a lot of extra income. This income is easily calculated as the fixed costs of running the operation basically stay the same. all the income associated with the increase in input is thus profit, meaning it amounts to relatively large sums quickly.

8.2. Implementation of the remanufacturing process control model

Then there is the question of how to implement the remanufacturing process control model in practice. In theory following the model steps as provided in chapter 4 gives a solid base for implementing the model, there are however some important aspects which could use extra clarification. First of all it is important to not that, as of writing this report, the implementation of the remanufacturing process control model has started at the oxygen bottle shop, making it the first shop where the model is actually implemented. The full implementation won't be until after this research is finished, but from the first stages some pitfalls did rise, which could have been avoided.

The first problem rose when the shift planning was constructed. For one of the operations performed by the oxygen bottle shop a shared test machine is utilized. This machine is only available for the oxygen bottle shop on Monday, Thursday and Friday, this however was unknown to the shift planner, so the first iteration of the shift planning could not be realized. Knowing these boundary conditions beforehand saves a lot of time and effort, so it is important to try and get all of these seemingly small conditions on the record.

Another problem which can come up during implementation is the fact that not every member of the team fully understands the need for the model, or is hesitant regarding the implementation of it. The implementation of the model should be carried out by a small core team, of process owners and supporting staff. If one of the members of this core team has doubts it is paramount to remedy this before moving on, as any of these doubts will inevitably be transferred to the other employees. Only when all of the members of the core team fully understand and support the changes which are to be made, is it time to present the changes.

Then there is the problem of giving all of the responsibility to one member of the core team. It is important to have an even distribution of the tasks associated with implementing the model. Otherwise the situation will arise where there is one expert, and the other members knowing too little. Furthermore having one person carry out too many tasks will inhibit them from doing their day job, as especially in the beginning stages of the model there is usually a lot of support required. The check in and out takes a long time in the beginning, and during the shift it is important to have someone walk by to answer any questions, and check if everything is still running smoothly.

Lastly, the team should not be discouraged by disappointing results when the model is just applied. Getting used to the changes takes time, and not all employees might be on board from the very beginning. This is all normal and part of the process. It is important to stick with the plan, and consequently stay on top of all important aspects like the check in and out. If this gets carried out the employees will start seeing the benefits of the new way of working, and start to gravitate towards it more and more. If there is still an employee who is reluctant to give the new of working a real try the this employee will, on the long term, be called out for it by his own colleagues, as they are all the victim of of this employee's behaviour.

When all of these pitfalls are kept in mind the implementation as was discussed in chapter 4 can simply be followed. If the regular model sequence as is presented is follows the model should prove to be quite foolproof and easy to implement.

8.3. Conclusion

This chapter focused on the implementation of the remanufacturing process control model in practice. If the model implementation is followed as described in the research there are some problems which can arise. These have been presented in section 8.2. When these pitfalls are kept in mind the regular model implementation as described in chapter 4 can be followed. Then the benefits of implementing the remanufacturing process control model were evaluated. As far as this model versus other models is considered the case was made that this remanufacturing process control model also aids in getting and sustaining control, rather than just improving already existing control. The financial benefits come in twofold, first off there is a lot of capital which gets freed up by reducing the necessary inventory to meet customer demands, and secondly there is the room for expansion of customers without needing to invest in resources, resulting in free extra profit.

Bibliography

[1] Colin M. Beale and Pat Monaghan. Human disturbance: people as predation-free predators? *Journal of Applied Ecology*, 41(2):335–343, 2004. doi: https://doi.org/10.1111/j.0021-8901.2004.00900.x. URL https://besjournals.onlinelibrary.wiley.com/doi/abs/10.1111/j.0021-8901.2004.00900.x.

[2] Gary G. Bergmiller. Lean manufacturers transcendence to green manufacturing: Correlating the diffusion of lean and green manufacturing systems. 2006.

[3] Jan Willem Marie Bertrand and Johan C Wortmann. *Production control and information systems for component-manufacturing shops*. Citeseer, 1981.

[4] R. Bueno, F. Girot, and M.E. Gutiérrez-Orrantia. An overview on european manufacturing research visions and roadmaps as an answer to economical and societal challenges and opportunities. *Procedia Manufacturing*, 13:1455–1462, 2017. ISSN 2351-9789. doi: https://doi.org/10.1016/j.promfg.2017.09.167. URL https://www.sciencedirect.com/science/article/pii/S2351978917308053. Manufacturing Engineering Society International Conference 2017, MESIC 2017, 28-30 June 2017, Vigo (Pontevedra), Spain.

[5] Hongyi Chen and Ryan Taylor. Exploring the impact of lean management on innovation capability. In *PICMET 2009 - 2009 Portland International Conference on Management of Engineering and Technology - Proceedings*, PICMET: Portland International Center for Management of Engineering and Technology, Proceedings, pages 826–834, November 2009. ISBN 1890843202. doi: 10.1109/PICMET.2009.5262042. PICMET 2009 - 2009 Portland International Conference on Management of Engineering and Technology ; Conference date: 02-08-2009 Through 06-08-2009.

[6] Eliyahu M. Cox, Jeff; Goldratt. The goal: a process of ongoing improvement. *North River Press*, 1986. ISSN 0-88427-061-0.

[7] Ana Julia Dal Forno, Fernando Augusto Pereira, Fernando Antonio Forcellini, and Liane M Kipper. Value stream mapping: a study about the problems and challenges found in the literature from the past 15 years about application of lean tools. *The International Journal of Advanced Manufacturing Technology*, 72(5-8):779–790, 2014.

[8] Bertus de Jager, Chris Minnie, Johan de Jager, Marita Welgemoed, John Bessant, and Dave Francis. Enabling continuous improvement: a case study of implementation. *Journal of Manufacturing Technology Management*, 15(4):315–324, January 2004. ISSN 1741-038X. doi: 10.1108/17410380410535017. URL https://doi.org/10.1108/17410380410535017.

[9] Navin Shamji Dedhia. Six sigma basics. *Total Quality Management & Business Excellence*, 16(5):567–574, 2005. doi: 10.1080/14783360500077468. URL https://doi.org/10.1080/14783360500077468.

[10] Jan Dul and Tony Hak. *Case study methodology in business research*. Routledge, 2007.

[11] E.P.Cornelisse. Modelling business process redesign strategies for improved reverse logistics in an aircraft component supply chain. *TU Delft*, 2018. ISSN 2018.TIL.8300.

[12] Eliyahu M Goldratt. *Theory of constraints*. North River Croton-on-Hudson, 1990.

[13] James Harnsberger Greene. *Production and inventory control handbook*, volume 1. McGraw-Hill, 1970.

[14] V.Daniel R Guide Jr. Production planning and control for remanufacturing: industry practice and research needs. *Journal of Operations Management*, 18(4):467–483, 2000. doi: https://doi.org/10.1016/S0272-6963(00)00034-6. URL https://onlinelibrary.wiley.com/doi/abs/10.1016/S0272-6963%2800%2900034-6.

[15] Daan Haak. Designing repair processes by introducing a return quality control model: A method for sustainable initial repair process design. 2019.

[16] Herbert Meyr Hartmut Stadtler, Christoph Kilger. *Supply Chain Management and Advanced Planning*. Springer, 2015. ISBN 978-3-642-55308-0. doi: https://doi.org/10.1007/978-3-642-55309-7.

[17] Mohamed K Hassan. Applying lean six sigma for waste reduction in a manufacturing environment. *American Journal of Industrial Engineering*, 1(2):28–35, 2013.

[18] Martin G. Helander. A guide to human factors and ergonomics. 2005.

[19] Peter Hines. How to create and sustain a lean culture. *Development and Learning in Organizations: An International Journal*, 24, 10 2010. doi: 10.1108/dlo.2010.08124fad.007.

[20] Ali Hosseini, Hossam A. Kishawy, and Hussein M. Hussein. *Lean Manufacturing*, pages 249–269. Springer International Publishing, Cham, 2015. ISBN 978-3-319-20152-8. doi: 10.1007/978-3-319-20152-8_8. URL https://doi.org/10.1007/978-3-319-20152-8_8.

[21] Ronald Jelinek. All pain, no gain? why adopting sales force automation tools is insufficient for performance improvement. *Business Horizons*, 56(5):635–642, 2013. ISSN 0007-6813. doi: https://doi.org/10.1016/j.bushor.2013.06.002. URL https://www.sciencedirect.com/science/article/pii/S0007681313000979.

[22] Carter Kerk Jon Walder, Jennifer Karlin. Integrated lean thinking & ergonomics: Utilizing material handling assist device solutions for a productive workplace. *Material Handling Industry of America*, 2007. URL https://www.mhi.org/downloads/industrygroups/lmps/whitepapers/Integrating_Lean_Thinking.pdf.

[23] Muris Lage Junior and Moacir Godinho Filho. Production planning and control for remanufacturing: literature review and analysis. *Production Planning & Control*, 23(6):419–435, 2012. doi: 10.1080/09537287.2011.561815. URL https://doi.org/10.1080/09537287.2011.561815.

[24] Tomas Karlsson and Benson Honig. Norms surrounding business plans and their effect on entrepreneurial behavior. *Frontiers of Entrepreneurship Research*, 27, 12 2007.

[25] Will Kenton. Manufacturing. *Investopedia*, 2020. URL https://www.investopedia.com/terms/m/manufacturing.asp.

[26] Mairi Kerin and Duc Truong Pham. A review of emerging industry 4.0 technologies in remanufacturing. *Journal of Cleaner Production*, 237:117805, 2019. ISSN 0959-6526. doi: https://doi.org/10.1016/j.jclepro.2019.117805. URL https://www.sciencedirect.com/science/article/pii/S0959652619326654.

[27] Tomasz Koch, Remigiusz Horbal, Robert Kagan, Tomasz Sobczyk, and Stanislaw Plebanek. 10 commandments for the boss of a company implementing lean philosophy. *Management and Production Engineering Review*, 3:62–78, 2012.

[28] John P Kotter. *Leading change*. Harvard business press, 2012.

[29] C.-T. Kuo, J.-T. Lim, and S. M. Meerkov. Bottlenecks in serial production lines: A system-theoretic approach. *Mathematical Problems in Engineering*, 2:853949, 1996. ISSN 1024-123X. doi: 10.1155/S1024123X96000348. URL https://doi.org/10.1155/S1024123X96000348.

[30] Jelena Kurilova-Palisaitiene, Erik Sundin, and Bonnie Poksinska. Remanufacturing challenges and possible lean improvements. *Journal of Cleaner Production*, 172:3225–3236, 2018. ISSN 0959-6526. doi: https://doi.org/10.1016/j.jclepro.2017.11.023. URL https://www.sciencedirect.com/science/article/pii/S0959652617326744.

[31] Emily Lawson and Colin Price. The psychology of change management. *THE McKINSEY QUARTERLY 2003 SPECIAL EDITION: THE VALUE IN ORGANIZATION*, 2003.

[32] A. Lemsom. Controlling the integrated component supply chain of aircraft mro from a service level perspective. *TU Delft*, 2017. ISSN 2017.TIL.8158.

[33] L. O. Levine. Remanufacturing strategy. *ASME paper*, 1993.

[34] Jeffrey Liker and Mike Rother. Why lean programs fail. *Lean enterprise institute*, 2011:45–79, 2011.

[35] Mohammad Ali Maasouman. Development of lean maturity model for operational level planning. *Concordia University*, 2014.

[36] John MacDuffie. Human resource bundles and manufacturing performance: Organizational logic and flexible production systems in the world auto industry. *ILR Review*, 48, 02 1995. doi: 10.2307/2524483.

[37] William Malsam. Top down vs. bottom up management: What's the difference? *ProjectManager*, 2019.

[38] Mitsutaka Matsumoto and Shingo Komatsu. Demand forecasting for production planning in remanufacturing. *The International Journal of Advanced Manufacturing Technology*, 79(1-4):161–175, 2015.

[39] T. Melton. The benefits of lean manufacturing: What lean thinking has to offer the process industries. *Chemical Engineering Research and Design*, 83(6):662–673, 2005. ISSN 0263-8762. doi: https://doi.org/10.1205/cherd.04351. URL `https://www.sciencedirect.com/science/article/pii/S0263876205727465`. 7th World Congress of Chemical Engineering.

[40] S. Nakajima. *Introduction to TPM: Total Productive Maintenance*. Preventative Maintenance Series. Productivity Press, 1988. ISBN 9780915299232. URL `https://books.google.nl/books?id=XKc28H3JeUUC`.

[41] Stephen C. Perry. The relationship between written business plans and the failure of small businesses in the u.s. *Journal of Small Business Management*, 39(3):201–208, 2001. doi: 10.1111/1540-627X.00019. URL `https://www.tandfonline.com/doi/abs/10.1111/1540-627X.00019`.

[42] Noureddine Zerhouni Rafael Goriveau, Kamal Medjaher. From prognostics and health systems management to predictive maintenance 1 : monitoring and prognostics. *ISTE Ltd and John Wiley & Sons, Inc*, 2016. ISSN ISBN 978-1-84821-937-3.

[43] Antonio F. Rentes, Cesar A. C. Araujo, and Victor C. Rentes. Best practice examples in sustaining improvements from lean implementation. *IIE Annual Conference.Proceedings*, pages 362–367, 2009. URL `https://www.proquest.com/scholarly-journals/best-practice-examples-sustaining-improvements/docview/192461115/se-2?accountid=27026`. Copyright - Copyright Institute of Industrial Engineers-Publisher 2009; Last updated - 2021-04-21.

[44] J. Rohde, Herbert Meyr, and Michael Wagner. Die supply chain planning matrix. *PPS Management*, 5, 01 2000.

[45] George Roth. Sustaining lean transformation through growth and positive organizational change. *Journal of Enterprise Transformation*, 1(2):119–146, 2011. doi: 10.1080/19488289.2011.579228. URL `https://doi.org/10.1080/19488289.2011.579228`.

[46] Mike Rother and John Shook. *Learning to see: value stream mapping to add value and eliminate muda*. Lean Enterprise Institute, 2003.

[47] Souraj Salah, Abdur Rahim, and Juan A. Carretero. The integration of six sigma and lean management. *International Journal of Lean Six Sigma*, 1(3):249–274, January 2010. ISSN 2040-4166. doi: 10.1108/20401461011075035. URL `https://doi.org/10.1108/20401461011075035`.

[48] Donna C.S Summers. Lean six sigma: Process improvement tools and techniques. *Pearson education*, 2011. ISSN 978-0-13-512510-6.

[49] Kerry-Lynn Thomson and M. Maninjwa. Information security governance control through comprehensive policy architectures. pages 1 – 6, 09 2011. doi: 10.1109/ISSA.2011.6027522.

[50] Tullio Tolio, Alain Bernard, Marcello Colledani, Sami Kara, Guenther Seliger, Joost Duflou, Olga Battaia, and Shozo Takata. Design, management and control of demanufacturing and remanufacturing systems. *CIRP Annals*, 66(2):585–609, 2017. ISSN 0007-8506. doi: https://doi.org/10.1016/j.cirp.2017.05.001. URL `https://www.sciencedirect.com/science/article/pii/S0007850617301403`.

[51] William Truscott. *Six Sigma.* Routledge, 2012.

[52] Maarten J. van Stuyvesant Meyen. Behold in the industry essentials in different manufacturing industries. *Delft University of Technology*, 2016.

[53] H.H.M. van Wezel. Design of a parcel hub scheduling process. *TU Delft*, 2021. ISSN 2021.TIL.8555.

[54] Darli Rodrigues Vieira and Paula Lavorato Loures. Article: Maintenance, repair and overhaul (mro) fundamentals and strategies: An aeronautical industry overview. *International Journal of Computer Applications*, 135(12):21–29, February 2016. Published by Foundation of Computer Science (FCS), NY, USA.

[55] Oliver Wyman. Number of commercial airplanes to reach 40,000 by 2030. *Consultancy.eu*, 2021. URL `https://www.consultancy.eu/news/5685/number-of-commercial-airplanes-to-reach-40000-by-2030`.

[56] Zheng Xue, Tao Li, and Shitong Peng. A model to predict bottlenecks over time in a remanufacturing system under uncertainty. *Environmental Science and Pollution Research*, 2021. ISSN 1614-7499. doi: 10.1007/s11356-021-15233-2. URL `https://doi.org/10.1007/s11356-021-15233-2`.

[57] Przemysław Zawadzki and Krzysztof Żywicki. Smart product design and production control for effective mass customization in the industry 4.0 concept. *Management and Production Engineering Review*, (No 3), 2016. doi: 10.1515/mper-2016-0030. URL `http://journals.pan.pl/Content/106257/PDF/mper-2016-0030.pdf`.

[58] Xugang Zhang, Xiuyi Ao, Wei Cai, Zhigang Jiang, and Hua Zhang. A sustainability evaluation method integrating the energy, economic and environment in remanufacturing systems. *Journal of Cleaner Production*, 239:118100, 2019. ISSN 0959-6526. doi: https://doi.org/10.1016/j.jclepro.2019.118100. URL `https://www.sciencedirect.com/science/article/pii/S0959652619329701`.

Appendices

A

Component Services structure

The following chart is a more detailed view of KLM E&M. Since this research was conducted at Component Services this department has been folded out the furthest.

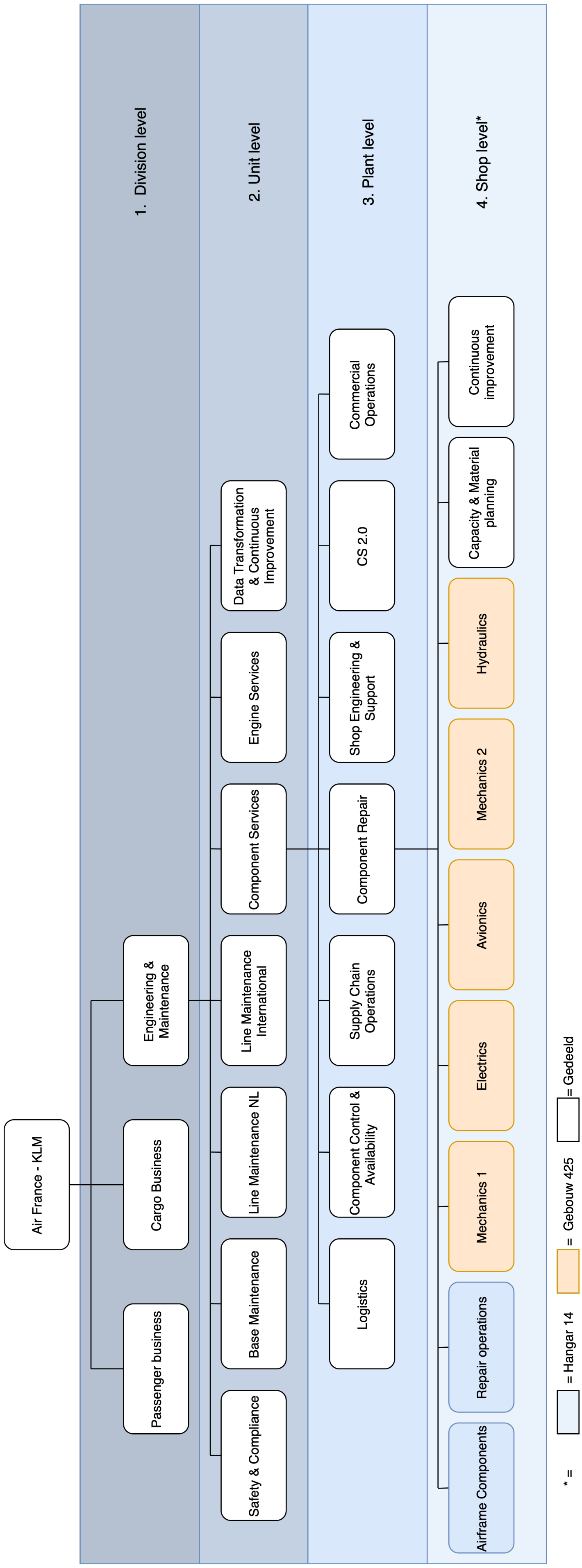

Figure A.1: The complete organisational structure of Component Services

B

PSA

As mentioned, the KLM utilises a sort of Value Stream mapping called a Process Stream Analysis. Such a process stream analysis can be made in numerous levels of detail. The example shown here is of the whole process within Component Services, and thus does not provide much detail about all the sub processes which take place. The PSA is usually iterated on, including the time each process step (depicted by an arrow) takes. Process times are then further divided into actual touch times, the time someone physically handles the part, and waiting times, the time a part spends waiting for another process step. This means that it will immediately become clear where the waste (in the form of waiting time) in the process is hidden, and subsequently where more managing is required in order to reduce said waiting time.

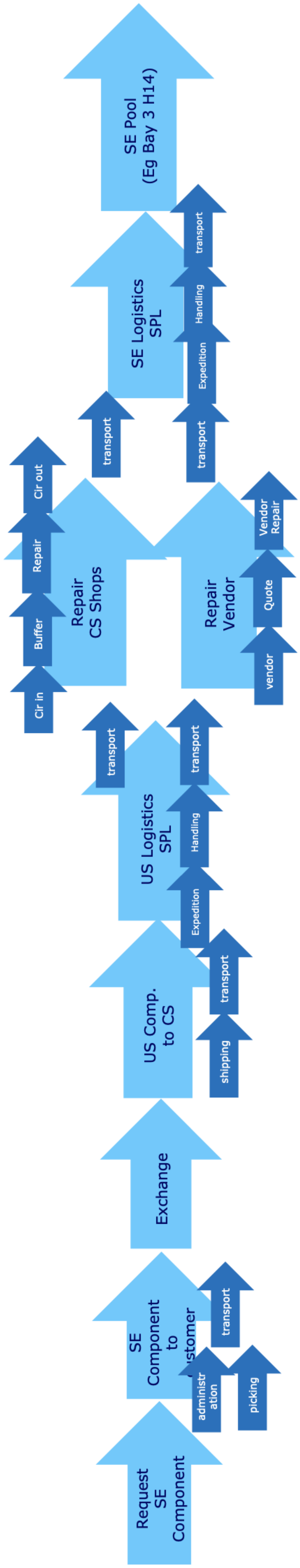

Figure B.1: A Process stream analysis of Component Services

C
KPI

In his research van Stuyvesant Meyen distinguished many different KPI's which were best suited for one, or in rare cases two different types of industry. These findings have been summarized in the table below. Of the different types of industry which were distinguished the only one which has overlap with KLM E&M, and thus is important for this research, is the maintenance industry. The three KPI's which are thus essential for the industry, according to van Stuyvesant Meyen are: Occupancy Ratio Personnel, Work in Progress and Production cost per produced hour.

Indicator	Management	Generic	High-Tech	Non High-Tech	Surface Treatment	Maintenance
Revenue per FTE	✓					
Added Value per FTE	✓					
Personnel Expenses per FTE	✓					
Overhead Costs per FTE	✓					
Added Value vs. Personnel Expenses	✓					
Net Margin	✓					
Personnel Expenses vs. Revenue	✓					
R&D Expenses vs. Revenue	✓					
Delivery Reliability on order level		✓				
Direct vs. Total FTE ratio		✓				
Indirect vs. Total FTE ratio		✓				
Absenteeism ratio		✓				
Rejection ratio		✓				
Productivity Direct Personnel		✓				
Intern Rejection ratio (of Revenue)			✓			
Extern Rejection ratio (of Revenue)			✓			
PC AC (on materials)			✓			
Average number of days orders sent too late			✓			
Occupancy Ratio Personnel				✓		✓
Number of over hours per day				✓		
(almost) accidents per day				✓		
Number of Complaints (intern and extern)				✓		
Delivery Reliability on materials				✓		
Work in Progress				✓		✓
Average Revenue per day					✓	
Production Costs per produced hour						✓

Figure C.1: The researched KPI's and which industry they're relevant for. [52]

D

Checklist Lean Maturity

In the Lean Maturity Model there are different levels of lean maturity. To asses which level a company is at control items are used. Sometimes these control items are somewhat qualitative, which makes them harder to asses. To aid in this process Maasouman [35] created the following list of sample questions. The way the scoring works is as follows, if for instance the standards are not at all up to date it would receive a 0 in the first question. If they are up to date, meaning no changes have been made in the standards since the last update the it would receive a 5. If there are no standards present then it would receive a N/A. From these questions it quickly shows whether a process is up to the required standard or not.

Control Item: Standard Operating procedure (SOP) Axis: 4 - Production Processes Level: 1- Understanding Control Item Code: L_{141}						
Questions	**Score**					**Evidence**
	0	**1**	**3**	**5**	**N/A**	
Are the standards up to date?						
Are the standards available in production cells?						
Are the key points written precisely?						
Are the reasons of key points written clearly?						
Are the works broken down into reasonable steps?						
Are the main steps detailed enough? e.g. way of picking up and grasp						
Are all fields of standard completed correctly?						
Are the sequences of operations clearly defined?						
Are the time of each main steps and total time calculated precisely?						
Are visual descriptions used in documentation of work description?						
Are the engineering specifications written in accordance with engineering requirement?						

Figure D.1: The questions developed by Maasouman [35], to check lean indicators

E

Example shift plan oxygen bottles

Table E.1: An example shift plan for the oxygen bottle shop

Monday	Tuesday	Wednesday	Thursday	Friday
1 FTE fill bottles (8 bottles)	1 FTE fill bottles(8 bottles)	1 FTE fill bottles (8 bottles)	1 FTE fill bottles (8 bottles)	1 FTE fill bottles (8 bottles)
1 FTE assembly&fill 4(wo) + step 1&2 overhaul (2 bottles)	1 FTE step 1+2+3overhaul (2 bottles)	1 FTE step 1+2 overhaul (2 bottles)	1 FTE assembly&fill 4 + step 1&2overhaul (2 bottles)	1 FTE step 1+2overhaul (2 bottles)
1 FTE step 3 overhaul (4 bottles) Adm+fill+rest (4 bottles)	1 FTE step 4 overhaul (2 bottles) + smokehoods (3)	1 FTE step 4 overhaul (2 bottles)	1 FTE step 3 overhaul (4 bottles) Adm+fill+rest (4 bottles)	1 FTE step 4 overhaul (2 bottles)
0.6 FTE smokehoods (3) + Test & deliver overhaul	0.6 FTE Test & deliver overhaul	0.6 FTE smokehoods (3) + Test & deliver overhaul	0.6 FTE smokehoods (3) + Test & deliver overhaul	0.6 FTE smokehoods (3) + Test & deliver overhaul

F

Production maturity checklist

As was mentioned in order to give a level to the maturity of certain aspects of the production control model a checklist has been created. The way this checklist works is quite straightforward. Per level there is a separate list of questions, which attribute to different model aspects. If for all questions of one aspect the questions can be answered with yes, that level of maturity is achieved. It can occur that for the first level not all questions can be answered with yes, but the second level can all be answered with yes. In this case the maturity is still at level zero, as a new level can only be achieved if the previous one is also achieved. The checklist shown below has been filled in for the current state of oxygen bottleshop.

Table F.1: The checklist for the understanding level of maturity

Model aspect	**Questions understanding**	**Yes/No**
PSA	The concept of a PSA is clear with all parties involved in the process	Yes
	The need for an improvement track is clear	No
Manpower plan	The concept of a manpower plan is clear with all parties involved in the process	Yes
	The incoming work, amount of workers and skills are known	Yes
Entrance control	The concept of entrance control is clear with all parties involved in the process	Yes
	The amount of work which is allowed into the process is known	Yes
Bottleneck control	The concept of bottleneck control is clear with all parties involved in the process	Yes
	The capacity of equipment used in the process is known	Yes
Target control	The concept of target control is clear with all parties involved in the process	Yes
	The necessary KPIs are being tracked	No
Sustainment of control	The concept of a future potential plan is clear with all parties involved in the process	No

Table F.2: The checklist for the Implementation level of maturity

Model aspect	**Questions Implementation**	**Yes/No**
PSA	The PSA has been constructed	Yes
	There is no ambiguity about the PSA	Yes
Manpower plan	A new shiftplanning according to the PSA is constructed	Yes
	OCAPs are defined	No
Entrance control	There is a backlog in place for too much incoming work	No
	Outsource options are known for too much incoming work	No
Bottleneck control	The first occuring bottlenecks are known	Yes
	An expansion plan for the bottlenecks is made	No
Target control	An overview of necessary KPIs is available	No
	Process Quality is being measured	No
Sustainment of control	A check in/ out is used at the ending and beginning of each shift	No
	Financial benefits of new way of working are calculated	No

Table F.3: The checklist for the Sustainment level of maturity

Model aspect	**Questions Sustainment**	**Yes/No**
PSA	The PSA is being used as the basis for control	No
	The PSA is kept up to date	No
Manpower plan	The designed shiftplanning is in use	No
Entrance control	No more has been allowed in to the process than it can handle	No
Bottleneck control	Bottlenecks are being kept up to date	No
Target control	The necessary KPIs have all improved	No
	The process quality results in a stable low TAT	No
Sustainment of control	Check in/ out takes only a short amount of time	No
	The future potential plan has been created	No

Table F.4: The checklist for the Improvement level of maturity

Model aspect	**Questions Improvement**	**Yes/No**
PSA	Due to process improvement the PSA can be simplified	No
Manpower plan	Manpower can be redesigned (due to better working rate for example)	No
Entrance control	The process can handle more than was initially designed	No
Bottleneck control	Old bottlenecks have been resolved and new bottlenecks arose	No
Target control	Set targets have all been achieved, new targets are required	No
	New lowest TAT is possible	No
Sustainment of control	Future potential plan is being followed	No

G

Overview of Simulink simulation logistic handling area

G.1. Simulation overview

As was mentioned in the report the simulations have been performed in Simulink, a simulation add on for Matlab. In figure G.1 an overview of the model can be found.

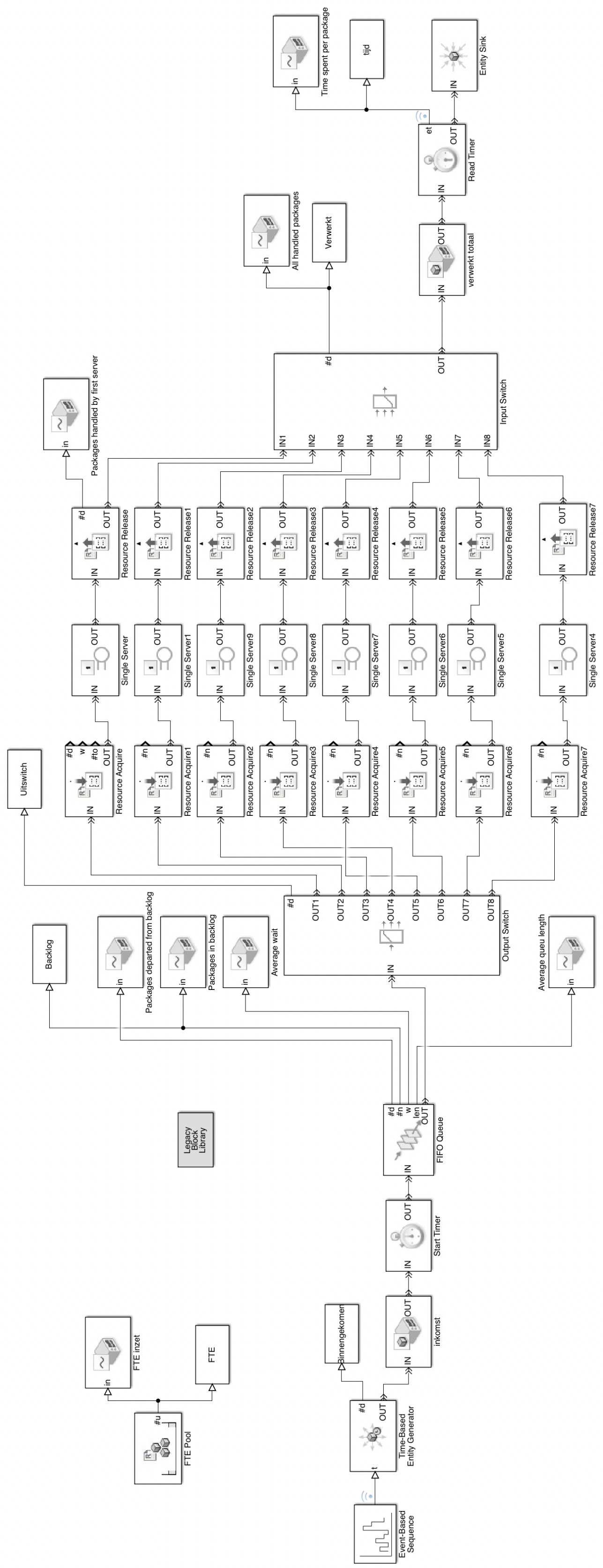

Figure G.1: Overview of the simulink model

G.2. Simulation results

Next up the results for all the simulations will be shown, starting with the results for the 77% input scenario. The first variation regarded 80% same day handling and a working rate of nine packages per employee, the Figures shown will be the backlog, the TAT and the FTE utilization rate.

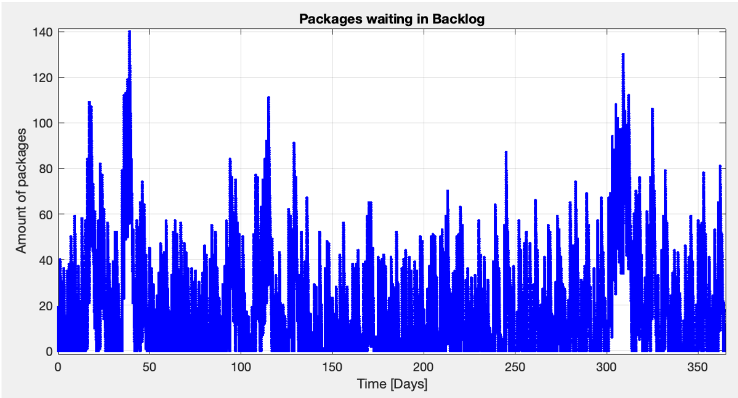

Figure G.2: The backlog size

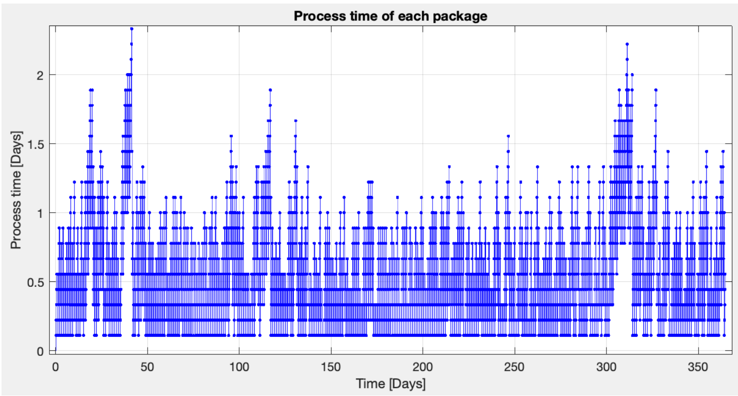

Figure G.3: The TAT per package

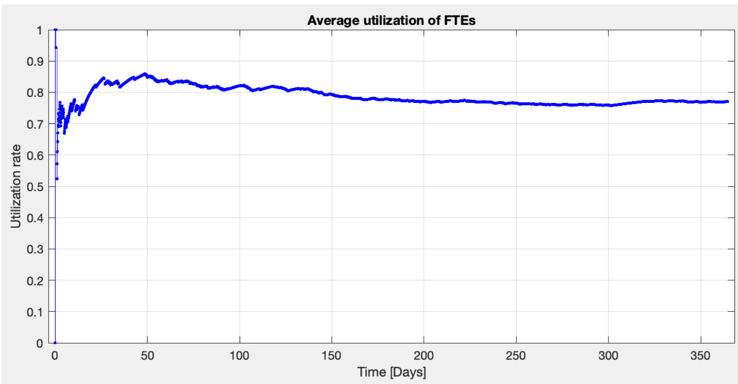

Figure G.4: The FTE Utilization rate

Next The variation based on a working rate of nine combined with 90% same day handling is shown, still based on 77% input of 2019.

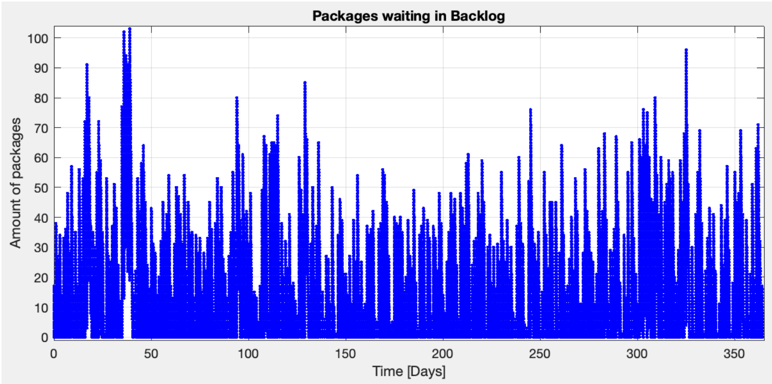

Figure G.5: The backlog size

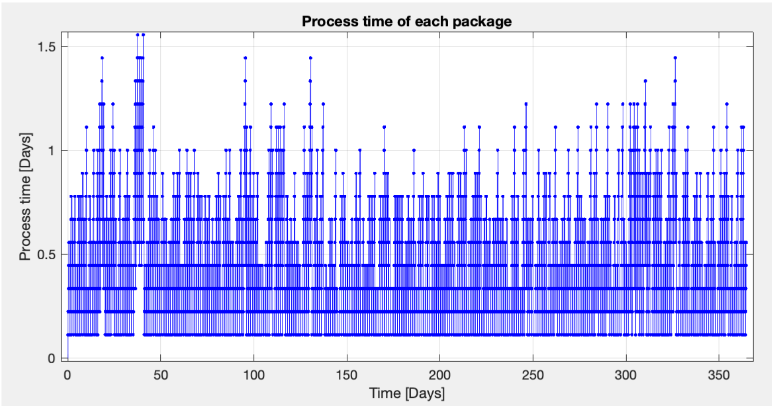

Figure G.6: The TAT per package

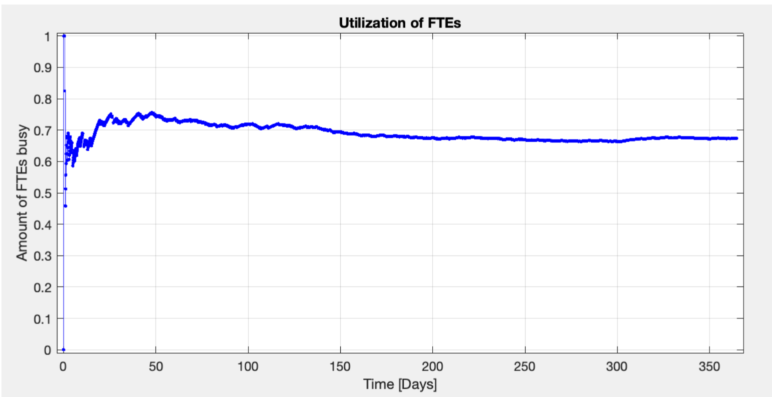

Figure G.7: The FTE Utilization rate

The the scenario of a working rate of twelve is combined with 80% same day handling, and the input at 77% of 2019.

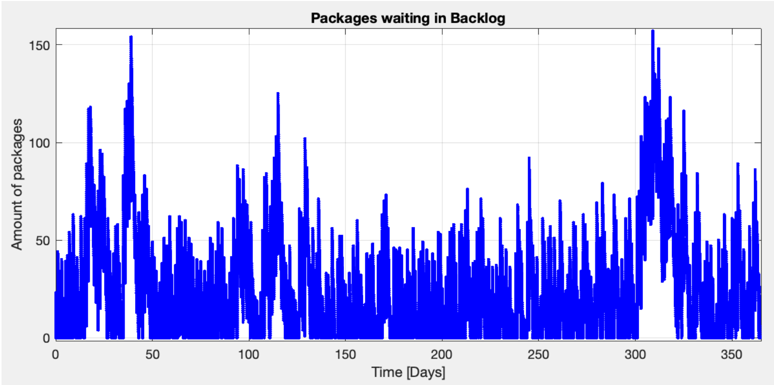

Figure G.8: The backlog size

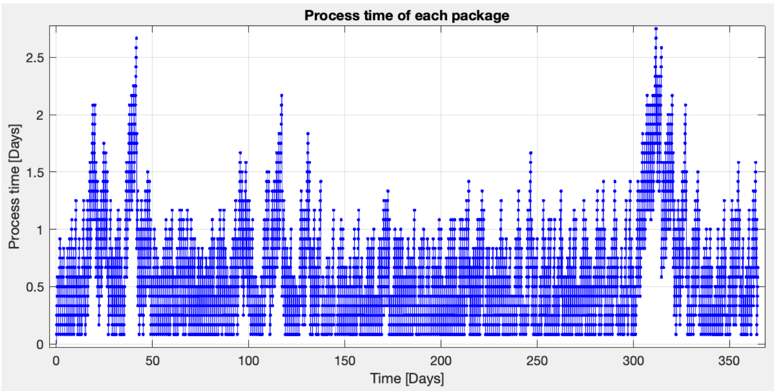

Figure G.9: The TAT per package

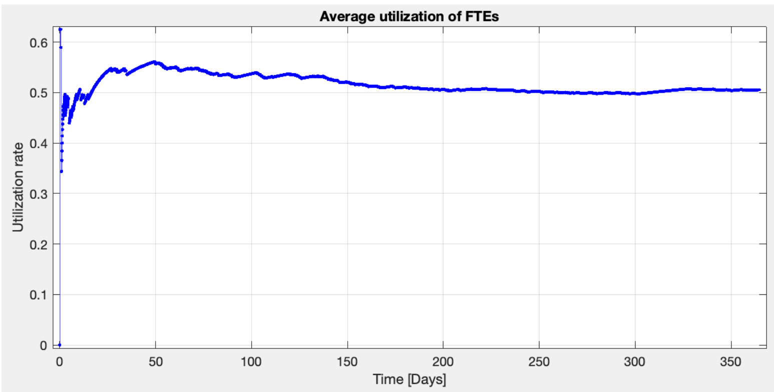

Figure G.10: The FTE Utilization rate

The last variation of the scenario based on 77% input with regard to 2019 is based on a working rate of twelve and a 90% same day handling concept.

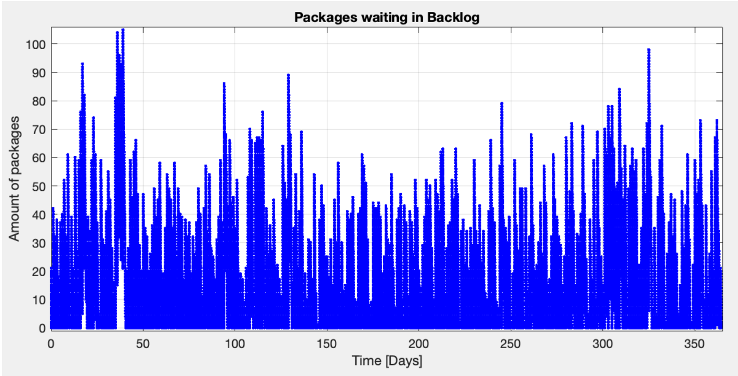

Figure G.11: The backlog size

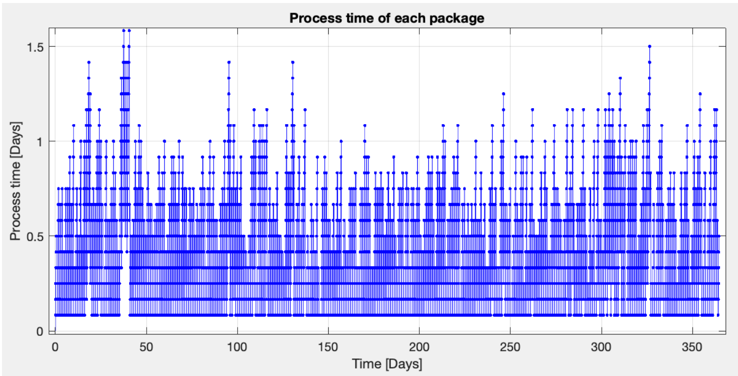

Figure G.12: The TAT per package

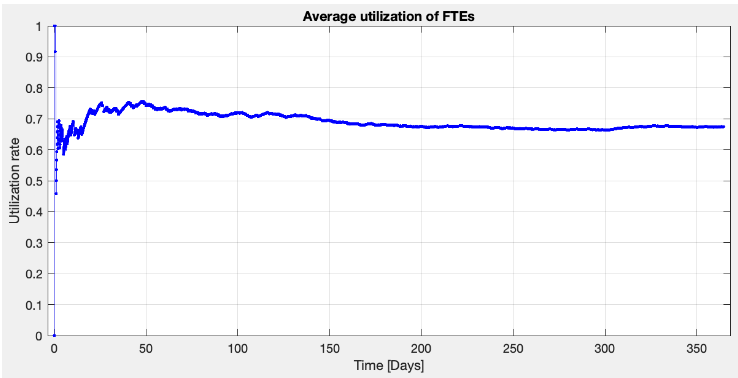

Figure G.13: The FTE Utilization rate

Then the scenario based on the same input as 2019 is evaluated, first with the variation of a same day handling concept of 80% and a working rate of nine.

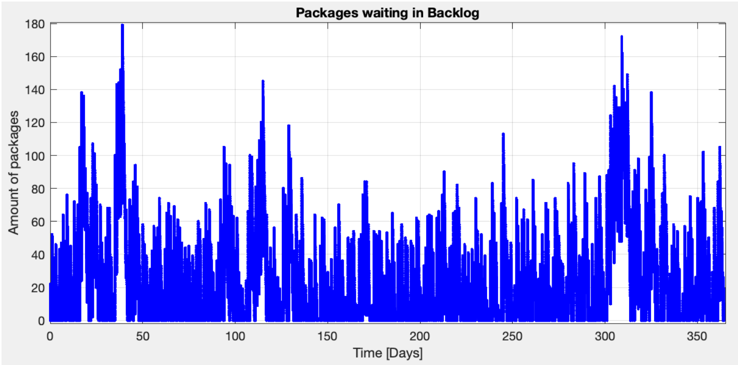

Figure G.14: The backlog size

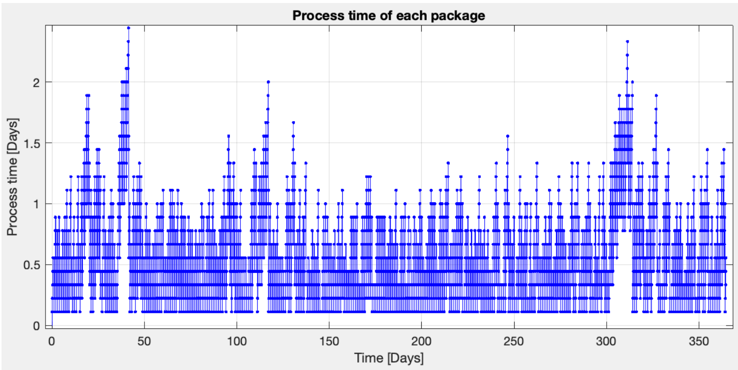

Figure G.15: The TAT per package

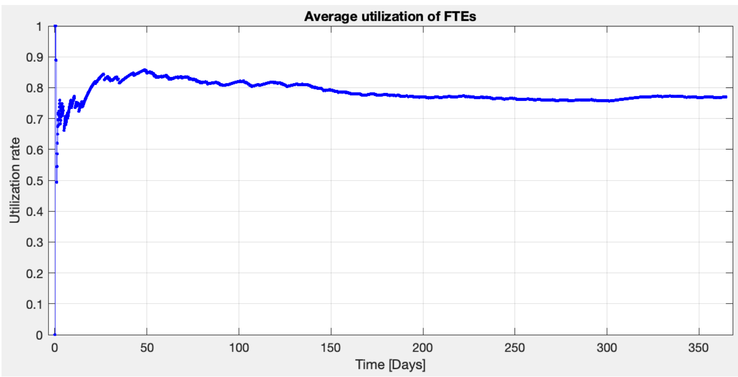

Figure G.16: The FTE Utilization rate

Next the variation still with a working rate of nine, but now combined with a same day handling concept of 90% is evaluated, based on the same input as 2019.

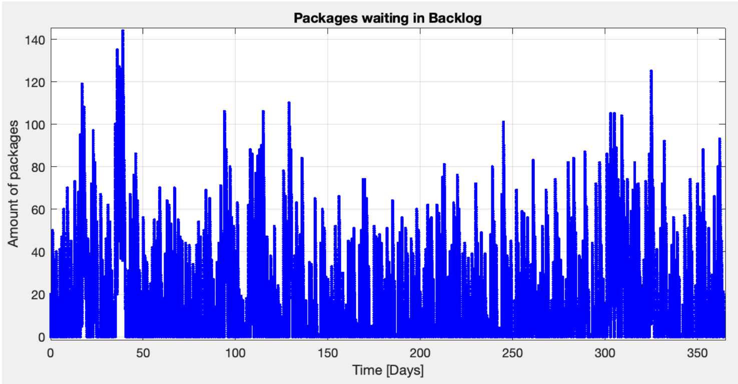

Figure G.17: The backlog size

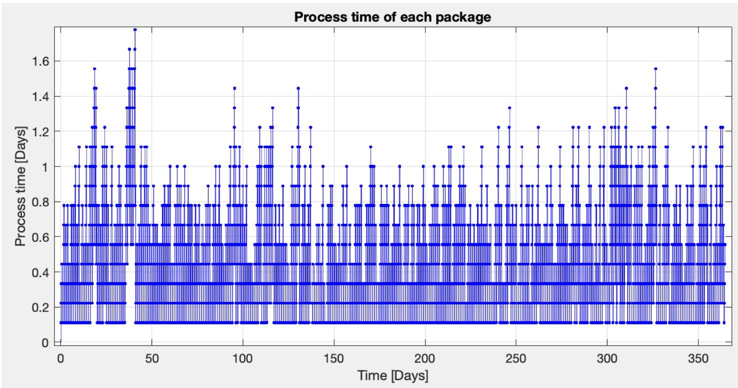

Figure G.18: The TAT per package

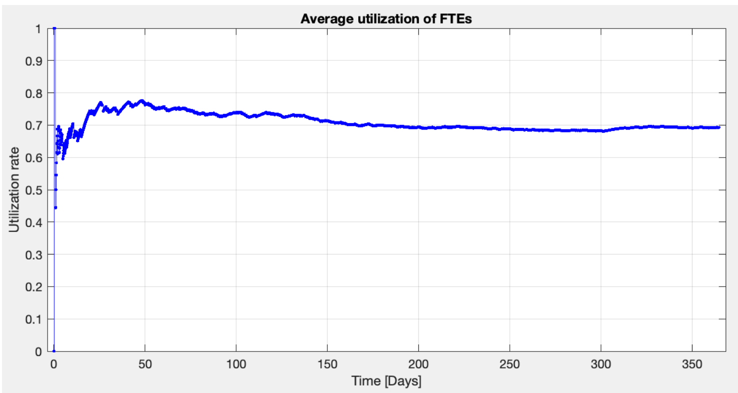

Figure G.19: The FTE Utilization rate

Then the variation based on a working rate of twelve and a same day handling concept of 80% is evaluated, still based on the same input as 2019.

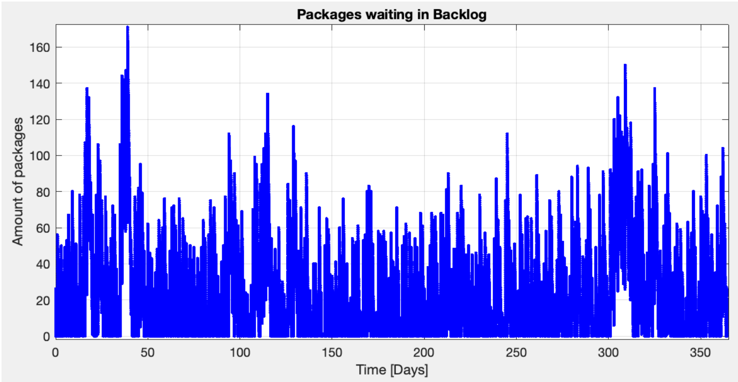

Figure G.20: The backlog size

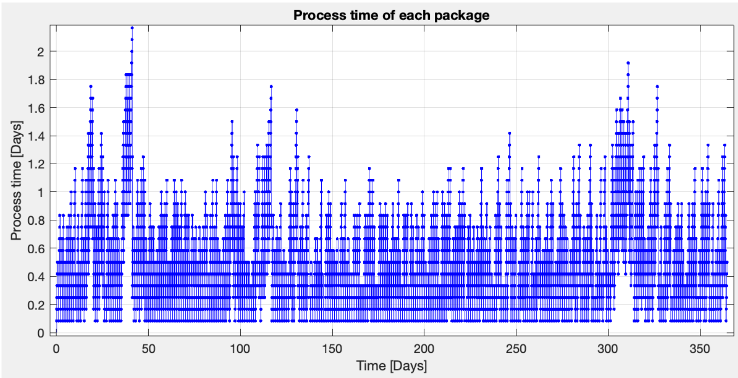

Figure G.21: The TAT per package

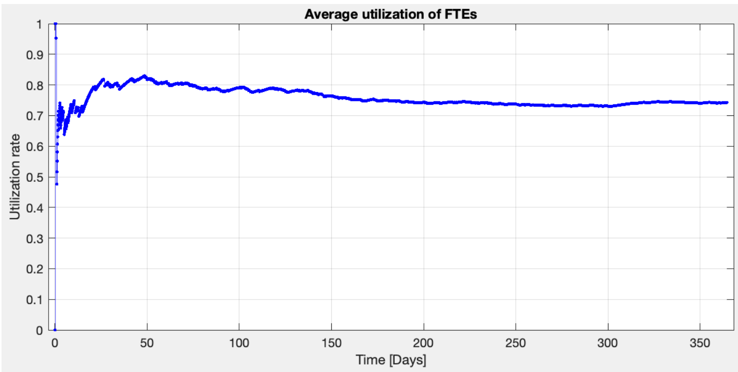

Figure G.22: The FTE Utilization rate

The next variation is based on a working rate of twelve, combined with 90% same day handling. Still based on the same input as 2019.

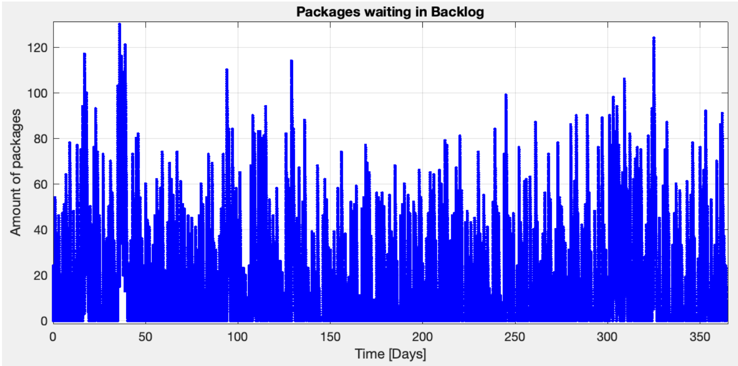

Figure G.23: The backlog size

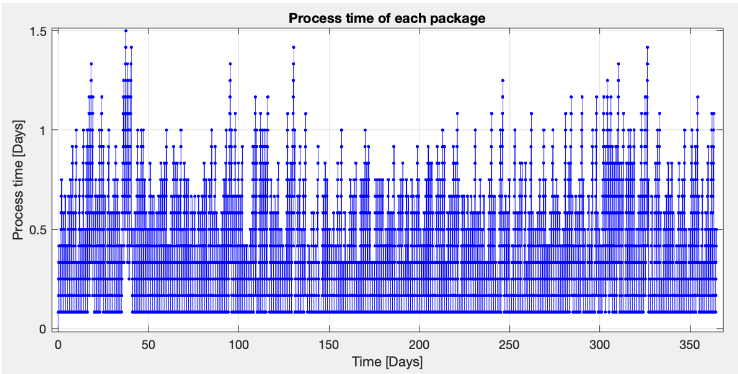

Figure G.24: The TAT per package

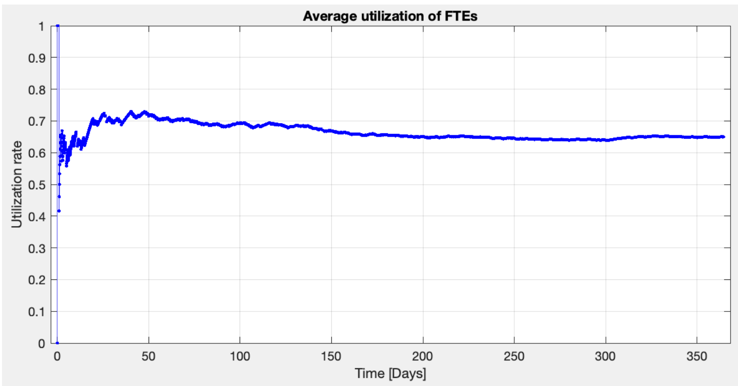

Figure G.25: The FTE Utilization rate

Then the scenario based on more input is evaluated, this is set to be 125% of the input of 2019. The first variation is again based on a working rate of nine and a same day handling concept of 80%.

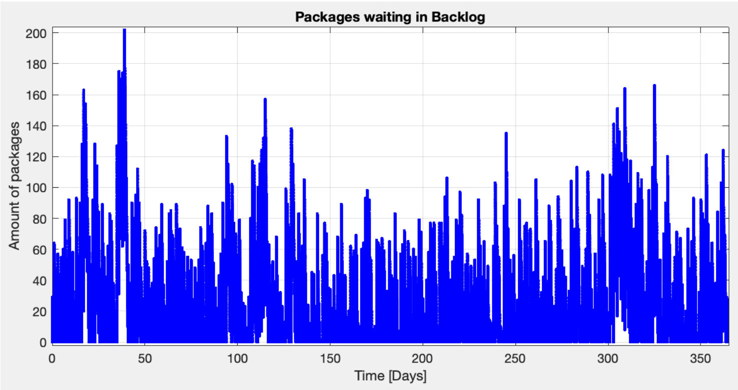

Figure G.26: The backlog size

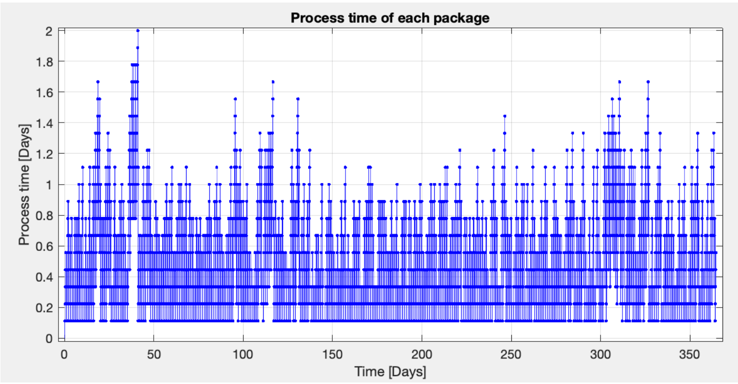

Figure G.27: The TAT per package

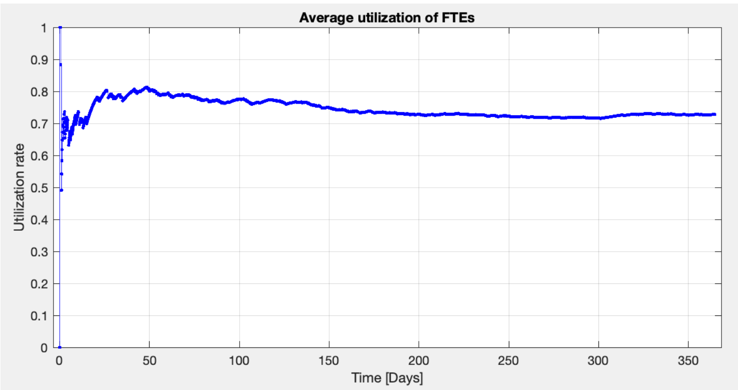

Figure G.28: The FTE Utilization rate

Then the variation with a same day handling concept of 90% combined with a working rate of nine is valuated. Still based on an input of 125% of that of 2019

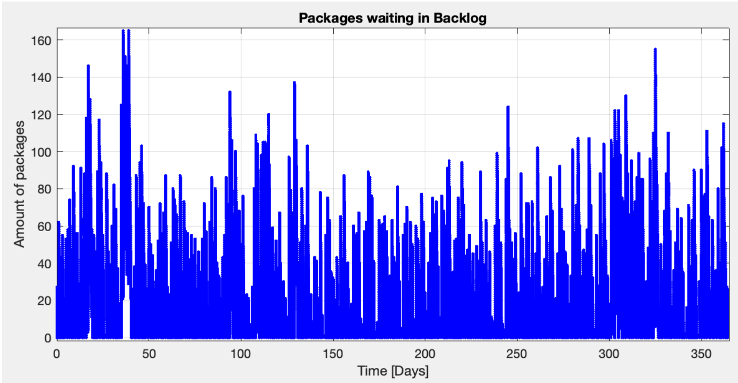

Figure G.29: The backlog size

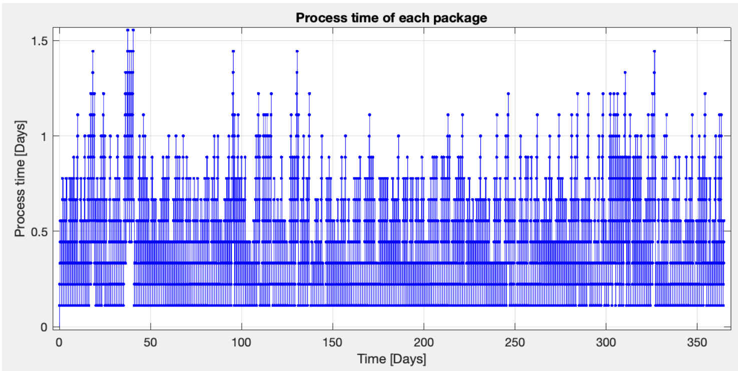

Figure G.30: The TAT per package

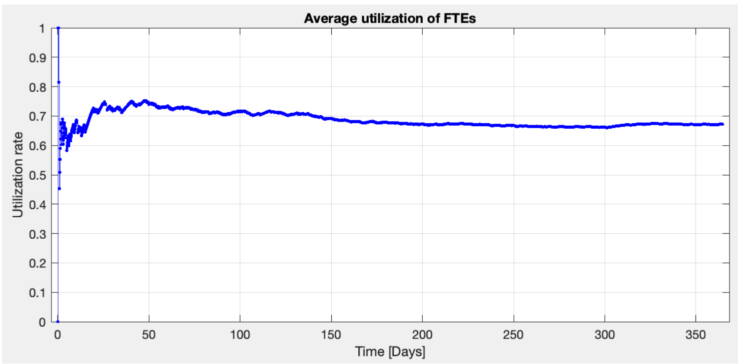

Figure G.31: The FTE Utilization rate

Then the variation based on a working rate of twelve is evaluated, first with a same day handling concept of 80%. And still based on the input at 125% of 2019.

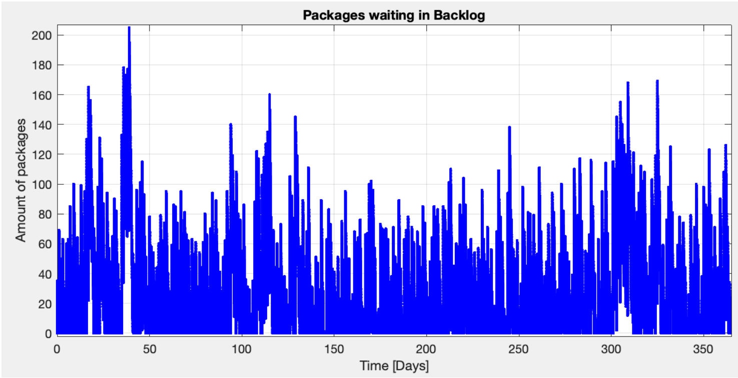

Figure G.32: The backlog size

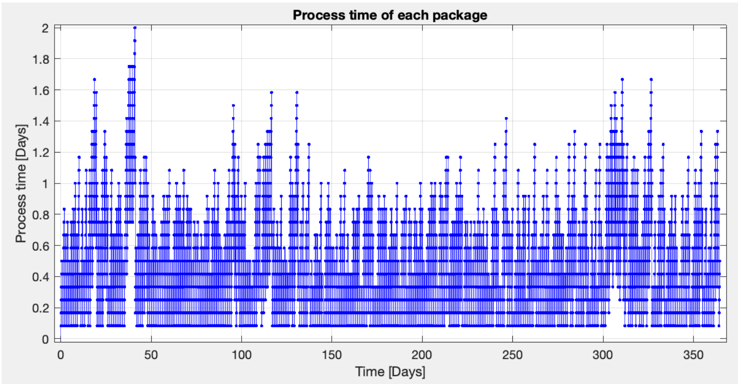

Figure G.33: The TAT per package

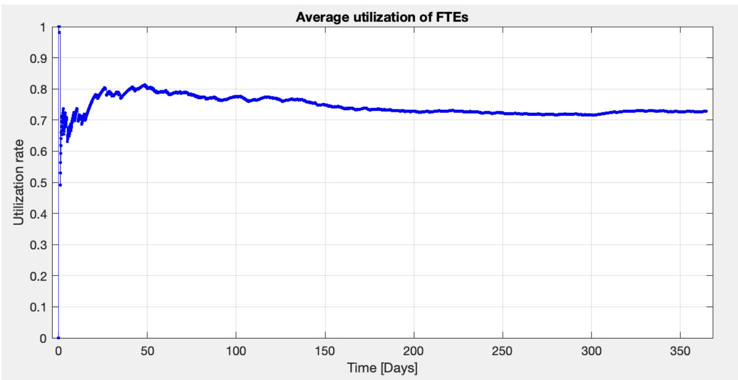

Figure G.34: The FTE Utilization rate

The last variation which is evaluated is based on a working rate of twelve combined with a same day handling concept of 90%, again at 125% input with regard of 2019.

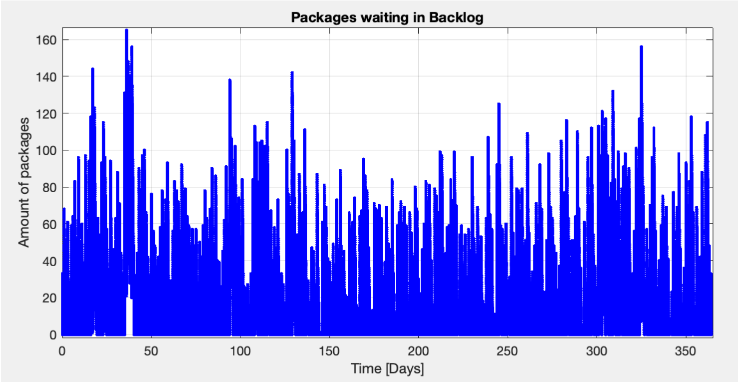

Figure G.35: The backlog size

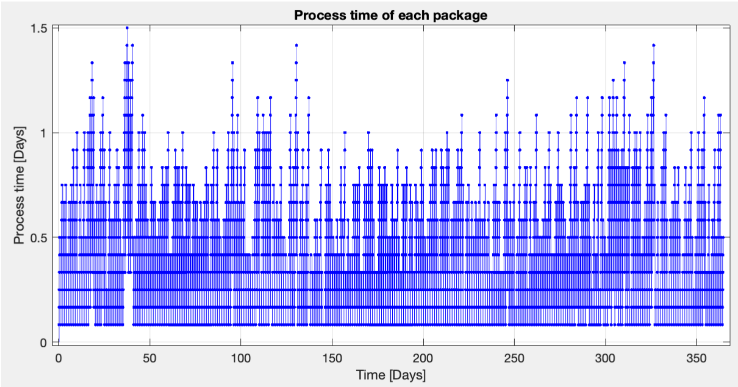

Figure G.36: The TAT per package

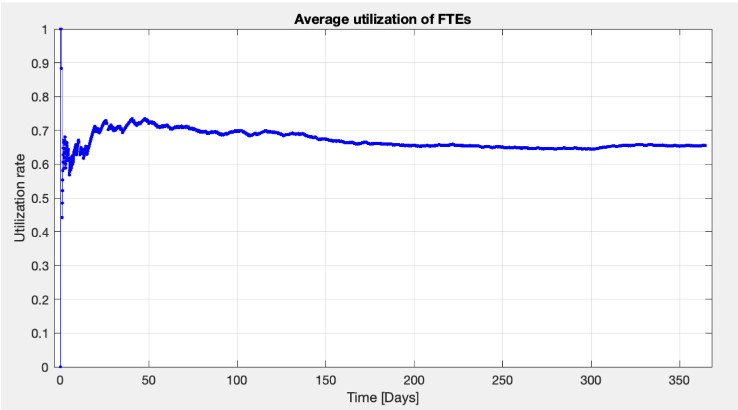

Figure G.37: The FTE Utilization rate

Designing a bottom-up Remanufacturing Process Control and Maturity Model for Airline MRO

Combining qualitative and quantitative aspects in a bottom-up designed control model

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Abstract

Purpose – In this day and age sustainability is becoming increasingly important. Even though the airline business is not the first thing which comes to mind when regarding sustainability there are huge efforts in play to extend the life of airplanes and its corresponding components. This is done via remanufacturing. Remanufacturing can here be defined as:" Returning a used product to at least its original performance with a warranty that is equivalent to or better than that of the newly manufactured product" (Gunasekara, et al., 2018). Even though numerous attempts using traditional techniques like Lean have been tried at KLM E&M, none have yielded the long term desired results, which is why a different approach is needed. Remanufacturing brings numerous problems with it, unknown to traditional manufacturing (Guide Jr & Daniel, 2000). These problems result in the operational level of the organisation not having control over the process, which leads to subpar performances. Furthermore, a gap originates between higher level management and the operations, which leaves a lot of potential uncovered as well as discourage operational level progress. The proposed model is designed to help gain control over an uncontrolled process, improve its performance and sustain the newly found control, which is also the purpose of this research. This is all achieved using a more bottom-up integral approach. This proposed model is combined with the operational lean maturity model developed by Maasouman (Maasouman, 2015), in order to create a Remanufacturing Process maturity model, which indicates the maturity level of each aspect used in the Remanufacturing Process control model, resulting in a model which has both quantitative and qualitative aspects.

Design/Methodology/approach – The proposed model has been designed as a result of a literature study combined with two separate case studies performed at KLM Engineering and Maintenance (E&M). The literature study was used to identify the gap, as well as provide elements which must be included in the to be designed model. After this the case studies served as practical experience. These case studies were chosen to be dissimilar, since one of the design criteria of the model was to be widely applicable. The case studies both had unique problems, which the to be designed model must be able to fix. Taking these possible problems into account, combined with the findings from the literature was the base for the model. The main research question was formulated as follows: *How to control, production performance on operational unit level using a Remanufacturing Process control model?*

When the model was designed it had to be tested. This was done by means of a discrete event simulation. One of the case studies was replicated in the Simulink environment, after which the uncontrolled state, last fully measured in 2019, was compared to twelve different future scenarios on numerous key performance indicators (KPIs).

Findings – Based on the combination of literature and practice it was possible to create a Remanufacturing Process control model which aids in getting control over an uncontrolled process, improves its performance and sustains this control. Furthermore, it was possible to combine the Remanufacturing Process control model with aspects of the Lean maturity model to create a Remanufacturing Process maturity model, which on its own aids in the implementation of the

Remanufacturing Process control model. The simulations were all very promising. The service level, or on time performance, of the worst performing variation was still 22% higher than the uncontrolled state, and the best performing variation was 38% higher.

Research limitations/ implications – This research is limited to the airline maintenance repair and overhaul (MRO) sector. The model is in theory applicable to the entire remanufacturing industry, further research could test this.

Practical implications – The time span of this research became a limitation to test real life results. A base line has been set for the oxygen bottle shop, which started the implementation of the model, but further research at a later interval should test if progress has been made.

Social implications – All parties involved in a process must understand the model fully before further steps can be made, people often want to rush progress however, so this should be monitored closely.

Originality / value – Using a bottom-up approach for process control in a remanufacturing environment is a novel idea, combined with the strategy chosen for uncovering potential in a process, results in a completely new method for process control. Combining this process control with maturity is also not been done before. Lastly the way Process Quality is used as a KPI is also original.

Keywords: Remanufacturing Process Control Model, Remanufacturing, Airline MRO, Maturity Model

Paper type Case study

1. Introduction

In the current day and age sustainability is getting increasingly important. Even though the airline business is not the first thing one thinks about when considering sustainability great efforts are in place in order to make the industry greener. One place where this is evident is in the airline Maintenance Repair and Overhaul (MRO). The airline MRO business is a remanufacturing business, which means it keeps extending the life of parts which are used up. This of course benefits the sustainability since new parts are needed less often, resulting in less production of said parts. Accompanying the environmental benefits remanufacturing also has economic benefits for a company (Zhang, Ao, Cai, Jiang, & Zhang, 2019) as expensive new parts have to be purchased less often, and planes are operational longer.

It is clear that remanufacturing is an important business for any company, but for airlines it is paramount, since airlines lose huge amounts of money every day their planes are unable to fly. In the airline MRO business, there is thus an enormous pressure to fix broken parts as fast as possible, while still retaining the quality needed to ensure safe flight. The pressures on European airline MRO businesses do not end there, with rising airline MRO companies in Asia, offering cheaper repairs due to low labour costs, along with high quality repairs and a low Turnaround Time (TAT) (Rodrigues Vieira & Lavorato Loures, 2016). Combine this with an expected aircraft fleet growth (Gelhausen, Berster, & Wilken, 2021) and it becomes abundantly clear that the European airline MRO market has to become more efficient in order to survive.

One such company which recognizes this need for improvement is KLM Engineering & Maintenance (E&M), a part of Air France Koninklijke Luchtvaart Maatschappij (AFKLM). KLM E&M is one of three subsidiaries of AFKLM, along with its passenger and cargo businesses. KLM E&M has three main departments, which are Airframe, Engine Services (ES) and Component Services (CS). This research is conducted within the Component Services department. The component services department of KLM E&M receives broken parts from both KLM's own fleet as well as other airlines. Since aircrafts on ground can cost airlines an estimated $150.000 per day (Seymour, 2019), it is desired to not have to wait on one broken part to be repaired. In order to avoid this wait KML E&M uses a pooled system. This means having large quantities of working, parts in stock which get send to the customer as soon as the broken part arrives. This broken part is then repaired and put in stock. This ensures short wait times for the customer but does result in large investments necessary to keep working parts in stock. If the turnaround time (TAT), the time it takes to repair a component, would be shorter the stock level could be brought down, resulting in both extra revenue through freed up capital, as well as more work being able to be handled per year, resulting in more income.

It is thus clear that reducing the TAT is ultimately beneficial for the entire operation. The aim of this research is to design a model which does this. One important aspect of improving a process which often gets overlooked is the fact that there must be control over the process first, as it is impossible to improve without having control. Hence, the model must also aid in getting control if necessary. Lastly, as (Liker & Rother, 2011) showed, only about 2% of organizations which implemented a Lean track saw the anticipated results when checking later on. This percentage is low because most companies loosen grip over the process as soon as the first results show improvement, which causes the process to fall back to old habits. So lastly the Remanufacturing Process control model must also encapsule a method for sustainment of control. One aspect aiding in this is making sure no new improvement tracks get started when previous ones are not yet the new standard. This can be achieved by monitoring the maturity of the process aspects.

This research is structured as follows, firstly introductory remarks are made in section 1, providing background information and the need from industry for this research. Next up in section 2 the literature will be examined, showing the gap which needs to be bridged as well as research existing theories related to the matter for design criteria. After this the two case studies will be examined in more detail in section 3. With theory and practice examined, the model design is described in section 4. Section 5 will show the verification and validation of the model through the used simulation. Section 6 will discuss the results of the simulation, after which the conclusion is shown in section 7.

2. Literature

The first aspect necessary to construct a Remanufacturing Process control model is defining what it is, this is done for production control in the remanufacturing environment by **(Bertrand & Wortmann, 1981)** as follows: ”production control includes long-range planning, product development, manufacturing process development, customer service control, factory-layout planning, transportation and physical distribution, manpower planning, materials supply control and materials handling, capacity planning, scheduling, loading, dispatching and expediting, and inventory control”. This shows that within production control for the remanufacturing environment much more than solely the (re)manufacturing of the product is encapsuled. The aspects which are directly applicable to the operational level of a remanufacturing organisation include: process development, manpower planning, capacity planning, materials supply, and inventory control.

In order to make sure the Remanufacturing Process control model tackles the problems tormenting the remanufacturing industry specifically it is paramount to know these problems, **(Guide Jr & Daniel, 2000)** listed the most common problems as: Uncertainty in timing and quantity of returns, disassembly of returned products, uncertainty of materials recovered from returned items, the need for a reverse logistical network, complication of material matching restrictions, variable processing times, stochastic routings for remanufacturing operations. From these problems design criteria for the eventual model can be determined. The operational level Remanufacturing Process control model must be able to handle a capricious input, and uncertainty of processing time.

As was mentioned the Remanufacturing Process control model will be based on a bottom-up design, instead of the traditional top-down. This is chosen since operational level managers have more knowledge of their process than high level managers. This enables the uncovering of the process's full potential. Furthermore, as (Solms & Thomson, 2011) established, there often exists a missing link in organisations, which causes a gap between high- and mid-level management, and operational level management. This is shown in Figure 1. Having a bottom-up approach for process control will avoid this gap, which eliminates the possibility of having miscommunications causing operational problems, as is currently the case.

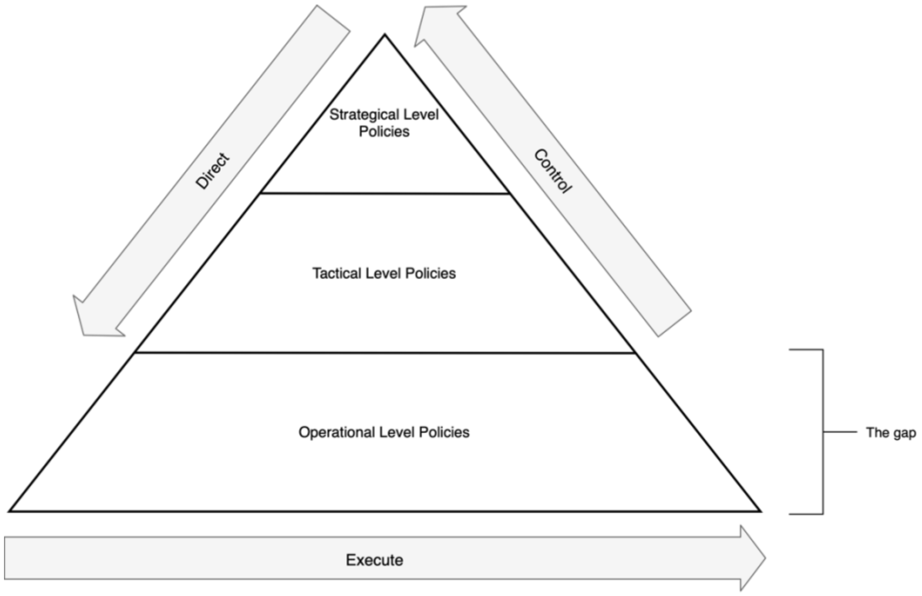

Figure 1: The gap between management levels in an organization (Solms & Thomson, 2011)

Then there is the research by (Maasouman, 2015) considering a Lean Maturity model. This research focussed on constructing a lean maturity model for the operational level of manufacturing cells. Since this research focusses on remanufacturing, it will not be directly applicable, but elements of the research will be. In his research Maasouman developed a framework consisting of maturity axes and levels. The axes were elements in the operational level of the organisation which could become increasingly lean. The levels were used to check how lean these axes were. The axes Maasouman distinguishes are: People, facilities management, working condition, production processes, quality, just in time and leadership. These different axes were tested on leanness according to four different levels, which from least to most lean are: Understanding, implementation, improvement, and sustainability.

One other aspect which usually causes problems is the sustainment of control. Sustainment of mainly Lean improvements is often a bottleneck for companies, as is also shown by (Turesky & Connell, 2010), causing processes to go back to their original state (Bateman & David, 2002). The first aspect of importance is thus to make the new way of working the new work standard (Habidin, 2012). Then there is the problem of management not being prepared for the future. In order to combat this, planning is crucial, as (Tapping & Shuker, 2002) showed. Mapping out the future state of the process enables an organisation to be ready for it, making it possible to plan ahead instead of reacting when it is already too late. One theory designed to ensure sustainment of lean culture was made by Hines (Hines, 2010). It states that sustaining lean culture can be compared to an iceberg, since most of an iceberg is underwater and thus invisible. However, without this part underwater the visible part would of course sink deeper. The most important part is thus the invisible part. For lean culture sustainment this boils down to the focus needing to be put on Strategy and alignment, Leadership and Behaviour and Engagement. The to be designed Remanufacturing Process control model must thus include a short-term sustainment aspect, through creating a new work standard, and a long-term sustainment aspect through planning, while keeping strategy, leadership and behaviour in mind.

3. Case studies

In order to develop the Remanufacturing Process control model two case studies at KLM E&M were conducted. This experience from practice shows first hand which aspects a Remanufacturing Process control model must be able to solve. The two case studies were conducted at the oxygen bottle shop and the logistic handling area. The choice for these shops came to be as follows, one of the requirements of this model was that it would be applicable to any shop at KLM E&M, and even in any remanufacturing environment. To achieve this the two case studies were chosen to be as dissimilar as possible, which inside the component services environment came down to these chosen shops. Furthermore, it was important that both shops had unique problems, as to design the model as versatile as possible.

First to examine the oxygen bottle shop. The oxygen bottle shop is a traditional remanufacturing shop, as it receives broken or empty oxygen bottles and smoke hoods, repairs or fills them and then they get send away, usually back into the storage pool. The shop is relatively small, consisting of only 3.5 full time equivalent employees, or FTEs. At the moment the service level of the shop is relatively okay, but it has been systematically going down for the past years, as is visible in Figure 2. This is cause for concern as the input has also been going down but is expected to go back up with flights going back up. The systematic descendance of the service level denotes there are problems in the shop. When analysing the shop, it shows that both the equipment and the manpower currently available are plenty for the current input and can even handle growth. Furthermore, the material required for repairs is kept at a three-month storage level, meaning there must always be enough storage to handle three months of work. This all indicates that the problems for the oxygen bottle shop come from the method used to control the processes rather than the resources utilized. When examining this further it turns out no control strategy is in use at the moment, coinciding with the findings from the analysis.

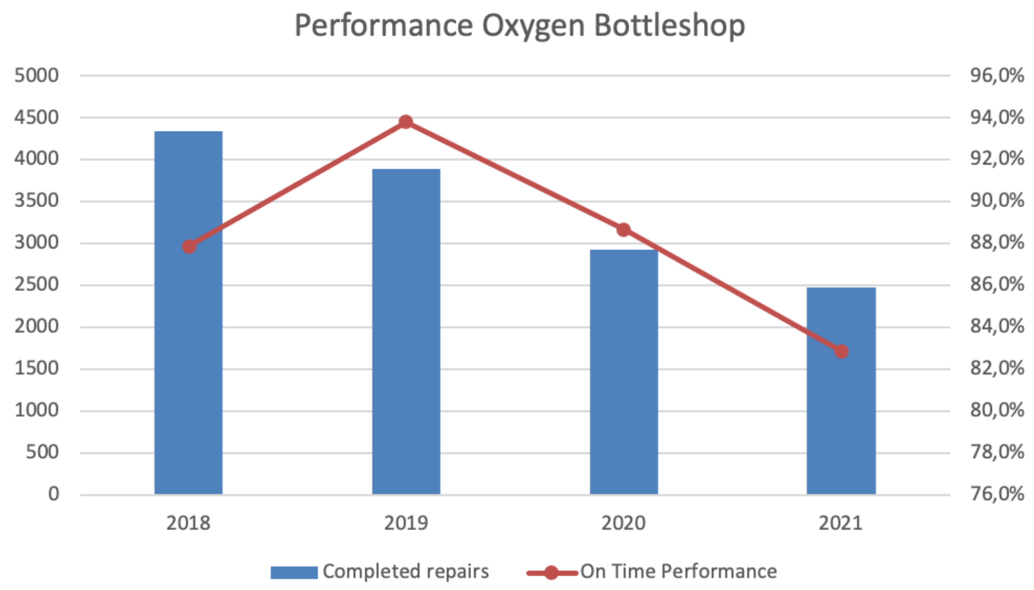

Figure 2: The performance and input of the oxygen bottle shop over the last 4 years

Then there is the logistic handling area. As was mentioned, this is a very different environment than most shops at KLM E&M. The logistic handling area handles all ‘clean’ parts, meaning all the parts which either are repaired or new buys. The clean packages get visually inspected to see whether the indicated component is in the package. If this is the case and no other flaws can be spotted the administrative tasks can begin. This is done by encoding specific information to the product ID. The logistic handling area is a much larger shop, as it has about thirty people on the payroll. The major problem which the logistic handling area faces is the backlog. The ambition set out by KLM is to handle all incoming packages the same day as they come in. However, at the moment this takes about two weeks. This results in a backlog forming. The root cause for this delay in handling must thus be found. When examining the resources, it quickly becomes evident that there is a manpower problem, as there are no real other equipment or materials used in the process. When examining the manpower further it shows that in theory there are enough FTEs, but they are not trained or distributed equally, especially this distribution of manpower is a problem as is visible in Figure 3. Constructing a proper manpower plan is thus necessary.

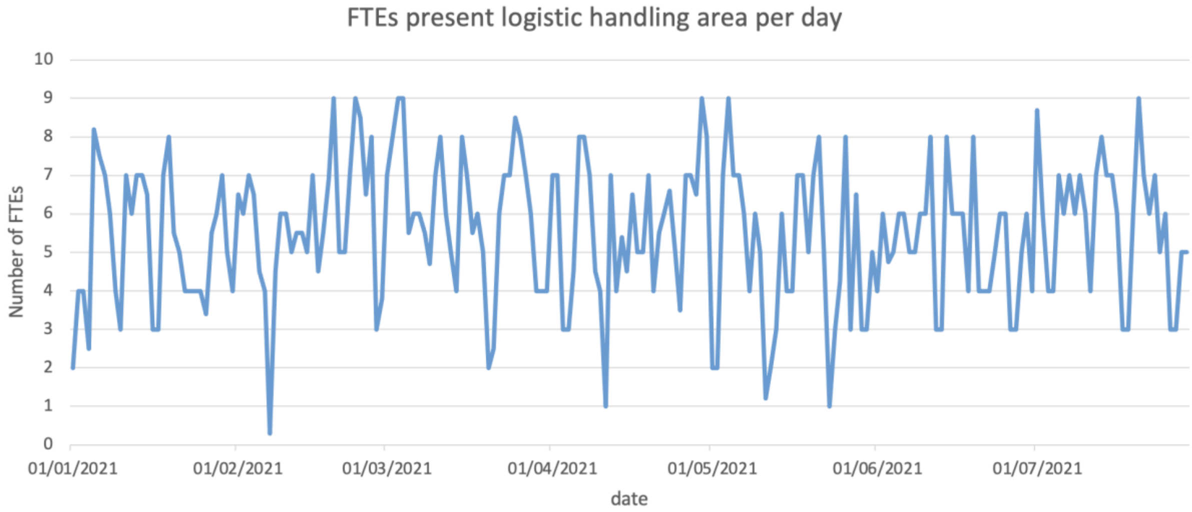

Figure 3: The amount of FTEs present in the logistic handling area per day in the first months of 2021

Research questions
Based on the combination between literature and practice the main and sub research questions can be formulated. The main aim of this research was to develop a model which aids in gaining control, improve performance when control is gained and to sustain the control/improvements, which is why the main research question is formulated as: *How to control, production performance on operational unit level using a Remanufacturing Process control model?* In order to answer this some sub research questions need to be answered. These are:

1. What requirements for design must the model include?
2. How can the maturity of the model, for future improvements, be assessed?
3. What pitfalls for implementation must be avoided?

4. Model design
The proposed model is built up as a road map which managers can follow step by step. The specific methods have been chosen to be easily implementable, without any specific training required, as is the case in some Lean or Six Sigma methods. The proposed model is shown in Figure 4.

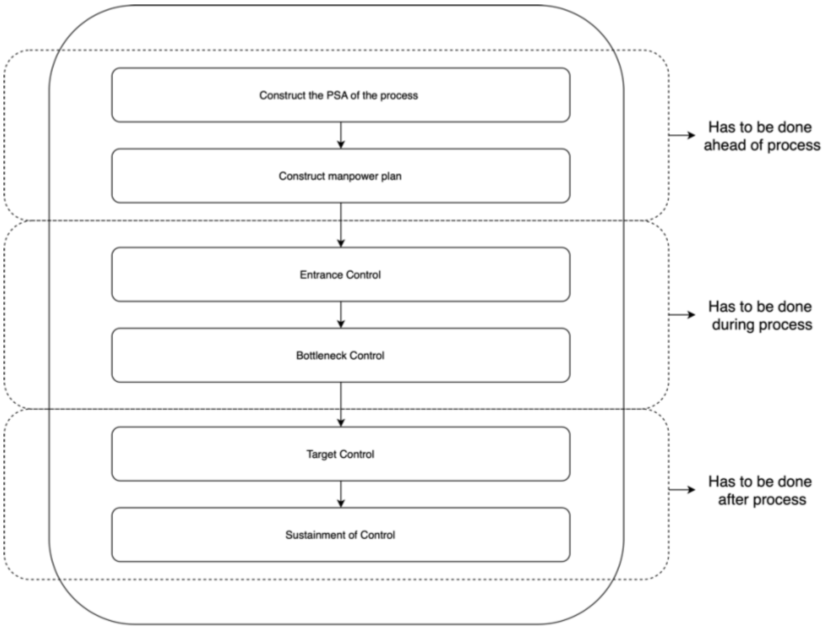

Figure 4: The proposed Remanufacturing Process control model

As is visible the model consists of three different intervals, before, during, and after the process. These intervals are not set in stone but help create a clear path which managers can follow when trying to get a grip over their process. The first interval, ahead of the process, has to be done in order to create the parameters on which the new process rests. The during the process interval is there to make sure the process is being performed as designed, not letting too much work in, or have unexpected bottlenecks build up. The after the process interval is there as a check to see if everything is going as designed, as well as help sustain the control over the process.

PSA

The first step which needs to be taken is constructing a Process Stream Analysis (PSA) of the process. In this PSA all the separate steps of the process become visible, as well as the touch times, process times and waiting times. The touch time is the time an employee is working on a product and can't do anything else. The process time is the time a product has to spend, but there cannot be any work done on the product, like paint drying. Waiting time is the time a product spends waiting for a next step when the product itself is ready for that step. Constructing a PSA shows where the process is lacking through the waiting time. Eliminating this waiting time is crucial for process improvement. When this waiting time is eliminated, a new TAT can be determined, upon which the future state of the process can be based. Using this method shows the hidden potential of a process.

Manpower plan

With the PSA constructed the next step is to construct the manpower plan for the process. In order to construct the manpower plan a few key pieces of information must be known. First of all, the amount of FTEs and their relative skill levels. Next to this the newly determined TAT and lastly the amount of incoming work. With these ingredients it can be determined how many FTEs must be present on which days to achieve the newly set TAT target. It is important to pick a strategy when constructing the manpower plan. Especially in the remanufacturing environment the amount incoming work is capricious and trying to exactly predict how much work is coming in when is nearly impossible. This is why in most cases it is better to choose a percentage of days in which the work should be able to be handled. Lastly it is important to have Out of Control Action Plans or OCAPs for when the input is too high for a sustained period of time. Already knowing what options are available when the process is overloaded makes it easier to implement said options when needed.

Entrance control

Then there is the entrance control. This is a vital step in order to keep a process operating smoothly. The necessity for entrance control is most apparent in processes which span multiple days. In these processes the first steps are usually administrative and can be performed quite quick, but down the line the steps get longer and more involved. At this point it is paramount to not stuff more work into the process than it has been designed to handle, otherwise a backlog will arise somewhere in the middle of the process, causing a bottleneck to clog up, resulting in a disturbed process. Entrance control at shop level brings along a second aspect, which is not allowing irreparable parts into the process. If a part is damaged beyond repair it should not be allowed to enter the process, otherwise man hours will unnecessarily go to waste. For the input check of a process, it is thus important to focus on the state of the products, as well as the number of products entering the process.

Bottleneck control

Next to the entrance control it is also important to keep a close control over the bottlenecks which might arise in a process. It is important to stay up to date on the possible bottlenecks of the process. The main bottlenecks which can arise if the manpower plan is kept up to date are regarding the equipment used or the material required. Therefor it is important to keep a close eye on these two elements. For the equipment used it is important to know what its capacity is, and what to do when this capacity is reached. It is also important to know what to do if the machine breaks down. For the materials traditionally a Just in Time (JIT) principle is chosen. This however is very industry specific. In the Airline MRO components are very expensive and having the TAT increase because a cheap part is not available is economically undesirable. Therefore, a limit should be set up to which price parts should be kept in stock plentiful.

Target control

When the previous four steps of the model have been carried out correctly the process should be under control and performing as desired. If the model is not performing as desired, it means something is wrong. This can be checked using target control. Using target control also transforms the control from being static to dynamic, which allows for changes to be made if necessary. Having too many KPIs is undesirable as they can cloud judgement and make it difficult to see which KPIs really matter. Therefor it is opted to look at only three different KPIs, which are: the amount of work completed on time, the amount of work waiting to be handled and the TAT of the process. The amount of work which was completed on time is a great indicator of how the process is performing. This is also called the service level. It is desired to have a service level of at least 90%. Then there is the amount of work waiting to be entered into the process. If this keeps climbing, then there is a problem with the designed process. It could be that the input has increased, in this case the process needs to be redesigned. This will show via the KPI. Lastly there is the TAT of the process. In most cases the contractual TAT is higher than the theoretical lowest TAT, so just looking at the amount of work completed on time does not paint a complete picture regarding the process. This is where a new KPI is introduced as well, the process quality KPI. Process quality is usually used as a resulting KPI, but now proposed to be used as a KPI necessary for steering a process. For process quality to be high it is necessary to have a stable lowest theoretical TAT without using OCAPs. If this is the case the process can be said to have a high process quality, if process quality is low, it means there is still room for improvement within the process and changes must be made.

Sustainment of control

Lastly there is the need to sustain the control over the process. This is an aspect in which most companies fail. The sustainment of control can be divided into two segments, long term sustainment and short-term sustainment. For the short-term sustainment it is important to make the new way of working the standard. This is achieved by utilizing a check-in check-out system. At the start of each shift, it is important to take some time to talk all employees through their coming shift. Most employees are used to a certain, non-optimal, way of working, focussing on the wrong tasks at the wrong times. In order to combat this their day should be planned out and this planning should be followed. At the end of the shift there should be a check-out where it should be confirmed whether the tasks were completed successfully and if not, why not. In the beginning this whole process will take some time, but within some weeks it will be second nature, meaning that it has become the new standard.

For long-term sustainment a different approach is needed. It is a common phrase that failing to plan is planning to fail, yet, at the operational level of organizations no form of business plans gets made at the moment, and even the inclusion of operational level managers in the construction of plans higher up is rare (El-Masri *et al.* 2015). Since operational level plans are not utilized at the moment it is difficult to asses their effectiveness. However, all the separate shops in a big organisation have their own employees, their own way of working and their own area. This resambles being a standalone small company. Such a comparison is also made by (Beelaerts van Blokland & de Jong, 2016), showing it can be beneficial to disconnect shops from the overall organisation for such comparisons. And as (Perry, 2002) concluded, there is a strong correlation for small companies in not writing a business plan, and the company failing. Hence, the future potential plan is introduced. The future potential plan is in essence a more practical business plan. In it must be concluded:

1. Observation of the shops and insight in the current production that is being achieved
2. If service level is not up to standard, how will it get it there?
3. What is used to achieve that production in terms resources?
4. What is the potential of the process with current resources as well as the future goal of this process?
5. What is the growth potential per resource?
6. What is the financial gain of the governed process and the grown process?

Where step one is used to establish the starting point of the process. Step two is necessary if performance is subpar. It shows the first steps necessary to get performance back on track. Step three shows how used-up each resource (e.g., manpower and equipment) currently is. Step four extrapolates the capacity of each resource to 80% of the maximum, since (Haak, 2019) showed that filling a process for more than 80% of its lowest bottleneck makes it fragile and shows the possible performance. With this possible performance a goal can be set. Step five shows how to expand each resource and the time it takes (e.g., hiring more manpower and training them). Lastly, step six shows the financial side of the possible growth, taking extra revenue, freed up capital and extra costs into account. One important aspect is the actual utilization of the plan. As (Karlsson & Honig, 2009) showed, business plans rarely get used after they have been constructed. As the future potential plan is much more aimed at answering the question ‘How can the performance improve?’ instead of ‘What performance is expected?’ it takes on a role of guiding the coming year, instead of trying to predict it.

Remanufacturing process maturity model

Lastly, the Remanufacturing Process control model can be combined with the lean maturity model to create a Remanufacturing Process maturity model, as shown in Figure 5. Often organisation rush into improvement tracks, before the ongoing improvement is even finished. In order to make sure that no new improvement track gets started prematurely the Remanufacturing Process maturity model can be used. This model shows the aspects of the Remanufacturing Process control model, combined with the levels of the lean maturity model. It is combined with a checklist to establish the maturity level. If all questions for one aspect can be answered ‘yes’, then that aspect has achieved that level of maturity, this checklist is added in the Appendix. Before a new level should be entered, all aspects of the Remanufacturing Process control model should be on the previous level. One aspect which differs from the lean maturity model by (Maasouman, 2015) is that sustainability is a level below improvement in the proposed Remanufacturing Process maturity model. This is done again to avoid improvement tracks being started before the previous improvement track becomes the new standard. Combining the lean maturity model with the Remanufacturing Process control model provides managers with both a qualitative and quantitative evaluation of their process.

Control sustainment				
Target Control				
Bottleneck control				
Entrance control				
Manpower				
PSA				
LEVEL	Understanding	Implementation	Sustainability	Improvement

Figure 5: The Remanufacturing process maturity model

5. Simulation & results

With the model completely designed and described it is ready to be tested. Since there is no time to run a pilot test in real life this has to be done based on discrete event simulations. The first step in evaluating the model and its performance is verifying that the model is right, and that the simulation used to check its results is correct. For the model this was done by first evaluating the model requirements, and to check whether it fulfils these. After this the simulation is evaluated in twofold by experts, checking whether the simulation has been constructed correctly, and checking whether the simulation matches reality closely. In both separate expert verifications, the simulation turned out to be correct. Next to the expert verification, which is more qualitative, there was also a quantitative verification performed. This was based on cause-and-effect relations which the simulation should perform correctly. All of the pre-defined relationships were simulated and behaved exactly as expected. With this the verification of the model and simulation was completed.

With both the model and simulation verified the validation could take place. With validation the aim is to answer the question is the model right? The model was designed to get control and to improve performance. In order to test if the model was right, it thus had to be tested if it performed those tasks. To test this a comparison against an uncontrolled state had to be made. For the uncontrolled state the year 2019 has been chosen, since this was the last year pre-COVID, showing the truest representation of the process, it had a fairly complete data set, and it was completely before the implementation of the CS 2.0 project. Even though it had the most complete data set of the past years there were still some crucial figures missing, like the TAT and thus the service level. These were determined using the simulation and the parameters of 2019. For the future states three different scenarios were introduced, the first based on the expectation of KLM E&M regarding the input of 2022, which was 77% of the input of 2019. The next scenario used the exact same input as 2019, and the last scenario used 125% of the input of 2019, which is an input higher than has ever been experienced or is expected in the near future. Then the KPIs on which the comparison could be based were determined. These were chosen as the backlog percentage, the TAT and the FTE utilization rate. The backlog percentage is defined as the maximum amount of packages in the backlog divided by the maximum amount of packages which came in on one day. This percentage will thus always be at least 100%, the closer the number is to this 100% the better the performance is. FTE utilization rate is the time an FTE is actually working, as input is capricious there will be times when FTEs are dormant, an FTE utilization rate of around 75-80% is considered ideal (Goldratt, 1990), but generally it is better to be lower rather than higher. Through these figures the service level of the process could also be determined, which gives a quick look in how well a process performs. Before running the simulations one last aspect is of importance. In the manpower plan it was introduced that when input is capricious, a percentage should be picked for the amount of days in which the process could be handled. For the logistic handling area this came down to either 80% same day handling or 90% same day handling. Furthermore, there is the expectation that the Remanufacturing Process control model, along with the new automated handling area will increase the productivity. For the last four years the working rate has been nine packages handled per FTE per shift. The expert expectation is that this working rate will increase to twelve. All different combinations of these factors were ran per scenario to cover all possible bases. When all of these different scenarios and variations were run the results could be evaluated, in order to answer the question if the model is right. For every scenario even the worst performing variation still well outperformed the uncontrolled state. With the worst performing variation of all having a service level of 82.3% and the best performing variation having a service level of 97.6%. The other relevant outcomes are shown in Figure 6. Based on the fact that even the worst performing variation still well outperforms the uncontrolled state the model is said to work as intended.

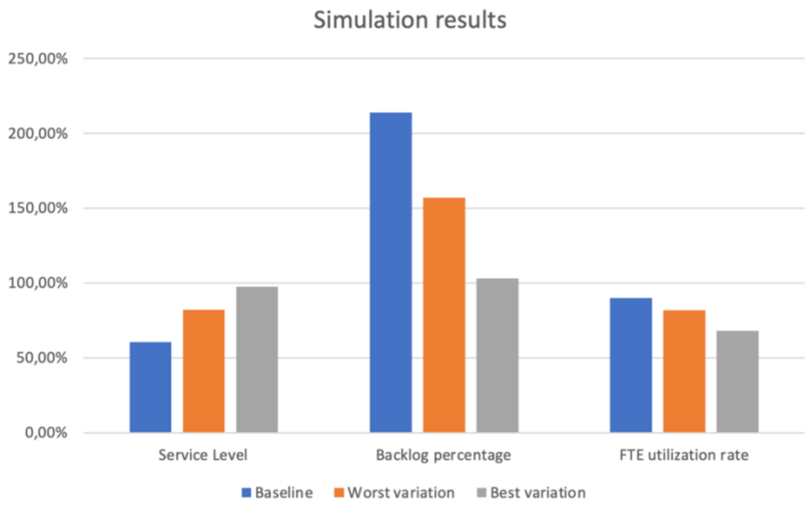

Figure 6: Results of the simulations

6. Discussion

The simulation shows remarkable improvements made in the service level and TAT of the process, but the question remains if this can be accredited to the Remanufacturing Process control model. An argument which might be against the Remanufacturing Process control model is that the future states simulate the process as it will take place in the near future, when the Component Services 2.0 project is fully implemented. This project automizes a big part of the logistic handling process, utilizing scanners, automatic backlog systems and a conveyor belt to transport the packages. However, when analysing the problems the logistic handling area faced the amount of manual labour was not necessarily the problem. As (Jelinek, 2013) showed, it is a popular misconception made by higher level management that automation leads to improvement. This is however a fallacy, as automation without control will yield no improvement. Hence it can be safe to say that the improvements are more due to the Remanufacturing Process control model, rather than just an automation track.

Implementation

The proposed Remanufacturing Process control model is already being implemented in the oxygen bottle shop. With this implementation some pitfalls rose which should be avoided, these pitfalls include the following problems:

The first problem arose when the shift planning was constructed. For one of the operations performed by the oxygen bottle shop a shared test machine is utilized. This machine is only available for the oxygen bottle shop on Monday, Thursday, and Friday, this however was unknown to the shift planner, so the first iteration of the shift planning could not be realized. Knowing these boundary conditions beforehand saves a lot of time and effort, so it is important to try and get all of these seemingly small conditions on the record.

Another problem which can come up during implementation is the fact that not every member of the team fully understands the need for the model or is hesitant regarding the implementation of it. The implementation of the model should be carried out by a small core team, of process owners and supporting staff. If one of the members of this core team has doubts it is paramount to remedy this before moving on, as any of these doubts will inevitably be transferred to the other employees. Only when all of the members of the core team fully understand and support the changes which are to be made, is it time to present the changes.

Then there is the problem of giving all of the responsibility to one member of the core team. It is important to have an even distribution of the tasks associated with implementing the model. Otherwise,

the situation will arise where there is one expert, and the other members knowing too little. Furthermore, having one person carry out too many tasks will inhibit them from doing their day job, as especially in the beginning stages of the model there is usually a lot of support required. The check in and out takes a long time in the beginning, and during the shift it is important to have someone walk by to answer any questions, and check if everything is still running smoothly.
Lastly, the team should not be discouraged by disappointing results when the model is just applied. Getting used to the changes takes time, and not all employees might be on board from the very beginning. This is all normal and part of the process. It is important to stick with the plan, and consequently stay on top of all important aspects like the check in and out. If this gets carried out the employees will start seeing the benefits of the new way of working and start to gravitate towards it more and more. If there is still an employee who is reluctant to give the new of working a real try this employee will, on the long term, be called out for it by his own colleagues, as they are all the victim of this employee's behaviour.

7. Conclusion

The aim of this research was to design a Remanufacturing Process control model which would aid in gaining control over an uncontrolled process, improve the performance of the process once control is achieved and which prevents loss of control through control sustainment methods. In order to design this model some sub questions were proposed which were:

1. *What requirements for design must the model include?* These requirements have been introduced as model aspects, which were: a PSA, manpower plan, entrance control, bottleneck control, target control and sustainment of control. Where a PSA gets constructed to get an end-to-end understanding of the process, as well as show where there is a lot of waiting time. Eliminating this waiting time has the potential to improve the service level of the process with little to no extra investment necessary. The manpower plan gets made combining the new theoretical TAT from the PSA with the amount of incoming work, keeping aspects like authorization and the percentage of same day handling in mind. Next to the manpower plan OCAPs are defined for the days when same day handling can't be achieved. Then there is the entrance control criterium, which works in twofold. First off, no more should be allowed into the process than it is designed to handle, and secondly broken parts should not be allowed into the process. Bottleneck control ties into entrance control, as one of the reasons for not over stuffing the process is to avoid bottlenecks clogging up down the line. Avoiding bottlenecks forming is important which is why it is necessary to keep a close eye on process capacity, if resources start getting to 80% capacity an expansion plan should be implemented. To see whether the model is implemented correctly target control is used. When checking the performance only three KPIs are necessary, the amount of work completed on time, the amount of work waiting to be handled and the TAT of the process. With these KPIs the resulting KPI process quality can be checked, as process quality is defined as a stable lowest TAT. Process quality traditionally only gets used as a resulting KPI, however, in this research it is suggested to look at process quality as an input KPI as well, if the process quality is not as desired even though the other KPIs are decent, the process can still grow. In order to not lose the control this model provided the last step is included, the control sustainment. For the short term this achieved using a check-in and check-out before and after every shift, ensuring the new way of working is enforced. For the long term a future potential plan is introduced, which is a road map made on the operational level of an organisation. Guiding a shop through the next year.
2. *How can the maturity of the model, for future improvements, be assessed?* It is desired to not only implement an improvement track and forget about it, but rather to monitor the progress of the improvement track. This is necessary not only to check how the track performs but also to see whether a process is ready for a new improvement track. This is achieved by combining the quantitative aspects of the Remanufacturing Process control model with the qualitative levels of the lean maturity model. Using a checklist, the maturity of each aspect of the Remanufacturing

Process control model can be checked and only if all aspects are on the same level can the process move on to the next.

3. *What pitfalls for implementation must be avoided?* When implementing the model there are a few pitfalls which must be avoided in order to avoid problems. These pitfalls are: Not knowing all ancillary matters surrounding the process, leading to future state designs which are unattainable. Having team members not fully understand the model or the need for it, this leads too added confusion alongside the implementation. Not dividing the implementation tasks equally among the managers responsible, this leads to one expert and some people with less of an idea. Lastly it is important to give the implementation time, as it won't run smoothly in the beginning. The old standard of working must be replaced with the new which is cause for some decrease in productivity before productivity will increase again.

Based on these sub questions the main research question, which was: *How to control, production performance on operational unit level using a Remanufacturing Process control model?* Can be answered. Production performance on the operational, or production unit level can be controlled by implementing the proposed Remanufacturing Process control model. Furthermore, adding on the Remanufacturing Process control model is the Remanufacturing Process maturity model, which aids in assessing where a process is regarding maturity, and whether it is ready to evolve.

Contribution

This research contributes to the academic literature in multiple ways. First of all, there is a missing link in plans made by higher levels of organisations, and the translation to the operational level. This missing link has the effect that a lot of potential is lost since plans made higher up don't account for this, and the plans which do get made often won't get performed correctly. To combat this the control is based on a more integral approach, starting with a bottom-up structure. The operational level has the best idea of what potential is hidden away in the process, and how to carry out plans made. Higher level management can check whether performance is as it should, as well as the maturity of the process if it so desires. This however is not a requirement as the well governed process is very independent. Then there is the fact that a control model for the Airline MRO business did not exist, and even for general remanufacturing systems there is no clear Remanufacturing Process control model. As was determined remanufacturing is an industry which differs much from regular manufacturing. With this come many different aspects which make controlling remanufacturing systems much more intricate than regular manufacturing. The Remanufacturing Process control model presented in this research aimed to overcome these difficulties and offer a clear framework which can be followed for achieving control. In doing so the model contributes to the academic literature, offering a clear Remanufacturing Process control model aimed at the Airline MRO sector, but easily applicable to any remanufacturing organization. The model also combines both quantitative and qualitative aspects in order to get a well-rounded model. Furthermore, the model emphasizes that automation does not automatically lead to improvement, which is a misconception a lot of organisations make. Especially with the rise of Industry 4.0 it is paramount to avoid this misconception. Automation tracks are usually very expensive improvement tracks, which if controlled can be beneficial, but if not, become a wasted investment. With this model control over the process can be gained also when a high level of automation is achieved. Which will ensure the automation is utilized to its full potential. Lastly this research introduces process quality as a steering KPI, instead of a resulting KPI. Traditionally process quality is considered as the result of other KPIs being up to standard. However, in this research it is suggested to lift it to the forefront and use process quality as a main driver for checking the performance of a process and to check if adjustments are necessary.

Further research

First of all, in simulating the future states only the regular flow has been taken into account, in real life of course this is not the case, and the disrupted flow can shake up a process if not handled correctly. Analysis shows that the disrupted flow for the logistic handling area accounts for about 8% of all flow. When handling a disrupted flow package, the process starts of normally, but then can't be finished. This results in the package being placed in a special disrupted flow gantry. When the problem has been fixed the process has to start off from the beginning again, basically in the end thus taking up twice as much time. Taking this flow into account as well would give more realistic results of the future states. Another aspect which would make the simulation more realistic is adding the prioritisation of certain parts. This is difficult to achieve since there is no log of the amount of prioritised parts, and there is some disagreement about the different levels of prioritisation. Adding this prioritisation would again increase the realism of the results, which would most likely effect the backlog size and duration. If however, same day handling is achieved the interference of prioritizing would be very minimal, which is why it has been left out of the future state for this research. Implementing disrupted flow as well as prioritisation into the simulation is something which further research could focus on. Furthermore, the simulation which got used for the evaluation of the model was only made for the logistic handling process, further research could test the model on different shops at KLM E&M. Further research could also enlarge the scope entirely and test the model outside of the Airline MRO sector for other remanufacturing industries, where the model should be applicable with little to no altercations. Testing this would show the models robustness. Another aspect which could not be tested was the sustainment of the newly found control, testing this without a simulation yields the best results, but would require a longer time span. If a longer time has elapsed since this research, it is also interesting to check the Remanufacturing Process maturity levels of the oxygen bottle shop, since they have just started the implementation of the Remanufacturing Process control model it currently is still in its infancy, however in some months the levels should be higher.

References

Bateman, N., & David, A. (2002). Process Improvement Programs: A Model for Assessing Sustainability. *International Journal of Operations and Production Management,* 515-526.

Beelaerts van Blokland, W., & de Jong, S. J. (2016). Measuring lean implementation for maintenance service companies. *International Joournal of Lean Six Sigma*, 35-61.

Bertrand, J., & Wortmann, J. (1981). *Production control and information systems for component-manufacturing shops.* Amsterdam: Elsevier Scientific Publishing Company.

El-Masri, M., Orozco, J., Tarhini, A., & and Tarhini, T. (2015). The Impact of IS-Business Alignment Practices on Organizational Choice of IS-Business Alignment Strategies. *PACIS* . Academia.

Gelhausen, M. C., Berster, P., & Wilken, D. (2021). Post-COVID-19 Scenarios of Global Airline Traffic until 2040 That Reflect Airport Capacity Constraints and Mitigation Strategies. *Aerospace*, 300.

Goldratt, E. M. (1990). *Theory of Constraints.* Croton-on-Hudson: North River.

Gunasekara, H., Gamage, J., & Punchihewa, H. (2018). Remanufacture for Sustainability: A review of the barriers and the solutions to promote remanufacturing. *2018 International Conference on Production and Operations Management Society (POMS).* Moratuwa: ResearchGate.

Guide Jr, R., & Daniel, V. (2000). Production planning and control for remanufacturing: industry practice and research needs. *Journal of Operations Management*, 467-483.

Haak, D. (2019). *Designing repair processes by introducing a return quality control model: A method for sustainable initial repair process design.* Delft: University of Technology Delft.

Habidin, N. F. (2012). The Development of Sustaining Lean Improvement and Sustainable Performance in Malaysian Automotive Industry. *International Journal of Lean thinking*, 79-90.

Hines, P. (2010). How to create and sustain a lean culture. *Development and Learning in Organizations: An International Journal.*

Jelinek, R. (2013). All pain, no gain? Why adopt automation tools sales force is insufficient for the solution of improving business results. *Business Horizons*, 635-642.

Karlsson, T., & Honig, B. (2009). Judging a business by its cover: An institutional perspective on new ventures and the business plan. *Journal of Business Venturing*, 27-45.

Liker, J., & Rother, M. (2011). Why Lean Programs Fail. *Lean Enterprise Institute*, 45-79.

Maasouman, M. A. (2015). *Development of Lean Maturity Model for Operational Level Planning.* Montreal: Concordia University.

Perry, S. C. (2002). The Relationship between Written Business Plans and the Failure of Small Businesses in the U.S. *Journal of small business management*, 201-208.

Rodrigues Vieira, D., & Lavorato Loures, P. (2016). Maintenance, repair and overhaul fundamentals and strategies: An aeronautical industry overview. *International Journal of Computer Applications*, 21-29.

Seymour, P. (2019). The Direct Cost Of Grounding The Boeing 737 MAX 8 Fleet. *IBA*.

Solms, R. V., & Thomson, K.-L. (2011). Information Security Governance control through comprehensive policy architectures. *Information Security for South Africa*, 1-6.

Tapping, D., & Shuker, T. (2002). *Value stream management: Eight steps to planning, mapping, and sustaining lean improvements.* . New York: Productivity Press.

Turesky, E. F., & Connell, P. (2010). Off the rails: understanding the derailment of a lean manufacturing initiative. *Organization Management Journal*, 110-132.

Zhang, X., Ao, X., Cai, W., Jiang, Z., & Zhang, H. (2019). A sustainability evaluation method integrating the energy, economic and environment in remanufacturing systems. *Journal of Cleaner Production*.

Appendix

The maturity checklist necessary for achieving new levels of maturity.

Table 1: Checklist to obtain the understanding level of maturity

Model aspect	**Questions understanding**	**Yes/No**
PSA	The concept of a PSA is clear with all parties involved in the process	
	The need for an improvement track is clear	
Manpower plan	The concept of a manpower plan is clear with all parties involved in the process	
	The incoming work, amount of workers and skills are known	
Entrance control	The concept of entrance control is clear with all parties involved in the process	
	The amount of work which is allowed into the process is known	
Bottleneck control	The concept of bottleneck control is clear with all parties involved in the process	
	The capacity of equipment used in the process is known	
Target control	The concept of target control is clear with all parties involved in the process	
	The necessary KPIs are being tracked	
Sustainment of control	The concept of a future potential plan is clear with all parties involved in the process	

Table 2: Checklist to obtain the implementation level of maturity

Model aspect	**Questions Implementation**	**Yes/No**
PSA	The PSA has been constructed	
	There is no ambiguity about the PSA	
Manpower plan	A new shiftplanning according to the PSA is constructed	
	OCAPs are defined	
Entrance control	There is a backlog in place for too much incoming work	
	Outsource options are known for too much incoming work	
Bottleneck control	The first occuring bottlenecks are known	
	An expansion plan for the bottlenecks is made	
Target control	An overview of necessary KPIs is available	
	Process Quality is being measured	
Sustainment of control	A check in/ out is used at the ending and beginning of each shift	
	Financial benefits of new way of working are calculated	

Table 3: Checklist to obtain the sustainment level of maturity

Model aspect	**Questions Sustainment**	**Yes/No**
PSA	The PSA is being used as the basis for control	
	The PSA is kept up to date	
Manpower plan	The designed shiftplanning is in use	
Entrance control	No more has been allowed in to the process than it can handle	
Bottleneck control	Bottlenecks are being kept up to date	
Target control	The necessary KPIs have all improved	
	The process quality results in a stable low TAT	
Sustainment of control	Check in/ out takes only a short amount of time	
	The future potential plan has been created	

Table 4: Checklist to obtain the improvement level of maturity

Model aspect	Questions Improvement	Yes/No
PSA	Due to process improvement the PSA can be simplified	
Manpower plan	Manpower can be redesigned (due to better working rate for example)	
Entrance control	The process can handle more than was initially designed	
Bottleneck control	Old bottlenecks have been resolved and new bottlenecks arose	
Target control	Set targets have all been achieved, new targets are required	
	New lowest TAT is possible	
Sustainment of control	Future potential plan is being followed	