Modelling business process redesign strategies for improved reverse logistics in an aircraft component supply chain

- A case study at KLM Engineering & Maintenance Component Services

E.P. Cornelisse

Delft University of Technology

TU Delft Delft University of Technology

Challenge the future

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Master Thesis Project

To obtain the degree of Master of Science in Transport, Infrastructure and Logistics at the Delft University of Technology.
by

E.P. Cornelisse

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This thesis is confidential and cannot be made public until December, 2020.

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Preface

This report contains the result of my MSc Thesis internship performed at KLM Royal Dutch Airlines. The work lying in front of you represents the final project to complete my master studies Transport, Infrastructure and Logistics specialising in Engineering Transport, Logistics & Supply Chains at the Delft University of Technology. During my graduate internship I was given the opportunity to explore the world of aircraft Maintenance, Repair and Overhaul at KLM Engineering & Maintenance division component services. The aim of this master thesis project was to contribute to academic literature as well as to practice through a business process redesign study. The study contributes academics by filling the research gap identified concerning modelling of reverse logistics in the presence of highly variable aircraft maintenance supply chain.

The CS2.0 project of KLM E&M provided the opportunity to contribute to the fundamental change of the way business in reverse supply chain channel at component services is conducted. The focus of the study, the component handling area was an very actual topic, of which I was given the opportunity to unravel its complexity and simulate scenarios which could be used in practice directly.

It has been a journey and I am grateful to those who helped me. Naturally, I could not have completed this project without the help of many others. I would like to use this opportunity to express my gratitude and appreciation. Especially, I want to thank Jan-Willem van Woerdekom for the opportunity to conduct my thesis project at KLM Engineering & Maintenance in the CS2.0 BPR project team. His knowledge, enthusiasm and feedback helped and challenged me to get the most out of my internship project. Furthermore I would like to thank Jeroen van der Jagt for sharing his visions on the component handling area which formed the base need for the development of the simulation model. Next, I would like to thank Jelle Roo for sharing his time, knowledge and data with me and both Scout Herremans and Simone Trampe for providing the opportunity to perform the process mapping sessions.

Furthermore I want to express my thanks to my graduation committee of the TU Delft: Dr. W.A.A Beelaerts van Blokland who helped me with process improvement theory and the scientific relevance of the research, Dr. Ir. J.H. Baggen who helped me with the research approach and advice to keep an academical view without getting absorbed by the case study company. Prof. Dr. R.R.Negenborn, thank you for your critical feedback during the meetings which helped me greatly to make this research both relevant for science as for practice. Finally I would like thank my girlfriend, friends, family, club and roommates for their patience and support throughout the project.

Enjoy reading,

E.P. Cornelisse
Delft, December 2018

Executive Summary

In the Aircraft Maintenance Repair and Overhaul industry, availability of aircraft rotable components is provided through availability contracts based on pooling stocks of components. Due to difference in failure rates of components and the typically extensive network of multiple customers around the globe, supply chains of aircraft rotable components are inherently unpredictable and associated with erratic and lumpy demand patterns. Especially the reverse flow of components, which concerns the logistical processes required to retrieve components from customers to the MRO provider, suffers from high variation. Due to high safety levels, the MRO industry is subjected to heavy regulations, resulting in many inter- en intra-organisational transactions and complex processes. As competition in the MRO market rises, MRO providers continuously need to find ways to improve their operations. Redesigning business processes is however challenging due to the complexity in operations and the MRO supply chain resulting in a need for new methodologies on how to improve and asses new strategies. Academic research in the MRO industry has mainly focused on novel availability models and repair shop optimisation over the past decades. Research on reverse logistics concerning aircraft MRO is scarce. In addition, supply chain management and operational excellence methodologies such as lean Six Sigma manufacturing are still in its infancy [33] [15]. Academical research concerning the field of MRO supply chains is inherently linked to practical applicability in real life. This study uses a case study in order link academical methods and theory to practice. This case study is carried out in collaboration with KLM Engineering & Maintenance (E&M). The aim of this research is to contribute academic research as well as improving the performance of the reverse component flow of an MRO provider through a redesign of the physical and non-physical processes and the construction of a model to assess the performance.

This research used a structure based on a the DMAIC cycle derived from Lean Six Sigma methodology. Where Lean Six Sigma promotes incremental improvement on a continuous basis, this research takes a more radical business process redesign approach. The improve and control phase are therefore replaced by design and evaluate phase. To support the methodology a combination of value stream mapping and swimlane diagram is suggested, the VSM-I. The classical VSM is useful for the identification of physical "waste" whereas crossfunctional charts can complement the VSM on the information flow between departments and the associated (IT) transactions. As the redesign is more radical, testing the potential in a more safe computer environment is desired. Discrete event models are considered best suited in environments of high stochastic variation and can be used to find optimal configurations of physical and administrative processes. The potential of the redesign is determined by evaluating the main KPIs; TAT, inventory (WIP) and resources in the simulation model.

The measurement phase in this study provided insight in the complete reverse logistic supply chain performance. Through coupling of multiple data sets it was concluded especially the handling and logistic operation in the current logistic centre was under-performing. Unservicable components spend 7 days on average in handling, whereas the actual process time is an hour. The measurement phase further showed reversed logistic supply chains of KLM E&M suffers from high internal and external variation. The highly variable inflow of components results in backlogs, long Turn Around Times (TAT). Following from SCM theory, two main strategies can be identified in which MRO companies can deal with this variable demand. The MRO provider can either aim to reduce the variation in the supply chain, or design its processes in order cope with the variable demand. In case a production system experiences variation, variability can be dealt with by either buffering in TAT, inventory or resource capacity. As aircraft components are expensive assets, buffering inventory results in an unviable business model due to the high levels of capital employed in stocks. Buffering in time (TAT) is also not acceptable as long lead times will result in dissatisfied customers and can cause Aircraft On Ground (AOG) situations.

The analysis phase investigated the sources of variation and concluded external variation is caused the nature of the MRO industry, however a lot of internal variation is caused by inefficient handling processes due to many handovers and transactions and an imbalance between capacity and demand. Through the construction of a VSM-I, processes where mapped and showed the physical handling and the administrative processes to generate repair orders is entangled. This result components are have to be stored and retrieved retrieved multiple times to perform the disposition. In addition, due the the large amount of data and

transactions required for the generation or repair orders components experience large waiting times in the process.

A redesign of the current process was presented in which the internal variation is reduced by separating the physical and administrative processes and automating the logistic handling operations. The design proposed the possibility of generating repair orders in advance (before the component arrives). The effect of the physical and administrative redesign was evaluated using DES modelling. The separation of the physical from the administrative flow, allowed components to be handled based on unit load size, in stead of by aircraft type. Measurements showed 85% of all components (servicable, unservicable and consumable) can be classified as boxed size components. For the physical process a combined AS/RS-workstation order picking system is designed. Through optimisation modelling, the optimal amount of resources, in terms of manpower and handling equipment required to handle the variable demand pattern to achieve a desired service level was determined. By allowing buffering of components only in to occur in central buffers (AS/RS-sytem) before the repair shops a pull mechanism from the shops can be introduced.

The redesign was evaluated using different levels of proactive repair order creation and skill requirements. Results from the case study showed the relationship between process efficiency, available capacity in terms of manpower, inventory, service level, and TAT. By installing capacity in the handling area to accommodate the variable demand, the total time components spend in the supply chain can be shortened.

To answer the main research question; How can the logistical and handling processes of a component MRO provider be redesigned in order to improve the performance from an integral supply chain perspective? Several principles are suggested. Firstly; it is advised to use the DMADE methodology in the MRO environment. The define phase is aimed to understand the business context, gaining knowledge about the sector in which the company competes and the way the company operates to satisfy its customers. Here the emphasis lies on identifying the current roles of supply chain management and IT technologies. In the measurement phase a complete picture of the supply chain in terms of TAT should be acquired for all reverse logistic activities (asset recovery, transport, identification, inspection, sorting and disposition). This in order to select a target for redesign. In the analyses phase a more detailed current state analysis can be performed using the VSM-I on transaction level. All possible improvements gained from the analysis phase forms an input for redesign. Results from The case study used in the MRO industry showed the total time in the supply chain can be gained through separating the physical from the administrative flow, reducing the number of transactions between departments and customers, acquiring data from customers the moment its generated, generating repair orders in advance and move from inventory buffers to capacity buffers. By introducing these principles the performance of the MRO supply chain can be improved from an integral perspective.

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List of Abbreviations

Abbreviation	Explanation
AFI KLM	Air France Industries KLM
AOG	Aircraft On Ground
CIRO	Customer Interface Repair Officer
CLSC	Closed Loop Supply Chain
CSL	Customer Service Level
CSM	Supply Chain Management
CV	Coefficient of Variance
DES	Discrete Event Simulation
DMADE	Define Measure Analyse Design Evaluate
FH	Flight Hours
FIFO	First-In-First-Out
FL	Forward Logistics
KLM	Koninklijke Luchtvaart Maatschappij
KLM E&M	KLM Engineering & Maintenance
KPI	Key Performance Indicator
MRO	Maintenance, Repair & Overhaul
OEM	Original Equipment Manufacturer
OTP	On time performance
RA	Repair Administrator
RL	Reverse Logistics
SD	System Dynamics
CSL	Service Level
CSP	Component Services Program
T&M	Time & Material
TAT	Turnaround Time
TOC	Theory of Constraints
TPS	Toyota Production System
US	Unservicable
SE	Servicable
OTP	On Time Performance
OTS	On Time Start
TQM	Total Quality Management
VSM	Value Stream Map
VSM-I	Value Stream Map - Information
WIP	Work in Process

Part I: Define

1
Introduction

In this chapter an introduction to this research is presented. First the research context and field are discussed, next the relevance is elaborated by identifying the knowledge gap(s) in literature. To fill the knowledge gaps a research problem and scope is discussed and research questions presented in section 1.7. Finally the research approach in order to answer these questions is presented in section 1.8. A general outline is indicated in Figure 1.1.

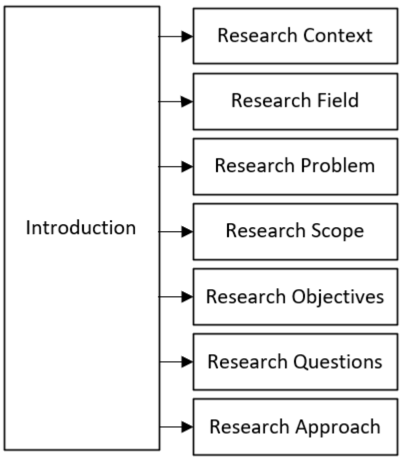

Figure 1.1: Outline Introduction

1.1. Research Context

Maintenance, repair and overhaul (MRO) is the term used in aeronautical industry to describe continuous maintenance activities of aircraft. The purpose of MRO in aviation is to reverse the ageing and wear-out process of aircraft, components and sub-assemblies early in the operational life. MRO activities generality include inspection and testing to determine the condition of the component, servicing, repair,modification, and overhaul [36]. The work in the MRO industry can be roughly divided into two different categories, standard scheduled maintenance and unscheduled (damage) repairs. In general, scheduled maintenance can be further categorised as proactive maintenance and is planned in advance before a failure of the part or assembly occurs, based on flight hours, flight cycles (landings), or lifetime. Unscheduled maintenance is usually categorised as reactive (corrective) maintenance where the component or assembly is repaired or replaced after it has failed. The global MRO industry can be further divided into several maintenance categories; line maintenance, heavy airframe maintenance, engines and component maintenance. Engine maintenance is with 40% the largest contributor to the global MRO spend (ICF International Global MRO Forecast [13]). Component maintenance is with 22% the second largest contributor. Line maintenance followed by airframe maintenance and modifications count for 17%, 12% and 8% respectively. This research focuses on component maintenance. Due to the high cost of aircraft on ground (AOG) many airlines keep stocks of spare parts to prevent these AOG situations. The organisations providing these MRO services are challenged by great variety and complexity in the work which varies from a minor repair on a coffee maker to a complete overhaul on a high frequency generator. Each maintenance task requires a unique combination of personnel, equipment, material and procedures. In order to assure high safety levels and high quality repairs, the MRO industry subjected to heavy regulations. Each part repair method is standardised and requires certificated mechanics and procedures in order to make a unserviceable part serviceable again. This makes the MRO industry conservative in nature as the heavy regulations create a reluctance to change as it is hard to adapt repairs methods and standard certified procedures. This results in the fact that implementation of new technologies and production methods, i.e. Lean Manufacturing in aviation MRO is still in its infancy [15]. In the present day competitive MRO environment however, service providers need to continually identify ways to gain an advantage and invest to maintain leadership in the industry. The challenge is to minimise the TAT, manual labour and production wastes to aid the company's competitiveness in the global market.

Currently, many different companies around the world are offering aircraft MRO services which can be divided into three main categories. The Original Equipment Manufacturers (OEMs) such as Airbus, Boeing, Embraer, Honeywell etc. who provide MRO for their own developed products. Second, the airlines providing MRO and third the non-OEMs that provide MRO and are not an airline. According to McFadden and Worrells [44] there is an increasing trend in airlines who outsource their maintenance to the MRO specialised companies. Especially smaller airlines, low-cost carriers (LCC's) and start-up carriers as they do not have the capital, or do not consider maintenance as their core business. This leads to a growing demand for spare parts availability contracts as these LCC are increasing their fleet size (ICF International Global MRO Forecast [13]). Forecasts by Cooper et al. [13] show the worlds fleet of in-service commercial airlines is expected to grow from nearly 25,000 aircraft at the beginning of 2017 to over 35,000 by 2027. As a result of this, commercial airline MRO is estimated to grow 3.8% annually over a 10-year period, growing from the current $75.6 billion to just over $109 billion by 2027. The importance of MRO is further supported by the fact maintenance is estimated to take up 10% to 15% of the total operating cost of an airline [44]. As many different companies around the world are offering aircraft MRO services, the MRO market is highly competitive and tends to create increasingly more demanding customers. MRO providers therefore continuously need to find ways to improve their business processes. Redesigning business processes is however challenging due to the complexity in operations and the MRO supply chain resulting in a need for new methodologies on how to improve and asses new strategies. In addition there is a need to change business processes to support new innovations in automation and IT. The 'best' way to organise and carry out maintenance a decade ago is different from the 'best' way of carrying it out today, since there are now many things possible which were not technically or economically feasible, ten years ago [1]. The challenge is to determine the potential for improving the MRO business with today's technology as innovations are changing the rules of the game.

1.2. Research Field: MRO Component Logistics

This research is performed within the field of aircraft component logistics. In the aviation industry aircraft components are referred to as individual parts of an aircraft that make up the aircraft. In the industry a distinction is made between repairable, 'rotable' components and expendables. Rotables are aircraft components which need to be 'rotated' at frequent intervals depending on a certain number of landings, flight hours or when (unexpected) damage is detected. Rotables can be exchanged, repaired, overhauled (in-house or by a vendor) and put in pooled stocks to be used again. In the industry, the fuselage, wings, and engines are seen as separate parts which in their turn are made can be made up of individual rotable components. Typical rotable components range from wheels and brakes to heat-exchangers, actuators, landing lights and actuators [51]. In this research, aircraft component MRO includes all the activities related to process of making an non-serviceable rotable component serviceable again. Due to the large variety of components with different OEMs and many repair vendors worldwide, the activities surrounding the repair processes of repairable components comprise complex, time critical operations and are logistical in nature. The logistic operations are crucial for MRO providers due to the many movements and handling required and time criticality for typically expensive parts. One of the challenges in the MRO industry is that the demand for serviceable parts is inherently difficult predict due to differences in failure rates between components [21]. The network of many customers, OEMs and vendors component MRO providers typically have, add to the variance of component arrivals at the repair stations and affects the efficiency of the repair processes. Due to this level of uncertainty, stock levels of rotables need to be relatively high to accommodate an acceptable service level. Maintaining a large inventory of spare parts is however very costly, due to the high cost of aircraft components. Insufficient stock levels on the other hand decreases the Service level and forces the MRO provider to buy or lease components. Insufficient stock levels can be caused by poor inventory planning methods, unexpected failures, unpredictable external factors and high turnaround times (TAT) in the supply chain. Reducing the TAT in any part of the supply chain has a direct impact on the stock levels and/or customer service level. This specific problem is one most MRO providers are familiar with. However, identifying the bottlenecks and non-value added in the processes in the complex MRO environment is challenging. According to [33] MRO businesses do not operate their business from a supply chain perspective but are more internally focused. Also the implementation of information sharing and electronic data interchange is lacking within the MRO supply chains. Academical research concerning the field of MRO supply chains is inherently linked to practical applicability in real life. This study therefore uses a case study in order link academical methods and theory to practice. This case study is carried out in collaboration with KLM Engineering & Maintenance (E&M), Division Component Services.

1.3. Company - KLM E&M

Air France industries – KLM Engineering & Maintenance, hereafter (AFI) KLM E&M is one of the major players in the MRO segment faced with the challenges of growing demand, unpredictable flows and capital intensive operations. The company provides airframe, line, engine and component maintenance. Component Services (CS) is the subdivision within KLM E&M performing component maintenance. The Component Services department is responsible for two main tasks; organise component availability and provide component MRO. Organising component availability concerns the maintenance of the stock level that needs to be available for the customers. Component MRO concerns the repair of unserviceable (US) components. The component MRO and availability are interlinked via the stock of spare parts in a component pool. Clients of KLM E&M have pool contracts to assure the availability of replacement parts. Hence, if a component is no longer serviceable (SE) and needs replacement, the part is sent to KLM E&M and the client receives a serviceable (repaired) component from of the pool. The unserviceable component then is then sent to component services for repairs and when serviceable sent back to the component pool warehouse to replenish the stock level. Since it is expensive to store huge amounts of spare parts for every component, it is important that the removed components are repaired quickly and returned to the warehouse. Hence, the workshops of the MRO should concentrate, for pooled items on repairing items in an order which maximises the service level. Managing and controlling the TAT performance is therefore key in achieving an optimal component availability performance [12].

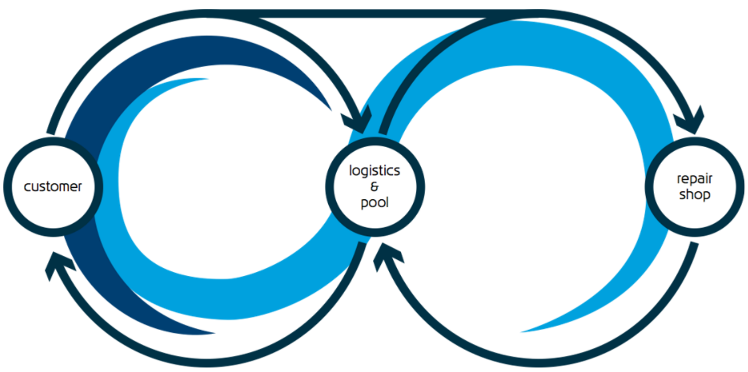

Figure 1.2: Component Services Loop

Aside from the component pool service KLM E&M also provides direct component repair services. In this case the unserviceable component is not replaced by one from the warehouse pool but directly sent to the MRO repair shops and after the repair the same component delivered back to the customer. This contract form is called a Time & Material contract, as the customer pays for the used materials and time spend on the repair.

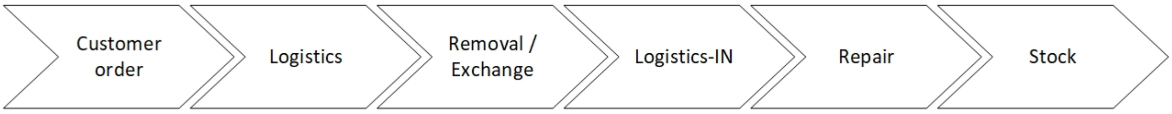

Figure 1.3: Overview supply chain

Figure 1.3 shows a simplified version of the component end-to-end process chain of a pool contract. The chain starts with a (expected)consumption of a serviceable part resulting in a costumer order. After this order has been processed a serviceable part is sent to the customer and is exchanged with the unserviceable one. Then the US part is shipped to Schiphol-East where it passes trough the logistics centre where administrative process after which the component can be repaired. When the repair is finished the component is declared serviceable and is added to the stock of the component pool.

Currently KLM E&M is moving its operations within the CS2.0 project. In the current situation component MRO at KLM E&M takes place takes place in two separate facilities with repair shops, named Shop HUB (Hangar 14) and Shop MRO (building 425). At a third facility, the logistics centre (building 440), the components are checked by customs (by Bolloré cargo) and handed over to the KLM E&M handling facility. Within the handling facility the components are sorted, inspected, the repair order is made and SE components are stored. With the new CS2.0 project, Shop MRO and the logistic centre are all moved to Hangar 14. Figure 1.4 gives an overview of the three facilities, indicated in dark blue.

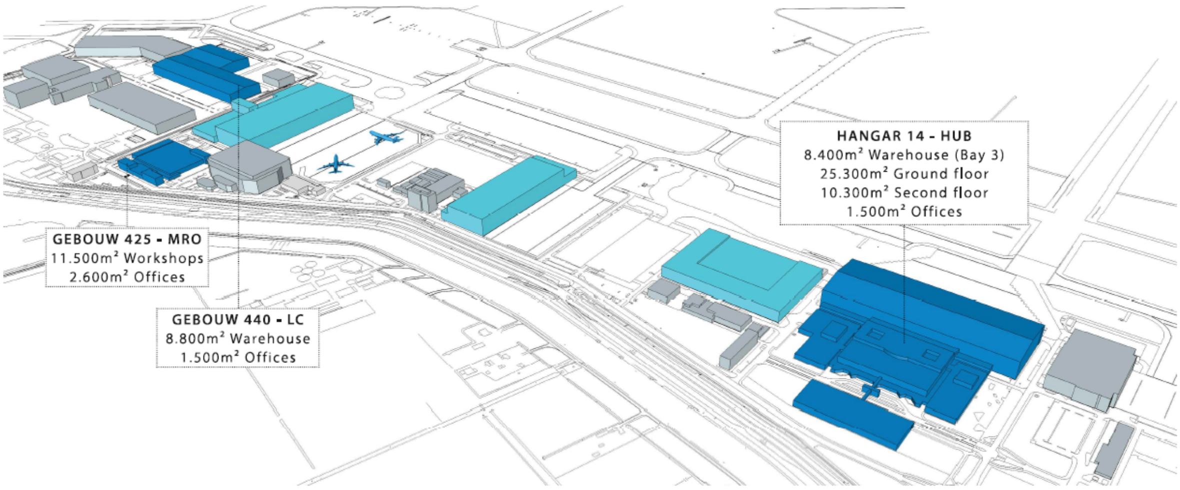

Figure 1.4: CS2.0 facilities

Aside from moving repair shops, a new automated storage facility for SE components and consumables is constructed in Baai 3 at Hangar 14. This storage facility will take over the storage function on the current logistics centre and the stocks of consumable parts in the expedition of the repair facilities. In the current situation, both repair shops have their own expedition in which components are received and administrative tasks are performed. Due to the many repair shops that will house in Hangar 14 there is not enough space to facilitate these activities in the CS2.0 situation. The current component logistic handling facility at the logistic centre and Bolloré customs facility will also be moved. As stated earlier, KLM E&M expects market growth and wants to accommodate to a larger flow of components. Here the opportunity has risen to make a redesign processes related to the handling and repair of components. KLM E&M CS is further interested in a redesign as its current performance is considered to be low. The redesign of these processes is a complex problem due to the many component flows and many inter-dependencies.

1.4. Research problem

With the gained understanding of the research area the next step is to define a tangible problem definition with a clear scope. In the current situation KLM E&M faces several challenges. The customer service level is structurally below target. This leads to dissatisfied consumers and a lower profitability as additional stock is bought or leased to assure component availability. With the ambition of KLM E&M to expend its business, the flow of components is expected to grow with 50 to 100% in the upcoming years. To facilitate the expected growth and increased competition, KLM E&M CS needs to improve their operations. Currently the performance of the component services is below the desired level, the agreed TAT is often not met and has a high variance. The lack of operational performance in the component MRO causes increased capital & operational costs and limits the potential of KLM E&M to remain world leader in 737 and become leader in 787 component availability.

Earlier studies performed at within the aircraft component business have mainly focused on novel availability models such as [65],[7] or on TAT reductions within repair shops ([70], [71], [41]). Literature on improving the logistics and handling processes of components within the supply chain is however lacking, see Chapter 2. Based on the the existing academical literature in the MRO industry and earlier studies at KLM E&M ([71], [70]) it can however be hypothesised that more efficient logistic operations can improve the performance of the maintenance operation. Especially the research area concerning reverse logistics. Within project CS2.0 the opportunity has risen to redesign these processes in a way the current waste in the chain is eliminated as much as possible.

Knowledge on how to improve the performance of the MRO operations and redesign the logistical processes is from a supply chain perspective, however, lacking. By analysing and re-designing on these operations CS could be able to be more competitive and reduce both operational and capital cost. As the MRO environment is a unique and complex environment with many inter-dependencies, methods are needed to design and asses the performance of the integral supply chain. The context description and the situation at KLM E&M leads to the following problem statement for this research:

Within the academics concerning aircraft MRO there is limited knowledge on how to determine the impact of redesigning the logistics and handling operations based on process improvement theory on the performance of the integral component supply chain.

This is not only a problem for KLM E&M CS, but also for other aircraft MRO providers in general which offer component availability and closed loop services for aircraft. A lack of performance within the component logistics chain causes increased TAT unnecessary capital & operational costs. By analysing, redesigning and assessing the business processes from a integral logistical perspective, increased performance can be achieved.

1.5. Research Scope

The case study at KLM E&M provides a great example of a complex MRO supply chain containing multiple flows of components with inter-dependencies. The complexity of the supply chain creates the need for a thorough analysis. When considering the operational performance of the component MRO it is tempting to consider every aspect of the supply chain as object for a redesign. As many factors and dependencies within this chain contribute to the TAT of components and aircraft, there are multiple opportunities to reduce it. However, this will result in a scope that is too large for a research given within a limited time-span. On the other hand, avoiding the supply chain perspective might result in local optimums and local productivity targets. According to de Jong and Beelaerts van Blokland [15] it is important to consider the higher level processes as well as the processes that are necessary to execute single transactions when analysing processes. Section 5.3 further elaborates on these transactions as that play an important role in the MRO supply chain. In order to analyse both the high level processes and lower level transactions, the scope is therefore limited to several layers of detail. The Levels are adapted form de Jong and Beelaerts van Blokland [15] and consist of; Company level (Level 1), Product group/department level (Level 2), Process level (Level 3) and transactions level (Level 4).

The component logistics and handling is chosen as a basis in the case study for the design as there is an opportunity to consider the handling as a greenfield for redesign in the new CS2.0 project situation. Aside form unserviceable components the flows of serviceable rotable components, consumables and other items needed within the hangar pass through the handling area. This combined with the high variance of component arrivals call for modelling study to take variance into account. For the (re)design of the new handling processes there is a need to find which equipment to invest in and find a balance between the number of resources (manpower) and the operational performance of the system within the supply chain.

The CS2.0 project furthermore provides an opportunity to review the current business processes and im-

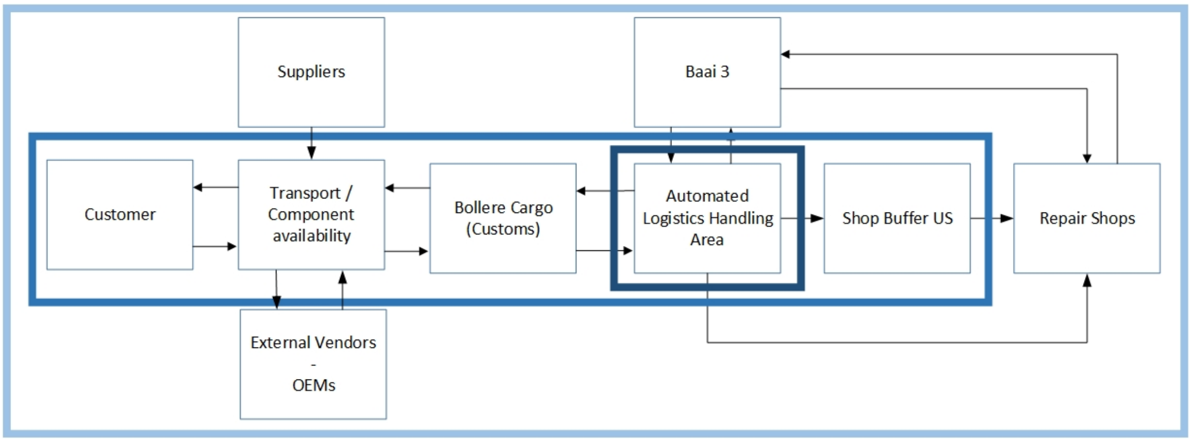

Figure 1.5: Scope with layout new handling area

prove through a complete redesign the logistic system. However, at the moment KLM E&M has no complete picture on the flows of components through the different facilities. As a result, design parameters to use for the design of the handling area in the CS2.0 context are difficult to quantify. As the handling area is a important link in the MRO supply chain its performance in the integral chain should be assessed. Hence, if an investment in handling equipment and capacity can improve the TAT, less inventory might be needed to guarantee the wanted service level. Currently, the contracted TAT of components is often not met and has a high variance. A longer TAT means that more components are in the system and large variance causes stocks to be higher than wanted (to assure the required service level). Characteristic of the aviation industry is that these components are expensive assets. Decreasing the total amount of inventory of components that are serviceable in the pool as well as components that are still unserviceable in the supply chain can add-up to large amounts of monetary capital. It can be hypothesised that through automation of physical and non-physical (information & control) processes operational performance can be improved in the MRO supply chain. A lack of operational performance causes increased and unstable TAT, capital & operational costs, limiting the potential of the company's competitiveness. By analysing, redesigning and assessing the performance of design options under different scenarios using simulation, design parameters can be identified. Based on relevant process KPI's, increased performance through the redesign can be achieved by influencing these parameters.

To describe the origin of flows the whole chain is described in high level indicated in light blue in Figure 1.5. The slightly darker blue frame indicates elements of the logistic system within Hangar 14 (the CS facility of KLM E&M). The process within Hangar 14 of concerns the component inflow at the MRO facility, storage facilities (BAAI 3 and expedition LC) and the repair shops. The highest detailed analysis and actual design is made for the component handling area and the logistics handling of US components through the repair shops as previous studies have indicated this being a bottleneck in the repair operation [71]. Due to the complexity of the system, a model to assist in the design of the handling system to cope with variance is needed. The model should also be capable of assessing the performance of the design form a supply chain perspective.

1.6. Research Objective

The objective of the research is twofold, first of all the objective is to enrich the academical community with new knowledge, which is discussed in Chapter 2. Secondly, there is a need for KLM E&M to improve on its performance and identify current and future problems and opportunities forming the second objective. In order to achieve both objectives a case study approach is used.

The balance between required resources and assets varies under different demand patterns. Therefore a model is needed to design the system so it can handle the variance in demand. However, basing the design of the system so it can handle the peak demand on the will result in a system that has an overcapacity most of the time. This is expensive, especially when skilled manual labour (i.e. for inspecting parts) is required. Therefore a strategy to assure the systems is operating as efficiently and effective as possible should be in place. Using a model which describes the behaviour of the system under different circumstances, expressed in KPI's is required. This model can be used to evaluate different design scenarios under these different circumstances. Furthermore a model should show different capacity and decision strategies based on the actual demand in the supply chain. These strategies can be used by the operational manager of the handling area to make decisions concerning required assets and resources. The objective of this research is therefore defined as;

The goal is to contribute to a to a lower and stable TAT (thus, reduction inventory & cost) of the component flow at KLM E&M CS through a redesign of the physical and non-physical logistical processes and the construction of a model to assess the performance from an integral perspective

To comply with this objective, the research includes the following deliverables:

- Create an insight from literature within MRO on process improvement, (simulation) models and performance measurement.
- Define operational KPI's of the integral system.
- Analyse the current state of the component MRO logistical processes at KLM E&M CS
- Analyse the current demand patterns & processes
- Conceptualise & (Re)design the logistics around the constraining processes within the scope.
- Analyse future scenarios using literature, expert knowledge and company data.
- Develop a model to evaluate the redesigned (integral) performance.
- Determine how future scenarios affect the processes & evaluate the redesigned operation.

1.7. Research Questions

Based on the described context, research problem, and the research objective, the main research question can be defined as:

How can the reverse logistical processes of a component MRO provider be redesigned in order to improve the performance from an integral supply chain perspective?

In order to answer the question several sub questions are formulated;

- How are component MRO supply chains described in academic literature?
- Which process improvement theories can be used to (re)design component processes?
- Which models can be used to assess the performance component supply chain?
- How is the MRO component supply chain currently structured?
- What is the current performance of the reverse logistic processes of KLM E&M CS?
- What are the constraints in the current processes?
- What are the relevant redesign criteria for the handling of the (reverse) flow of aircraft components?
- What is the potential of automation on process performance?
- How can the system be configured in order to perform optimally in terms of KPI's during peak demand patterns?
- How does growth affect the performance of the logistic and handling activities of components?

1.8. Research Design

In order to answer the research questions a research approach based on the case study methodology by Dul and Hak [17] is used. According to Dul and Hak [17] the case study approach can be applied when the real-life context is important and specially when the boundaries between object of study and context are not clearly evident. Case study research can lead to new and creative insights, building of new theory and can have high value for practitioners which are the ultimate user of research. As the objective of this study is to both contribute to theory and practice this approach is well suited. In addition, many of the breakthrough concepts and theories in the field of Operations Management from lean production to manufacturing strategy have been developed through case study research and further validates this choice.

In case study research first a general choice between a theory-oriented and practice-oriented research must be made. The aim of practice-oriented research here is to contribute to the knowledge (through research) of practitioners in order to support them in acting effectively. Theory-oriented research is defined as research that is aimed at contributing to the development of theory [17]. This research uses the latter. Although the choice of research is theory-oriented research, it can contribute to practice. Quoting Van de Ven [69]; "Nothing is quite so practical as a good theory".

According to Dul and Hak [17] the next step in case study research is to choose between theory-building and theory-testing research. Theory-building is research generally used to form new propositions based on the evidence drawn from observations the object of study. This means that a relevant proposition has not yet been formulated, resulting in a research 'gap'. This 'gap' is then filled by formulating a new proposition based on the case study. Dul and Hak [17] state there also is a "gap" if a proposition is not, or not yet, sufficiently tested. Theory-testing research can then be used to "fill the gap" in theoretical knowledge. Theory-testing is used in this research study by using and combining process improvement theories to design the logistic system and test this re-design. Conform with [17] proposition that any theory-oriented research should start with an exploration of theory and practice to find out whether a proposition regarding the research topic of interest is available, and initial exploratory study is performed. This literature study is presented in Chapter 2.

Aside from the case study approach a research design has been made that forms the research methodology in this paper. The DMADE methodology by (Dr.W.W.A.Beelaerts van Blokland, 2017) is adapted and used to structure the research. DMADE stands for Define, Measure, Analyse, Design and Evaluate. This method is derived from proven DMAIC cycle originating form Lean Six Sigma theory (define, measure, analyse, improve, control). Where Lean Six Sigma promotes incremental improvement on a continuous basis, this research takes a more radical business process redesign approach. The improve and control phase are therefore replaced by design and evaluate phase. To support the methodology a combination of improvement theories

is used. To answer main research question, a literature review was conducted to find the best methodologies to guide the business process redesign using the DMADE structure. The review found that a number of methodologies tend to be more useful in relation to some phases than others. Thus a combination of different methodologies for a better result is proposed. The combination of Lean Six Sigma, business process mapping, transaction cost theory and simulation modelling is suggested. The methodology is applied on the reverse logistic flow of rotable components of KLM E&M CS. This choice is further elaborated in section 3.
Define: In the define phase the field research is defined combining practice and theory. Using information on the object of research, the problem, goal, objectives and scope are determined. Finally the the research questions are stated and a research design is presented.
Measure:In the measure phase the current state processes are identified using a combination of a swimlane and the value stream map (VSM-I), in line with the lean Six Sigma theory. The goal of this phase is to gather all the data needed to analyse the problem. Furthermore are the process performance measurement is performed in order to quantify the current performance. The measure phase ends with a target for redesign and preliminary theory for analysis.
Analyse: In the analyse phase, all the collected measurements are analysed. The information is analysed to identify the constraints in the current process. In this phase the process constraints and its root causes are identified.
Design: In the design phase, the design options are proposed and a simulation model is developed. The impact on the processes is measured using a simulation model as test platform, which is an iterative process. Future state design scenario's are elaborated. The potential of redesign is quantified simulation. With the simulation models different designs and growth scenarios can be evaluated.
Evaluate: In the evaluate phase the impact designs on the systems performance under different scenarios is determined. The evaluate phase concludes with a contribution to theory and practice and a reflection upon the work.

1.8.1. Outline

In Figure 1.6 the outline of the research is presented with the corresponding chapters. The research starts with description of the context and questions, then a theory analysis is performed based on the required theories. Using the theories form lean manufacturing an combinations of mapping methods such as Swimlane and Value stream mapping the system can be conceptualised. From this conceptualisation requirements and specifications for the future system can be determined. These form the input for a conceptual design which is tested in a simulation model. By running experiments with the model optimal layout and capacity can be obtained. Although the building of the model to assess the design is presented is Chapter 5, the actual model building can start earlier in the design process. The model then can be build by incrementally adding complexity to the model. Using the simulation results, the design and future scenarios are evaluated in Chapter 7.

1.9. Data

The supply chain can be redesigned based on historic data and different growth scenarios of component flows. Several data sources are available that give insight in the amount of package arrivals and component types. these are SAP iMRO, CROCOS, Tracking and Link. KLM E&M uses the ERP system SAP IMRO for the administration of tasks throughout repair process, from check-in to checkout. CROCOS is a system that holds all the information for the conditions of rotable components in the Component Availability system. Link is used by the Bolloré (3PL provider) that imports and export components for KLM E&M CS from and to the LC at Schiphol. Tracking is a track and trace system. All the components are tracked and traced using bar-codes and hand-held scanners. Tracking data consists of a pick and drop moments at certain locations throughout the supply chain. Tracking is used parallel to SAP, CROCOS and iMRO.

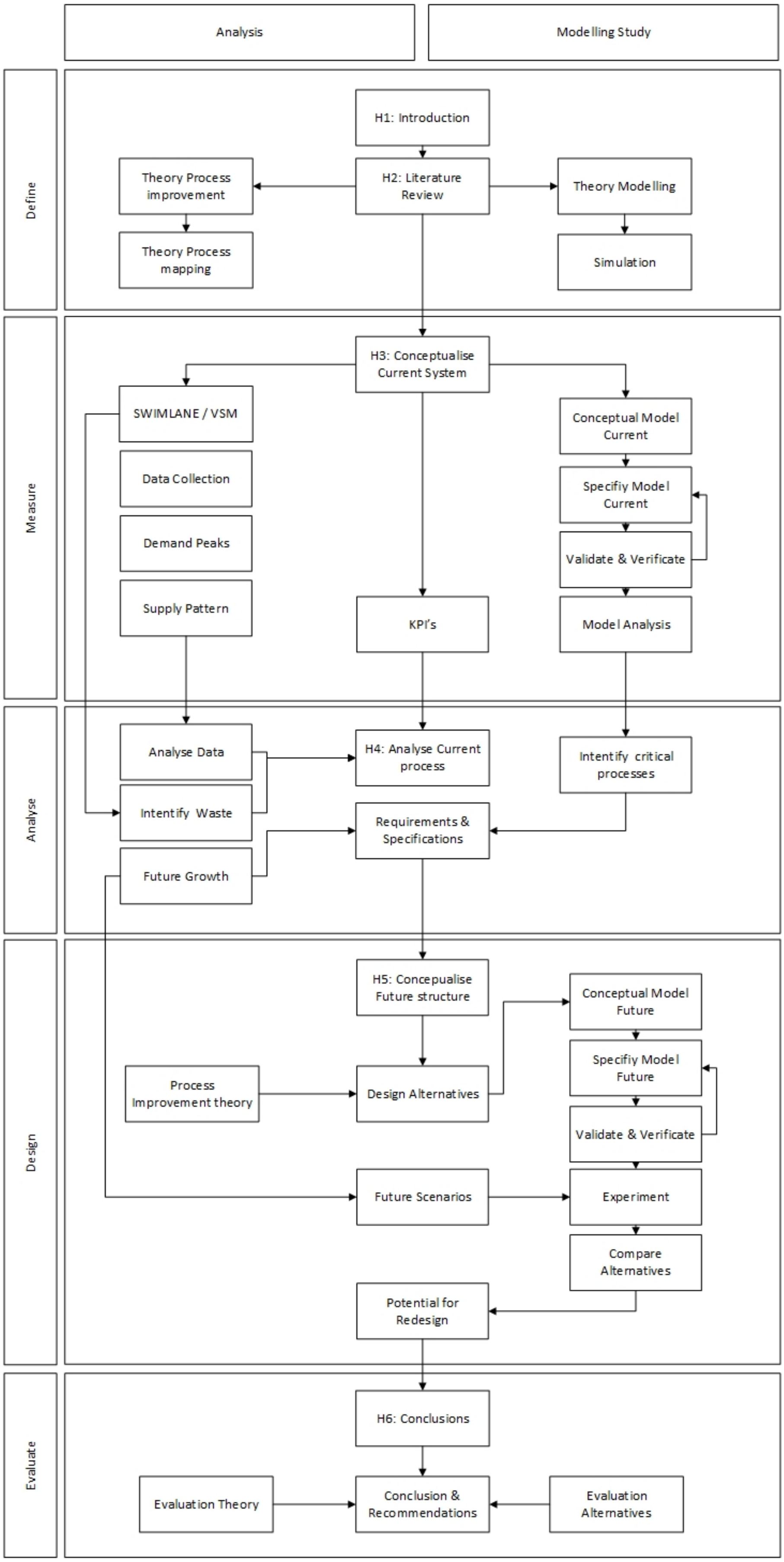

Figure 1.6: Outline thesis

2 Literature review

In this chapter, a review of the relevant scientific literature is presented in order to provide a backbone for this research. The review uses scientific papers, journals and other studies in order to gain a clear image on the research topics and methods. This serves as an important step towards finding knowledge gaps in the current scientific research concerning component MRO. Furthermore it can help to build a successful conceptual design, as it provides insights and ideas to build and elaborate the design on. By reviewing the existing literature the state of the art logistic optimisation can be identified and the main used methodologies for designing these systems. This chapter answers the first research question;

- *How are component MRO supply chains described in literature?*

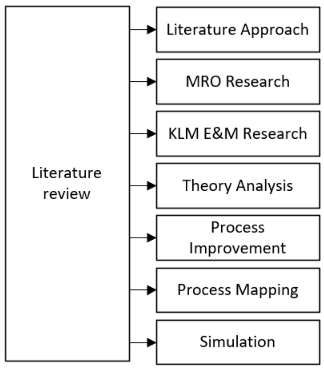

Figure 2.1: Outline Literature

2.1. Literature Approach

Conform the proposition of Dul and Hak [17] that any theory-oriented research should start with an exploration of theory and practice to find out whether a proposition regarding the research topic of interest is available, and literature review is performed. The literature being reviewed concentrates on prior research in aircraft MRO, MRO supply chain logistics and modelling within the MRO industry. The literature used in this research is sourced from the library of the Delft University and on-line databases for academic papers such as ScienceDirect, Scopus,and Google Scholar.

2.2. Academical Literature within the MRO context

As briefly described in Chapter 1, the airline component MRO industry is complex in its operations. In order to maximise up-time of aircraft, most components in modern aircraft are designed to be quickly exchangeable and repairable [34]. These components are designed in a way that they can easily be replaced between flights if necessary. Hence, if a component has failed or needs replacement based on flight cycles (hours), the component is removed from an aircraft and replaced with a (new) serviceable component. A component failure therefore causes a demand for a serviceable spare component and a supply of an unserviceable one. In order to maximise aircraft utilisation, airlines stock spare units to be available when needed. These stocks provide what is called 'component availability'. By doing so the demand for a serviceable component immediately satisfies, allowing the repair to be performed independently. As soon as a component is removed from an aircraft (after becoming unserviceable), the component needs to be repaired in a workshop. Depending amount of damage and reason for removal a repair order is made and the defined work-scope is executed. After the repair, the component is certified. With this certification the component becomes airworthy again. The component can be then installed in an aircraft or sent back to the available spare supply [34]. In order to assure a certain availability level for a fleet of aircraft, inventories of spare components are required. Storing large inventories of components is very costly due to the high cost of aircraft components. Airlines therefore try to keep the inventories as low as possible whilst still providing an acceptable availability level. Several different strategies to assure the availability of components are described in literature. These strategies include standardising the fleet composition, inventory pooling and outsourcing the availability service [64] [34].

Benefits of economies of scale are gained through the pooling of components. With pooling the demand from several aircraft fleets operated by different airlines can be satisfied. More customers can be supplied with serviceable components from a relatively smaller shared pool then the sum of the individual inventories needed without pooling. With the pooling strategy, risks and costs are shared. Furthermore, demand peaks of airlines due to seasonality can be accommodated for by the use of a component pool. Kilpi and Vepsäläinen [35] identify two types of component pools; commercial pools and cooperative pools. In commercial pooling several customers (airlines) buy component availability (at a certain service level) from the service provider. In cooperative pooling airlines share their spare units between each other according to a mutual agreement. The level of cooperation can vary from an ad hoc cooperation with loan arrangements to relatively tight cooperation[35].

Sufficient component inventories are paramount for component availability. Hence, fast replacement of components in case of failure can prevent AOG situations and resulting flight delays. However, large inventories entails lots of monetary capital due to the high value components [34] [71]. Literature describes many different methods in order to determine the number of serviceable components needed in order to provide maximum component availability with minimal expenses. The essential question which these methods (mainly mathematical models) try to answer is how many serviceable components should be stocked in order to ensure a wanted service level given a certain fleet of aircraft and depot locations. The availability models can be classified either in Single-echelon (one warehouse) and Multi-echelon (multiple warehouse) models [65]. The key to a accurate availability model is a proper choice of probability distribution that can accurately model the demand (Mean Time between Repair, MTBR) and variation in the repair loop. As these models depend on the time component spent in the pipeline (from US removal to SE in stock) individual process steps and queuing is often neglected. As stated earlier the repair loop of a component consists at least the shipping, logistic handling, and the repair process. By reducing the time required for any of the sections the overall TAT can be reduced and the model will calculate a lower required inventory. Due to the computational load of the algorithms used and complexity of modelling queuing, variation in the pipeline cannot be accurately described in these models. Therefore most inventory optimisation models use a constant to model the TAT.

The Airline MRO sector has been experiencing considerable growth over the past decades [48]. The main drivers affecting this growth are the appearance of low cost carriers and new aircraft technology. This increase in fleet size brings an increase in the number of aircraft systems to be maintained and repaired. In order to remain competitive, MRO providers are aiming to improve their supply chain processes. Next to this, there is a notable trend towards outsourcing airline maintenance. According to the Federal Aviation Administration (FAA) there is an increase in outsourcing of aircraft maintenance from 37% in 1996 to 64% in 2007 McFadden and Worrells [44]. Especially smaller airlines, LCC's and start-up carriers outsource MRO activities as they do not have the capital, or do not consider maintenance as their core business. Al-Kaabi et al. [2] describes four different MRO outsourcing models including; fully integrated, partially outsourced, mostly outsourced and wholly outsourced. Within the fully integrated model all the MRO activities are provided in-house. In this model the the airline's capabilities can be extended to support other airlines. In partially outsourced maintenance most of the the MRO activities are performed in-house and a small portion is outsourced. This model allows for more flexibility regarding seasonality and trends, and is well-suited for airlines with a limited number of different aircraft types [2]. In the mostly outsourced model only the most critical activities for the operation are performed internally and the rest is outsourced. Critical MRO activities are typically line maintenance, while activities with low demand at an airline level such as engine maintenance are often outsourced. The wholly outsourced MRO model considers outsourcing of all the MRO activities. LCCs such as Ryanair and Easyjet represent the majority of airlines using this business model. According to Al-Kaabi et al. [2] the outsourcing decision is mostly influenced by what is considered by the airline as a core competency as well as what level of criticality is associated with each MRO activity. In addition, economics of scale have a large impact on outsourcing. Large legacy carriers have invested in in-house repair capabilities throughout many years. Decisions to extent these capabilities and increase capacity are easily justifiable due to economies of scale. In contrast, starting-up MRO activities as a newcomer requires a major capital investment, which not all airlines are capable or willing to make.

2.3. Previous Research KLM E&M

In academic research the aviation MRO environment has often used as object of study due to its unique characteristics which differentiates it for the more traditional production environment. One of the main characteristics is that the MRO industry volatile nature of the demand for MRO services. MRO services are generally sensitive to trends, and have a relatively high degree of seasonality [16]. Academical studies have therefore been dedicated to predictive maintenance and forecasting methods to cope with trends in demand and accommodate capacity. A study performed at KLM E&M Component Services by Lemsom [41], studied how to control the aircraft wheel supply chain from a service level perspective. In this research Lemsom [41] proposed a framework controlling the supply chain based on several control methodologies derived from literature. This research concluded that active predictive control is best suited for controlling MRO component supply chains based on a case study of one particular wheel type. However, when dealing with multiple different parts and multiple customers in the same organisation, component replacement become harder to predict. Especially when service providers do outsourced work form other airlines, predicting component arrivals becomes almost impossible and must fall back on only seasonal influences which are absent with most components. Another complication in the MRO environment according to Boydstun et al. [11] is that the degree to which work content is known and the point at which it is identified is non-uniform. Hence, the knowledge about the actual repair workload is only gained when the inspection is completed and can increase during the process. Next to this, the degree to which the MRO system relies on shop floor knowledge and adaptive flexibility is generally higher than in traditional environments and the processes have a high variability in processing times [11]. These characteristics make the MRO industry unique, hard to predict and require a careful management of the internal processes.

Aside from forecasting the demand, MRO service providers are, according to Ayeni et al. [6] generally more focused on their most important factors which are typically the quality, the turnaround time (TAT) and the price. According to Cobb [12] controlling the TAT is key in achieving an optimal component availability performance and higher service level. Several past studies have therefore been dedicated to process improve theories (i.e. Lean Manufacturing) in order to identify bottlenecks and reduce the turnaround time (TAT) of parts and aircraft. Most of these studies have focused on individual repair shops. Several of these academical studies have been performed at KLM E&M component services (Shop MRO) [51],[70]. Papadopoulou [51] used the observe, plan, do, check, act (OPDCA) cycle to improve the performance of the Avionics and Accessories (A&A) Repair Shop using the theory of constraints. van Rijssel [70] used a a framework to find flow improvement measures to lower the turnaround time for aircraft component MRO processes at the A&A repair shop. Using Lean six sigma theory and a simulation model to determine TAT improvements within the repair shop. These studies have in common that the where internally focused on individual repair shops and a particular type of component. van Welsenes [71] studied the KPI measurements at component services with a brother supply chain focus. This research studied around time through shop MRO in relation to the component availability stock taken into account the incoming logistics. His study focused on determining the effect of eliminating TAT constraints on the amount of inventory in stock. van Welsenes [71] identified further research is necessary in implementing planning and control of manpower capacity at the logistic-In process in Shop MRO as this process was identified as a bottleneck. As these findings are resent, The study presented here is aimed to complement the performed studies at KLM E&M CS by focusing on the logistic and handling processes as these processes have been under-explored in the previous studies performed. Furthermore This research focuses on the CS2.0 project with combines the processes of Shop HUB and Shop MRO and the logistic centre which in all previous studied where investigated separately.

In addition, a recent study by Heath and Yoho [29] within the research domain of military aerospace MRO, states that research which addresses bottlenecks and or inflexible capacity in operations and identifies methods and opportunities to manage them would be useful for the academic community. As well as work that explores the impact of variability of work on individual aircraft on total throughput. Understanding the impact of the variability in aircraft component turnaround times, and quantifying the value of having flex capacity to act as a 'shock absorber' in the system would be valuable to the commercial and military MRO sectors [29]. According to Heath and Yoho [29] more efficient processes can be achieved when traditional planning, scheduling, and materials management decisions move closer to the shop floor to the point of discovery where information distortion and delays in the management and supply chain can be minimised.

Studies on improving information flows within the MRO processes are scarce. It would therefore be interesting to research is to investigate the potential in the MRO industry to eliminate "waste" linked within the information and goods flow as depicted in the theories around Lean Manufacturing. Research topics emphasise the digital coupling between departments and its processes of the company, its customers and its supplier's processes to shorten lead times and increase the flow through the processes. Research within the MRO industry is necessary to design and test new concepts of processes to show this potential.

2.4. MRO Supply chains

A supply chain can be defined as: "a system of organisations, people, activities, information, and resources involved in moving a product or service from supplier to customer". For an aircraft maintenance supply chain, the products can be specified as aircraft components. The activities are focused on repair and maintenance of the components, suppliers are the repair stations, and customers are contracted airlines. According to Tzafestas and Kapsiotis [68] when optimising the performance of processing within a chain processes, three options can be identified:

- Global supply chain optimisation: assumes direct and cooperative relationship between all stages of the supply chain.
- Manufacturing facility optimisation: minimise cost from manufacturing only.
- Decentralised optimisation: individual optimisation of each of the supply chain entities.

Given many research studies have been performed on individual repair shops this can be considered of lesser academic and practical value to scope on this part of the aircraft component supply chain. The global supply chain optimisation option can however result in a scope which is too large for one research, limiting the in-depth analysis that makes a research valuable. The options named above should not exclude one another. For that reason the focus should be on the decentralised optimisation while still linking the results to the supply chain. Validating the choice for decentralised target for the redesign and its link to the supply chain are of major importance, especially in the MRO supply chain. Guide Jr [25] mentions seven key characteristics in remanufacturing organisations which are; the uncertain timing and quantity of returns, the need to balance returns with demands, the disassembly of returned products, the uncertainty in materials recovered from returned items, the requirement for a reverse logistics network, the complication of material matching restrictions, and the problems of stochastic routings for materials for remanufacturing operations and highly variable processing times. These factors make differentiate the MRO industry from the standard manufacturing industry. Section 2.5 further elaborates on the particularities of the MRO supply chain which makes it a unique business environment.

2.5. Reverse logistics & Closed loop Supply chains

The key feature of aircraft MRO supply chains is that material flows occur in both directions [42]. This is in contrast to standard forward supply chain models of "consumable products" where there is a one-way flow of materials toward the customer. Physical flows of materials in the opposite direction towards the supplier are referred to as reverse logistics. These flows are rare in consumable product supply chains. However, in the MRO supply chain, there is an equal flow of unserviceable components from customer to supplier, with re-manufactured components flowing in the conventional downstream direction. The combination of the forward and reverse flow results in a closed loop supply chain, allowing the movement of rotable items [18].
This structure comes forth from the need to reduce the downtimes of aircraft. To prevent AOG situations unserviceable components are exchanged on site. The demand for service replacements associated with long lead times require spare parts stocking. In order for a company providing component availability to be competitive, the spare parts inventory level as well as the repair cycle should be optimised under consideration different performance aspects. The closed loop structure of the supply chain is presented in Figure 4.3.
The majority of material flows in the manufacturing industry consist of forward logistics, from suppliers to manufacturers to distributors to retailers. Forward logistics (FL) is therefore the focus of most research supply

chain management (SCM) research. Literature which falls under the he general umbrella of reverse logistics and closed-loop supply chain is relatively new in academical literature although is has gained considerable attention in industry and academia over the past decade [75] [57] [26].

According to the American Reverse Logistics Executive Council, reverse logistics (RL) is defined as; *"The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal"* [57].

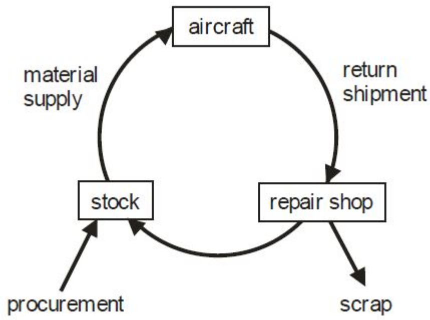

Figure 2.2: Closed loop supply chain MRO

Closed-loop supply chain (CLSC) research focuses on taking back products from customers and recovering added value by reusing the entire product, and/or some of its modules, components, and parts. The management of CLSC is defined as; *"The design, control, and operation of a system to maximise value creation over the entire life cycle of a product with dynamic recovery of value from different types and volumes of returns over time."*

RL and Closed-loop supply chains open up a new and interesting issues [23]. When compared to forward logistics, RL presents more complicated operations due to the uncertainties inherent in product returns, complex nature of re-processing, and high implementation costs of RL systems. Hence, optimisation of RL supply chains, and development of efficient information management systems is essential.

In literature several activities in RL supply chain can be identified which are generally divided into four different levels. The first level is collection or asset recovery the second is the combined inspection / selection / sorting process, the third level is disposition and re-processing and the fourth level is redistribution [14]. Asset recovery or Collection concerns the processes needed to obtain the products from the end-users. This includes the transportation and reverse logistics the activities needed to move the products from the points of use to the point of disposition, inspection, sorting, to determine the product's condition and the most economically feasible reuse option (Direct reuse, repair, overhaul, disposal etc.) [24]. According to Guide et al. [24] many firms use a silo approach to reverse supply chains, considering each activity in isolation without considering the integrated nature of reverse supply chains. Furthermore, companies tend to look at re-manufacturing as a technical operational problem: how to turn a returned product into a functioning product that satisfies all the quality requirements of a new product. This focus results in the fact companies often passively accept returns from the market or the channel. They do not actively manage the process of acquiring returns; hence, returns are uncertain in quality, quantity, and timing. Concentrating on the technical aspects of re-manufacturing, will result in ineffective reverse supply chains[24].

Collection
Asset recovery or product acquisition is the process of acquiring the used products or components from the customer for further processing. According to Fleischmann et al. [20] the acquisition is very important for the success of RL, since product returns are uncertain in terms of time, quantity and quality. According to Guide Jr and Van Wassenhove [26], product acquisition is the first step and is critical process for establishing the profitable RL. At this point it is decided which products are allowed to enter the system. This first step is essential in order to succeed in managing the system and controlling costs [57]. In conventional RL supply chains 'Gate keeping' represents the main entrance of RL. Gate keeping concerns the decision making process which parts are allowed to enter the reverse supply chain. The MRO supply chain differs form

the conventional reverse supply chains in this part, due to the high value of the components all components removed from the aircraft are fed into the reverse supply chain.

Next the products need to be transported to the companies facility for inspection, sorting, and disposition. Collection refers to the activities needed for the company to gain possession of the products [20]. Three collection methods where discussed by [37]. Either manufacturers directly collect from customers, manufacturers collect via retailers or manufactures collect through third party logistics. The take back methods for collection which can be distinguished by the "degree of control" on product returns. Individual collection of components gives complete control to the manufacturer. According to [5] the choice of collection method depends on the cost structure and collection quantity decisions Decision of collection centres and related parameters must be involved considerably in designing RL for its operational efficiency.

Selection, Inspection & sorting

Rogers et al. [57] reports that the customer may return the products because of known or unknown reasons, and the condition of returned products may differ greatly. So in reversed logistics a separate inspection of each item is required for sorting the products. Its overall appearance and state of the constituting elements need to be evaluated. Products and components are sorted out based on this evaluation.

Disposition & Re-processing

Once the products are inspected, next step is to take a disposition decision for further processing. At that moment, the company may decide what to do with the product, be it subject to inspection, tests, or other manipulations [57]. In the MRO industry the disposition consist of choosing the right repair shop to make the part serviceable again, or to scrap the part if a repair is not economically feasible. This last decision can also be made in the repair shop itself if the damage detected is worse than anticipated.

Redistribution Redistribution is the process of bringing the recovered goods to new users. Within the MRO supply chain the redistribution is done by the availability department who deliver components from the serviceable pool towards the customer.

According to Lambert et al. [38] there is no single reference model that all organisations can use to make their supply chains more efficient; each company must find a solution that best fits its specific situation. The activities stated above however give an indication of the essential steps in the reverse flow of the supply chain. By process mapping the company specific processes with respect to these activities, the reversed logistical processes can be optimised. Many mapping methodologies i.e. Value Stream Mapping, BPMN, Swimlane exist in literature. The best methods in order to map the performance of the reverse supply chain are discussed further in section 3.5.

2.6. Information Technology & EDI

The evolution of technology and the Internet has allowed the development of web-based systems that can lead to improved collaboration within the supply chain. Even though the importance of the value of information sharing in multi-level supply chains is well recognised, not much literature addresses this issue in the field of a closed loop supply chain [43]. Within the manufacturing industry, digital systems are used daily to design, develop, produce, deliver and support products for global markets. However, the wide range of systems used such as Enterprise Resource Planning (ERP), customer interface software, warehouse management systems etc. tend to create a the landscape of "Isolated Islands of Information" [43]. Information is stored in different systems making it difficult to share. Although some of these systems allow the data exchange in a dynamic and direct way, organisations still need to work closely with suppliers to improve the decision making process and the entire supply chain performance. Electronic Data Interchange (EDI) is the computer to computer interchange of business documents and/or information in standard, structured, machine retrievable data format (computer can process the information without human assistance). The use of information technology (IT) essential the effective control of today's complex supply chains. Langnau [39] mentions that successfully integrating an information system in the RL chain is the biggest hurdle and requires the most effort and time.[39] further states that the information system is a crucial actor in the success of the RL system. Today, the availability of commercial systems has increased, yet these systems still require a fair deal of customisation. Knowledge Management System is a unique element in the design of a conceptual framework for reverse logistics. RL differs from FL also in the way Information and product flow in the logistics networks. In FL, information and products flow in opposite direction in between the manufacturers, distribution centres and retailers while in RL information and product flow in the same direction in between the process facilities, distribution centres and collection points. Electronic data interchange receives much attention in literature as it is a key to optimise supply chain performance through cost reduction and improved process efficiency [9]. According to MacDonnell and Clegg [42] potential benefits from e-business applications for Airline MRO business are in the area of inter-organisational transactions, the ability to track components status, increased visibility, speed of communication, and reduction in inventory levels. However, the level of EDI in MRO supply supply chains is considered low, resulting many physical paperwork transactions and email communication. Basak [9] highlights the importance of e-procurement for MRO to enhance supply chain performance of the aviation industry. As literature shows that there is a tendency to follow traditional procurement process in MRO supply chain due to low volume and less importance of indirect materials [54]. The process followed in the MRO organisation is therefore time consuming, manual and paper based procedure. The process therefore suffers from significant disadvantages as higher lead times, high volume of inventory to stop loss of shut down, increasing cost, less communication with the supply chain partners [9].

2.6.1. Simulation in MRO

MacDonnell and Clegg [42] discusses how a contract with multiple part numbers should be optimised by trading-off mean time between repair (MTBR) and cost. However, the complex inter-dependencies of random effects (i.e. component failures), response mechanisms, multi-airline schedules, delivery time constraints and service level commitments to multiple airline operators can only be sufficiently addressed through simulation analysis [48]. According to Alabdulkarim et al. [3], simulation studies on the closed-loop inventory systems where the failed part is repaired and returned to storage as is the case in typical in aerospace MRO systems is lacking. Especially, the interaction of maintenance policies with other system interactions such as labour. Alabdulkarim et al. [3] state there are examples of modelling the MRO operation in isolation, but there is a lack of understanding of modelling for maintenance of assets where the spares stock is refilled using MRO functions. Alabdulkarim et al. [3] further state; "The use of optimisation with simulation is generally low, particularly in the areas of operations and staffing. Also, the modelling of inventory used for maintenance operations receives little attention even though it has the potential to impact asset repair time".

2.7. Conclusion literature review & Scientific gaps

From the literature review it can be concluded that several different studies have been devoted to aircraft MRO. A part of these studies have been devoted to component service companies. Within the business of companies with contract for availability the majority of the academical research has been devoted to novel availability models [65]. A few studies have been devoted to the production and use of process improvement theories within the production [70], [71], [41]. A neglected part of the component MRO business is the reverse flow of components. The logistics and handling operations concerning the MRO field are unique due to the heavy regulatory obligations concerning the spare parts.

The review of existing literature further reveals that, academical research that studies the the impact of new process designs of the (reverse) logistics flows and handling of components on the performance of a MRO provider in the component availability sector are scarce. In addition, the most recent development in supply chain optimisation is the use of simulation based optimisation. Simulation based optimisation allows for detailed, and more complex representation of the supply chain. A simulation based optimisation can capture the behaviour of all the processes involved, their interactions, and the uncertainties associated with these systems. The knowledge on how to improve the performance of the MRO operations and redesign the logistical processes using simulation is however lacking in literature. Furthermore, Heath and Yoho [29] states research aimed at understanding the impact of the variability in aircraft component turnaround times, and quantifying the value of having flex capacity to act as a 'shock absorber' in the system would be valuable to the commercial (and military) MRO sectors [29]. The research gap identified can partly be filled by researching the potential for improving operations using the combination of advanced operations management, innovations in automation and information technology and the practical application in the unique MRO environment. Therefore a case study at KLM E&M is performed as currently there is an opportunity to redesign the logistic processes using automation in physical and administrative tasks. This study therefore aims to contribute to theory in several ways. By thoroughly analysing the reverse logistic chain of an aircraft MRO provider and redesigning the processes linked to information and physical flow. The potential of automating tasks in the aircraft MRO supply chain is evaluated using simulation. This is an area of research that has been neglected, and as a result is not well served by current systems solutions. Optimising the logistic and handling from a supply chain perspective will further result in better processes the current operations of KLM E&M, and will simultaneously contribute to the state of the art literature.

3

Theory Analysis

In this chapter, the theory analysis is presented. The theory analysis is focused on theory around operations in production management, lean manufacturing, six sigma methodology process mapping an theories on transaction cost as result from complex information flows and types of modelling approaches. The theory analysis is answers the following sub research questions;

- *Which process improvement theories can be used to support redesign of the component flows?*
- *Which models can be used to assess the performance of logistic handling systems?*

3.1. Process improvement in operations & production management

The complexity of the MRO supply chain with its many customers and locations and operations, requires thorough analysis. In order to find a well suited methods for this analysis, scientific literature was consulted in the field of operations management. Operations management provides many different theories and methodologies for process improvement. This field of research concerned with designing and controlling the process of production and redesigning business operations in the production of goods or services. The classic definition of operations management concerns "managing the process that converts inputs into outputs by transactions in the form of goods and services efficiently, effective, in quality and accuracy". Adapted by (W.W.A. Beelaerts van Blokland, 2016), Advanced Operations & Production Management concerns "balancing customer demand pull with supplies for generation of continuous flow of value efficiently, effectively in quality and accuracy by coordination of products and processes in the company whilst continuously reducing all kinds of non value add or “waste” in processes". Within this field of research process improvement theories such as lean manufacturing, six sigma, the theory of constrains, statistical process control and many more are used to analyse and improve businesses mainly in the manufacturing / production domain. Each theory has its own history within this domain focuses on different aspects. Generally the theories have in common they use some form of business process mapping, process analysis to gain a greater understanding of the process and identify targets for possible re-design. In the following sections elements of these theories are analysed to asses there usefulness within the scope of this thesis.

3.1.1. Lean Manufacturing

Lean manufacturing principles are widely accepted in the industry and academical studies since the early 1990s. Lean Manufacturing or lean thinking is a theory that focuses on minimising Muda (waste) while maximising customer value [77]. First introduced by Toyota founders Eiji Toyota and Taiichi Ohno, it describes the collection of synchronised methods and principles for controlling production sites [46]. Key characteristics of Lean Production are the strict integration of humans in the production process, a continuous improvement and focus on value adding activities by avoiding of waste. Womack et al. [77] identified five core principles of the lean organisation:

1. Specify value
2. Identify the value stream
3. Establish flow throughout the proces

4. Implement Pull systems
5. Pursue perfection continuously

Aside from the five core principles, 8-types of waste are identified which are non-value add to customer Womack et al. [77].These are arranged according to the popular acronym TIMWOODS, as indicated below.

- T – Transport – Moving people, products & information
- I – Inventory – Storing parts, pieces, documentation ahead of requirements
- M – Motion – Bending, turning, reaching, lifting
- W – Waiting – For parts, information, instructions, equipment
- O – Over production – Making more than is IMMEDIATELY required
- O – Over processing – Tighter tolerances or higher grade materials than are necessary
- D – Defects – Rework, scrap, incorrect documentation
- S – Skills – Under utilising capabilities, delegating tasks with inadequate training

by identifying the TIMWOOD(S) wastes in a (manufacturing) process opportunities for improvement arise. In addition lean manufacturing provides key performance indicators such as work in process (WIP), cycle time, on-time performance and inventory. Implementation of lean manufacturing is well settled in the production industry, however, in the aircraft maintenance industry, it is still in its infancy.

3.1.2. Theory of Constraints

One of the most cited and widely used theories in process improvement is the the Theory of Constraints (TOC) by Goldratt and Cox [22]. The TOC focuses on achieving the company's 'goal' by identifying the constraining processes and finding ways to elevate these constraints. Identifying bottlenecks is key in this theory. As Goldratt states, 'an investment in a non-bottleneck activity has little, if effect on overall throughput' the method focuses on improving the output of the total chain. Namely the chain is as strong as its weakest link.So in order to reduce the total throughput time in a process, the bottlenecks in the process should be eliminated. The TOC depends on several key steps in process improvement.

1. Identify the constraint: Identify the limiting processes within the whole chain. These include physical and non physical processes.

2. Exploit the constraint: Exploiting the constraint is aimed at achieving the best possible performance from the constraint. By making sure the bottleneck is working on maximum capacity, the effect of the bottleneck is minimized.

3. Subordinate all other processes to the constraint: By aligning other operations to the constraint

4. Elevate the constraint: In case the the process constraint still does not generate the desired output, input can be increased by investing in new equipment, workforce etc.

5. After implementing the previous steps, repeat from to step one: Asses to see if another operation or process has become a limiting constraint. the final step is consistent with a process of ongoing improvement.

Within the component MRO supply chain the TOC is useful to find the main constraint. Constrains can lead to unwanted buffering at several parts in the supply chain leading to high levels of WIP which in turn is very costly due to the price of the spare parts.

3.1.3. Six Sigma

Six Sigma is a methodology widely used in process optimization. The methodology was developed by the company Motorola in the 1980s. The aim of Six Sigma is to maximize the probability that the system output complies with the customer expectations. The variability of the amount of defects in the output determines the quality. The less variability in the output of the system, the smaller the chance of defect in the system and thus the smaller the chance of dissatisfied customers. Motorola set this goal so that process variability is ±6 S.D. from the mean. Six Sigma projects follow the DMAIC cycle inspired by Deming's Plan-Do-Check-Act Cycle. this methodology is composed of five phases by the acronyms DMAIC[50]. DMAIC stands for Define, Measure, Analyse, Improve and Control. Aside from this cycle, a wide variety of tools to measure analyse and improve business processes are described in literature. One of the main tools used in six sigma is the probability plot. The Probability Plot can help to analyse if a certain process is normally distributed or not. Six Sigma says that when there is a lot of variation in the plot (skewed graph) then there must be waste in the process (Beelaerts van Blokland, de Waard, & Curran, 2008). Next to the probability plot pareto analysis is used to extract the main causes from a range of phenomena. The methodology is closely related to 80/20 rule which follows the reasoning that 20% of the causes is Responsible for 80% of the consequences.

3.1.4. Business Process Re-engineering (BPR)

BPR is a business management strategy, focusing on the analysis and design of work flows and business processes within an organisation [27]. BPR is defined as;

"The fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of performance, such as cost, quality, service and speed"" [27]

As the definition states the focus is on fundamental and radical changes. The word "fundamental" here is aimed at the core business of a company. In BPR one should ask the most basic questions about the companies and how they operate: Why do we do what we do? And why do we do it the way we do? Asking these fundamental questions forces people to look at the (tacit) rules and assumptions that underlie the way they do their businesses. According to BPR theory, these rules often turn out to be obsolete or false. The word is radical is aimed to avoid small improvements and superficial changes to what is already in place. Instead of this one should think of completely new ways in which the business can satisfy its customers. According to Hammer [27] “Re-engineering should be brought in only when a need exists for heavy blasting. Marginal improvements require fine tuning; dramatic improvements demand getting rid of the old and replacing it with something new”. Business Process Re-engineering contains five major steps that managers should take:

- Refocus company values on customer needs
- Redesign core processes, often using information technology to enable improvements
- Reorganise a business into cross-functional teams with end-to-end responsibility for a process
- Rethink basic organisational and people issues
- Improve business processes across the organisation

3.1.5. Conclusion process improvement theory

In order to improve the processes with in the MRO process improvement theories can help with different aspects of the supply chain. As the TOC states it is important to define a clear goal of the company and find process constrains hindering the achievement of that goal. Lean theory can assist in finding (obvious) waste in the system by looking different aspects of the production system. Six sigma provides tools that compliment the lean theory. Six Sigma is connected to lean as both method both aim to reduce variability. However, Six Sigma is a methodology for variability reduction, not a general strategy for improvement (e.g., Six Sigma does not address obvious waste). BPR has its focus on process identification, process analysis and process change. These are similar to Lean Six sigma approaches. However, the goals and approach for bringing about change are fundamentally different. Whereas lean six sigma promotes incremental improvement on a continuous basis, BPR promotes fundamental rethinking and radical redesign. For this study the goal is to look for the more radical changes possible in the process as the logistics department and repair shops are moved to a new location the opportunity is there to use BPR thinking instead of incrementally improving the processes.

3.2. Theory on process variability

One of the key works on variation in production systems is described by Hopp and Spearman [32]. In their book 'Factory Physics', Hopp & Spearmann give a description of the underlying behaviour of manufacturing systems. Understanding the specific behaviour of such systems enables one to find opportunities for improving existing systems, design effective new systems. variability can take on many forms, such as variability in process times, delivery times, staffing levels, demand rates etc. Anything in the system that is not absolutely regular and predictable produces variability. The causes of variability can be classified into internal factors and external factors. Internal factors include downtime, operator-induced fluctuations in production rates, rework etc.External factors include i.e. irregular demand, product variety, customer change orders, etc [32]. Variability is and important characteristic with a large impact on the supply chain and its performance. Especially in MRO where the demand (or supply of US components) is highly volatile. Demand can be classified

Table 3.1: Methodologies

Process improvement methodologies					
Methodology	Description	Key tools	Main target	Limitations	Used in thesis
Lean	Theory focuses on reducing waste process by eliminating non-value add activities.	Reduce waste & Create customer value	VSM, 7 wastes, Pull, Kanban, 5S, 4M, Just-Intime	Focus on incremental improvements, not complete redesign, less focus IT	VSM, 7 wastes, customer demand pull
Six Sigma	Six sigma is aimed to Improve the quality of the output of a process by identifying and removing the causes of defects and minimizing variability in manufacturing environment	Reduce process variation	Normal probability plot, Pareto analysis,SIPOC, RCA	Mainly useful when processes are normally distributed	Pareto analysis, Normal probability plot
Lean Six Sigma	Combination Lean and six sigma methodiologies	Reduce waste& variation	DMAIC cycle and comibantion lean six sigma tools	Focus on continues practical improvements	Adapted DMADE structure
Theory of constrains	TOC is aimed at identifying and eliminating the key constraining process limiting the company's goal from being achieved.	Identify an eliminate constrains	Constraint identification framework	Improvements mainly on short term	Constraint identification current state
Statistical Process Control	The goal of statistical process control is to findand monitor the variations in a process.	Focus uncontrolled variation	Framework causes variation, control charts	Focus on identification, less on solving and eliminating	Theory on variation and its causes
Business Process Re-engineering	Fundamentally rethink processes in order to dramatically improve customer service,cut operational costs, and become world-class competitors	Re-engineer processes	Framework for redesign	Not well suited for small improvements	Framework adaptation

using the 'the average inter-demand interval (ADI) and its coefficient of variation (CV)' as indicated in Figure 3.1. The ADI measures the average number of time intervals between successive demands. The coefficient of variation (CV2) is the standard deviation of the demand divided by the average demand. Using both parameters the demand can be classified in categories smooth, intermittent, erratic, and lumpy based on specific cut-off values. Studies by Syntetos et al. [66] and set cuf-off for ADI to 1.32 CV2 to 0.49 based on empirical studies. The amount of demand uncertainty affects the process performance. In case of smooth demand, demand is relatively stable and predictable. When demand is classified as erratic or lumpy, variance is large and has a negative impact on the process performance unless appropriate action is taken. Hopp and Spearman [32] state that the essential components of all value streams, production processes or service processes are demand and transformation. Relating to buffers, Hopp and Spearman [32] state that in the presence of variability, there are only three buffers available to synchronise demand and transformation with lowest cost and highest service level; capacity, inventory and time. This is called the buffering law.

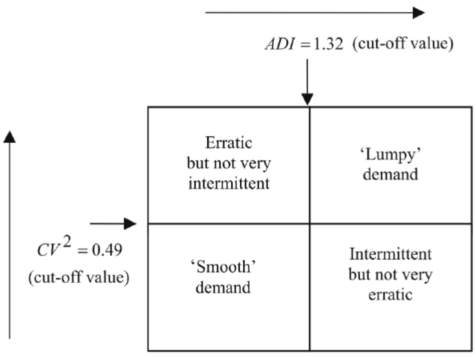

Figure 3.1: demand characteristics [66]

Buffering Law: Systems with variability must be buffered by some combination of:

- inventory
- capacity
- time

The interpretation of the buffering law is as follows. If you cannot 'pay' to reduce variability, you will pay in terms of high WIP, under-utilized capacity, or reduced customer service (i.e., lost sales,long lead times, and/or late deliveries). Following from the buffering law Hopp and Spearman [32] state the variability law.

Variability Law: Increasing variability always degrades the performance of a production system.

- Higher demand variability requires more safety stock for same level of customer service
- Higher cycle time variability requires longer lead time quotes to attain same level of on-time delivery time

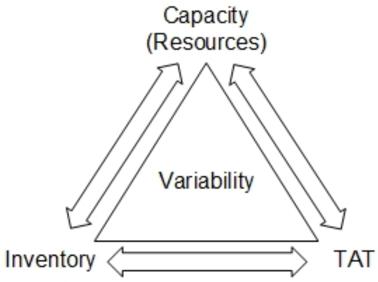

Figure 3.2: Trade off Capacity, Inventory, Time

Hopp and Spearman [32] therefore state lean as: "Production of goods or services is lean if it is accomplished with minimal buffering costs." The exact mix of buffers is a management decision, the decision of whether or not to buffer variability is not. Conclusion: if you can't pay to reduce variability now, you will pay later with lost throughput, wasted capacity, inflated cycle times, excess inventory, long lead times,or poor customer service [32].

There are however causes of variability that result in a buffer that are not considered "waste". This can be the case when variety is added to a product mix to accommodate customer's demands. Although this will reduce efficiency and increase buffers, it cannot be considered as waste. According to Hopp and Spearman [32] Lean is better defined as "best buffer" production than "low waste" or even "low buffer" production. As variability will always be part of production systems. Therefore, the decision of how to buffer the variability requires attention. What the appropriate buffering strategy is depends on the production environment and business strategy. For cheap products such as ballpoint pens, buffering in time (long lead times) or capacity (make-to-order) is not viable and therefore the product is buffered in inventory. Hence, customers will not order ballpoint pens or accept waiting times. For emergency services to the hospital demand is also unpredictable. Buffering in time here is obviously not acceptable as is buffering in inventory (hospital trips cannot be stored as inventory). Thus, capacity is buffered in terms of ambulances and personnel and low utilisation rates are accepted as part of the service, covering the peaks in demand. Related to the MRO industry buffering in time is not acceptable as long lead times will result in AOG situations. Buffering inventory is possible and is done in spare component stocks. In MRO buffering capacity is also possible and will result in a shorter return flow of components to the stock. This is however a form of buffering that is often overlooked and therefore is taken into account in this study.

3.3. Transaction Cost Economics

One of the key characteristics of the The MRO industry is that it is subject to regulations and certifications of processes, assets and components due to government laws for safety of the customers making use of airlines [15]. This results that assets to be used for MRO services can only be used exclusively for this type of service and worthless in any other type of industries [4]. In literature this is referred to as asset specificity. Asset specificity is described in the Transaction Cost Economics (TCE) theory of [76]. TCE underlines the importance of transactions within and between companies. The definition of a transaction is described as *"A transaction occurs when a good or service is transferred across a technologically separable interface"*. Transactions are necessary elements for a value system to generate value.Williamson [76] states that three factors play a fundamental role transaction costs: uncertainty, frequency of transactions and asset specificity which are subject to conditions of bounded rationality and opportunism. While uncertainty and frequency play some role in creating transaction costs, Williamson considered asset specificity the most important dimension. Bounded rationality and opportunism do not play a role in this research. According to Williamson [76] there are four types of asset specificity; site specificity, physical asset specificity and human asset specificity and dedicated assets. Site specificity means a natural resource is only available at a certain location and movable only at great cost. Physical asset specificity describes e.g. specialised tooling or complex computer systems designed for a single purpose. Human asset specificity includes highly specialised human skills (i.e. arising in a learning by doing fashion). Dedicated assets are assets in a plant that cannot readily be put to work for other purposes. Another important addition is time specificity. An asset is time specific if its value is highly dependent on its reaching the user within a specified, relatively limited period of time. A transaction can have different levels of asset specificity. Low asset specificity means that little information has to be exchanged with the transaction partner. High specificity is related to complex information for complex products, processes and services dominated by extensive regulations and certification by airline authorities for safety reasons [15]. In case of high asset specificity, complex information and / or products have to be exchanged, before, during and after the exchange of goods [4]. High levels of asset specificity therefore lead to higher transaction cost. These transaction costs complement the production cost. As [15] states that transaction cost should not be seen as a stand-alone: the total costs of a system need to be minimised. The total cost of the component MRO supply chain which is subject to high levels of asset specificity should be taken into account then measuring and analysing its performance.

3.4. Model Design

Aside from process improvement theories one of the objectives of this research is the development of a model to optimise and evaluate performance. The Delft Systems Approach (DSA) by Veeke et al. [72] is a systems engineering approach well for the design of a new systems. It uses an iterative system design approach. The DSA is suitable to use as a basis for simulations. It provides a through methodology containing multiple useful models to determine the structure of systems, based on describing systems in terms of functions, process design and control. The DSA divides the design phases in function design and process design and later focuses on functional and process control. Function design determines if a systems configuration is able to provide the intended result/service with acceptable efforts/costs. It is determined what functions need to be fulfilled, what is required and what alternatives are feasible. A basic input-output model of the DSA is illustrated in in Figure 7.1. in the DSA approach each individual system is considered a subsystem in its environment. The subsystem fulfils the requirements of the environment and provides the environment with its performance [72].

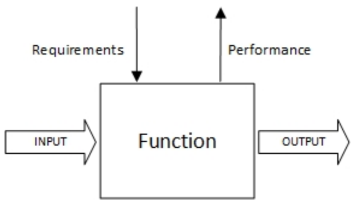

Figure 3.3: Delft Systems Approach Basic elements [72]

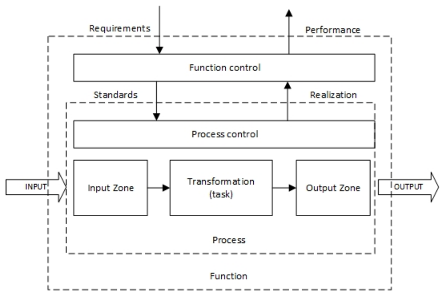

Figure 3.4: Delft Systems Approach Basic elements [72]

This model can be further improved by including control layers. Within the DSA approach three layers can be distinguished: the physical process, process control and function control, see Figure 3.4. The physical process includes all activities that need to be done within the handling area, such as sorting packages and transporting the components to repair shops and the warehouse. Process control directly controls the physical processes and deals with disturbances in these processes. In case a process TAT is about to be violated, process control needs to act to prevent this expected violation from happening.In function control decisions are made for the medium- to long-term process organisation, in order to match functionality and reality. This includes setting standards to reach the target state of the system, for example by appointing the maximum allowable waiting times for US components. Function control does not react to individual events in the daily process, this is solely the task of process control. The result of realisation and function control is the performance of the system: the extent to which the requirements are met [72].

3.4.1. process control

The DSA provides an extensive description of various control systems. Process control consists of two forms of control. The first is feed forward, as illustrated in Figure 3.5;

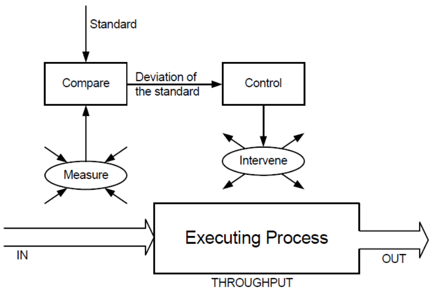

Figure 3.5: Feed forward control [72]

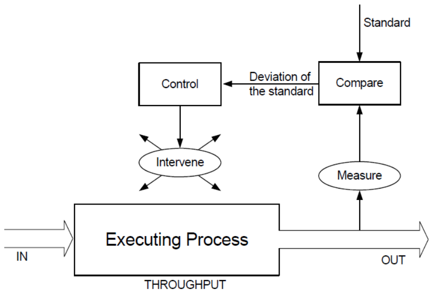

Figure 3.6: Feedback control [72]

Here, the disturbance is determined, after which is compensated for the influence of the disturbance. The disturbance can occur in the input or during the throughput. The disturbance can occur upstream or downstream with respect to the intervention. The key point is that the disturbance is measured and that from this measurement the compensatory intervention can be determined. Cause determines intervention [72]. The second form of control is feedback, as illustrated in 3.6. In feedback control the value or state of the output is measured in this control loop. This (real) situation is compared with the standard situation, in a comparison function. The real situation is the state as it actually is. The standard situation is the state as it must be. In the case of a detected deviation between reality and the standard, this information is passed on to a control function. This control function determines the intervention such that it can be assumed that the output value or the state will adhere to the standard afterwards. This is feedback (reacting). by doing this, it becomes possible to react to unknown and immeasurable disturbances that occur during the throughput. The consequence of the disturbance is measured and not the disturbance itself. in short; result determines intervention [72].

3.5. Business Process mapping

A fundamental part of many process improvement theory is a good understanding of the current state. This understanding of a the companies process within a supply chain can be gained through business process mapping. Business process mapping can help to understand, visualise, and document a process as it is. According to Palma-Mendoza and Neailey [48], business process maps are useful in analysing flows, clarifying the relationships and sequence of operations. One of biggest benefits of process maps, is the fact that it enables to visualise complex processes. Several methods for gaining an understanding and identifying waste in the process through business process mapping are known in literature. These individual methods tend to be more useful in relation to some projects than others. Combining different methodologies for a better result is therefore attractive. In order to do so first the most used business process mapping methodologies are described and compared for their usefulness in the MRO supply chain.

3.5.1. Swimlane

A cross-functional process map or swimlane map is a useful of business process map which illustrates work flow in organisations. It is a a visual aid for picturing work processes and shows how inputs and tasks are linked. It highlights the steps required to consistently produce a desired output. The work flow consists of a set and series of interrelated work activities and resources that follow a distinct path as work input get transferred into outputs that costumers value. The name cross-functional process map means the whole end-to-end work process crosses several functions or other organisational entities. The term swimlane diagram come from the pattern of the horizontal bands similar to Olympic swimming pools. Aside from the visual representation of the work flow the swimlane map helps to build understanding between cross functional departments that contribute in the same supply chain. The cross functional flowchart or swimlane can also be used to again a better business understanding and individual process steps.

3.5.2. Value Stream Mapping

Aside from the Swimlane Map, Value Stream Mapping (VSM) can be used to map processes. The VSM method originates from the Lean manufacturing philosophy and is useful for analysing the current state and designing a future state of a value chain based on the the value added at each process step [59]. The VSM was introduced in the book ”Learning to see - value stream mapping to create value and eliminate muda” [59].

The aim of the VSM is to reduce waste by identifying the value-added and non-value-added processes in the end-to-end chain. A value-added process here is defined as a process step that does add value to the end-product and is valuable for the customer. A non-value-added process step is a step that is not required to meet customer needs [59].The advantage of VSM is that it both shows the sequence of actions in a process and data on material flow, information flow, inventories, process times, set-up times and delays. “value” is defined as a capability provided to a customer of the highest quality, at the right time and at an appropriate price. The VSM does however also have a few shortcomings. The effect of inter department relations and transactions within the value chain are not shown explicitly in the VSM.

3.5.3. Cross functional VSM/ VSM-I

In this research the focus is on the physical and information flow between different departments in the MRO supply chain. In order to visually show the MRO processes is a clear way a combination of the VSM and Swimlane analysis is constructed. This combines the cross functional and decision aspect of the Swimlane with the ability to add buffers, process-times and applications such as pull and Kanban triggers from lean manufacturing in the process map. In this way transactions between departments concerning information flows become visual as well as the effect on the value adding processes. An earlier study Hooft [31] used the combination of VSM and swimlane mapping in the supply chain of empties return at a large brewer. The combined map dubbed VSM-I (value stream map - information) has never been used in an aviation (MRO) environment. Due to the complexity of flows through different departments and many information transactions, the combination has huge potential. Hardly any industry knows its components in the life cycle as detailed as the aviation Industry, due to FAI and EASA regulation traceability should be guaranteed for each component. A lot of data is collected but it is barely used as a resource to solve other problems apart from its original purpose. Data is often not combined for improving processes from a supply chain perspective due to the many departments and different systems involved. The combined VSM and swimlane map can therefore have the potential to find data points for process improvements as well as serve as base for a redesign.

3.5.4. IDEF0

IDEF0 or Icam DEFinition for Function Modeling (where ICAM stands for "Integrted Computer Aided Manufacturing") is another well known method for process mapping. IDEF0 diagram exists of one main building block, the activity box and four different arrows going in or coming out of the box. "The Activity may be a decision making activity, an information conversion activity or a material conversion activity. The Inputs are the items that are transformed by the Activity; the Output is the result of the Activity. A Control is a condition needed to perform the Activity. The Mechanism is the means by which the Activity is realized. The boxes together with their interfaces (Input, Output, Control and Mechanism) form the Diagrams of the methodology". The diagram has a top down approach, where every activity consists of multiple lower level activities. IDEF0 shows the main activity A0. At the IDEF1 level the main activity is split up in lower level activities A1, A2.

3.6. Modelling MRO

3.6.1. Mathematical Modelling

Following from the academic literature review several studies have been devoted to modelling in MRO. In this research mathematical models can be used in order to determine the potential of different process redesigns on the KPIs. Mathematical models can quantify the performance of different designs scenarios within the supply chain in respect to a set of parameters. Understanding the dynamics of the supply chain and component flows in a computer environment is one of the main benefits of using models. Furthermore, models can be used to include stochastic variance of arrivals, process times and unexpected events. In addition computer models can be used to optimise capacity of resources.

According to Law et al. [40] there are different ways to study and experiment with a system, indicated in Figure 3.7. Aside form experimenting with the actual system, which is expensive and often impractical, models can be used. Models concerning the optimisation of systems are often solved analytically. These models are defined by a set of mathematical relationships expressed as constraints. A algorithmic solver is then used to find a solution to the analytic model that satisfies the constraints while striving to meet an objective such as minimising the number used resources. However, most complex, real-world systems with stochastic elements cannot be accurately described by a mathematical models which can be evaluated analytically [40]. In addition, the mathematical approach has a few other shortcomings. Accurately representing the system by a set of mathematical constraints is a very complex and expensive process. Important constraints in the real system often cannot be accurately modelled using mathematical constraints and must therefore be ignored. The resulting optimisation using analytic models may satisfy the model, but may not be feasible in the real system.

Various analytic and statistical modelling approaches have been widely utilised in maintenance research. Queuing theory has been employed as an analytic instrument for various of applications, i.e. telephone traffic, aircraft landing, repair of machinery, and taxi stands. Queuing models assume that the arrival and service times have particular distributions [56]. Hence, when attempting to model complex systems with bespoke queuing logic, it is difficult to capture and represent complexity using analytic queuing theory. Furthermore, if the probability distribution varies with time, then it may be impossible to generate analytic solutions and for such problems simulation is a more appropriate tool for such situations. Simulation has been widely used for manufacturing systems as well as defence operations, health care services and public services. It is defined as “experimentation with a simplified imitation of an operations system as it progresses through time, for the purpose of better understanding and/or improving that system” [56]. Simulation techniques have the capability to analyse the performance of any operating system without affecting the real system. for this study therefore Simulation is chosen, because finding a solution by analytic methods for this type of problem with so many parameters and restrictions would have been to complex to get to valid representation of the real world.

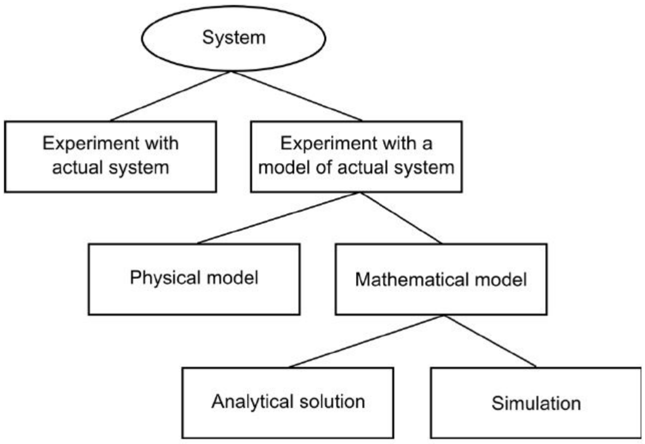

Figure 3.7: Ways to study a system

3.6.2. (Discrete Event) Simulation

Simulation can be considered as the study of the behaviour of actual systems by experimentation of models. Generally, simulation is recommended when problems are impossible or expensive to be solved by actual experimentation or when problems are highly complex to be treated analytically. In view of the fact that simulation considers the stochastic characteristics of a system, it can reproduce system behaviour with greater realism. There are three main simulation techniques described in literature for the purpose of representing real world systems. Discrete event simulation (DES) is one of these main simulation forms next to ’Agent based modelling’ and ’System dynamics’ [67]. System Dynamics (SD) studies system behaviours by investigating structure of a system using an influence diagram or a stock and flow diagram. Discrete Event Simulation (DES) was defined by as the modelling of systems which state changes occur at a discrete set of points in time. Whilst SD captures the cause-effect structure of a system, DES models the flow of entities through a system. The potential of this technique lies in its ability to track the movement of entities, and incorporates rich performance measures. Typical questions in developing an discrete event model are, what is flowing in a system, where does it collect, and what cause it to flow. Agent-Based Simulation (ABS) models a system as a collection of agents that can assess their situation individually hence can make decision based on a set of rules. Unlike other techniques, ABS takes into account complex relationship where agents (people, products, assets, etc.) can have different histories, intentions, desires and individual properties, and agents are able to influence each other. In comparison, SD allows top level system’s evaluation, DES is suitable for detailed system investigation, whereas ABS can capture for both levels from individual perspective. Discrete event simulation (DES) and system dynamics (SD) are two modelling approaches widely used as decision support tools in logistics and supply chain management. According to Palma-Mendoza and Neailey [49] SD is mostly used to model problems at a strategic level, whereas DES is used at an operational/tactical level.

For the purpose of this study a discrete-event simulation model Law et al. [40] is used for the evaluation different designs under different scenarios. Discrete event simulation modelling can be used to analyse the operational performance of a redesign of the handling area and is able to locate the bottlenecks, as it does offer the possibility to include stochastic variances over time and to run replications to perform sensitivity analysis and experiments under different circumstances. The discrete event simulations in this research are conducted in the SIMIO software package. The modelling process starts with the most basic conceptual design that is able to (partly) represent the real word environment. This will then be coded into a simple intermediate design. When more factors can be added successfully to the conceptual design, making it a more complex and more accurate model, it can be implemented in the software. These steps are repeated several times to finally obtain a more detailed design model which can be used to answer the modelling questions presented in this research. In discrete event simulation, the operation of a system is modelled as a discrete sequence of events in time. Each event occurs at a particular instant in time and marks a change of state in the system. Between consecutive events, no change in the system is assumed to occur, hence the simulation can directly jump in time from one event to the next [40].

3.7. KPIs in MRO & reverse logistic chains

In order to measure, analyse and redesign the MRO supply chain processes insight is needed on how exactly performance can be measurement. For this purpose the formulation of performance measurements (KPIs) is essential. In their book on Supply Chain Management, Handfield and Nichols [Handfield and Nichols] state that "Performance measurement is the glue that holds the complex value-creating system together, directing strategy formulation as well as playing a major role in monitoring the implementation of that strategy". Metrics are therefore needed to evaluate how work is done and to direct the activities, since what is been measured indicates how companies intend to deliver value to our customers. Paulen and Finken [52] define key performance indicators (KPIs) as key organisational metrics that drive the performance of businesses. Several papers have been reviewed on performance measurements in reverse logistics, closed loop supply chains and MRO component availability systems to construct a list of KPIs for the selection in this research. In order to evaluate the correctness and suitability KPIs Rezaei et al. [55] developed a list of criteria based on a literature review of performance measurement in logistics chains. In this study, all these requirements are considered for selecting the KPIs. According to Rezaei et al. [55] the KPI must;

1. Be measurable in physical and financial units
2. Be Specific, realistic and representative
3. Be performed, defined, and quantified consistently
4. Reflect the responsibilities of the involved departments/ managers,
5. Make the costs elements transparent
6. Must be aligned with overall organisational goals, when used by a particular department

3.7.1. KPIs in reverse logistic chains

The Reverse Logistic Association defines several sectors of Reverse Logistics Performance Indicators, which can be used for measuring the performance of reverse logistic supply chain. These sectors are: Customer Satisfaction, Financial Performance, Internal Business Process Perspective, Warehousing, and Transport [47]. Within each section, key performance indicators can be established. several KPIs for each of these of these sectors where defined by [47] following from a literature study on reverse logistic KPIs.

Financial Performance Typical indicators for financial performance are the return on Investment. Every firm aims at achieving high return on investment. Reverse flow offers profit margins to the company, increase the number of its customers.Profit reflects how much the operations are earning, in absolute terms. Needed apart from ROI.

Internal Business Process Perspective In the internal business process perspective the service of inspection of reverse logistics activities is also included. Internal business process perspective: This section is defined because the better the internal processes the better for the customer and shareholders. The most interesting KPI for this section is the cycle time of the product within the internal scope of the company.

Warehousing Warehousing facilities and operations play a vital role in the overall supply chain process, which includes reverse logistics. Warehouses Pagona et al. [47] states warehouse should achieve both efficiency and effectiveness in supply chains. For companies that operate reverse logistics, any item that has been returned is received into the warehouse and stored until it is examined for repair or enter the next hub in the reverse logistics channel. This shows the extremely high value of warehouse space and operations, for reverse logistics operations. Reverse logistics services such as repackaging, relabelling, restocking are also included in warehousing. Some performance indicators of warehouse for reverse logistics are the cost of the process to receive back product, productivity (volume received per man-hour), quality of returned products, quality of the package of the products, and cycle time [10].
Transport According to Pagona et al. [47] the role of transportation in reverse logistics is essential as the inbound and outbound transportation have a crucial role in reverse logistics operations. The services of transport of the returned products, the redistribution as well as the visibility are also included in transport. Without proper transit of returned goods from the point of consumption to the processing service centres and then shipping the re-manufactured products to new customers, reverse logistics operations cannot be sustained.
Customer Satisfaction According to Govindan et al. [23] Customer satisfaction is important to any company that has a return flow supported by reverse logistics. According to Govindan et al. [23] customer satisfaction is affected by the behaviour of the employees (courteous, knowledgeable, helpful), accuracy of billing, service quality, quick service and flexibility. In addition quality comes first for the majority of customers. fast delivery, extra costs and information regarding the available reverse logistic services affect the quality of the reverse logistic services.

3.7.2. KPIs in MRO supply chains

Two main quantitative performance measures can be identified in traditional supply chain management that are used to measure the efficiency and effectiveness of the supply chain; Cost and service level [10]. According to Kilpi et al. [34] the performance of MRO companies contracting for availability are generally measured using the 'Service Level'. Here the service level equals the percentage of the requests that are successfully fulfilled by spare parts in stock. A limitation of this measurement is that it is focused on the forward logistic part of the supply chain and amount of parts stocked. The performance of the return flow of US components can easily be compensated by investing in more inventory [71], [34]. Customer service level is can also be used for individual parts within the supply chain, for example the repair shop service level or vendor service level. Another performance measure is cost. Cost in the MRO maintenance supply chain consist of both direct as well as indirect cost. Direct cost include cost for transport, storage, repair, and personnel. Indirect cost are caused by buy-in and lease-in of additional stock due to disruptions in the supply chain, such as longer turnaround time or reduced service level. Service level and cost in MRO supply chains are inter-related; a lower SL generally results in higher cost whether direct or indirect. This can be illustrated by the stock calculation with respect to the TAT.
As stated, within MRO industry the service level is defined as the probability that an occurring demand can be satisfied. Demand can be satisfied as long as there are components in stock. As stocking of components is expensive for many of the MRO rotables, stock levels are determined based on the cycle time of components. The number of required components in stock is therefore dependent on the end-to-end TAT. Other dependent parameters are;

1. Mean Time Between Removal (MTBR)
2. Number of contracted aircraft
3. Quantity of units per aircraft (QPA)
4. Flight Hours (FH)
5. (end-to-end TAT)

The demand for an aircraft rotable from the inventory pool is equal to the expected number of removals of a particular item. A common reliability parameter of a component in the aviation industry is the mean time between removals (MTBR). The MTBR is expressed in hours, can the expected removals be determined using the amount of flying hours with this component. The total flying hours of the entire fleet is captured in a parameter called fleet hours (FH). For redundancy purposes, aircraft often contain several times the same component. The quantity of identical components in an aircraft is given by the quantity per aircraft parameter (QPA) [61]. With these three variables the expected number of removals can be defined according to;

$$expectedremovals = \frac{FH \cdot QPA}{MTBR} \tag{3.1}$$

The number of failures and therefore the number of demands within the turn around time (TAT) is often considered Poisson distributed whereby the turn around time equals the repair time of a component at the workshop plus the transport times [61]. The amount of components in the pipeline, λ can be calculated by;

$$\lambda = TAT(days) \cdot expectedremovals \tag{3.2}$$

So by knowing the the demand per day of a component and the length of the TAT interval the probability P(λ,n) that n demands occur during the TAT interval can be calculated by:

$$P(\lambda, n) = \sum_{k=0}^{n} \frac{(\lambda^k * e^{-\lambda})}{k!} \tag{3.3}$$

In addition the service level can also be calculated. The service level is defined as the probability that an occurring demand can be satisfied. This is the case if there is at least one item in stock or equivalently if at most x-1 demands occurred during the turn around time. where x represents the amount of stock. Therefore the service level SL(x,λ) of a component can be calculated as follows:

$$SL(x, \lambda) = \sum_{k=0}^{x-1} \frac{(\lambda^k * e^{-\lambda})}{k!} \tag{3.4}$$

By illustrating how stocks are calculated direct link between the reverse flow of components in the supply chain and stock levels can be made. reducing the variance and end-to-end TAT in the reverse flow can therefore lead to a leaner supply chain which needs less stock. The calculations can also be used to determine possible savings in stock levels considering a performance improvement in TAT and keeping the same service level. Other key parameters that affect the service level and cost can be the available resources, productivity, and throughput. Using literature and previous studies performed at in airline MRO ([70] [71] [51] [60] [30]) a list of process improvement KPI's was be constructed. The selection for the measurement of the performance of the component MRO supply chain results in the following KPIs;

KPI	Description	FLOW
Service Level (SL)	Percentage of the times a component is available at the moment its required	Forward
Lead Time (LT)	Time between the customer's request initiation to customer's request fulfilment	Forward
E2E TAT (E2E TAT)	Time between US component removal to SE in stock	Reverse
Time at Customer (TC)	Time between component removal and component shipment	Reverse
Time in Transport (TT)	Time component is in shipment	Reverse
Time in Handling (HT)	Between a component receipt until ready for the shop	Reverse
Buffer time (BT)	Time component spends in the buffer	Reverse
Time in repair (RT)	Time component spends in repair	Reverse
Workforce Productivity (WP)	Measures the amount of components processed during a work shift per employee	Both
Throughput (TH)	Measures the output of components per time unit	Both
On time performance (OTP)	The amount of goods or services delivered according to target on time	Both
Work in progress (WIP)	Measures the amount of components between the start and the end points of a process	Both
Standard deviation TAT (SD)	Variance of the TAT measured in standard deviations from the mean	Both

The KPI's indicated in the table above give an indication of the most frequently used and recommended process KPI's in literature and previous studies at KLM E&M. Using these KPIs constrains in the supply chain become visible providing the target for the redesign.

3.8. Conclusion theory analysis

In this Chapter the sub-research question; Which process improvement theories can be used to support redesign of the component flows? Several process improvement theories and research methodologies where explored including; Lean Six sigma manufacturing, the theory of constraints, transaction cost theory, business process redesign and theories on operations and production management. In order to improve the processes with in the MRO process improvement theories can help with different aspects of the supply chain. In addition business process mapping methodologies and process modelling methods for evaluation where discussed. Based on the literature a business process redesign is desired in combination with the lean six sigma methodology. Although the goal and approach for bringing about change are different in these theories they do not exclude one another. Lean six sigma promotes incremental improvement on a continuous basis, BPR promotes fundamental rethinking and radical redesign. The Define Measure and analyse phase of lean six sigma can be used in order to find the opportunities for a more radical redesign. To support the methodology a combination of value stream mapping and swimlane diagram is suggested. The classical VSM is useful for the identification of physical waste whereas cross function charts can complement the VSM on the information flow between departments and the associated (IT) transactions. Instead of implementing a small improvement the redesign can be evaluated using simulation modelling. As the redesign is more radical testing the potential in a more safe computer environment is desired. Discrete event models are best suited in environments of high stochastic variation and can be used to find optimal configurations of physical and administrative processes. The potential of the redesign can be measured by evaluating the appropriated KPIs. Theory analysis show that in reversed logistic supply chains that suffer from high internal and external variation, performance should be evaluated by measuring performance on time (here TAT), inventory and used resources. In MRO TAT and WIP in the supply chain are the most important KPIs as due to the high value of aircraft components stock levels in the closed loop supply chain lead to high amounts of unused monetary capital. Based on the theory analysis a framework based on [47] is presented in Appendix A.2 which summarises the preferred methodologies to use when redesigning business processes in reverse logistic supply chains.

Part II: Measure

4

Current state MRO Supply chain

The goal of this chapter is to provide an overview of the current state structure of the MRO supply chain of KLM E&M CS. The chapter provides a clear current state baseline performance measurement which forms the bases for the analysis and design phase of this research The measurements of the current state is performed in different levels according to the research design presented in Chapter 6. It answers the following sub research questions.

- *How is the KLM E&M supply chain currently structured?*
- *What is the current supply chain performance?*

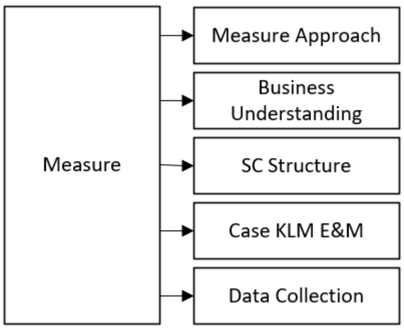

Figure 4.1: Outline Literature

4.1. Current state Approach

In this section the approach to measure the current state structure and performance of the KLM E&M supply chain is described. The purpose of this phase is to acquire all knowledge, information and data needed to analyse the current performance. The measurement phase is divided in several levels of detail. It is essential to consider the high level processes as well as the in depth processes to prevent optimising for local optima that have little to no impact on the overall supply chain. The first step in this approach is to develop an overall understanding of the business in which KLM E&M operates. According to [48] this understanding can be divided into two parts: understanding he business context and understanding the business logic. Understanding the business context is aimed at gaining knowledge about the sector in which the company competes, the market characteristics and company's history. The business logic, means how the company operates to satisfy its customers. Here the emphasis is on identifying the current roles of actors within the supply chain. The MRO supply chain consists of different processes so when preforming a supply chain re-design, is essential to identify the relevant supply chain processes present and select a valid target for re-design. For this purpose, processes have to be mapped. This is done using a combination of the VSM and swimlane map (VSM-I) based on observations and work sessions with the involved actors. After which data is gathered from different sources in order to quantify current state performance of the component MRO (Reverse) logistical processes. To conclude:

1. First, a high level context analysis is presented based on desk research and knowledge from literature.
2. Second, Using mapping sessions, interviews and company data, the handling processes and different flows are identified and presented using VSM-Swimlane mapping.
3. Third, data is gathered from different sources in order to quantify current state performance of the component handling and logistical processes.

4.1.1. Supply chain Stakeholder analysis

Identifying the supply chain stakeholders helps to understand which parties are responsible for which part of the supply chain. First high level overview of the most important stakeholder groups is presented, next a more detailed actor analysis of KLM E&M then helps to identify all the relevant organisational specific departments, inter-dependencies and accountability of these departments. The high level stakeholder groups are within the MRO supply chain are obtained from Vieira and Loures [74] and are presented in Figure 4.2. In general four different groups can be identified: aircraft OEMs, part suppliers, customers and MRO repair shops.

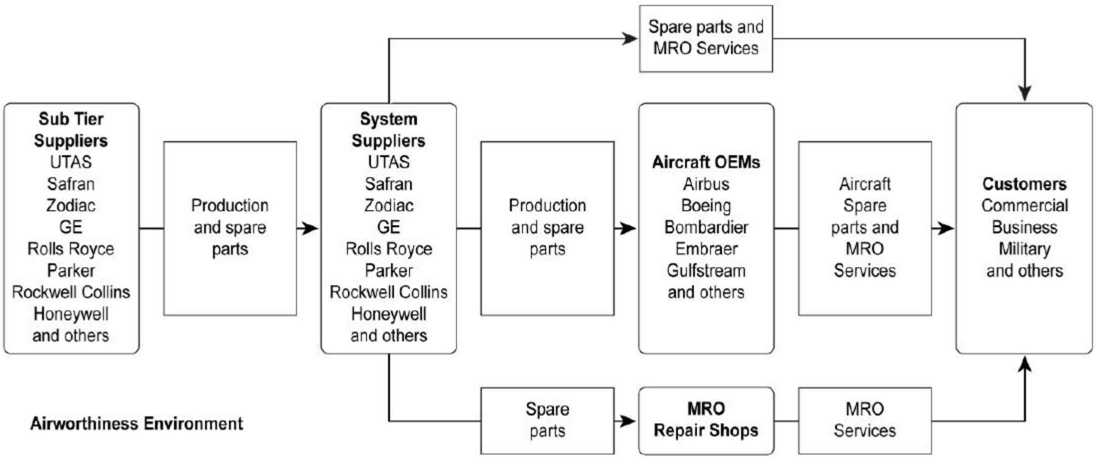

Figure 4.2: MRO Environment [74]

Aircraft OEMs: Within the aviation industry there four main aircraft Original Equipment Manufacturers or OEMs, namely Boeing, Airbus, Bombardier and Embraer. These OEMs design and build aircraft. In today's environment Aircraft are being constructed from components produced all over the world. The Leading OEMs have adopted a 'systems integrating' production strategy in which key components and sub-assemblies are designed and manufactured by external partners and suppliers [53]. The OEMs have close relationships with the sub tier suppliers. So when, when Boeing sells an aircraft, the customer has the option to also include a maintenance package, meaning that Boeing will be responsible for maintaining the aircraft and its components.

Sub tier/System suppliers: Due to the high level of requirements to qualify a supplier, there is only a limited number of companies authorised to provide parts and services in the aeronautical industry [74]. These companies i.e. Zodiac, UTAS and Honeywell act as system suppliers for the OEMs, but also act as suppliers of MRO repair shops. The system suppliers also act as competitors of the OEMS by providing maintenance contracts to customers.

MRO Repair shops: Most major aircraft maintenance and repair work is provided by repair shops, which carry out MRO operations for the aircraft operators [74]. There are several different companies providing component availability contracts like KLM E&M.

Customers: The customers of aviation MRO consist of airline companies that offer passenger and cargo transportation services. There are approximately 230 major airlines operate throughout the world and are registered with the International Air Transport Association (IATA). Customers can either have contracts with the OEMs, systems suppliers or with one of the companies providing MRO such as KLM E&M.

4.2. Supply chain Structure

As stated in section 2.5 the structure of the airline MRO can be described as a closed loop supply chain. This structure comes forth from the need to reduce the down times of aircraft. To prevent AOG situations unserviceable components are exchanged on site. The demand for service replacements associated with long lead times require spare parts stocking. In order for a company providing component availability to be competitive, the spare parts inventory level as well as the repair cycle should be optimised under consideration different performance aspects. The overall structure of the supply chain is presented in Figure 4.3.

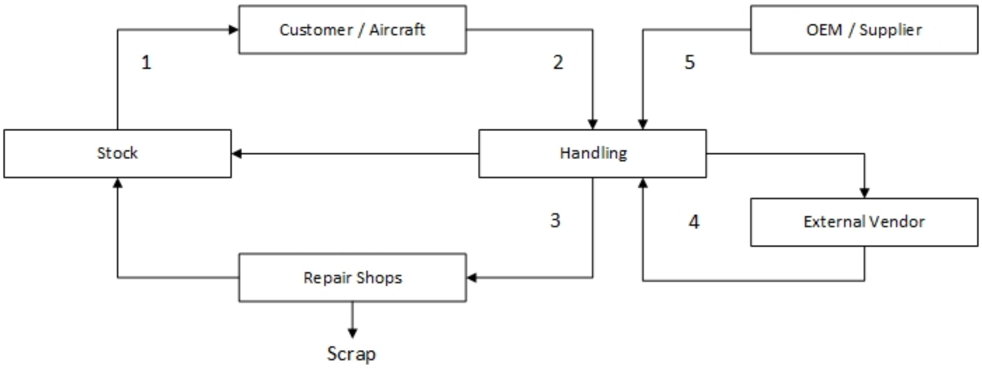

Figure 4.3: Closed loop supply chain MRO

Figure 4.3 shows that the component service supply chain essentially consist of five main flows:

1. Delivery of serviceable components to customers.
2. Reverse logistics flow of unserviceable components from customers. '
3. In-house repair and maintenance and overhaul of unserviceable components.
4. Repair and maintenance and overhaul of unserviceable components by external vendors
5. Procurement of serviceable components and materials from OEMs and other suppliers.

These activities are necessary for each MRO provider in the market. As indicated in Figure 4.3 handling of component flows is a key link in the closed loop supply chain. In order to gain an understanding of the performance and the systems used to support these activities the case study of KLM E&M component services is used.

4.3. Case Study - KLM Component Supply Chain

With the understanding of the relationships in the MRO supply chain and the main logistical flows a more detailed description can be given by analysing the case study of KLM E&M. The scope of the case study is demarcated by the logistic & handling activities required to provide the MRO service from the logistic centre and maintenance facilities at Schiphol-East.

4.3.1. KLM E&M Stakeholders

In this section the most important stakeholders in the supply chain are briefly described. According to Enserink et al. [19] stakeholders are; *"those parties that have a certain interest in the system and / or that have some ability to influence that system either directly or indirectly"* Identifying the stakeholders within the KLM E&M supply chain gives insight in the responsibilities of the different departments and their interrelations.

4.3.2. Customers of KLM E&M

KLM E&M CS has a large base (47) of customers around the world to whom the company provides component services. These services can be divided into roughly two different contracts. Time & Material contracts and pooled contracts. In Time & Material the costumer is owner of the component, in pool contracts the availability of components is shared in a pool. In the case of KLM E&M several pool contracts can be identified adding to the handling complexity. KLM pool contracts, Boeing CSP (component services program) contracts and Closed Loop Amsterdam (CLA).

KLM Pool: The KLM Pool is the largest component pool and consist of the KLM fleet itself and all other customers that have a availability contract with component services. The KLM pool provides component availability at Schiphol and the hubs in Kulala Lumpur (Asian market) and Miami (American market). For customers in the KLM pool, KLM E&M is repair responsible. This means the choice to repair components in-house or at an external vendor is made by component services.

Actor	Function	Objective
Customer	Request, exchange and ship components, provide information	Reduce ground time of aircraft with lowest cost by contracting the MRO availability provider with lowest cost and highest performance
Component Pool Availability	Assure availability of components at the Pool conform the service level agreement with the customer	Provide maximum service level performance with the lowest inventory levels and TAT
Logistics department	Receive, identify, sort and transport components & materials.	On time delivery of components to right departments
3PL (Bolloré logistics)	Transport of components between all KLM E&M locations and customers and Customs operations at logistic centre	On time transport and customs operations
Inspector incoming goods	Inspect certification all inbound serviceable and consumable components	On time administrative handling of components
Repair administrator (VC)	Make Repair Orders (RO) and Proforma Invoice (PI)	On time administrative handling of components
CIRO	Generate internal 'repair order'	On time administrative handling of components
Internal Repair Shops	Perform MRO functions. Inspect, repair, overhaul components	On time performance of MRO fictions with lowest cost
External vendors	Perform MRO functions. Inspect, repair, overhaul components	On time performance of MRO fictions with lowest cost
Contract management (VY)	Responsible for compliance of customers according to contractual agreements	Ensure customer compliance.

Boeing CSP Pool: The Boeing CSP pool (Component Services Program) is a joint pool between KLM and Boeing. this pool provides component services on the Boeing 777 and 737 next-gen parts. The Repair responsibility of the CSP pool is divided between Boeing and KLM E&M. Depending on repair responsibility the disposition choice is made by KLM CS or by Boeing, the handling of components is however provided by KLM E&M. The SE parts within the CSP pool are stored separate from the other components as dictated by the contracts. The handling of components of the CSP pool is completely done by KLM CS.
Closed Loop Amsterdam: Closed Loop Amsterdam (CLA) is a shared pool of three large customers of KLM E&M namely Jet Airways, Royal Air Maroc (RAM) and ATLAS air. The CLA customers have outsourced the MRO operations to CS, but remain owner of the components in the supply chain.
Time & Material:
Aside from the availability contracts CS also provides 'power by the hour' services called Time & Material contracts. Here the customer sends a broken part to CS Which then is repaired and returned to the customer. The cost of the repair are invoiced depending on the hours and materials spend on the repair.

4.4. Component Flows

The current value chain of component services is similar to the one described in Figure 4.3. In order to accurately describe the individual departments and process of KLM E&M are mapped and described in Section 4.4.1. Aside from the rotable component flow several other flows can be identified in the MRO supply chain. Components can be roughly distinguished in components in rotable components and consumables. The rotable components can further be classified in serviceable and unserviceable. The unserviceable flow consist either of a pooled item or a time & material contracted part. These unserviceable components are either repaired in-house or are outsourced, which leads to another distinction. Lastly the components which are part of the CSP pool are treated different from the other pool types due to specific transactions due to joint ownership with Boeing. Figure 4.4 gives an overview of these flows.

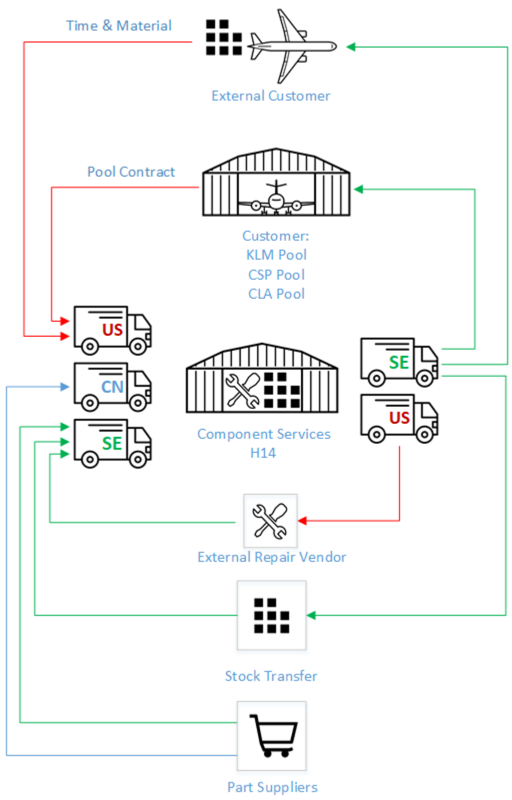

Figure 4.4: Flows Through handling

As stated in Chapter 1, this research focuses specifically on the handling and logistics of the components is the supply chain. From a handling and logistic perspective components can further be classified based on their size, weight, and packaging. Aircraft components vary from small and delicate measurement equipment to giant steel wheel rims. The packaging of components therefore is dedicated to the specific component. In order to classify the components from a handling perspective three types are used. Box size, Pallet size and Odd-sized parts. The handling of consumable components is a relatively straight forward process, the focus of the analysis is therefore on the rotable components.

4.4.1. Operational processes VSM-I rotable flow

To map current state of the component supply chain a several workshops with stakeholders from different departments where organised. Using the process improvement mapping based on the VSM and swimlane chart, the current state process was mapped. The key of the methodology is map the the physical flow across the departments within the supply chain. The boxes in the VSM-I diagram represent processes in the the end-to-end chain involving both the physical flow and the information flow across departments. The process map (Figure 4.5) shows the responsible departments vertically. The process starts at the upper left corner with the customer placing a request for a component replacing a component and returning it to KLM E&M. The process finishes when components are repaired and stocked again ready to be shipped again to the customer. The purpose of this map is to show the overall structure and departments of the complete supply chain. In the analysis phase presented in Chapter 5 a more detailed map is presented for a single case.

4.4.2. Delivery of serviceable components to customers.

The delivery of SE components is a straightforward process which concerns the forward flow within the closed loop supply chain. This process starts when a customer places a request for a certain component at component availability department though customer interface. In this request the customer states which component is required and when the component is needed. The notification for the request of a serviceable component can be sent in different ways depending on which system the customer uses. Aside from customer AFI-KLM which have a direct link to SAP (and maintenix), AeroXchange is used in most cases, however when a customer does not have a AeroXchange licence, notifications are send via Email. After receiving the request,

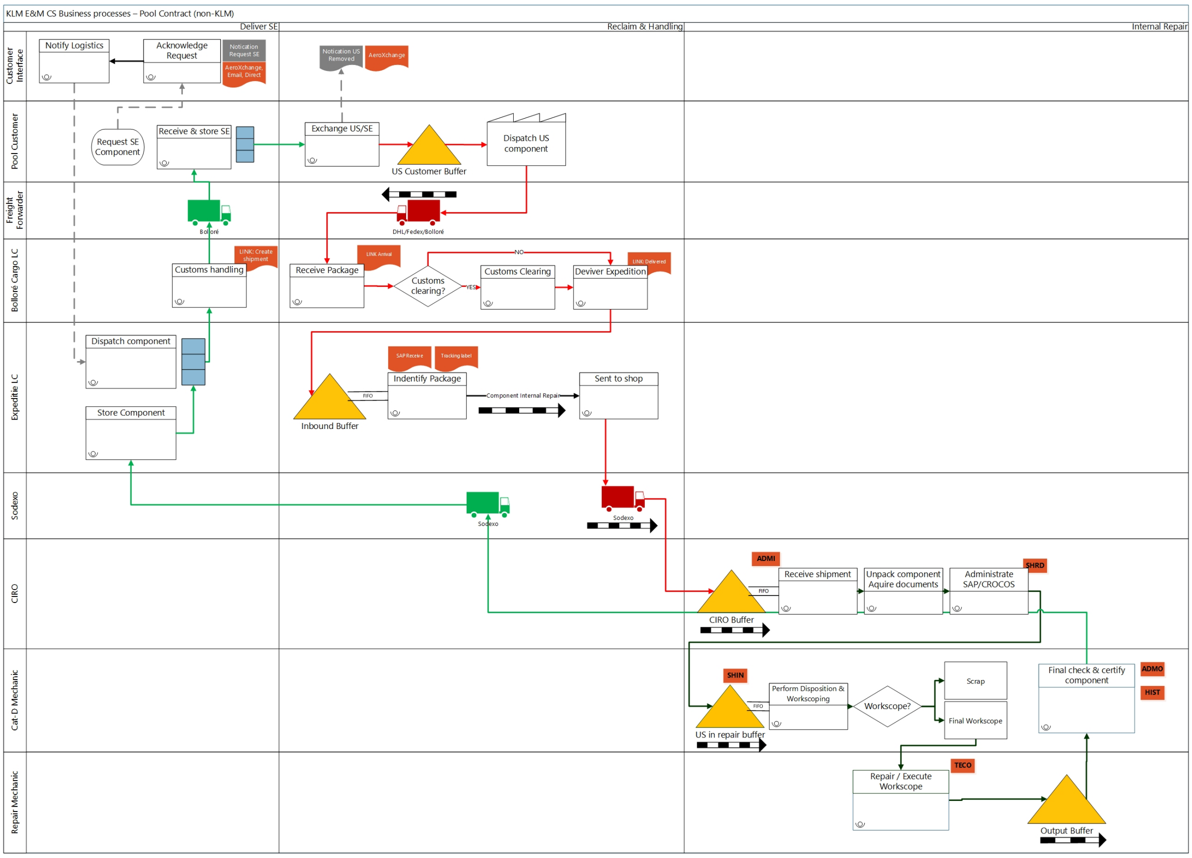

Figure 4.5: VSM-Swimlane component flow

the availability department acknowledges the request and when the part is on stock, it notifies the logistic department via the ERP system. Next, the component retrieved from the storage area and shipped via the third party logistics provider. On arrival the customer confirms the arrival and the demand is satisfied and the reverse flow can start. Issues with delivery of serviceable parts occur when the stock is not sufficient to fulfil the demand. Stock-outs can be caused by unexpected variation is demand or when the reverse logistic flow of US components and repair activities can not replenish the stock in time. In the case the absence of a component results in an AOG situation for the customer, component services has to lease or buy a component to fulfil the customer demand. The stability of the repair and return logistics is therefore of major importance.

4.4.3. Reverse logistics flow of unserviceable components

The Reverse flow of components starts when a unserviceable component is removed from an aircraft during an aircraft maintenance check (usually an A- or C-check). After the part is removed the customer sends a notification to KLM E&M customer service. The component is then send either with KLM E&M preferred 3PL provider (Bolloré) or by using their own preferred logistic provider depending on the contract. On arrival the part is declared (if needed) by Bolloré which acts as customs agent. When the part is cleared by customs, the component is handed-over to the logistics expedition of component services. The logistics expedition then has to identify the package and sort the components. After identification and sorting the expedition adds a tracking sticker for internal transport and the logistics department brings the package to the inbound buffer of the corresponding repair administrators (RA). On arrival the unpacks the component and starts administrative tasks and makes the repair order. Once the repair order is made the component can be sent to a repair shop. The return flow of MRO components can be classified by; differences in size, differences in information quality, uncertain arrival time and the status of components and packaging.

4.4.4. Repair and maintenance and overhaul of unserviceable components

The MRO of the US components is done either in-house or components are outsourced to a vendor depending of the in-house capabilities. When a component is outsourced a repair order and proforma invoice is generated by a repair administrator. These documents are attached to the part (box) and the component is sent to the vendor. If a component is repaired in-house only a internal repair order is generated using SAP and the component is sent to the shop, this is done by the CIRO (customer interface repair officer). As indicated in Figure 4.5, several information systems are used in the supply chain. In order to accurately describe the transactions in the information systems in more detail a process map with the IT systems is described in more detail in section 5.3.

4.4.5. Inbound flow consumables and SE Rotables

One of the necessary evils of component MRO is to check and update the documentation of attached to the components. One of these processes is called Inspect Incoming Goods (IIG), and is required to be performed if a component is to be installed into an aircraft. This process is required for the incoming flow off serviceable goods and for the incoming flow of consumables (i.e. check the part/serial numbers, EASA form 1 certification, update internal systems etc.). For the consumable parts the IIG activity is straightforward and consists of mainly administrative actions in the internal systems. The inspection of serviceable rotables is more time consuming and includes a inspection of the part to guarantee the certification is done right and is therefor more knowledge intensive. These processes are executed in the same warehouse as the inbound for US parts.

4.5. Warehousing: Current Logistic centre

In the current situation the logistic centre of KLM E&M is located in a separate facility away from the internal repair shops. In the logistic centre (LC) most handling and administrative operations take place. Aside from components removed at the exchange location at Schiphol centre and inside aircraft hangars all components are sent to the LC. At the LC the customs agent is located as well as the physical stock of serviceable components. The main activities within the logistic centre are identification of components, cross-docking of flows to internal repair shops, the repair administration for outsourced repairs (components can also be internally outsourced) the inspection of the SE and consumable components and the delivery of SE components to customers. Schematically these activities are indicated in Figure 4.6. Section 4.6 describes these individual processes in more detail and includes the performance measurements.

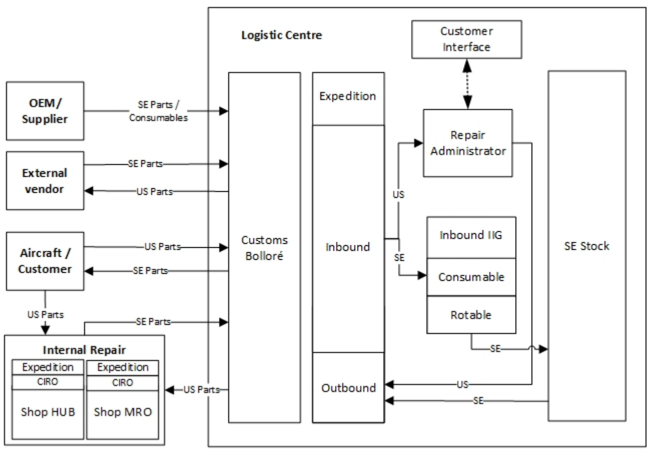

Figure 4.6: Schematic elements Logistic centre

4.6. Current state performance measurement

In the current state the performance of KLM E&M is measured using data from the ERP system and the availability system CROCOS. The performance of the processes is evaluated using the throughput time of the components, the service level and the on time performance of sub processes in the repair chain. A limitation of this measurement using data from the used systems is the lack insight in the end-2-end performance of the reverse flow. The first notification in the from either CROCOS or the ERP system happens after the components arrive at the logistic centre. In order to measure the current state performance of the compete component supply chain, data from multiple sources is required. Due to the many hand-overs and transactions within the component supply chain many different systems are used to store data on the components and their locations. Using data from all systems provides insight in the complete logistics chain. KLM E&M and its partners several different ERP and component tracking systems. These data sources are briefly described below.

AeroComponent is an electronic platform for the exchange of data between customers and KLM E&M. It is provided by the company AeroXchange which was founded by different airlines around world. The platform enables data automatic exchange which otherwise would take place via fax, telephone or email. AeroComponent holds data of the request notifications, component removal dates, shipment data, part & serial numbers of individual components, customer information, hours cycles and reason for removal. AeroXchange is used by approximately 80% of the customers.
CROCOS is system developed by KLM itself and holds all the information on the conditions of rotable components in the component availability system. In this system the number of hours and cycles a component is used and where the components position within the chain is registered.
LINK is the tracking system used by Bolloré, the third party logistics provider and customs agent of KLM E&M. Link holds information on the shipments of components and provided customs services. Components that are sent to KLM by other logistic forwarders i.e. DHL/FedeX are also declared by Bolloré and enter the LINK system.
SAP is the ERP system of KLM E&M. SAP is used for the administration of tasks throughout repair process, from check-in to checkout. It holds information on parts, repair orders, work-scope and routings of repair paths and more.
Tracking is used to track and trace components intern. Components are tracked by manual scanning of barcodes with hand-held scanners. Tracking data consists of drop and pick moment at certain location throughout the repair chain. Parallel to tracking, Scoretrace is used which uses RFID tags to keep track of components at automatic scanning points.
CSP.net is the ERP system of the Boeing CSP program. This system hold the information on hours and cycles of the CSP components as well as their status and location. As these parts are partly owned by Boeing they are registered separately from CROCOS.
Colors is the ERP system for the Boeing CSP program. It has the same functionality as SAP. As Boeing does not use SAP, part information of the CSP program are stored in this system.
In the current state there is no digital coupling between the individual systems named above. As data from several of the individual systems form the input for others, data is manually transferred. Section 5.3 further elaborates on these transactions to give a complete overview of these type of translations between actors in the supply chain.

4.7. Measurements

In this section measurement results are presented of the current state component supply chain. The measurements are gathered from different data sets in which components data is stored, as discussed in Section 1.9. First the main flows (forward and reverse) of the rotable components are described. Components can be classified in multiple ways. For the purpose of this study the classification is done from a logistic handling perspective. Unserviceable, Serviceable and consumable components receive different handling activities and are considered separate. The US flow can further be divided in outsourced and internal repaired components based on handling and required transactions. The components in the CSP pool are also considered separate as the handling operations are different from the KLM pool due to the required transactions the availability system of Boeing. For the performance measurement the US flow of components is measured and presented in section 4.7.1.

4.7.1. Reverse flow of unserviceable components

As discussed in Section 1.9 there currently are no KPIs available to KLM E&M to get insight in the reverse flow and handling time of components. In addition, there is no identification number within the supply chain to track the component flows. So, in order to measure the performance of the reverse flow data from multiple systems has to be coupled. This coupling is dependent on the transactions within information systems in the supply chain. Information transactions in these systems usually follow a logical sequence and therefore have detailed historic timestamps. In the current state these sources of information are not jet combined and used for the purpose of performance measurement. In order to know how well a reverse supply chain is performing all the elements, as discussed in Chapter 3 of the RL should be measured. These elements consist of the collection, transport, inspection & sorting, disposition and redistribution. Figure 4.7 shows the physical transactions in the complete closed loop supply chain (forward and reverse) of a rotable component which is repaired in a internal shop.

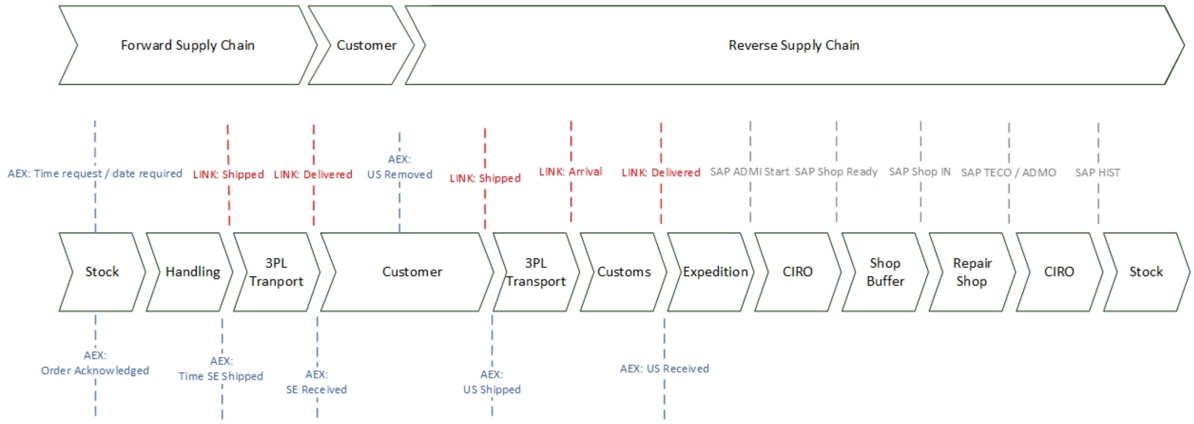

Figure 4.7: Data transactions

Figure 4.7 shows the end to end process steps of a rotable component that is repaired in-house. To quantify the end to end TAT, data from AeroXchange, SAP and LINK has to be coupled to acquire a complete picture of the supply chain. For internal administration KLM E&M use a TAG number to refer to a component. This TAG number is also listed in AeroXchange therefore both can be linked. The Logistics provider Bolloré only refers to a component by using the Purchase Order number of the customer. The customer PO number can also be found in SAP so this is used match historic data. The coupling leads to several timestamps that give insight in the whole end to end reverse supply chain. The Component removal date, shipping date, part received at logistic centre, date part administrated in SAP, repair start date, repair end and finally the last administration before the part becomes serviceable again. The results of these time-stamps are indicated in Table 4.1. The measurements cover 10% of all internal repaired components and 13% of all outsourced components.

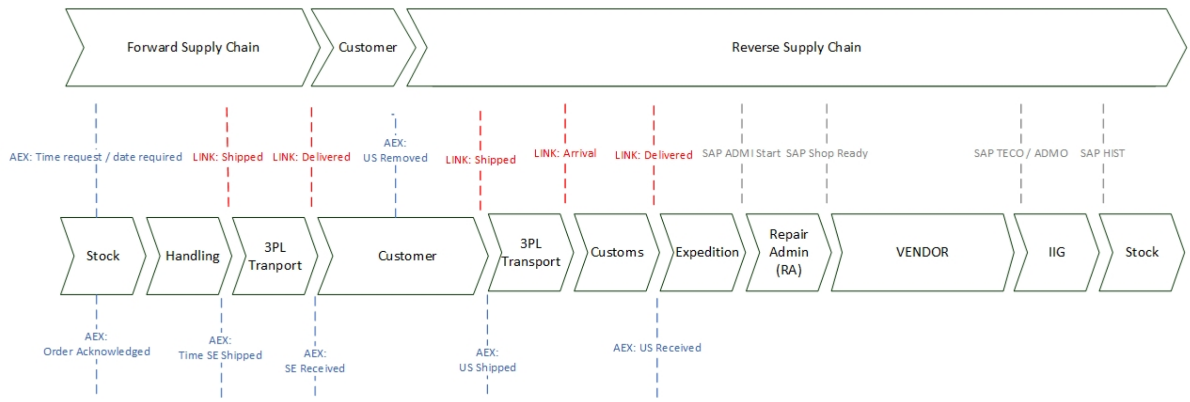

Figure 4.8: Data transactions External Vendor

4.8. Collection - Days at customer

Retrieving components form customers is done separate from the delivery of SE components. Depending on the contract type and request of the customer the SE component is sent (days) before the component is exchanged in the aircraft. In case of scheduled maintenance the US component can also be removed from the aircraft before the SE is requested, for instance when the aircraft is subject to longer maintenance. Aside from Email communication customers can request parts in AeroXchange. In AeroXchange the removal date of components from the aircraft is registered. Using the difference between the removal date and the date the component is shipped, the time a component spends after removal at the customer can be calculated. Hence, the time between the delivery of a SE component and the shipment of a US part often results in negative values due to the contract types indicated. The reverse logistics chain therefore starts when a component is removed from the aircraft. Figure 4.9 and 4.10 show the time between removal and shipment. In the service level agreements with the customers the maximum time a customer may take to ship the components is stated. If this term is overdue, customer interface must contact the airline and ask for the component. Depending on the contract type, penalties are and can be determined for late shipments. Although data data shows TAT days could be gained, for the purpose of this research this part is considered out of scope.

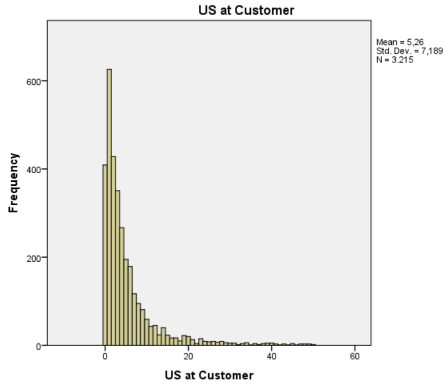

Figure 4.9: US removal date - shipment date

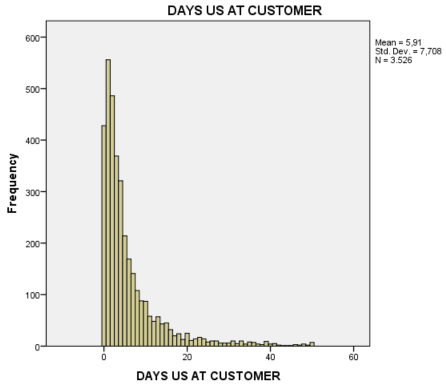

Figure 4.10: US removal date - shipment date External Vendor

4.9. In transport

The next step in the reverse flow is the transport of components. As stated, KLM E&M has outsourced the logistics and transport of components between customers and KLM E&M. The components are retrieved from the customer and shipped to the logistic centre via a combination of truck and aircraft shipments. The receiving date of the components at the logistic centre is documented by the customs agent. Using the shipment and received date the time components spend in transport can be measured. The total time of all shipments is indicated in Figures 4.11 and 4.12.As expected there is hardy any difference between the return flow to the logistic centre for internal and external repairs. Naturally, the transportation time is an external factor in the reverse TAT on which there is little to no influence can be exerted. For the outsourced repairs, days are to be saved by direct outsourcing the components to the vendors. As direct outsourcing is already being implemented at KLM E&M this part is not within scope.

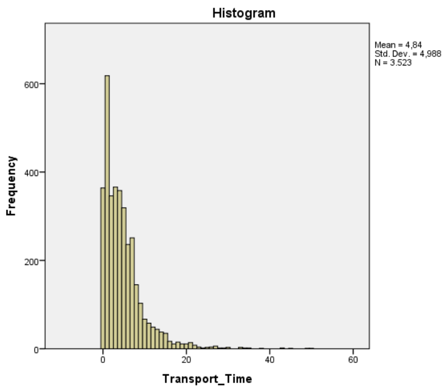

Figure 4.11: Transport Time Internal

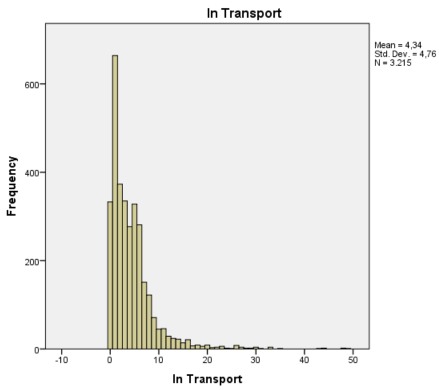

Figure 4.12: Transport Time External Vendor

4.10. Sorting, inspection, disposition - Handling

The handling process of components consists physical and administrative steps. The physical steps include the inbound transport, sorting of packages, storage and outbound transport. The administrative steps concern the updating of the internal systems and repair order generation. For Internal repairs, this order contains a work-scope and repair path in the ERP system. For internal repairs the repair order is generated by the Customer Interface Repair Officers (CIROs). The CIROs are responsible the administrative tasks within the process and contact with customer. For external repairs the repair order is made by the Repair Administrator (RA). The RA has essentially the same tasks as the CIRO, but has to perform extra steps to make a repair order for the Vendor (more transactions). In the current situation the process of repair order generation takes place after the component has arrived at the LC at Schiphol. The process of generating a repair order is quite complex due to the many information systems used per flow. Delays in the handling process have a direct impact on end to end tat and therefore should be minimised. Figure 4.13 shows the distribution of the handling processes from the point the package is received to the point the part is ready to enter the shop buffer. As can be seen in Figure 4.13 the process is not normally distributed as it does not follow the standard bell curve.

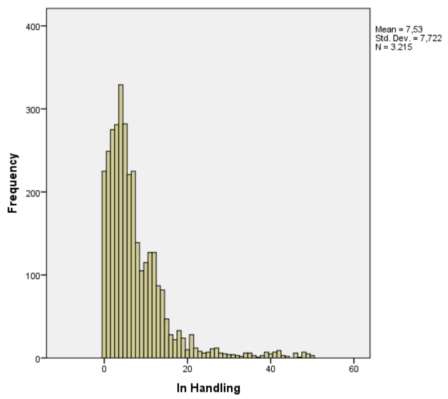

Figure 4.13: Distribution time in handling

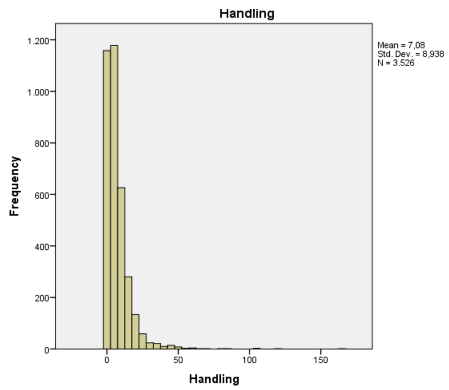

Figure 4.14: Distribution time in handling outsourced repairs

The standard deviations (SD) of the steps in the reverse flows are measured by means of statistical analysis using a descriptive statistics and a normal probability plot. The SD gives an indication of the spread of the TAT performance. A normal probability plot that does follow a straight line, indicates the data is not normally distributed. According to Six sigma theory, this is an indication of waste in that process as the process. The handling of components is of interest as it is the factor on which the MRO company has a major influence.

4.11. Repair & Redistribution

After the handling process the components for internal repair are send to the repair shops. The repair shops are responsible for the final inspection, repair and overhaul of the components. KLM E&M has multiple repair shops with in-house capabilities to repair a specific group of component. The performance of the repair shops is measured with their own service level. Indicating a the percentage of components that are repaired conform their productivity targets. For this purpose KLM E&M uses data from ERP notifications. The repair time for components can therefore be measured for internal repairs by using notifications from SAP. Currently the repair shops are divided in Shop HUB (mainly large components that are typically repaired at an HUB airport) and shop MRO (consist of mostly pooled items for availability contracts). In the CS2.0 project both shop types are combined in a single hangar. As can be observed from Figure 4.15 most of the internal repairs are completed within a few days. Some components have longer process times, especially for shop HUB, in which the larger components are repaired, take longer on average. The repair time for the outsourced repairs is naturally much longer than internal repairs. For the generation of this data the moment of repair order creation until the moment the component has arrived in the LC and is inspected is used. The repair TAT for external repairs therefore include transport times to and from the vendors.

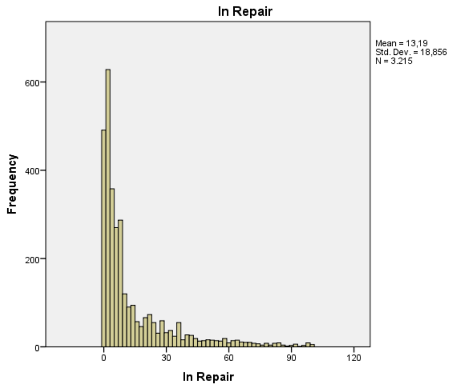

Figure 4.15: Internal repair TAT

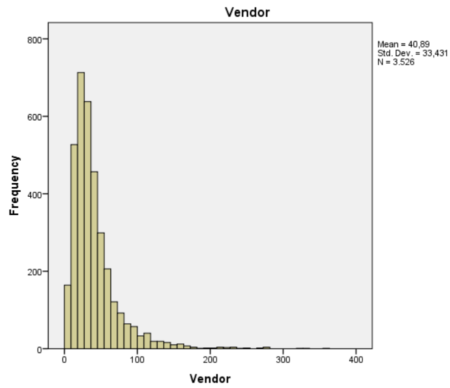

Figure 4.16: End-to-End External Vendor reverse flow

In the current situation each internal repair shop has its own buffer within the shop. The components are delivered using a push mechanism. Hence, after a repair path has been created in the ERP system by the CIRO or Repair administrator, the component is 'pushed' toward the shop. Once delivered the shop mechanics can start the repair on the components. When a repair is started or finished, a notification is made in the ERP system. Measurements from these notifications show components spend an average of eleven days in the repair shops. As the processing time of the components is much less than the indicated shop time, it can be concluded a lot of waiting time is included in the shop time. Hence, mechanics start with the repair on a component but often do not finish within the process time. The shop time obtain from the ERP system is indicated in Figures 4.17 and 4.18. A notable difference can be observed between components in the current shop HUB and the shop MRO. This difference comes forth from the type of components handled in HUB and MRO. The components repaired at shop HUB mainly consist of large mechanical components such as heat exchangers an brakes. In shop MRO smaller avionic components are repaired which generally have a shorter repair time. The repair shop TAT has been subject to many research in the past, see [70], [41],[71] and therefore not in the interest of this research to optimise this part of the reverse supply chain.

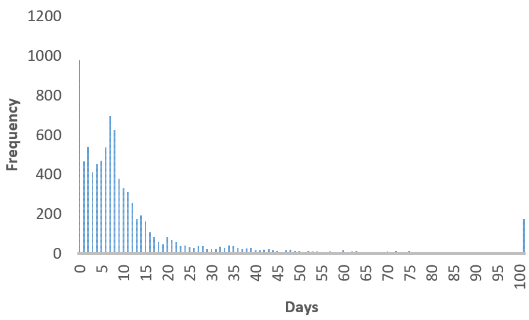

Figure 4.17: Shop time HUB

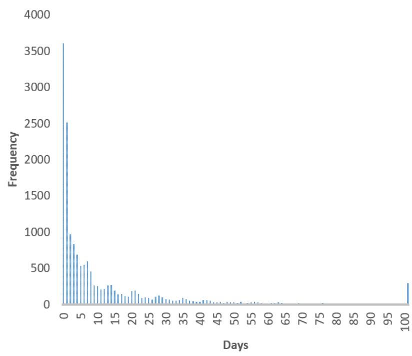

Figure 4.18: Shop Time MRO

4.12. Total reverse logistic time

The total TAT of the reverse component flow over the year 2017 is indicated in Figures 4.19 and 4.20. The graphs are the result of the individual parts of the end-to-end flow in the supply chain. As discussed there is still a lot room for improvement in this flow in the supply chain.

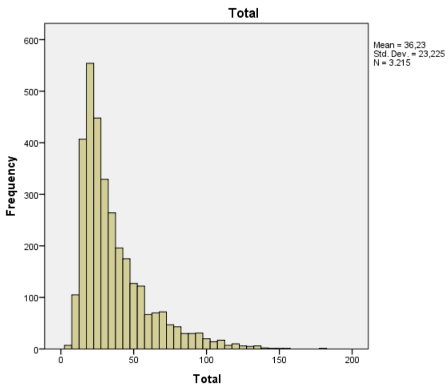

Figure 4.19: End-to-End internal repair

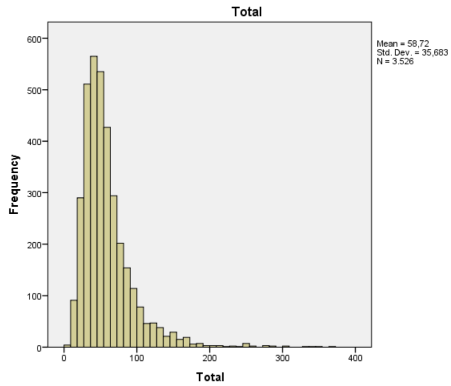

Figure 4.20: End-to-End External Vendor reverse flow

The individual components have different origins, repair times, and thus different end to end TAT. It therefore is interesting to know which part of the supply chain has the largest contribution to this TAT. This is illustrated in Figure . The pie-charts show the handling time of the components contributes to 24% of of the total TAT of components. This underlines the need for a redesign of the handling processes. Section 4.10 further elaborates on this part of the supply chain.

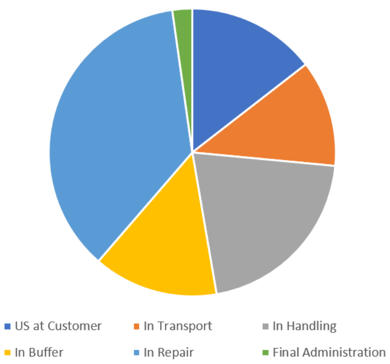

Figure 4.21: Percentage of TAT - Reverse flow

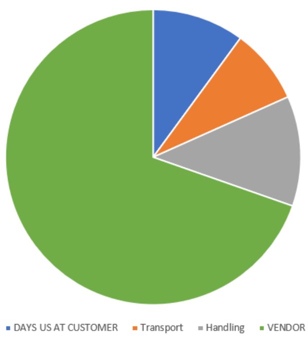

Figure 4.22: Percentage of TAT - Reverse flow External Vendor

Internal	Mean	Std.dv	Median	Outsourced	Mean	Std.dv	Median
US at Customer	5,3	7,2	3	US at Customer	5,9	7,7	3
In Transport	4,3	4,8	3	In Transport	4,8	5,0	4
In Handling	7,5	7,7	5	In Handling	7,0	8,9	5
In Shop Buffer	5,1	7,5	3	Vendor	40,8	33,4	32
In Repair	13,2	18,9	5				
Final Admin	0,8	2,1	1				
Total	36,2	23,2	29	Total	58,7	35,6	50

Table 4.1: Summary of TAT measurements [days]

A limitation of this measurement is that there is no distinction between process time and waiting time. In line with lean manufacturing theory, in order to improve the business processes measurement should separate the waiting time and process time. In the current situation the touch time of handling process within the logistic centre cannot be accurately extracted from the data because of insufficient measurements and different workers involved in the handling of a single component. So to give an indication of the process time a more detailed analysis is required, this is presented in Chapter 5.

4.13. Conclusion current state measurement phase

This chapter aimed to answer two main research questions namely; *How is the KLM E&M supply chain currently structured? What is the current supply chain performance?*
The structure of the supply chain of is structured as a closed loop supply chain with a relatively short forward and long reverse supply chain of components. The supply chain of an aircraft MRO company consist of a network of suppliers, OEMs, repair vendors and customers. In the current situation, a very limited set of KPIs used to evaluate the performance of component services and its reverse supply chain. The focus of the existing KPIs is mainly in the internal repair processes. The TAT and service level is measured mainly for the performance of the repair shops. Although a lot of data is stored in the different systems named in Section 1.9, these are not used due to the absence of couplings. The reverse flow is of special interest as for this part the are involved. Due to the many transactions and different systems in which data is stored. In the current situation managers have no complete picture of the overall performance as data in not coupled to acquire a complete picture. In this phase this coupling was made for a large part of the component flow. The measurements concern the individual steps in the component closed-loop supply chain. The data shows the scope of the research to focus on the handling and logistical processes is justified. This process takes up around 25% of the total reverse flow TAT. The handling time has mean value of more then seven days and similar standard deviation, which make it a major bottleneck in overall supply chain. Now there is a clear target for a redessign, the next step is to analyse the causes of the measured performance and analyse the process on a more detailed level. In the chapter 5 an analysis on the measured results is described in more detail using the 7 wastes and a 4M analysis.

Part III: Analyse

5

Current state Performance Analysis

This chapter will combine the knowledge from Chapter 4 and Chapter 2 to analyse the current state. The current state performance is assessed using process improvement theories described in Chapter 2. An essential part of the theory of constrains in [22] is to focus the optimisation and redesign of processes on the bottlenecks in the process. From the measurement phase it became clear the focus of the analysis should be on the reverse flow process of components and the handling of components in the logistic centre in particular. First the approach for the performance analysis is presented in Section 5.1 next results from the analysis are elaborated upon in sections 5.2, 5.4 and 5.5. These analysis together answer the following research question;

- *What are the constraints and bottlenecks in the current handling processes?*

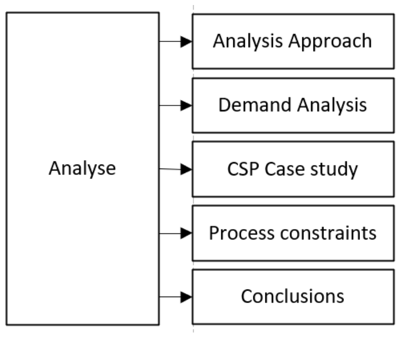

Figure 5.1: Outline Literature

5.1. Current state approach

In order to accurately analyse the reverse logistical processes and determine the most important bottlenecks and constraints a case study approach is taken in this chapter. As indicated in Chapter 5 there are many different reverse flows of MRO components that are handled by component services. In order to perform a relevant and valuable analysis this analysis is scoped to a single case study for the evaluation of the physical and information flow of US components. Given the methodology in Chapter 1, the aim of the analysis is to provide a solid base for a redesign on a case applied in the MRO industry. According to Dul and Hak [17], a single case study only one single instance of the object of study must be selected from the domain to which the theory is assumed to apply. In order to analyser the current state performance on both the physical flow of components as well as the information flow in line with theory on reverse logistics and process improvement theories, a flow with the largest number of transactions was chosen, namely the CSP pool for which KLM CS is repair responsible. The reason for this choice is that this particular flow has similar transactions that are present in the other flows, but more. In addition the performance of the CSP flow is considered low.

5.2. Identification of constraints in the reverse flow

The MRO supply chain consists of different processes and transactions, for the re-design it is necessary to identify the relevant processes to target in the redesign. Wastes in the current state physical flow are identified using the TOC and Lean Six Sigma methodology as described in Chapter 3. The focus of the analysis is both on the physical and information flow. The goal of is to identify the key areas of waste, while indicating possible improvements and providing a business case for the re-design. First the 'obvious' waste as described by Hopp and Spearman [32] is identified using process mapping. Such waste includes operations that are not needed, rework, poor layout that leads to excessive material handling etc.

Lean six sigma projects use the 8 TIMWOODS wastes to identify different types of waste in the process. These wastes consist of Transport; the unnecessary movement of a product, Inventory; holding places for unnecessary inventory, Movements; unnecessary movements of people and equipment, Waiting; excessive wait times, over-production; producing more than customer demand,over-processing; performing additional, unnecessary steps and defects. As the scope of the study is the handling and logistics of the components the TIMWOOD waste are determined for these processes.

In addition to the 8 wastes the four four M's; man, machine method and material can be a cause of waste or variation in the process.

1. Man: stands for the right worker for the right job. Workers must be qualified to do the work for which they are assigned and have appropriate experience, and workers must work their assigned hours.
2. Method: stands for the right way of working. Work must be standardised in order to maintain a consistent quality of the output and maximise the flow through the process.
3. Material: stands for the right amount of the right material needed to execute the process
4. Machine: indicates it right capacity and right capabilities of equipment needed to execute the process.

Next to the seven wastes from lean manufacturing, seven types of information waste were identified by Verhagen et al. [73]. In his research Verhagen et al. [73] defined these seven types of information waste in order to determine potential for automation and applied it to a case considering deferred defects in aircraft line-maintenance. These types are indicated in Table 5.1.

Table 5.1: Information waste types [73]

Information waste type	Description
Transport	Time and resources needed to extract information from multiple information sources, transforming and loading it into another information system
Inventory	Time and resources necessary to house and maintain redundant information (i.e. too much information, outdated information, "just-in-case" information) Resources spent on redundant information sources
Motion	Time and resources spent on moving information caused by lack of collaboration and/or real-time access Time and resources spent on digitising information provided in paper form
Waiting	Increase in lead time as a result of information that has been created and is waiting to be applied Increase in lead time as a result of a process actor waiting for input information to be created and shared
Overproduction	Time and resources necessary to create excessive information (i.e. information overload due to non-relevant information or information duplicates) Time and resources spent on creating unnecessary level of detail and accuracy
Over-processing	Time and resources needed to transform information into the desired format Time and resources needed to create workarounds when information is unavailable
Defects	Time and resources necessary to verify and correct provided information Time and resources necessary to hunt down missing information

5.2.1. Demand analysis

The measured data Chapter 4 considered data from the freight forwarder, concerning all shipments of components to the logistic centre of KLM E&M. On a component level less data is available as the inbound flow of US components as this not accurately tracked in the internal systems. Hence, most systems are administrated after the component has arrived and is opened by a repair administrator or logistic handler. Data was available on the US and SE flow of CSP type contract flows based on manual counting of packages each day. These measurements are captured in Figure 5.2 and 5.3 for SE and US flow respectively.

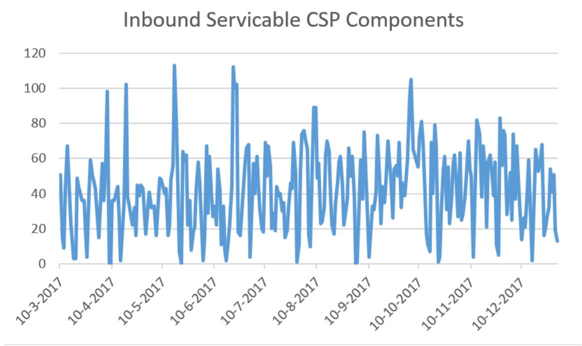

Figure 5.2: SE arrivals CSP

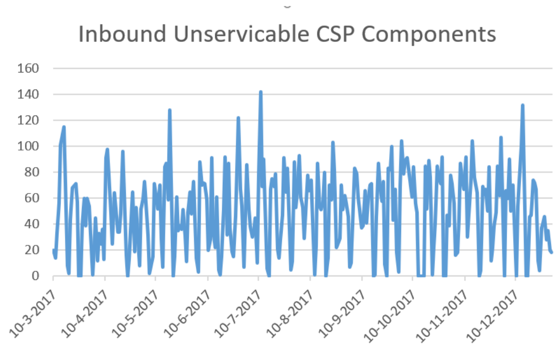

Figure 5.3: US arrivals CSP

Using the Crostons method [66] as discusses in 3 for demand classification, the coefficient of variation and the ADI is calcylated for the CSP flow. Both the US and SE flows show a highly lumpy, almost erratic demand pattern given de stated cutoff values of

Flow	CV2	ADI	Classification
US IN	0,492	1,461	Erratic
SE IN	0,512	1,233	Lumpy

Table 5.2: Demand classification

The Figures 5.2 and 5.3 shows a similar pattern in weekdays as the data concerning all the component shipments. The Demand variation causes unwanted queuing of components in the handling operations. As a result components are buffered in the logistics handling area and causes reduced service levels and long reverse flow TAT. In order to deal with variation a company generally has two main options. Either the company tries to control the demand in order to reduce variation, or does not try to control demand but rather aims to increase flexibility in the operation and find the right amount and combination of buffers in the supply chain. Increasing flexibility in the operations can be done in multiple ways, through work planning, scheduling or redesigning the processes. To shorten throughput times, it is most essential to consequently eliminate buffers. buffering is problematic especially if it does not accumulate in one place but are scattered throughout the process. In the case KLM E&M a view of the entire process chain is currently missing, since every step in the process chain is the responsibility of another organisational unit.

5.2.2. Case study CSP flow - Boeing 737 components

To find the root causes of the long handling times a case study is performed on the flow which has the highest target handling time and was considered a difficult flow by CS operators, namely the CSP outsource flow which KLM is repair responsible. The choice for this case is justified as is contains most of all the other handling processes of the other flows. For this case study multiple mapping sessions where organised with representatives of all the involved stakeholders in the process. Based on the knowledge from the mapping sessions the business process map VSM-I map presented in Figure A.2 was developed. The map shows the IT and physical process steps from the moment a customer ships a US component. The VSM-I shows that there are many IT transactions needed in order to generate a repair order for an outsourced repair and similar so for the internal repair order. The physical processes are indicated in red the other colours indicate a different data information system is used. These processes currently require a significant amount of knowledge of the internal systems and are time intensive tasks resulting in a total regular flow touch time of several hours. Furthermore, there are several hand-overs between the customer interface and repair administrator via email which can lead to delays. Aside from the physical and information transaction, buffers are indicated using a triangle. The buffer can be either a physical buffer or a information buffer, which indicates digital requests are waiting for the process to start.

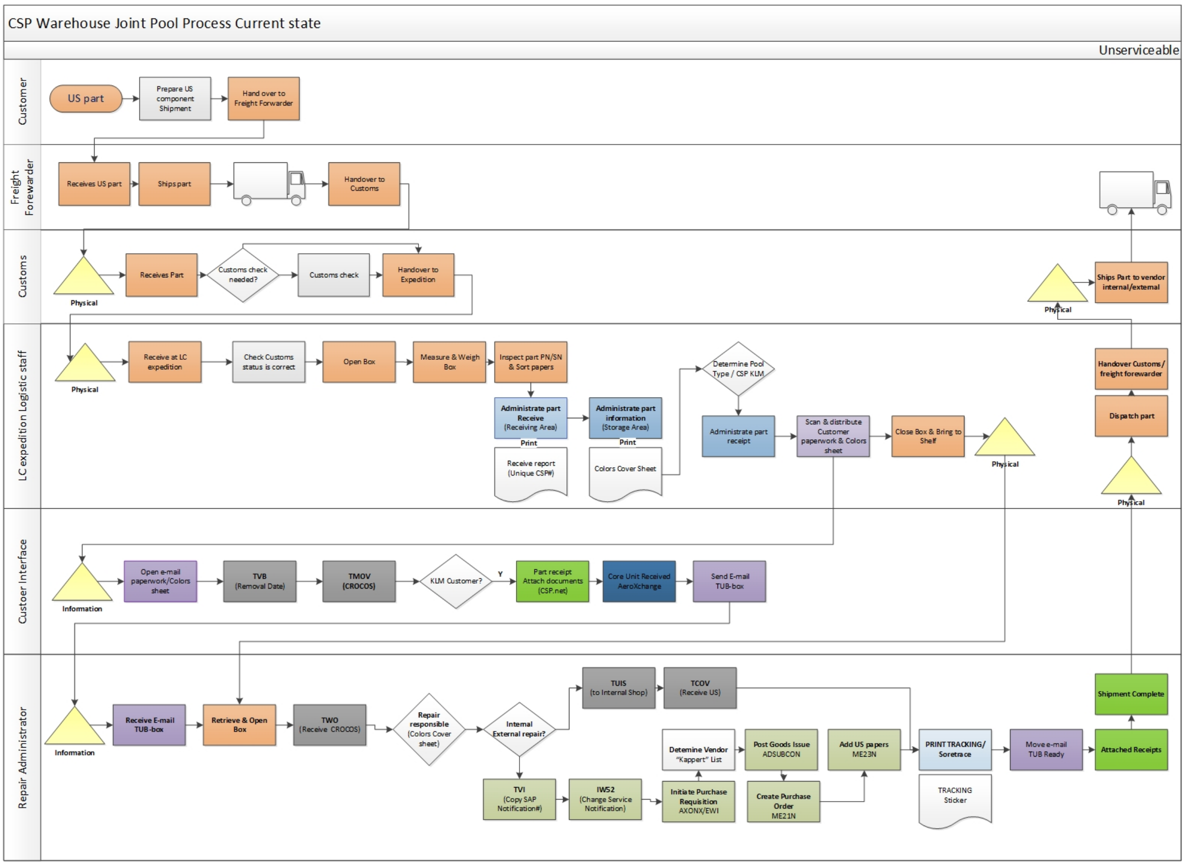

Figure 5.4: Current State CSP VSM-I flow with detailed IT transactions

The process starts at the customer, within the CSP pool both KLM and Boeing customers share in the component pool. After removal of a component the customer notifies the freight forwarder to pick up the component and ship it to the logistic centre of KLM E&M. The component are received by Bolloré and depending on the need for customs clearing, a customs action is performed. After clearing customs the components is handed to the logistic expedition department. Expedition then has to determine the type of component and print a tracking/scoretrace label and add it to the component packaging. The component is then brought to the logistic handler queue for inspection. In this process the component an packaging is weighed and measured. Next the documents included with the components are retrieved and the part and serial number is checked if the provided documents match the component. Next a receive notification is made in Colors which is the warehouse system of the CSP flow. After the received notification the provided documents are scanned and sent to the customer interface. Customer interface then has to manage several transaction the three different systems, nalemly CROCOS, CSP.net and AeroXchange. CROCOS for KLM pool tracking, AeroXchange for customer interface, and CSP.net for the CSP pool management. After these transactions are finished the RA is notified via email and via an outlook bin called the TUB-box, once received the RA searches for that component and retrieves it from the storage location. Next the RA determines whether the component is repaired in-house or by a vendor and performs transactions in CROCOS and SAP based on the repair shop responsible. Once finished the repair order documents and the proforma invoice is added and location is assigned, which is either an internal repair shop or an external vendor.

5.3. Transactions

From the VSM-I analysis several transactions between departments can be identified. In this research these transactions are divided in physical and information transactions. The physical transactions within the supply chain concern the handling and handover of the actual component. The information transaction concern the handover of data, documents and other sources of information. Due to safety regulations information about the component life cycles and history must be documented and stored. Without this information the component cannot be certified and therefore has no value to the customer. Figure A.2 shows the physical

Process	Time [minutes]
Measure, weigh , PN/SN check + handling	10
Customer interface administration	20
RA activity administration + handling	30

Table 5.3: Process times CSP

transaction in red the information transaction are indicated by a different colour and the associated system is indicated in the map. It can be observed there are 6 point buffering can occur due to handovers between departments. Especially the handovers between the logistic staff unpacking components, the customer interface registering the receipt and the repair administrator making the repair order are crucial to the operation. As outlook is used as a work-flow system no measurements about the performance of each of the tasks is available.

Figure 5.5: Component packaging

Figure 5.6: Component packaging

The touch times involved with the actions named above have been measured manually as there are no time stamps available that indicate a natural start of the transactions. In addition the buffers are not quantifiable, especially the information buffers as the request for the start of the process is 'buffered' in an email box. The total process times of the CSP US flow indicated in Table 5.3. These measurements where obtained obtained from the work floor and count for the regular flow of components, where no data is missing and were validated with two lean six sigma black-belts at KLM E&M. Table 5.3 shows the time the handling process takes was found to be 10 minutes for PN/SN check, digitising the documents, measuring, weighing and assigning the location in Colors. The customer interface transactions, hence the removal notification in CROCOS, CSP.net and repair responsible check in Colors takes 20 minutes. The physical and administrative steps of the RA, including the determination of work-scope in SAP, making of the repair and purchase order, handling transactions in CSP.net and Colors, adding the destination to the box takes 30 minutes. The remaining time the component is in the logistic centre of the time is caused by waiting times as a result of waste and waiting times between the RA, CI and handlers. Other waiting times are imposed due to the imbalance between capacity and demand.

5.4. Physical process constraints

Transport Unnecessary transport happens for the internal repaired parts due to the current physical location of the logistic centre. The internal shops are located at different locations (Hangar 14 and Building 425). Parts are received and the repair order is made in the logistics centre whereas the repair takes place in the internal shops away from the logistic centre. In the CS2.0 scenario this transport will no longer take place as all components will be receipted in Hangar 14. For outsourced parts there also is unnecessary transport from a global perspective. currently many parts are shipped via the logistic centre in Amsterdam even tough there is no internal repair capability. After making the repair order and proforma invoice the part is then shipped to the vendor. This could be avoided if parts would be directly outsource to the vendor from the customer.within the logistic centre manual transport takes place between the receiving area and the inbound and outbound buffers of the logistic handlers and repair administrators.

Inventory In the current situation, the available surface area in the LC and expeditions is used to buffer components during peak hours which can cause buffering multiple days. Inventory rises due to the lack of balance between manpower capacity and input. As followed from the measurement phase the demand is highly volatile. Aligning capacity on the average input results high levels of inventory in the logistics centre. In the future situation there is much less the buffer-space due to the lack of surface area in the new hangar. Especially on peak days it is therefore necessary to store components in different places or find ways to perform peak-shaving.

Motion Logistics staff and repair administrators have to retrieve boxes themselves which takes a several minutes, in addition handlers have to walk to printers and scanners to copy the attached documents. This results in unnecessary motion. Another large source of waste is the time spend on searching for the right package. Repair administrators have to retrieve a part linked to the email notification form customer interface. These packages containing the parts are stacked in racks sorted by aircraft type (737,787,etc.), finding the right one does however takes several minutes.

Waiting Waiting time in the physical handling occurs many due to a imbalance between the capacity of the repair administrator and logistic handlers. The imbalances causes the buffering of components before the measure and weighing stations as well as the buffer for the repair administrator and customer interface.

Over-production Over-production is not a direct form of waste in the current physical handling process. due to the nature of the closed loop supply chain, the amount of repair components which need handling is determined by the exchanges of components.

Over-processing In the current state the part and serial-number of each component is manually checked by the repair administrator, this is not necessary as it will also be checked by the customer and in the repair shop itself.

Defects Defects in the repair order process mainly happen due to incorrect information form the customer, faults in the certification (mainly wrong part number) and the absence of documents. Other defects are issues with the packaging. If a component packages is damaged the component is repacked by KLM. Other defects in the process can occur due to errors in scanning locations of the components. If components are not assigned correctly to a storage location employees have difficulty finding the right components.

Skills Skills play an important role in the handling process, repair administrators are currently divided in "type teams". Each aircraft type (737,787,747 etc.) has their own repair administrator. The repair administrators has to know all systems used to administrate the part which requires experience and tacit knowledge. In expedition the identification of components done by experienced workers, for the generation of tracking/scoretrace labels the destination is required. This is not always evident form the paperwork attached to the outside of the box en therefore boxes are opened sometimes by the expedition to determine the right type team for the component. As component packaging is reused, many labels stay attached from previous shipments adding to the difficulty (see Figures 5.5). The logistics staff carrying the components from expedition to the RA and weighing the components mostly consists of temporary employees.

5.5. Information process constraints

Transport Within the component handling processes many manual transactions and additional effort is required to convey the information from the paperwork in the box of the components to the ERP system, warehouse database, and availability system. It requires data from multiple screens to be copied in order to fill in all the forms.

Inventory The information exchange between the logistic handlers and the repair administrators is performed by means of e-mailing. Microsoft Outlook is used as the information source. The same holds for trouble shoot parts, which are parts of which information is missing from the customer. If that is the case the customer interface notifies the customer and asks for the appropriate data. The only way to know which components are in the on hold and waiting for this data is to track the e-mail conversations.

Motion The paperwork provided with the components is scanned manually this results in physical waste in terms of the walking to the printers as the process of gathering the information provided with the component.

Waiting Waste in terms of waiting time occurs due to processes which are linked via email communication. Hence, customer interface only starts after it has received an email the component has arrived in the LC. The repair administrator only starts after receiving an email from the customer interface has done their part of the administration.

Over-Production Overproduction of information related to the detail and accuracy of the processed infor-

mation was not indicated as a waste during the mapping session.
Over-processing When data from the customer about installed hours is missing the numbers of hours can manually be calculated by the RA. This workaround due to the unavailability of data can be considered a processing waste.
Defects One of the major defects is missing data from the customer. Around 55% of the components the calculation of hours and cycles is missing, for 22% aircraft registration is missing. and another description core unit problem: 22% is missing a problem description. Other defects occur in the process itself. due to to the manual entering of data in the systems errors occur in copying part/serial numbers. When data is missing the customer interface must either look up data in the internal system (Aircraft registration number for instance) to correct the data. Or do an hours and cycles calculation based on paperwork provided with the component. In some cases when no information is provided the customer interface has to put the component on hold and email the customer for the information.

5.5.1. Man: Imbalance Between input and capacity

An earlier studies by [71] has indicated there is an imbalance between manpower and capacity within the expedition of shop MRO. This analysis was not performed at the logistic centre, therefore it was performed for this study. Using data from buffer counts determined for the incoming flows for the repair administrators in the LC. The gap between in/outflow and manpower capacity is indicated in Figure 5.7. It can be observed that the differences between the input of manpower and required capacity to handle components based on norm hours is often negative. This means the amount of work exceeds the amount of input man hours which causes the WIP and buffer before the US CSP RA to rise.

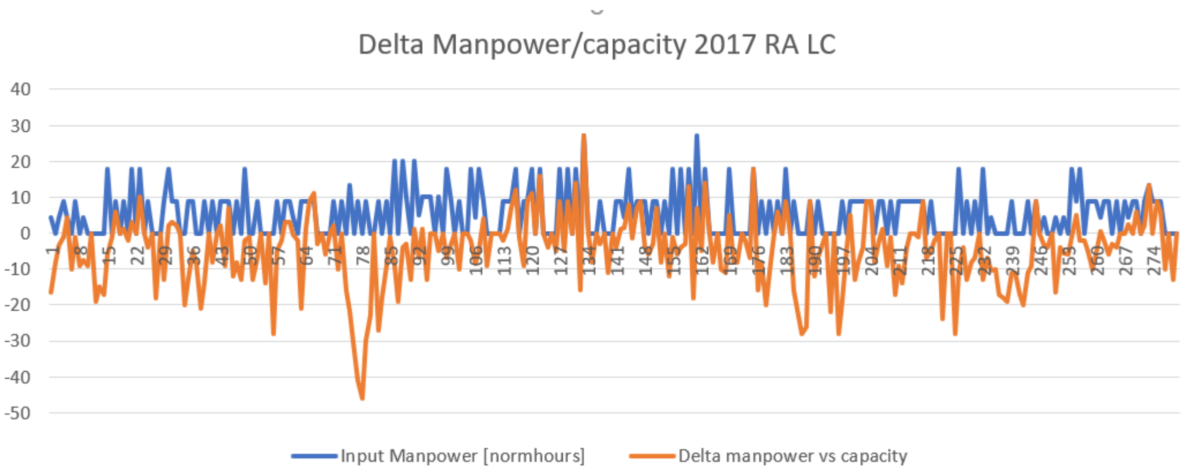

Figure 5.7: manpower vs capacity, Source data from MLC

5.5.2. Method

From the mapping session presented in Figure A.2 it became clear the many transactions are needed using different systems to generate a repair order. The repair order process managed manually in the different ERP applications. This process is subject to human error as it requires the manual entering of (often long) numbers in the systems multiple times. Because the customers ERP systems are not interconnected, it is not possible to perform automatic transactions in the current situation. Another observation is the start of the repair order generation happens after the component has arrived at the logistic centre at Schiphol-East. All the information needed to make the repair order could be from the point when the component is being shipped from the customer. In the current situation however it is not communicated properly in the current state.

5.5.3. Machine: equipment as constraint

Equipment does not seem to constrain the current processes. For the handling of components mainly computers are used. Although computers sometimes subject to this was not indicated as a bottleneck as it only rarely happens. The equipment needed to move the parts are mainly forklifts for large parts. The amount of components that this lifting is limited therefore this cannot be indicated as a bottleneck.

5.5.4. Material

The material needed to perform the process is limited. Only when boxes or wooden containers arrive that have been subject to heavy wear, packaging is exchanged and new packaging material is required. In the current state the is plenty of spare packaging at the LC eliminating this as a bottleneck.

5.6. Conclusion Analyse Phase

From the analyses presented in this chapter answer is given to the research question:

What are the constraints in the current processes?

In the analyses step of the case study the shows that Repair Administrator and logistic operations of the reverse flow are the main constraining processes, with a handling time of 7 days on average. The root cause of these constraints was determined using the 7 types of waste and a 4M analyses.The analyses shows that logistic and handling operations have several root causes. First of all, the demand can be classified as lumpy/erratic demand. Due to the fluctuations in demand buffering occurs due to a imbalance of manpower related to the input. Furthermore mapping analysis has shown that there are many handovers and transactions necessary in the process that are subject to errors due to the manual entering of part and serial number. The VSM-I was used to identify all physical hand-overs and IT transactions, which proved valuable in both understanding the processes at hand as well as posing a base of a redesign. Repair orders are currently made after the component has arrived, due to the intertwining of the administration process with physical handovers the the logistical flow is constrained. Another observation is that is it difficult for the logistic department to identify packages as they do not have standardised labels so often boxes have to be opened to determine what is destination should be. Other types of waste where identified in the repair administrator process. RA's often have difficulty finding the right box with the paperwork resulting in searching for the component in racks and extra handling time. Summarised the main observations are:

1. The arrival pattern of US and SE components is highly variable.
2. Repair orders are made after the arrival of components entangling the logistic and administrative processes.
3. Many systems are involved in the repair order process resulting in many transactions.
4. The generation of repair order process is time and labour intensive.
5. Defects occur due to incorrect data from the customer.
6. Trouble shoot flow and regular flow are not separated
7. The majority of the components comes in boxes.
8. Repair Administrators often are spending their time searching for right components

In the next chapter a design is presented which is aimed to reduce and stabilise the TAT focusing on the new handling area in Hangar 14. Increasing the performance of the handling of components will result in a higher service level. This will consequently result in cost savings by reducing the over TAT and thus the required stock levels. The relationship between handling performance, TAT and required stock level however is complex and dependent many parameters. For example reducing the TAT of an overstocked item will not result in a higher service level to the customer. It will however result in the opportunity to either lower the amount of stock or contract new customers in the component pool. In addition improved handling performance can reduce the Aircraft-On-Ground (AOG) time in some cases, although this is much harder to quantify. The relationship between handling performance measured can however be translated to TAT relatively straight forward; a decrease in Handling TAT with x days will result in x days reduction in the reverse flow TAT, assuming other parameters remain the same. As erratic or sometimes lumpy demand variation is common in the MRO industry the aim is to adapt and redesign processes in such a way the operations deal with the demand in a way performance of the complete supply chain is optimised. The redesign of the processes is discussed in the next chapter.

Part IV: Design

6

Process redesign

Based on the analysis in the previous phases presented in Chapter 5 and Chapter 4, options for redesign of the handling processes within the reverse component logistic flow are presented in this chapter. The redesign consist of two parts; the redesign of the physical flow and the redesign of the (non-physical) information flow. The scope of the redesign is limited to the handling processes of the reverse flow of aircraft components as these have been identified as a bottleneck in the complete closed loop supply chain in Chapter 4. The design for the physical handling of components is evaluated for the new location in Hagar 14. These design options will be tested under different circumstances (scenario's) using discrete event modelling, which is presented in Chapter 7. This chapter answers the following sub research question;

What are the relevant redesign criteria for the handling of the (reverse) flow of aircraft components?

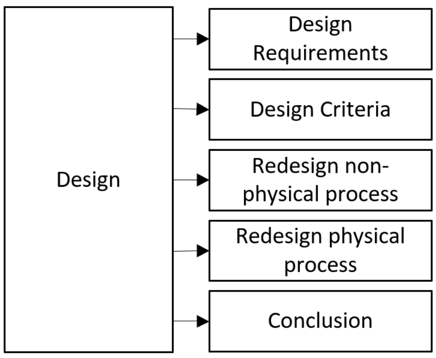

Figure 6.1: Outline Design

6.1. Requirements component handling Re-design

As discussed in Chapter 4 the performance of reverse flow components in the MRO industry can be evaluated using several parameters. As the the handling activities and redistribution of components was identified as a bottleneck in the MRO reversed supply chain of KLM E&M, the design is therefore based on improving this part of the supply chain. To determine the relevant Key Performance Indicators (KPI's) on which the evaluation of the designed system will be based, it is important to state the needs and objectives of the redesign. Sage and Rouse [62] define a need as "a lack of something desired or required", while an objective "describes everything that the project is intended to accomplish" [62]. From the specified needs and objectives it is possible to derive clear user requirements. These requirements can be divided into functional or non-functional requirements. Functional requirements or constraints are mandatory requirements the system must comply with at all times, or what the system must do. Non-functional requirements are elements that a system should have. These non-functional need to be optimised as much as possible. The requirements for the component MRO where determined using subject matter experts of KLM E&M, logistic team leadersin the current logistic centre. handling are as follows:

Functional requirements

1. The re-design must be able to physically handle MRO components in different sizes.
2. The re-design must be able to physically handle inflow fluctuations.
3. The re-designed system must be able to handle the administrative actions of components.
4. The re-design system must must be applicable in the assigned space in Hangar 14 of KLM E&M.

Non-functional requirements

1. The re-design should minimise the throughput time of components through handling.
2. The re-design should maximise workforce utilisation

These requirements can than be measured and using the relevant KPI's. Within the MRO supply chain, the throughput time plays the most important role. Long lead times lead to the fact components are unavailable for service somewhere in the closed loop supply chain. This leads to high amounts of capital employed within the chain, hurting the financial performance of the business. In addition the distribution of the TAT is of major importance. Hence, having a relatively short TAT with high standard distribution will still require the availability department to stock a lot of components to compensate for the unreliable reverse flow filling up the stock levels. As the handling time in the logistic handling area has a direct influence on the overall TAT the handling time should be as short as possible. This holds especially for rotable components as every minute spent in handling increases the overall TAT of the reverse flow. For the case study at KLM E&M this goal is to handle components which arrive before 21:00 o'clock the same day. The on time performance (OTP) of the system can therefore be evaluated by comparing the actual throughput times with this benchmark goal. van Rijssel [70] pointed out, when introducing an OTP, it is important to define a "On Time Start" (OTS) of a process. The OTS can be determined determined through the planning in the repair shops and critically of components in stock. The planning of repairs within shops in the supply chain can however only start when all repair order administration is complete and an initial work-scoping has been performed. The handling should therefore be performed as soon as possible. Logically striving for to this goal comes with a cost. The cost of the handling system can represented through capital and operational expenditures (OPEX & CAPEX). The focus of this study is mainly on the determination of the operational requirements under different scenarios and configurations, although an indication of the CAPEX can be acquired from the market value of the equipment required. The required equipment is further elaborated in section 6.4 and is in addition to the other KPI's determined in the simulation model presented in Chapter 7.

- Low throughput time (handling time) [hours]
- High Throughput [Components/hour]
- High On Time Performance [%]
- Low OPEX [manpower requirements]
- High Labour utilisation [%]

6.2. Design criteria for optimal performance

The redesign presented in this chapter is developed in order to improve performance the current performance of the reverse logistic flow of rotables within the MRO closed loop supply chain. The redesign is based on literature on process performance improvement, reversed supply chain theory and the context of component MRO. The theory and the conclusions from the analysis phase of the processes in the case op KLM E&M form the bases of several design principles presented in this section.

As stated in Chapter 4, in the current state the physical and information flow are entangled. This results in the fact that components which have to wait in the logistic centre until administration by the repair administrator and customer interface has been performed. In the current situation the repair order is created only after the customer interface is done doing administrative tasks. Lean theory Womack et al. [77] states that in order to improve a process, waiting times should be be removed or reduced as much as possible. Untangling the administrative process and the physical process, will in theory therefore reduce the TAT of components in the logistic centre by reducing the waiting times. A scenario that arises from untangling the administration is the possibility of creation of repair orders before the component arrives. From the analysis in Chapter 4 followed that a lot of time is spent on generating these orders, and waiting for this process to take pace, delaying the flows of components. From the mapping session performed it became clear the physical inspection of the component is not necessarily needed for the repair order generation process as long as the correct data is available to make the repair order. Due the the regulations in the MRO industry, customers are obligated to administrate the history of the components, such as; installed hours, flight cycles, reason for removal etc. In fact, all the information required for this process of generating repair orders should be known although it is not communicated and shared properly. In addition, if data is missing the point of notice is only after the component has arrived, so delays in the process has a direct influence on the end-to-end TAT.

From a transaction cost perspective the amount of transactions in a process should be kept to a minimum as transactions result additional costs. A translation here is defined as "one stage of activity terminates and another activity begins". The total amount of transactions is shown in the VSM-I,using this definition for both the current state and in the new design scenarios. As discussed in Section 5.3, asset specificity the most critical driver of transaction cost. The MRO industry has high asset specificity due to the large amount of paperwork attached to the components. The high levels of regulation furthermore result in the fact many different systems used to document and track the status of the components throughout its life-cycle. The administrative tasks within these systems not only consist of many transactions adding to the transaction cost, but also require specific knowledge of the components and systems requiring asset specific labour. From Chapter 5 it became clear variability is another main source of the lacking performance in the current state. According to the variability law described by [32], one has no choice but to buffer in either capacity (resources), inventory (stocks) or time (TAT) when a system experiences variability. Within the component supply chain buffering in the current system happens mainly in time (long TAT) and inventory (high stock levels). Buffering inventory is, as stated earlier, expensive due to the nature of the aircraft industry. According to [32] one of the most revolutionary, and overlooked, steps taken by Toyota was a conscious shift from inventory buffering to capacity buffering. With capacity buffers as backup for variability, Toyota for instance could afford to run much leaner process with respect to inventory. In a highly asset specific environment such as the MRO industry, having flexible capacity as buffer is more expensive due to the knowledge intensive tasks. It can therefore be stated that for the design of the logistic handling area, it is beneficial to redesign the process in a way buffering capacity can be done for the lesser knowledge intensive tasks, as these tasks can be done by more flexible labour sources. To do so, the specific task for generating the repair orders and registering information in the different systems can be separated from the physical handling flow. Lastly, the waste identified in the measurement phase can be reduced by (partly) automating the physical and non-physical processes. The impact of automation has been visible for a long time, e.g., in automotive assembly lines but also in warehouses and distribution centres (Automatic Storage and Retrieval Systems), generally consisting of high bay storage racks which are served by fully automated crane and equipped with automatic identification. Automation can reduce the need searching, handling and motion. In essence, two core questions must be answered when justifying the development of an automated solution for any engineering task, namely: Is the process suitable for automation, i.e. is it feasible to automate a process? and; What is the potential of automating the task or process? The first question is elaborated upon in Section 6.3, the second is evaluated using simulation. Concluding from the above six main design principles where identified using process improvement theory in the MRO context. These principles form the bases of for the redesign of the handling processes in the logistic centre.

- Separate Physical and Non-physical flow.
- Shift from time (TAT) and inventory buffers to capacity buffers.
- Generate repair orders before arrival.
- Reduce the number of transactions.
- Automate Identification, sorting, storage and transport.
- Eliminate rework.

6.3. Redesign Component logistic handling processes

As discussed, the redesign of the handling of components consists of two parts. A redesign of the business processes and a redesign of the physical handling of components. The business process redesign focuses on the reversed logistic flow of US components including the generation of repair orders and the distribution to external vendors or in-house repair shops. The redesign of the physical handling area focuses on the redesign of the layout of the handling area in which the handling processes take place.

6.3.1. Non-physical (administrative) Process Redesign

The administrative handling of components concerns all the tasks related to the exchange of data between the actors in the supply chain. The main administrative task of the rotable components is the registration of the life cycle history of the parts in mandatory systems, the generation of repair orders and sending proforma invoices to the vendors. For the redesign the VSM-I is used, similar to the one in Section 5.2.2. The use of the VSM-I as illustrated in Figure 6.3 clarifies how IT transactions can be separated from the physical process. By taking out the individual IT transactions and separating them from the physical-handovers it becomes possible to generate repairs orders in advance.

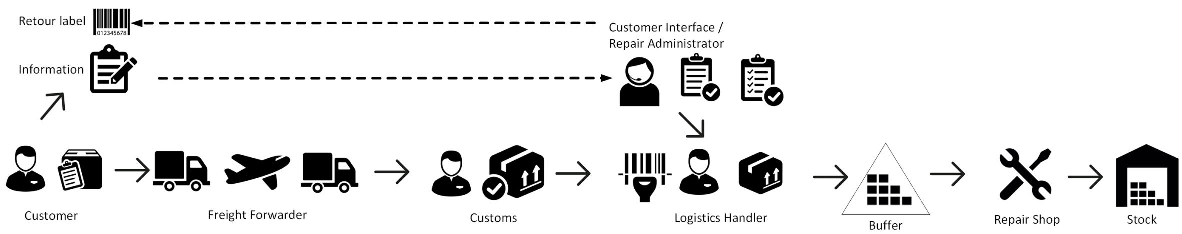

Figure 6.2: Concept Future State Process

The result of the future design is presented schematically in Figure 6.2 and in more detail in Figure A.3. The redesign is based on elevating the constrains in the current state, namely the difficulty of identifying components and requiring the physical documents attached the components for the administration and repair order generation. In the future scenario the customer is asked to provide the necessary data about the component in a shared information system. In the KLM E&M case this is done in the system AeroXchange. After filling the fields correctly the customers receives an message with a return-label which can be printed and attached to the component packaging. This can be done using a standard barcode. A study by Ngai et al. [45] investigated value of implementing RFID in the MRO supply chain, although concluded that here the biggest challenge lies in integrating the RFID technology with the legacy systems and data bases as well make the RFID technology accessible for customers and other business units within the company to fully leverage the benefits of the technology. For the ease of implementation a barcode is proposed in this study. After receiving the barcode the component can be shipped. During shipment the customer interface has all the data available to make he repair order and do the other administrative tasks indicated in Figure A.3. On arrival the barcode can be scanned either manually or automatically and distributed to the right destination. rom the analysis followed a lot of time is spent on generating these orders delaying the flows of components although the component is not necessarily needed for the process as long as the correct data is available. All the information required for this process is known at the customer and consists of;

- Customer Name
- Aircraft registration
- Hours installed on aircraft
- Flight cycles
- Date of removal
- Reason of removal
- Fault description
- Part number
- Serial number
- Customer PO number

The role of the repair administrator in the current situation is changed by removing the repair administrator from the logistic process. The IT transactions still need to be carried out, these tasks can be combined with the customers interface transactions. However not all customers can be obligated or will share accurate data, resulting in unrecognised components. Therefore a new skill is introduced; Part ID. As indicated schematically in Figure 6.3 the part ID skill has the task to identify components and provide the customer interface with the documents inside the box to make the repair order.

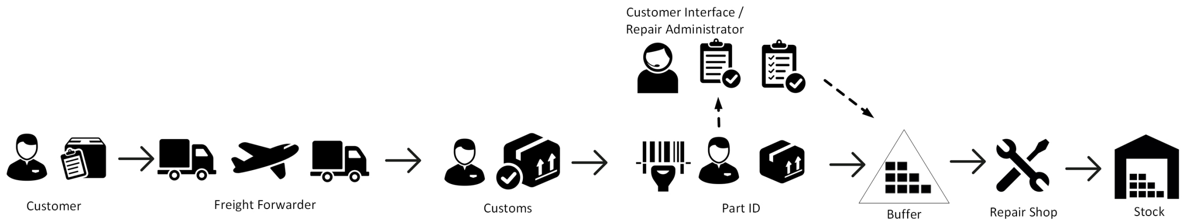

Figure 6.3: Concept current State Process

One of the scenarios following from the redesign is the is the effect of generating repair orders before the component arrives. The percentage of repair orders in advance has an effect on the logistical performance of the reverse supply cahin and is therefore elaborated in section 7.

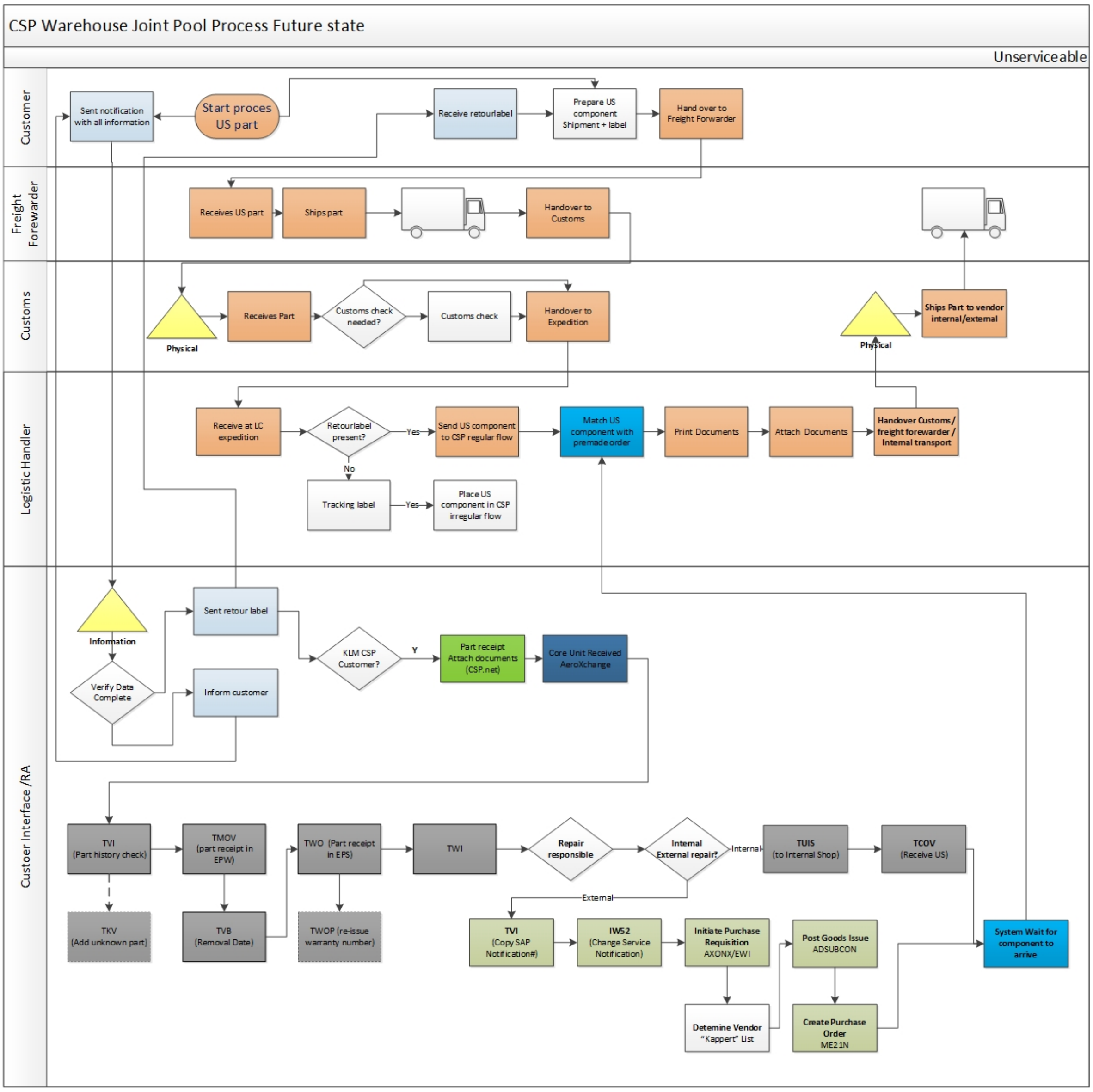

Figure 6.4: Future State CSP VSM-I with detailed IT transactions

From a transaction cost perspective it is recommended to reduce the number of transactions, whether administrative or physical as much as possible. In the case of KLM E&M the minimal number of transactions in the internal is shown in Figure A.3. The timing of the information transactions dos not have to take place after the physical transaction take place and therefore can be done while the component is in transport. By doing so the time spend on performing the IT transactions does not have a direct influence on the TAT of the component.

6.4. Physical Handling & Warehousing

As discussed Chapter 1 the logistic centre is to be moved from the current location towards Hangar 14. The design and layout of the handling area (warehouse) is essential to the operational performance in the supply chain. As the design of the warehouse facility plays an important role in the operational performance level that can be achieved. Decisions about the facility design are usually hard or expensive to change and thus, considering the operational performance during the design phase is very important. The functions of the handling area consist of the physical handling of components, sorting, transporting and storage and inspection of the physical component and packaging. According to Baker and Canessa [8] there is no "standard protocol" or work flow for warehouse design. Although there are essential common steps in warehouse design, which include:

1. Defining data needed and developing the instance data to determine requirements
2. Data analysis to define warehouse requirements
3. Specifying the units of handling and the basic flow pattern through the warehouse
4. Selecting, sizing, and configuring technologies to support the flow pattern
5. Physical arrangement of warehouse systems
6. Detailed warehouse performance evaluation.
7. (iteration of steps)

The data needed for the design of the handling area can for a large share be derived from the measure and analysis phase in this report. In Chapters 4 and 5 the individual flows that move through the handling area have been described and quantified. A basic flow pattern through the warehouse can be created by taking the design principles into account. The selection, sizing, and configuring of technologies technologies to support the flow pattern is described in the Section 6.6. The focus of the alternatives of the design is aimed at automating the physical and the information flows. The selection of specific equipment is considered out of scope, however the type of equipment used concerns common standardised warehouse handling equipment. Using these elements a conceptual physical layout of the of handling area is presented in section 6.6.4. The performance of the handling configuration is evaluated using Discrete Event Simulation presented in Chapter 7. The flow pattern through handling follows from the physical layout of Hangar 14. The dark green space indicated in Figure 6.5 shows the available space for the to be design handling area in the future. Components are handed over by the 3PL and customs agent which will be located at the entrance of the building. The central buffer and warehouse for component stock are indicated in yellow and green respectively.

6.5. Basic flow pattern & units of handling

To illustrate the basic flow the seven different flows of component types identified in the analyse phase are used. All serviceable and consumable parts are stored in the storage facility in "Baai 3", indicated in green in Figure 6.5. US flows (including CSP) can be stored in the central buffer indicated in yellow. The repair shops are indicated in blue. After the components have been repaired the components are sent to the high bay warehouse for storage.

Component maximum dimensions			
Size classification	Length cm	Width cm	Height cm
Box	80	60	40
Pallet	120	100	152
Odd size	>120	>100	>152

Table 6.1: Component class dimension

The units of handling consist of different sizes, namely box pallet odd-size parts. The size is determined by standard warehouse equipment and was determined in collaboration with DENC consultancy, who designed the high bay storage system in "Baai 3" for serviceable components. The maximum dimensions are indicated in Table 6.1. The box size is determined by a size of a standard tote of 60x40x40cm (LxWxH). The pallet size used has a base of 120x100cm, and height height of 152cm as upper limit. All larger components are considered odd-sized. In addition a "direct transportation class" is added for components which need cleaning first.

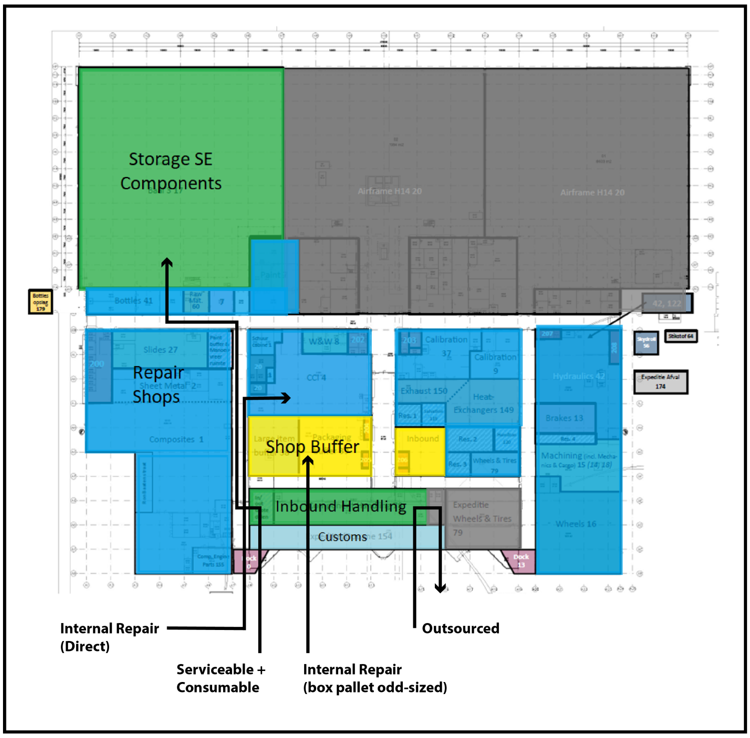

Figure 6.5: layout of Hangar 14

Shop internal	location	Total 2017	Percentage	Box	Pallet	Odd size	Direct
Airframe Components	HUB	3454	10,02%	40%	8%	52%	
Audio, Panels & Indicators	MRO	4113	11,93%	99%	1%	0%	
Bottles	MRO	5530	16,04%	62%	38%	0	100%
Brakes	HUB	647	1,88%	0	100%	0	
Crew Seats	HUB	389	1,13%	0	100%	0	
E-mechanical	MRO	1961	5,69%	80%	15%	5%	
Flight Guidance	MRO	2196	6,37%	86%	14%	0%	
Galley	MRO	3909	11,34%	90%	10%	0%	
Heat Exchangers	HUB	2190	6,35%	14%	84%	2%	
Exhaust	HUB	87	0,25%	0%	0	100%	100%
High Frequency	MRO	1988	5,77%	96%	4%	0	
Hydraulics	MRO	3493	10,13%	68%	32%	0	
Machining, Mechanics & Cargo	MRO	1124	3,26%	72%	19%	9%	
Slides	HUB	1079	3,13%	1%	99%	0	100%
Water & Waste	HUB	1111	3,22%	24%	76%	0	100%
Outbound H11	H11	1199	3,48%	100%	0	0	
Total		**34470**	**100%**	**55%**	**16%**	**6%**	**23%**

Table 6.2: Size class identification based on SAP notifications and CROCOS data internal components

Aside from the unsearchable rotables, consumables and serviceable parts move through the handling area. Much less data is available on these types of parts and therefore measurements where conducted by

KLM to give an indication of the size of these components. The result of these measurements provided by KLM resulted a ratio of 0,85%, 0,13% and 0,02% for the consumable and serviceable flow. Consumables is the collective name for all parts used in the repair of a component and vary from nuts and bolts to oil, values etc.

6.6. Physical handling design; Selecting, sizing & configuration

The redesign consist of several design elements, namely the identification, sorting, disposition (inspection), storage and transportation of components. To accommodate all the required activities in the warehouse a combination of warehouse equipment is required to accommodate the demand. An AS/RS-workstation order picking system is introduced divided into four main elements, namely an automated sorter, AS/RS (miniload), workstations, and conveyors. All elements are discussed in the following sections. AS/RS systems have been widely used in warehousing for storing and retrieving finished products and parts. The benefits of AS/RSs include low labour cost, enhanced space exploitation, improved material tracking and high system throughput [58].

6.6.1. Sorting

An alternative for the current manual weighing and sorting of components in the handling area is the use of an automated sorter. The sorter relies automated scanning of the component packaging. For a large share of the components, this can be done without any problems. As discussed, with the introduction of automating the identification process, constraints are introduced regarding the dimensions, weight, contents and other characteristics of the packaging of components. It is important to prevent certain products from entering the automated sorting process, as it may result in blockages. In the current situation, products are not sorted based on their size, but only on their destination. Furthermore, the ability to accurately identify a component is dependent on the information attached to the packaging. The constraints associated with automated sorting are therefore evaluated in the design and simulation model described in Chapter **??**. As the detailed design of the sorters/identifiers is considered out of scope for in this thesis, Expert knowledge was used determine the physical constraints of a carton identifier, which are:

1. Dimensions: Max [800 x 600 x 400 mm] (L x W x H)
2. Weight: Max [35 kg]
3. Content: No Dangerous Goods (DG); Fuel, Biohazard, compressed gasses.

Part of the automated sorting system is the use of (roller) conveyors for the transportation of the components and packaging which is currently done manually. The component then are conveyed to their destination determined by the sorter.

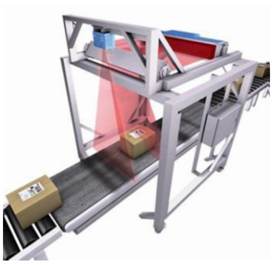

Figure 6.6: Automated (volume)scanning & weighing of box-size components

6.6.2. Storage of components

Due to the smaller space in the new hangar it is important to model the impact of growth scenarios on the required buffer spaces for the handling of components. The analysis in Chapter 5 showed the day-pattern of component arrivals. This pattern consisted of morning peaks and a lower arrival rate in the afternoon. Buffering components from the morning peak for a more even spread across the day requires physical storing of components. Furthermore, components which still require administration, need to be stored somewhere. Ideally this is done separate from the handling area due to limited space. The same holds for components with customs issues, these are currently stored in a separate quarantine storage location in the logistic centre. Aside from the storage requirements from the inbound handling perspective, a requirement comes from the internal repair shops. Due to the limited space in the repair shops it is desirable to store components outside the shops. From a Lean perspective the buffer outside of the shops can be used to implement a pull system limiting the WIP in the shop. Hopp and Spearman [32] state the benefits of a pull environment are more a result of the fact that WIP is bounded, than to the practice of “pulling” everywhere. In order to have a WIP cap Hopp and Spearman [32] propose a hybrid push/pull system known as CONWIP that possesses the benefits of kanban, but can be applied to more general manufacturing setting. In addition, a previous study by van Rijssel [70] stated it is better that one technician handles a component in aircraft component MRO. Therefore, a CONWIP system is preferred in MRO services. The result of using a CONWIP system that pulls from a buffer, is that the input of the shop stabilises. As the input into the buffer still varies this requires a controllable and flexible system to handle the components to be buffered for the shop. This is conform Hopp and Spearman [32] statement "the magic of a pull system is to have a WIP cap". One note that should be taken is that the decisions of whether to make-to-order or make-to-stock and how to rely on forecasting and inventory management are also important but are orthogonal to the push versus pull decision considering CONWIP.

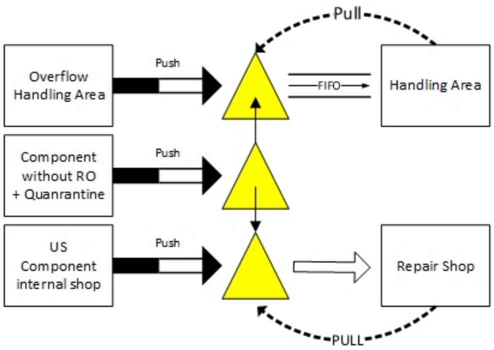

Figure 6.7: Pull mechanism

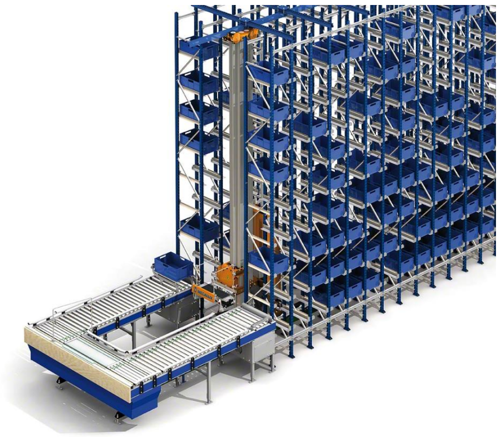

Figure 6.8: mini-load system AS/RS

Again for the design of the storage buffer it is beneficial from process control perspective to automate the storage of components. One way to automate storage activities is by using an automated storage and retrieval system or AS/RS. An AS/RS can be defined as "a storage system that uses fixed-path storage and retrieval machines running on one or more rails between fixed arrays of storage racks" [58]. According to Roodbergen & Vis [58], an AS/RS typically consists of storage racks, separated by aisles with one or multiple automated cranes travelling from input/output-points to the storage locations or vice versa. At the storage locations, the cranes pick or place a load that is often of a standardised size (e.g. pallets, bins/totes etc.). In the broadest sense, an automatic storage and retrieval system (AS/RS) is one that automatically stores incoming material and extracts material from storage without direct handling by a human worker. Figure 6.8 shows an example of an AS/RS. Advantages of AS/RS compared to manual order picking and storage are [58]: savings in labour cost and floor space, a high throughput capacity, increased reliability, reduced error rates, decrease in damage and loss of goods, better process control and improved safety conditions. Two main disadvantages are however also well-known: the high investment costs and the inflexibility of operations due to the physical structure of the system Measures. As stated by Roodbergen and Vis [58] the performance of an AS/RS is strongly coupled to the performance of other warehouse systems and that the total warehouse performance is different than simply adding the performance of all individual systems.

6.6.3. Conveying of components

For the conveying of components many of today’s distribution centres use with roller conveyors because it allows accumulation of products. Accumulation is a way to make the conveyor store product for a determined amount of time then released into an automated sorter AS/RS. As the transport required between the AS/RS and the work station in both ways continuously a loop conveyor is preferred. The conveyor loop transports products (in totes) from the sorter to the AS/RS area to the workstations, and the other way around. An extra advantage of the loop conveyor is components can be temporary stored on the belt waiting for handling space to clear. As all components have to be placed in totes before being stored in the AS/RS using the conveyor as a 'buffer' is desired.

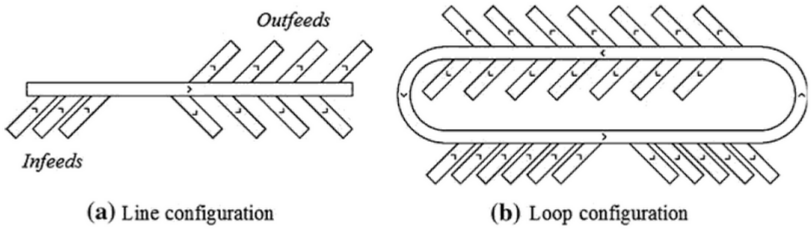

Figure 6.9: Basic sorter configurations [8]

6.6.4. Design of layout handling area

The proposed layout for the physical inbound handling area is schematically presented in Figure 6.10. The physical design was based on the requirements for a automated identification, transportation and storage as discussed in the previous sections. The fact most of the components come in box and pallet sizes resulted in the layout of workstations. The sizing of the physical system and the effect of the redesign of the information flow and handling transactions to be performed using this infrastructure are determined through the use of simulation as presented in Chapter 7. The base for the handling transaction of the in formation flow follows from the current state measurement and analyse phase and the improvements made in on this process. The design parameters yet to be determined are presented in Section 6.7.

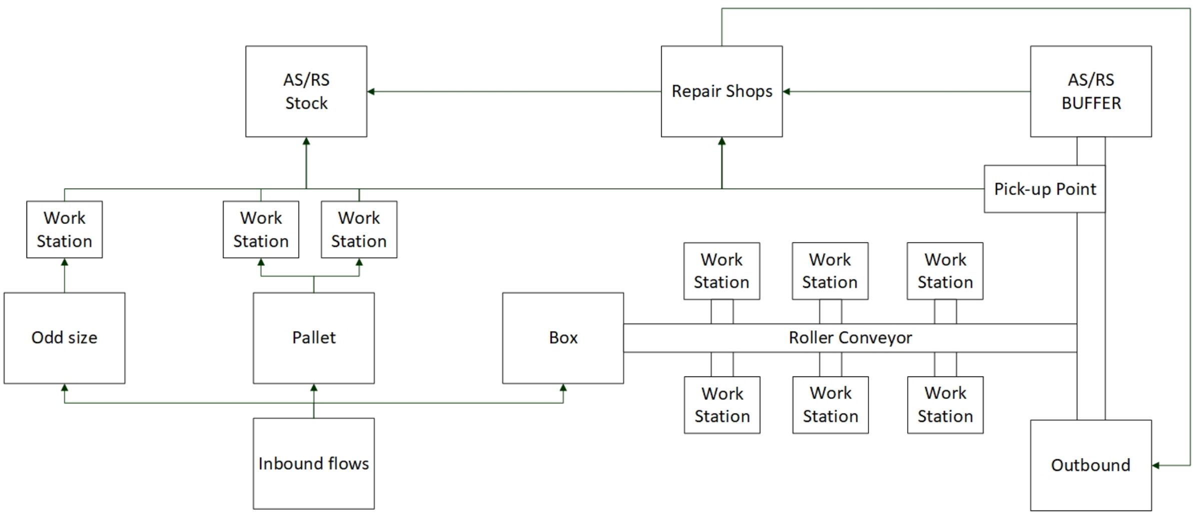

Figure 6.10: Physical configuration Handling area (Schematic)

The handling area for components is located at the front of Hangar 14 as indicated in Figure 6.5. Components for storage are done so in the storage bay, components that are bound to the shop are be stored in central buffers next to the handling area. One of the mayor benefits of automating the handling area in the new facility is the ability to control the incoming flow of components. Whether an component can be identified by the scanner or when not still an action has to be performed or the component will be transported on the conveyor belt indefinitely.

6.7. Design Parameters AS/RS-workstation system

With the proposed automated system several parameters for the design need to be evaluated. First of all the design parameters for the physical infrastructure needs to be determined. In the proposed design the infrastructure consist of several workstations, roller conveyors and a AS/RS. The physical system has to be able to handle perform according to the requirements of KLM E&M the coming years it must be able to handle growth. In addition, the main driving principles of lean manufacturing theory advocated the creation of flow in the process and the enabling of pull processes [77]. Pull is introduced in the reverse supply chain by using the AS/RS as a central buffer for shops from which components can be "pulled" by the repair shops. By buffering capacity in terms of handlers in the handling area buffering of physical components anywhere but the central buffer is eliminated. As a benchmark the capacity in handling is set to physically handle 95% of components that arrive before 21:00h on the same day. The parameters needed investigation therefore are;

- Number of workstation Box line [workstations]
- Number of workstations Pallet Line [workstations]

From a administrative perspective more design parameters of the proposed design need to be tested. These include the manpower requirements and their associated skills.

- Number of Repair administrators [number workers]
- Number of inspectors for consumables and rotable components [number workers]
- Number of Part ID skills [number workers]
- Number of logistic handlers [number workers]

6.8. Conclusion

VSM-I process map was used to determine the information as well as the physical flows in the reverse supply chain. By doing so the transactions and handovers become clear and a rearrangement of necessary steps can be achieved to separate the physical flow form the administrative flow enabling the design of an automated AS/RS-workstation order picking system. Furthermore a data analysis was performed on the demand for handling of components of different flows and unit load sizes. To enable standardised logistic handling of components using automation, component packages are divided into three main handling classes; namely box-, pallet- and odd-sized, in addition a direct flow is identified which due to bio-hazard and fuel related reasons can not be handled before special cleaning treatment. A layout is presented based on standardised warehouse automated warehouse equipment. Part of the design is the introduction of an AS/RS-workstation order picking system which has the functionality to store temporary overflow of the handling area as well as function as a central buffer form which repair shops can pull components by request. By eliminating the need for searching, walking identification of components, and handling components as a one piece flow, handling time could be reduced. By introducing a pull system for repair shops the overall repair process can be ran more efficiently. As buffering capacity in workshops is expensive due to high knowledge intensive skills, repair shops should start repairs based on component criticality in the supply chain. This is only possible is components are 'ready' for the shop in the central buffer. It is therefore essential to perform the handling activities as soon as possible. The required capacity in terms of equipment and skill requirements is discussed in Chapter 7.

7

DES model design

In this chapter the redesigned processes and handling layout discussed in Chapter 6 are modelled and evaluated under different circumstances through the use of a simulation modelling. As stated earlier, most complex real-world systems with stochastic elements cannot be accurately described by a mathematical models that can be evaluated analytically. For these type of problems simulation is preferred. For the purpose of this study a discrete-event simulation model is developed for the evaluation of the redesign [40]. The simulation software that was used is Simio LLC, Version: 9.147.14284 (32 bit). This chapter will answer the following sub-question;

- *How can the redesign be modelled in order to asses the the performance in terms of KPis?*

In the first section, the model is conceptualised, the scope, assumptions, the specific fixed parameters and the input and output data explained. Following this, Section 7.9 presents the verification and Section the validation of the model. After proceeding with the experimental plan , Section presents and provides the discussion of the model results. Next, in order to test assess the performance of the system in terms of KPIs with regard to the future scenarios. The models have to be simulated.

7.1. Conceptualisation

The first step in a simulation study is the generation of a conceptual model from the problem described in Chapter 6. The conceptual model forms the basis of the computerised simulation model. In the conceptualisation phase the system boundaries, the model properties, assumptions and simplifications are elaborated upon. The model boundaries are determined with respect to the scope of the research. It is essential to scope it precisely. Hence, the model model is only valuable if the system boundary is such that the processes can be evaluated using the defined KPI's.

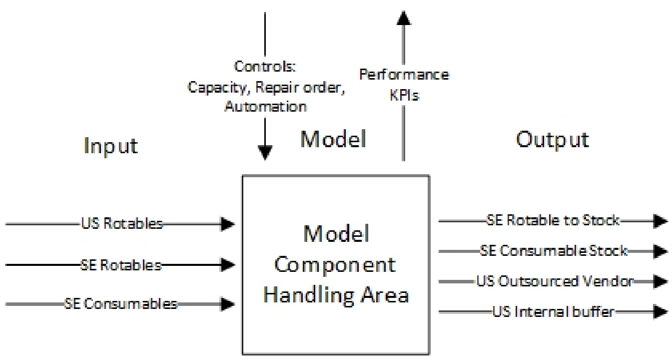

Figure 7.1: I/O model component handling area

7.1.1. Model scope

In line with the designs presented in Chapter 6, the model scope is limited to the the handling and logistics of aircraft components in the new handling facility of KLM E&M. All Aircraft related flows through this handling are taken into account. The flows include the revere logistic flow of US components from KLM CS and Boeing customers. Secondly the serviceable components received from vendors, stock transfers and newly acquired components. Thirdly, the flow of aircraft consumables are part of the scope. For each of these flows the identification, sorting, temporary storage and administrative processes are considered part of the handling activities and included in the model. For the reverse flow of the US components, the effect of generating the repair order in advance is taken into account as well as the component buffer for internal repairs. To gain an understanding of what input and output variables are present and which assumptions are in place. In order to do this a conceptual meta-model is used. this model serves as a representation or description of the model to be simulated. A meta-model is a simplification that highlights the properties of the simulation model, this meta-model defines the concepts, relations, rules and constraints. The most common methods and tools used for the meta model are BPMN flowcharts as they provide a good overview of the process flows and decisions.

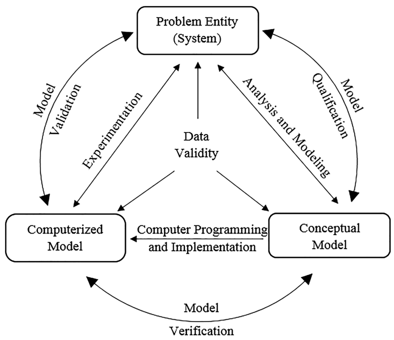

Figure 7.2: Modelling cycle Sargent [63]

7.2. Model outputs

The next step is to determine the the objectives for the model. In this research the objective is to assess the influence of the proposed process redesign on the performance of the handling and logistical operations. Furthermore the optimal configuration of handling capacity should be determined under different scenarios. The effect of optimising the logistics and handling operations can be related to the performance of the supply chain. The most important mechanisms in the MRO is the relation between TAT, inventory and resources. The model should therefore not only evaluate and optimise the performance, it should create a better understanding of the mechanisms that drive this performance. By knowing which strings to pull to achieve the desired performance and which cost (in terms of resources) are associated with this performance it enables managers to make better decisions. In addition it provides insight in the control levers to keep the processes under control. The key performance indicators measure how the system is performing. Several KPIs are calculated in the simulation model. The aim of the KPI can be related the three main aspects of MRO performance; WIP (inventory) throughput time TAT and capacity (resources). For measuring each of these aspects there are several KPIs in the simulation model.

To measure the part of the TAT a component spend in handling the 'handling time' of the component is measured. The handling time is related to the component and is calculated at the point of handover from customs to the point the component is either put in stock, shipped to a vendor or ready for a shop. this time includes processing time of the component and process waiting time. The amount of resources is determined by the number of employees per skill level. In the model the resource requirements per day are fixed 24/7 and work in two daily shifts. The fixed amount of workers per day can be varied in the experiments to determine the required resources to achieve a desired performance in terms of handling time. Inventory in handling is taken into account by evaluating the amount of work in process (WIP). The WIP is recorded for each flow of components and for the information processing. Hence, components can be waiting for physical handling (inspection of goods, adding labels for shipping) or components can be waiting for a repair order to be generated. For the information flow the request related to the component repair order creation is considered as inventory (WIP) to.

Concerning the TAT, the throughput time through handling or handling time is calculated. In addition the on time performance (OTP) is measured in the model. The OTP depends on the goal of the system. A problem with calculating the OTP is that is a fraction of the components handled. Therefore the components still in the system (inventory) are not taken into account. The fraction of components handled and the amount of components in the system should be used in combination with the OTP.

Manpower capacity used

The manpower capacity is one of the main controls in the model. the capacity is expressed in the number of workers of each skill level per shift [manpower] and can be incremented in the experiments.

Average and maximum Handling Time

The average handling time is the the mean of the time time all components spent in handling expressed in [days]. It is calculated by evaluating the time the component has entered the handling area until the time a component is handled. For serviceable and consumable components this is after handling by the IIG inspector. For US components the handling time stops when a component is shop ready, meaning it has been assigned a repair order and physically is located in the US buffer (note it does not matter if the component is handled through Part ID or via a logistic handler). The maximum handling time of all individual components handled in the component handling area [days].

$$Handling time = Time\ leave - Time\ entered \tag{7.1}$$

On time performance The On Time Performance is based on the benchmark of same day handling. Components are assigned a arrival-time time-stamp to a resource state of the entity. on leaving the system the date-time is evaluated against the departure time and in case the entity is considered late, the model state 'late components' is incremented by 1.

$$On\ time\ performance = \frac{components\ handled\ on\ time}{total\ number\ of\ components} \tag{7.2}$$

Resource utilisation

The utilisation of skills in the handling area is determined by the fraction of two resource states, time busy and time available. The available time includes the whole time a worker is on shift. The shifts are determined by work schedules in the model.

$$Ui = \frac{Time\ busy}{Time\ available} \tag{7.3}$$

The resources used can be varied in the model and the effect on the other KPIs can be related to the used resources. The resource related to the automated box and pallet handling system is considered as a given for all scenarios. The amount of manpower used is varied in the model taken the skill level into account. As a result the amount of workstations for boxed components and pallet size components should be able to accommodate the desired amount of manpower capacity in the process.

7.3. Conceptual Model & Process Logic

The conceptual model serves as a representation or description of the model to be simulated. It is a simplification that highlights the properties of the model. In Figure 7.3 the conceptual model with the routing of entities to the stations is indicated. Entities arrive in the assigned pattern and are split in pox,pallet,odd sized and direct transport (fuel related) flows based in a discrete distribution. On creation of a an entity a signal is sent to the repair administrator (RA) with the information about a repair order, when correct the RO is made and the component can be detected by the automated sorter upon arrival. If this is not the case entities are labelled as unidentified and routed to a part ID station where inspection of part and serial numbers takes place and the documents in the box are inspected to identify the part. If the part is a US component the documents are scanned and sent to the RA to make the repair order. the box is routed to the AS/RS where it waits for clearance to the internal shops or is routed to handlers for shipment to a vendor. For SE parts the same inspection takes place when the part is not identified, with the difference no repair order is needed.

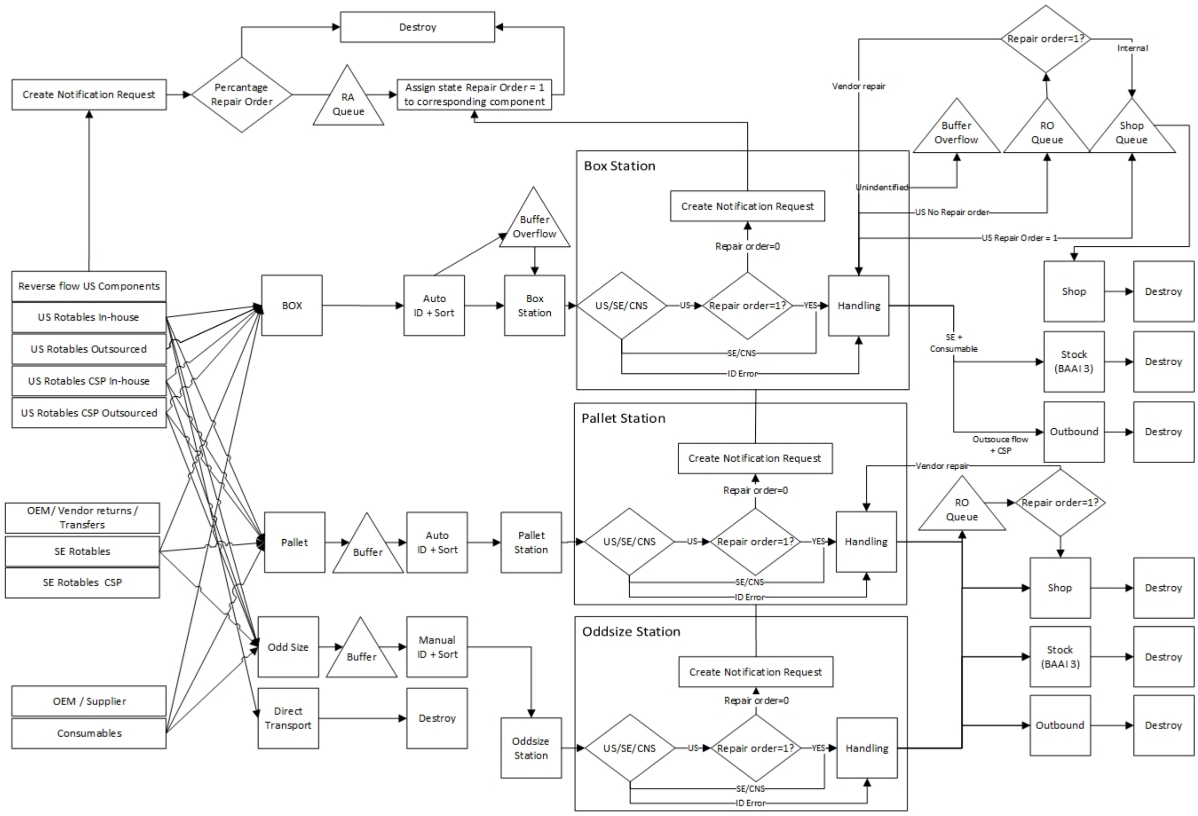

Figure 7.3: Conceptual model component handling area

7.3.1. Model inputs & Assumptions

The input of the simulation model can be divided into model constants (fixed parameters), and variable model parameters. The fixed parameters remain constant in the experiments and evaluation of the scenarios. The variables in the model are varied in the design scenarios. The values for both type of parameters are obtained from the measurement phase and are complimented by literature and the consulting of experts. Where accurate data did not exist assumptions where made as an estimate for the input values. These assumptions are described in the section as well.

Flow	Box [%]	Pallet [%]	Oddsize [%]	Direct [%]
SE Rotable	85	13	2	0
SE Rotable CSP	85	13	2	0
Consumable	85	13	2	0
US Rotable CSP External	85	13	2	0
US Rotable External	85	13	2	0
US Rotable Internal	47	8	20	25
US Rotable Internal CSP	85	13	2	0

Table 7.1: load class distribution

Based on measurements from KLM E&M in the current logistic centre the ratio between box, pallet and odd sized flows was determined by sampling component package sizes on multiple days during this research project. This due to unavailability of accurate data in the internal systems. The outcome from these measurements are presented as ratios per flow in Table 7.1. The internal repaired components show a different ratio from the other flows as these include rotable components from the airline KLM. Due to high transport cost of large components KLM E&M has in-house capabilities for these larger parts. In the MRO market, large components are often repaired at the HUB station of that airline, as is the case with KLM. A large share of in-house these components are categorised as biohazard and fuel related aircraft parts. These fall in the category of direct shipment to the shops as the do not follow the standard logistical and administrative procedure as they undergo cleaning first. The ratio presented in considered constant in all scenarios. Based on standard equipment and consult from the company DENC the speed of the AS/RS and conveyors was determined, the length of the paths was determined in scale with constructional drawings from Hangar 14.

The model uses four types of manpower resources for the handling of components based on skill levels. The inspector incoming goods for the rotable flow (IIG Rotable), an inspector incoming goods for the consumable flow (IIG Consumable), repair administrators (RA) and logistic handlers and a part ID skill. The values of these resources are varied in the model under different scenarios. Aside from the RA all others perform their tasks while present at a workstation.

The manpower is divided into two shifts of 6,5 hours per day in an 24/7 operation. The internal repair shops pull components from the central buffer on weekdays during an 8,5 hour shift. The pull behaviour of the repair shops for the box flow is assumed constant over a workday based on the average amount of expected boxed components per year. The pull for pallet and odd size parts is considered out of scope as these do not influence the buffer size within the handling area. Based on current state measurements the inter-arrival time between pull request is exponentially distributed.
The physical touch times of components are based on measurements form the current state situation for all the administrative and logistic handling operations. For the automated ID station an ID error of 5% was assumed on all flows for both pallet and box identification. The serviceable flow of components from vendors and consumables parts have unique identification numbers and are known in the internal systems up front therefore the assumption can be made the level of identification for these flows are relatively high. The identification error was assumed based on estimates form Schaeffer. For the identification of the reverse logistic flow of unserviceable components the data quality is not as good, as determined in the current state measurement phase. The model further assumes there are no breakdowns of failures in the handling system. A summary of all model inputs is presented in Appendix A.

7.4. Specification

In this section the model specification is presented. In the specification phase, the model concepts are translated into the simulation model. As discussed in Chapter 3 discrete event simulation was chosen as is was considered the best type of modelling for the purpose of evaluating the component flows and determining the required capacity in order to meet the desired service level. Essentially, a discrete-event simulation is model in which the state of a model changes only at a discrete, but possibly random, set of simulated time points, called event times. Simio LCC is chosen as a simulator for the DES methodology. Simio is an object-based modelling package which lets users model in both 2D as 3D. This visualisation allows for easy model verification, validation and understanding of the processes.

7.4.1. Building blocks of the SIMIO model

SIMIO uses object-based modelling, this means the simulation model consists of different objects. Each object represents a different part of the system. The simulation package provides several standard objects. This paragraph will explain per object what it does and what it represents.

Entity - Component The first object is the entity. Entities flow through the system and can change the system state variables. In the simulation model the entity represents different components. Each flow is represented by a different entity. The entities are created in a source object depending on their arrival pattern and leave the system trough a sink object. The entities are transported through the model using paths until they are destroyed in a sink object. This happens when components are stored in the serviceable storage location, shipped to a vendor or after internal repair. For serviceable flow of rotables and consumables the amount of rotables in stock is considered out of scope. The shipment to the external repair vendors is also out of scope, so US components leave the systems after handling when shipped to the vendor.
Source- Arrivals: The source generates entities of a specified type, at a specified moment. The creation of entities is determined by their inter-arrival time. The source can be seen as the arrival of components after the handover by the customs agent. For the generation of arrivals the distribution conform the real world observed arrival patterns are used.

Sink - Entity leaves system: A sink object may be used to destroy entities that have finished processing in the model. The sink is used to indicate the boundary of the model.
Server - workstations/sorter: A server is a capacity-constrained resource with optional input and output buffers. The server represent places where a form of processing takes place such as the workstations. Servers can seize resources when needed and are useful for simulation queuing effects.
Resource Resources can be seized and released during processes. In the model its main use is to constrain capacity track use of materials, cost etc. . Common examples of resources are workers, machines, nodes etc. In the simulation model the IIG inspectors, repair administrators and logistic handlers are modelled as resource objects.

7.5. Arrival patterns

As discussed by Hopp and Spearman [32] variation degrades the performance of production processes. By analysing the deliveries of components, insight is gained in the various peak-patterns. This analysis forms the basis for the demand which can in future scenarios. The stability of the arrival process is indicated in Figure 7.4. Data on the individual flow types was not available for the evaluation of the designs proposed in the case of KLM E&M. Therefore data from the logistic service provider was used. This data showed several inflow patterns which are translated into the model. First of all there is a significant difference between week and weekend days. Figure 7.4 shows year-flow of shipments delivered by Bolloré to the KLM E&M expedition in the logistic centre. The graph shows the variable demand in the component deliveries. In a weekend significantly less packages are delivered. However, analyses the peak demand pattern on weekdays show a similar pattern. To show this the variation in arrivals can be measured by fitting a distribution. Figure 7.5 and B.6 show the distribution of all shipments and weekly shipment only respectively. Both graphs did not significantly differ from a normal distribution after evaluating the kolmogorov-smirnov test and shapiro-wilk test for normality with a significance level of 0.05.

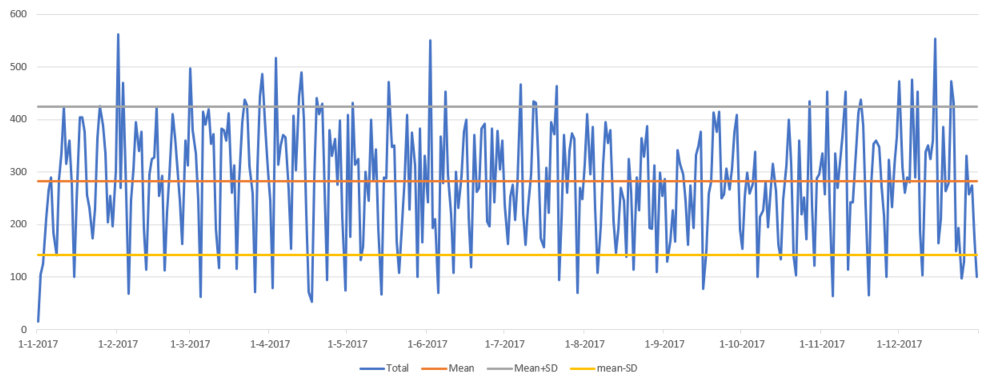

Figure 7.4: Year flow all shipments 2017

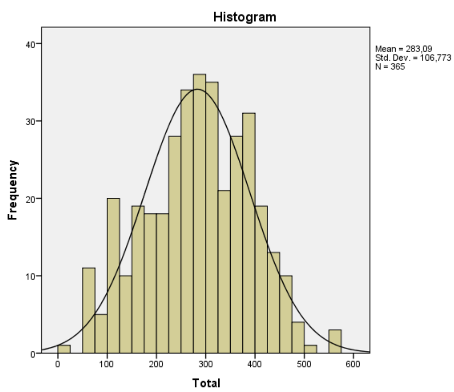

Figure 7.5: Distribution Year inflows

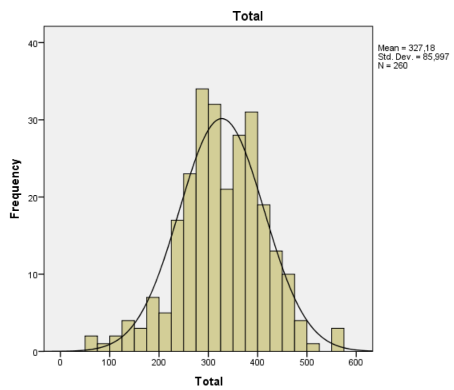

Figure 7.6: Distribution Weekday inflows

Next to this a variation of inflow per day. The distribution of the total inflow of components per day taken from data of 2017 follows a normal distribution with a standard deviation that equals a quart of the mean. Filtered for weekdays the amount of arrivals per day does not significantly differ from a normal distribution. For weekend days the arrivals did not test significant from the normal distribution, but for the ease of modelling the arrivals on weekdays is assumed to be normally distributed. Aside from this behaviour a notable difference was identified in distribution of arrivals over the day. it is assumed 80% of the components arrive between 7:00 and 12:00 and other 20% between 12:00 and 00:00.

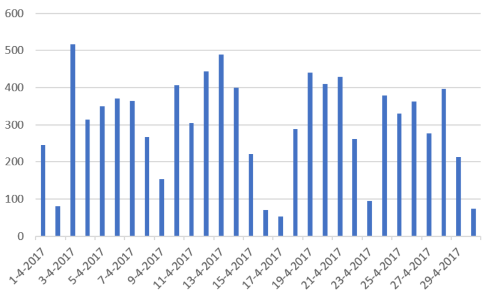

Figure 7.7: Month pattern all shipments

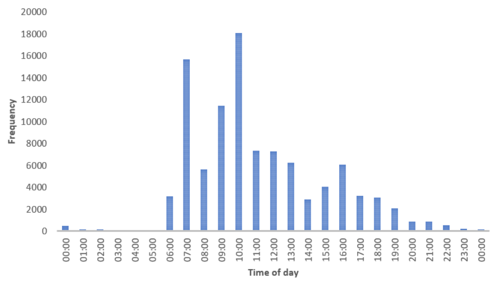

Figure 7.8: day pattern all shipments

In order to translate this behaviour to the simulation model, the model draws a random sample of a normal distribution at the start of each day which determines the amount the amount of components that will arrive that particular day. The mean and standard deviation of this normal distribution differs between week and weekend days. This amount is then distributed using two separate intervals. One between 7:00 and 12:00 in which 80% of components arrive, and the second between 12:00 and 00:00 for the other part. The exact arrival of a components is determined by the interarrival time which is calculated by using the arrivals for that interval.

7.6. Processing times

The processing times specified in the model differ per flow type and are presented in Table 7.2. The processing times are based on historic data and productivity targets in the current logistic centre as discussed in Chapter 4. The historic times are used as mean for a stationary Poisson process to model variance in handling activities. For processing the different flow of components the physical handling by the logistic handlers and part inspectors (IIG) is separated from the administrative handling by the repair administrators.

Flow	Skill	Box Physical [min]	Pallet Physical [min]	Oddsize Physical [min]	Administrative [min]
SE Rotable	IIG Rotable	19	19	29	0
SE Rotable CSP	IIG Rotable	19	19	29	0
Consumable	IIG Consumable	7	7	17	0
US Rotable CSP External	Handler + (RA)	5	5	15	49
US Rotable External	Handler + (RA)	5	5	15	19
US Rotable Internal	Handler + (RA)	5	5	15	10
US Rotable Internal CSP	Handler + (RA)	5	5	15	39
Unindentified	Part ID Skill	20	20	30	0

Table 7.2: Processing times

Aside from the different processing times different skill levels are required for the handling of the different flows. These skills can be divided in a logistic handler, Inspector incoming goods (IIG) for consumable and rotable parts and a part ID handler. The last skill is required when a package is not recognised by the automated sorter. When this is the case the component packaging has to be opened and its paperwork inspected to determine the contents and destination.

7.7. Pull behaviour repair shops

The pull behaviour of the individual shops can be quantified by looking at the distribution of ERP notifications over the day. The pull behaviour of the shops is of influence on the size of the AS/RS buffer and the number of crane movements over the day. Figure 7.9 and 7.10 show the amount of shop in notifications over the year 2017 obtained from SAP. Shops work during weekday is shifts from 7:00 to 17:00, during these period components enter the repair shops. The inter-arrival time between shops is plotted in Figure 7.10. As can be observed the inter-arrival time follows an exponential distribution. This distribution is therefore used to model the shops pull behaviour.

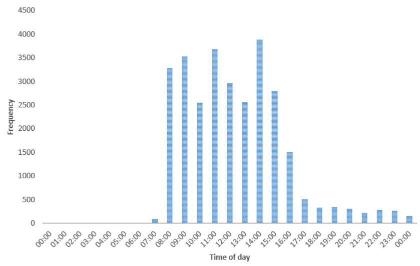

Figure 7.9: Pull behaviour shops

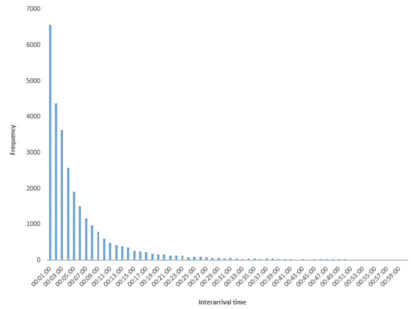

Figure 7.10: Interarrival time Distribution

7.8. Process logic

Besides the standard objects SIMIO provides the opportunity to program custom logic. This is done by modelling add-on processes. Add-on process logic is can be used to customise the model completely. It can be used for evaluating decisions, define routines, determine state changes, search lists, fire events and more.

Creating components and request As stated earlier components are generated according to the arrival pattern obtained from arrival data at the handover from customs. At the same time components are created a notification request for the generation of a repair order is created as a member object of that particular component. In that way the model state of the request can be coupled to the state of that component. The repair order request must however be sent to the repair administrator before the components arrive. To model this all components are delayed 2 days with respect to the request, so a component arrives two days after the RA has been notified. On creation the components are separated based on the ratio; box, pallet, odd size and direct transport.

Sorting For the box and pallet flow an automated sorter is modelled as a server. The server sorts the components based on their type and value for repair order (1 if Repair Order has been made in advance 0 if not). Next the sorter checks if there is a workstation available, and if the skill associated with the specific component is available at that station. By evaluating a list of all workstation for these conditions the component is routed to the workstation. If no workstation fits the condition the component is put on the conveyor for temporary storage until the desired station and skill becomes available.

Storage Boxed components can be stored in the AS/RS. Storage is needed for components that are waiting for an repair order, overflow of components, and components that have a repair order but are waiting for the pull signal from the internal repair shops. In addition the option is added to model the effect of storing the component packaging in the AS/RS, which might be needed as there is little space in hangar 14 for storage of these boxes. The model logic of the model processes as described are presented in Figure 7.11.

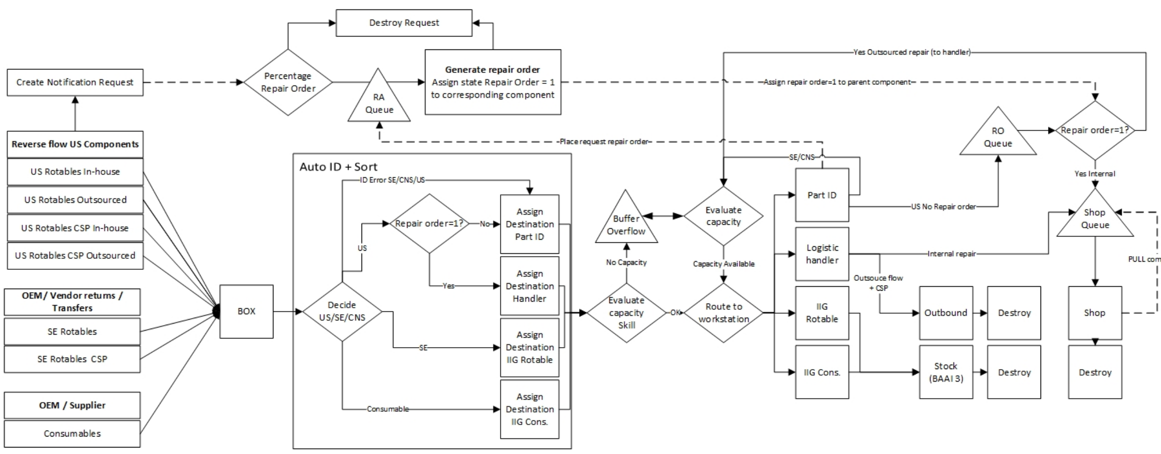

Figure 7.11: Model logic box flow

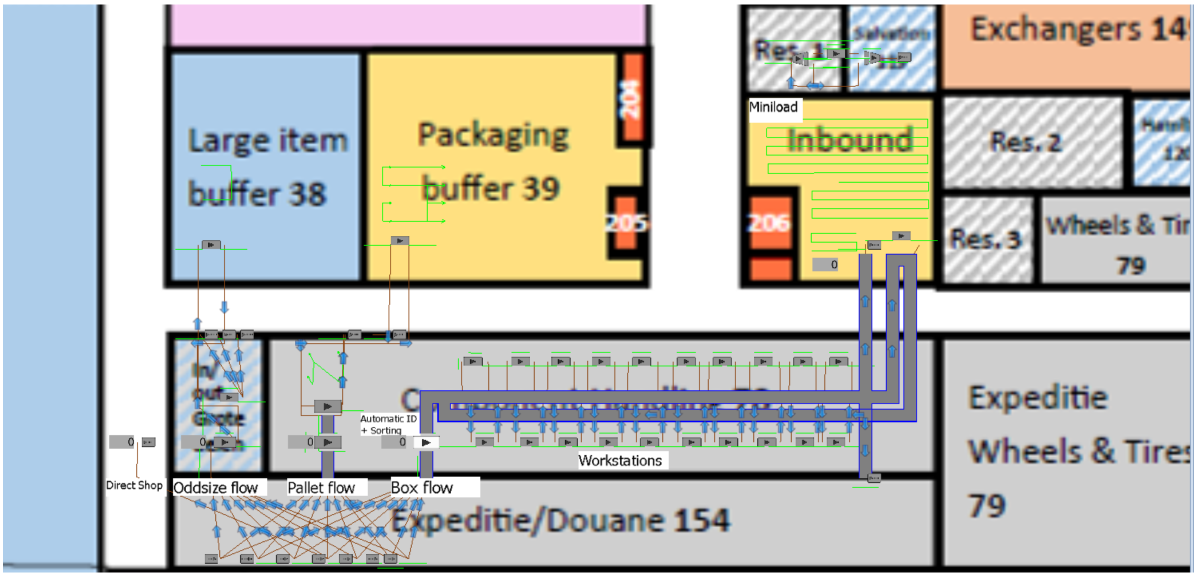

Figure 7.12: Schematic layout of the simulation model

7.9. Verification - is the model right?

In the verification, it is necessary to check whether the conceptual model is translated into the specified model correctly, or in other words does the model what it should do? As mentioned earlier, verification is performed in the modelling cycle in conjunction with the specification and validation of the model, as indicated in Figure 7.2. There are two main parts to a verification process. The first is to perform verification checks with the model. Here the functioning of the model is tested against the requirements. This can be done While building the model and verifying the step-wise implementation of the different mechanisms and processes in the model. Next, once the model is completed, verification runs can be performed.e

7.9.1. Model checks

Several model checks have been performed with the model, these include a model trace, run time visualisation and input checks. The result of these checks are presented in this section.

Model trace In order to support the model verification, the 'model trace' in Simio is used. This function allows one to see what happens in the model, step by step. The behaviour of different specific entities (components) can then be followed in the model (traced) to determine whether the model logic is correct and whether the required accuracy is obtained. This verification technology verified that the structure of the model is in accordance with the structure of the conceptual model. Using the model trace several entities of each flow have been traced, all entities of the different flows follow the right path towards the stations and get the right processing time appointed.

Run time visualisation Using status plots and counters the behaviour of the model is inspected during a run. The visual graphics of the model further enhances the understanding of the behaviour of the model. By plotting the arrivals of components per day the arrival patterns used where verified. in addition, counters on the percentage of size of the components and level value for repair order show the model is capable of calculating the behaviour from the conceptual model.

Input checks By analysing on the arrival rate components and the associated repair order request per US component type, it can be verified that the model creates the expected number of components. In addition, all workstations where checked in order to assure the correct processing times and resource requirements matches the component type.

7.9.2. Verification runs

Beside the model checks the model can be verified using verification runs. There are three types of verification test described by Sargent [63]; continuity, degeneracy and consistency tests.

Continuity test In the continuity tests the , the results of the model runs are tested with slightly different parameters. The key here is to investigate sudden changes in output. The effect of adding station capacity when the available skill are not modelled as a constraint is indicated in Figure 7.13. As expected the utilisation decreases with the incremental adding of stations. the effect on the on time performance is indicated in Figure 7.14.

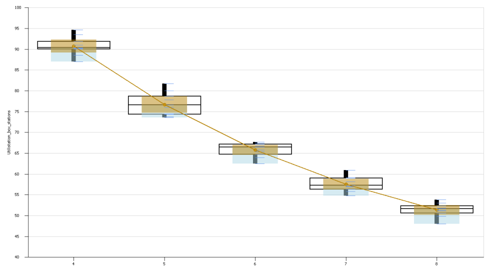

Figure 7.13: Effect on utilisation of stations when adding stations

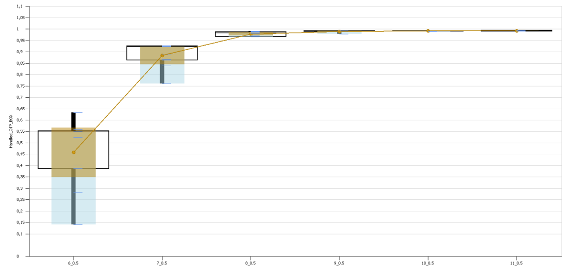

Figure 7.14: Effect on OTP of stations when adding stations

Degeneracy test In a degeneracy, or extreme conditions test the response of the model to extreme cases is verified. The test are performed by changing several variables to zero or infinity. For this test the year total of entities was set to zero and to 10 times the yearly average. For the maximum value immediate queuing of entities was visible conform expectations. When setting the yearly arrival to zero no components where generated by the model.

Consistency tests Consistency tests are used to check that a model produces similar results for input parameter values that have similar effects. For example, two sources with a rate of of 100 components per day per should each should cause approximately the same mount of components as four sources with arrival rate of 50 components per day each. This behaviour was checked and verified for the sources an servers in the model. In addition the total input in the model is compared to the expected yearly inflow in the base scenario.Results are indicated in Table 7.3. Based on the performed checks and verification runs it can be concluded that the model is translated to the computerised model correctly. In other word the model does what it should do given the model conceptualisation.

Flow	Expected	Model	Difference	Delta
SE Rotable	25000	25125	125	0,50%
SE Rotable CSP	15000	14950	-50	-0,33%
Consumable	34700	34860	160	0,46%
US Rotable CSP External	8700	8954	254	2,92%
US Rotable External	16000	15742	-258	-1,61%
US Rotable Internal	26300	26275	-25	-0,10%
US Rotable Internal CSP	8700	8968	268	3,08%

Table 7.3: Validation model input

7.10. Validation - is it the right model?

Now the model is verified the next step is to check whether the model can represent the real world situation accurately enough. Only when this is the case the model can be used for supporting real world decisions. Perfect validation of the model is impossible because the only perfect model is the real system itself. The goal of the validation therefore is to demonstrate that the model is valid enough for project purposes. There are several techniques to show this is the case. One common validation technique is to compare the results of the simulation model against the performance of the real system. As the results of the simulation model are compared to the real word, this is called results validation [63]. The challenge of this type of validation is to get accurate data about the performance of the real world system. As the proposed design tested in the simulation does not exist yet only the input parameters, and model logic can be analysed to validate the model. Data on inputs was available and can be compared with the model, the rest of the model is validated by using experts.Sargent [63] describes various validation techniques and tests used in model validation. For the expert analysis, the Face Validation and Animation techniques are used.

Expert validation As stated the model can is validated by using the experience of the experts. Experts in the field of handling of components know the system well and are able to watch an animation and provide some measure of confidence. If the results and global structure of the model are consistent with how they perceive the system should operate, then the simulation model is considered to have face validity. In Face Validity individuals knowledgeable about the system are asked whether the model and its behaviour are in line with the real world perception. The correctness of the logic in the conceptual model together with the model's input-output relationships are tested. For this purpose face validation has been performed with several MRO experts from KLM E&M. The validity was checked using three steps, check the input parameters and distributions, next check the model logic and assumptions, and finally examine the experimental results. By performing these steps it was concluded that, taking the model assumptions into account the model is good enough in order be used to evaluate different scenarios under different growth scenario's and levels of information. To illustrate Figure 7.15 show the demand pattern of components as a result of the modelling and Figure 7.16 the WIP inventory in handling and the effect on the OTP.

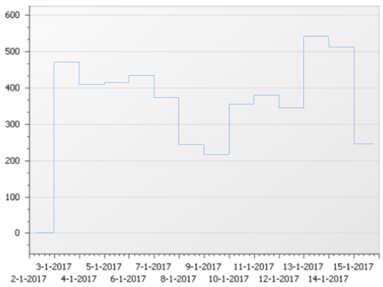

Figure 7.15: Inflow of components simulation model

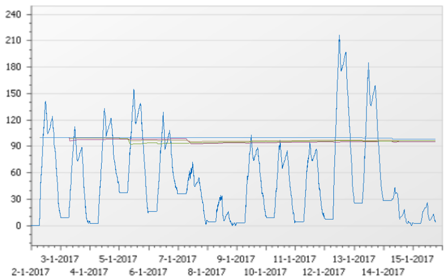

Figure 7.16: WIP in handling and OTP

7.11. Conclusion model design

Now the model is verified and validated different scenarios can be run with the model. The first optimisation in the model is the optimisation of the capacity terms of manpower per day and automation requirements based on historical data considering the highly variable demand. In addition, analysis of multiple scenarios provides insights in the effect of capacity on performance, and vice versa. For the optimisation of capacity of the manpower resources are increased by 1 after each iteration of the simulation scenario. Until the service level (OTP) is sufficient. For this purpose the Optquest optimiser in Simio is used to increment the scenario runs. The optimisation is split in optimising the manpower capacity for the serviceable and consumable flow, which requires component inspectors, and optimisation for US component flow. For the consumable and serviceable parts the 2017 year flow and the 10 year growth scenario is evaluated. As the process of the SE and consumable flow is not part of administrative process redesign only the effect of the physical infrastructure an manpower capacity is determined. The US reverse flow is part of the redesign and for these flows several scenarios are evaluated. A 'current state' scenario in which no information is sent in advance, and two scenarios in which 50% and 80% of the information is known in advance. For each scenario the current and 10 year growth scenario is evaluated. The results are presented in Chapter 8.4

Part V: Evaluate

8 Simulation results

In this chapter, the results of the model are analysed running experiments with the model. The goal of this chapter is to evaluate the performance and design parameters of the proposed handling system. The results are discussed scenario using the key performance indicators. In order to do this, first, an experimental design needs to be set up. In order to do this, the warm-up period and the number of replications need to be determined. The following sub research question will be answered;

- *What is the potential of redesigned logistics handling on the performance of the reversed logistic chain of aircraft components?*
- *How can the system be configured in order to perform optimally in terms of KPI's during peak demand patterns?*
- *How does growth affect the performance of the logistic and handling activities of components?*

8.1. Set-up of model experiments

Now the model has been developed, verified for its correctness and its adequacy is validated, the next step is to experiment with the model. In order to test and assess the performance of the redesign in terms of defined KPIs, an experimental plan needs to be determined. For this purpose, the warm-up period, run length and the number of replications needs to be defined. The first step in the process of setting up the model is the determination of the model type. Simulations model can be distinguished in two types; terminating or non-terminating systems. In a terminating system, the simulation ends when a critical event occurs. In other words, a system is considered to be terminating if the events driving the system naturally cease at some point in time. In a non-terminating system, no such critical event occurs and the system continues indefinitely. A non-terminating simulation does not mean that the simulation never ends, nor does it mean that the system being simulated has no eventual termination. It only means that the simulation could theoretically go on indefinitely without a significant change in behaviour. This state in which the performance is no longer influenced by the initial state of the system is called the steady state of the system. The state of the model before the steady state is reached is called the transient state. The case the component handling of KLM E&M can be considered a non-terminating system, as there is no natural event to stop the system. The fist step in terminating systems is to determine a suitable warm-up period and length of time to run the model.

8.1.1. Warm-up period & Run length

For non-terminating simulations a steady state has to be determined in order to interpret the results. Determining the starting conditions to acquire the steady state can be a difficult task. Therefore many non-terminating systems start as empty, idle systems. In this condition there are typically is no steady state condition. Therefore, the model needs to be ran until the system reaches this steady state before data can be gathered. This waiting time is the model warm-up period. During the warm-up period, also known as the transient state, the distribution of the output is constantly changing, and therefore unrealistic. In this research the handling operation should not take more one day, components that are waiting for repair orders or need to be stored due to a lack of capacity are done so in the AS/RS. As the AS/RS is empty at the start of the simulation the transient state can be determined by evaluating the amount to components in the AS/RS. According to Verbraeck & Valentin (2006), the required warm-up period can be acquired graphically by looking at the point where a KPI value or graph becomes periodically stable for the rest of the run. The operation cycle of component handling case as determined in the measure phase shows a pattern over the day and has a pattern over a week. According to [67] the ground rule for determining run length is that a simulation needs to be run at least 3 times the longest cycle time. For this purpose the cycle time can be determined as one week, so the model is ran for three weeks.

8.2. Number replications

There are two options in order to assure enough accurate output data is generated by the simulation model. By either a long single run of the model, or by performing multiple replications. According to Robinson [56]; "A replication is a run in a simulation model that uses specified streams of random numbers, which in turn cause a specific sequence of random events". The number of replications make sure the specified randomness and distributions in the arrival patterns and handling processes will not individually affect the simulation results significantly. By using the set of random numbers for each run the model is able to create unique statistical results. As a consequence the runs are independent of each other and can be seen as an equivalent to taking multiple samples in statistics. By testing different replication numbers, the outcome of the model runs can be compared. If the difference is significant, it means that the similarity between runs is not guaranteed. The number of replications should ensure that the half-width or margin of error of the KPIs is below 5. This applies evidently for a level of confidence of 95%. According to Robinson [56] "A confidence interval is a statistical means for showing how accurately the mean average of a value is being estimated" . If the level of confidence were to change, the associated significance factor would change respectively. Law et al. [40] states a general rule of thumb that an experiment should at least have three to five replications. The required replications can however be more accurately determined by taking the wanted confidence interval (CI) into account. "A confidence interval is a statistical means for showing how accurately the mean average of a value is being estimated" [56]. The narrower the interval, the more accurate the estimate is. In general, the higher the number of sample data, the narrower the result. If there is more than one KPI, as is the case in this simulation study study, the number of replications is determined on the basis of the response that requires most replications. In practice the number of replications is determined from an analysis of the base model alone and than applied to all the experiments. It is preferable to overestimate the number of replications opposed to underestimating to provide a margin of safety. The confidence interval method described in [56] is used to determine whether the number of replications performed is sufficient. In this method a confidence interval CL around a mean output statistic is defined as:

$$Cl = \overline{X} \pm h \tag{8.1}$$

In which $\overline{X}$ equals the mean output result and the half-width h is expressed by:

$$h = t_{n-1,\alpha/2} \frac{S}{\sqrt{n}} \tag{8.2}$$

where $t_{n-1,\alpha/2}$ is the value from the Student t-distribution with n-1 degrees of freedom and significance level of $\alpha/2$. And the standard deviation S is expressed by:

$$S = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{X})^2}{n-1}} \tag{8.3}$$

A significance level alpha of 5% is proposed, as this gives a 95% probability that the value of the true mean (obtained if the model is run for an infinite period), lies within the confidence interval. In line with the calculation the required number of runs can be derived iretatively using the method proposed by [67]. A summary is provided of the above described model characteristics is presented in Table 8.1.

Model Characteristics	Value
Length of Simulation	35 [days]
Warm-up Period	7 [days]
Number of Replications	10

Table 8.1: Run setup

8.3. Scenarios

In this section the scenarios of the model are discussed. For these scenarios the choice for the specific characteristics of the automated infrastructure is considered as a given.The scenarios which need evaluating using the simulation model will therefore focus on the parameters for the proposed design as indicated in Section 6.7. The scenarios for which these parameters will be tested come forth from the design of the information flow of the components and different future growth scenarios and the ability to automatically recognise components. Together the scenarios from an the base of the experimental plan evaluated with the simulation model elaborated in Chapter 7.

8.3.1. Growth

The physical infrastructure must be able to handle components in the year the to come. For this purpose growth scenarios for each flow have to be evaluated. The base for the growth scenario was developed in collaboration with the management board of KLM E&M. KLM E&M has the largest share in component availability market for the Boeing 737 and 787 components. The amount of these aircraft is expected to grow for the coming ten years based on sales-orders from Boeing. This growth results in larger flows in SE and US components. In order to accommodate for this growth a 10 year scenario has been developed and is indicated in Table 8.2

Flow	Growth in 10 years	Current	10 years
SE Components (rotables + hangars)	110%	25000	52500
SE Rotable CSP	110%	15000	31500
Consumable	70%	34700	58990
US Rotable CSP External	150%	8700	21750
US Rotable External	60%	16000	25600
US Rotable Internal	60%	26300	42080
US Rotable Internal CSP	150%	8700	21750

Table 8.2: Volumes and growth

8.3.2. Proactive repair order creation

The level in which repair orders can be generated in advance is has an influence on the physical flow of components. Hence if customers do not send the required information digitally in advance, the repair order cannot be created in time. This will result the sorter will not be able to link an incoming component to a component already registered and thus will not be recognised. As it cannot be expected all customers of KLM E&M will provide the components with the return labels and information knowing the influence of the repair order in advance on the performance of the handling is of interest. The impact of receiving all required information in advance therefore is therefore varied in the experiments.

Current state - no proactive repair order creation

In this scenario the current state is translated to the automated handling area in H14. In this scenario no repair orders are made in advance. This means the component can not be identified by the automated sorter and is sent to a part ID station. Here information on the component is retrieved form the box, the part is identified, checked on part and serial number and the documents scanned and sent to the repair administrator (Similar to the situation in the current logistic centre). The component and box is stored in the AS/RS and waits for the repair administrator to finish and once the administration is the the component can either be sent back to the logistic handler to add shipping labels or be added to the central shop buffer by receiving a shop ready status. The the effect on the handling time, and in process inventory is determined for component flows in 2017 and for the growth scenario. For this scenario there is a dependency between The amount of employees with knowledge on the information system that can do part ID and the number of repair administrators for the administrative tasks.The performance of the handling of components depends on the amount of resources, the number of resources is optimised using Simio and evaluated for different configurations.

US flow redesign - proactive repair order creation

When all information on the component is sent in advance repair orders can be created while the component is in transport. On arrival the component is recognised, routed to a handler (when the resource is available) and either shipped to a vendor or stored in the shop buffer for internal repair. As the repair orders are being created while on transport the repair order generations does not longer directly influence the TAT of the component. This scenario was evaluated for a 50% and 80% repair order in advance creation. Results of the simulation is resented in Section 8.4 for both current an future demand scenarios.

8.4. Modelling results

To analyse the results of the experiments the Simio Measure of Risk & Error (SMORE) plot is used. A SMORE plot displays both the estimated expected value of a scenario and multiple levels of variability behind the expected value. The plot displays results across replications, for each scenario. A SMORE plot consists of a Mean, Confidence Interval for the Mean, Upper Percentile Value, Confidence Interval for the Upper Percentile Value, Lower Percentile Value, Confidence Interval for the Lower Percentile Value, Median, Maximum Value, and Minimum Value. In Figure 8.1 an example of a SMORE plot is presented.

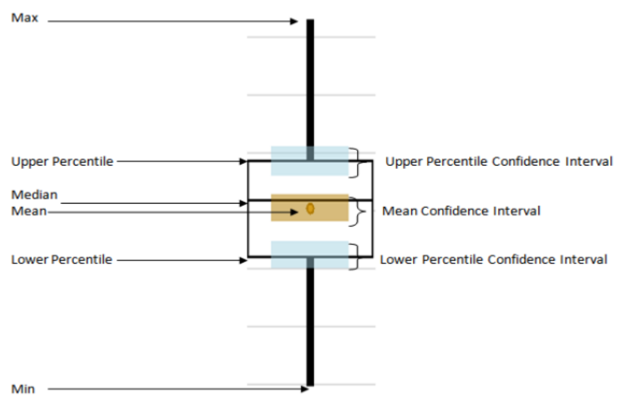

Figure 8.1: Smore plot in Simio [40]

The results of the simulation runs for workstation capacity of the design is are presented following sections. The main KPI is the throughput time and related on time performance of the component handling given a number of manned stations and proactive repair order creation.

8.5. Serviceable rotables & consumable flow optimisation

For the consumable and serviceable flow no information is needed in advance to handle the components, so only the capacity of manpower at workstations and process time are of influence on the throughput time, OTP and inventory in handling. For the optimisation of the serviceable and consumable flow two scenarios are ran; the current amount of components and the scenario of ten years of growth. For both scenarios the handling time, capacity in terms of workstation capacity for each skill and average inventory is indicated. For the handling time of serviceable components the same reasoning as for unservicable components is applicable. Every day spent in handling is results in a longer TAT and thus means more US parts are in the supply chain and more stock has to be in place to satisfy the customer demand. Therefore, the handling time of SE components should be as short as possible. In Figure 8.2 and 8.3 the average throughput through handling is shown for a number of manned box stations. At the box stations IIG inspectors are stationed 24/7 in and scheduled into two 6,5 productive hour shifts per day (In practice shifts are generally 8,5 hours, but include brakes). By incrementally adding stations in the optimisation in Simio (using OptQuest) for each scenario the effect on the throughput time becomes visible. To illustrate the SMORE plots including the confidence interval are presented in Figure 8.2 and 8.3. Note that the goal of the model is not to make a workforce scheduling, it does however show how many manpower capacity should be attributed to the workstations to acquire the throughput time indicated.

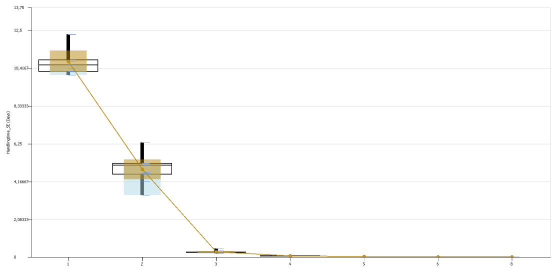

Figure 8.2: Handling time average [days] Box stations SE current flows

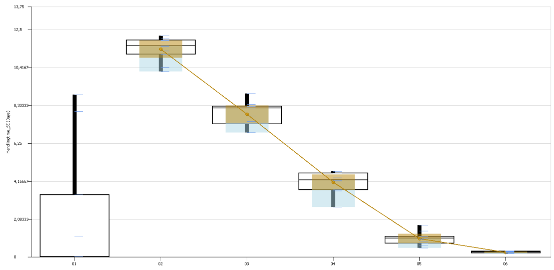

Figure 8.3: Handling time average [days] 10 years growth

For the servicable component flow the goal of the system is set to handle serviceable and consumable components the same day of the arrival day. As a reference, the on time performance can therefore be calculated evaluating this benchmark. For the calculation it was stated components that arrive any given day before 21:00 should be delivered the same day, 5% of components are considered to be trouble shoot parts which first go to a part ID station for identification. A summary of the effect on the on Time performance, inventory in handling and utilisation's of the IIG inspectors at the box workstations in the combines AS/RS-workstation system is presented in Figures 8.4 ,8.5, 8.6 and 8.7. The results on the individual runs with confidence interval are presented in Appendix..

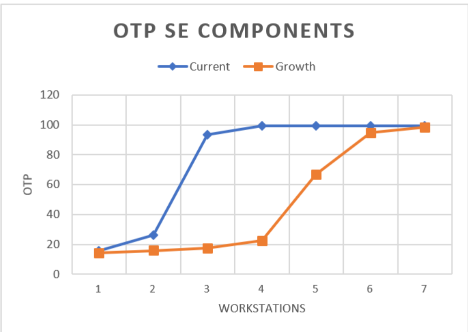

Figure 8.4: OTP SE flow 2017 demand

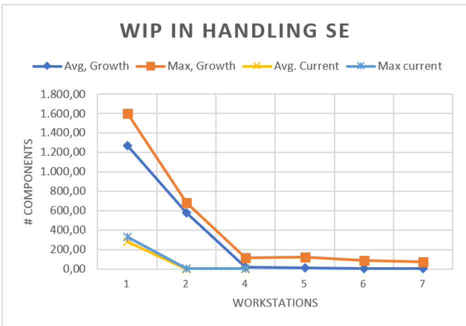

Figure 8.5: OTP future demand

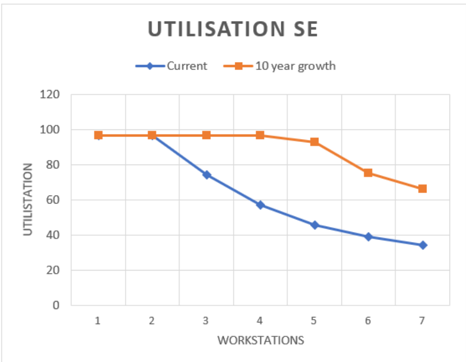

Figure 8.6: OTP SE flow 2017 demand

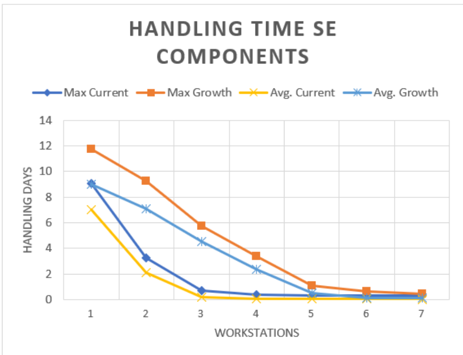

Figure 8.7: OTP future demand

The same modelling optimisation is done for the consumable flow. Resulting in the OTP, handling times and utilisation rates indicated in Figures 8.8, 8.9, 8.10 and 8.11.

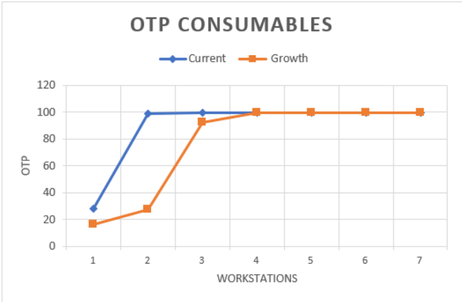

Figure 8.8: OTP consumable flow 2017 demand

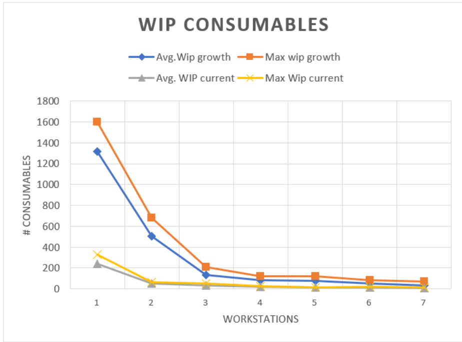

Figure 8.9: WIP consumable future demand

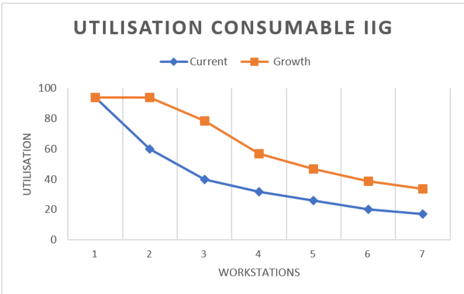

Figure 8.10: Utilisation consumable flow 2017 demand

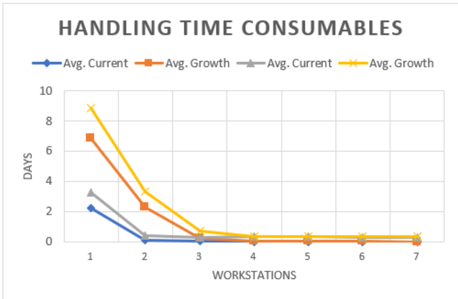

Figure 8.11: Handling time consumable future demand

8.6. US flow optimisation

For the optimisation of the handling equipment for the US flow of components through handling, three scenarios are evaluated using the current amount of flows and a growth amount in 10 years. The scenarios are evaluated for respectively 0% 50% and 80% percentage proactive repair order creation. The total results of the simulation optimisation and the resource requirements to achieve the goal of 95% SL performance considering same day handling for components that arrive before 21:00 the resources required are indicated in Table 8.3. Due to the lower amount of pallet and odd-size arrivals one dedicated station for each of the skills is sufficient for the timely handling of components, resulting in 4 pallet stations for each of the scenarios.

The utilisation rates of the workstations used in the optimisation scenarios is around 60%-80% in these scenarios. Installing capacity less than the amount calculated for the arrival pattern will result in backlogs of components waiting for handling and waiting for repair orders to be generated. One way to enhance the utilisation of the workstation capacity is the use of flexible stations. The results of the optimisation is presented in Table 8.4.The total number of flexible stations is equal to the number of required stations for boxes and pallets. Compared to the simulation with dedicated stations, an indication of the equipment to handle the same demand patterns is presented.

SL 95 dedicated box stations	Current 0% RO	Current 50% RO	Current 80% RO	Future 0% RO	Future 50% RO	Future 80% RO
IIG consumable	2	2	2	3	3	3
IIG Rotable	3	3	3	6	6	6
Part ID	5	2	1	9	4	2
Handler	1	1	1	2	2	2
Total Box Stations	11	8	7	20	15	13

Table 8.3: result optimising workstations

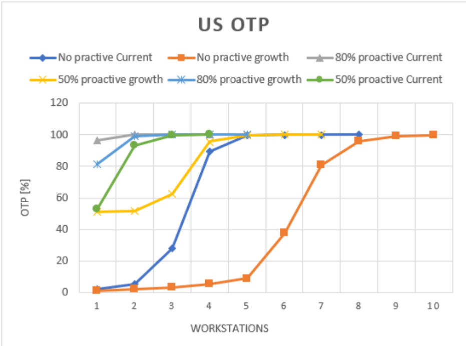

Figure 8.12: OTP of Part ID with varying demand and proactive repair order creation

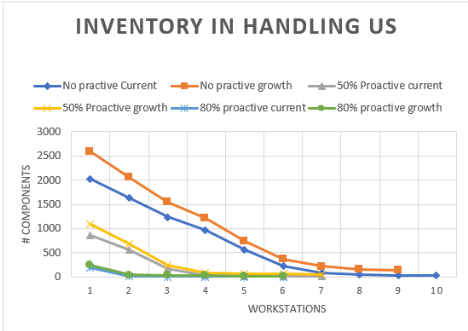

Figure 8.13: WIP inventory in handling US flow with varying demand and proactive repair order creation

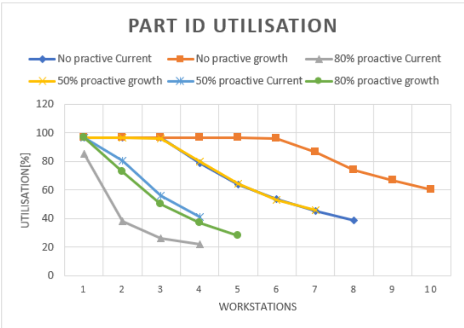

Figure 8.14: Utilisation of Part ID with varying demand and proactive repair order creation vs. capacity

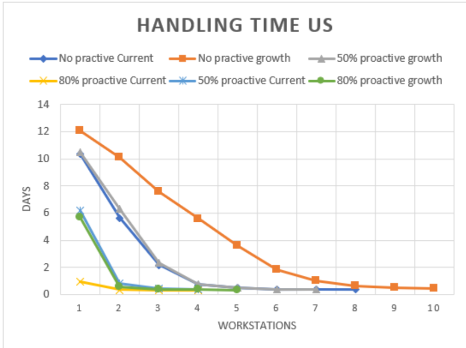

Figure 8.15: Time in handling US with varying demand and proactive repair order creation vs. amount of required part ID station

		Current 0% RO	Current 50% RO	Current 80% RO	Growth 0% RO	Growth 50% RO	Growth 80% RO
Dedicated stations	Box	11	8	7	20	15	13
	Pallet	4	4	4	4	4	4
	Odd	4	4	4	4	4	4
Flexibe stations	Box	10	8	6	19	14	11
	Pallet	2	2	1	4	3	2
	Odd	1	1	1	1	1	1
Total Skils	IIG SE	2	2	2	4	4	4
	IIG Consumable	4	4	4	7	7	7
	Part ID	5	3	2	10	5	3
	Handler	1	1	1	2	2	2
	RA	6	6	6	12	12	12

Table 8.4: Summary optimisation stations and skill resource capacity

8.7. AS/RS capacity

Besides the number of workers and required automated stations, the AS/RS is an essential part of the redesign as it eliminates the waste for searching an unnecessary moving components. As the system has to be build the required space needs to be know under the different scenarios. In order to calculate the required storage space in the AS/RS the components waiting for a repair order as well as components waiting to enter the internal shops needs to be calculated. For the evaluation of the storage space the optimal configuration of the box station is assumed and the shop capacity is assumed to be able to handle the growth scenario. The shops do however pull a stable amount of components per day based on historic data. The fluctuation of the inflow of components is therefore buffered in the AS/RS. The possibility of outsourcing components based on shop capacity and inflow is considered out of scope. The requirements for the AS/RS are indicated in Table 8.5.

AS/RS	Max movements [1/h]	Max positions [numer]
Current	82	830
Growth	93	1652

Table 8.5: AS/RS storage locations and crane requirements

8.8. Conclusions modelling study

From the modelling study several configurations are determined to cope with the highly variable arrival pattern of the aircraft components. Through evaluation of several parameters on utilisation, WIP inventory and time spend in handling, incriminating the amount of resources, insight is gained in the relation between the arrival uncertainty of components and the amount of resources required and the relation to TAT and WIP. scenarios where evaluated under the redesign strategy of generating repair orders in advance. When considering fixed workstations, stations are utilised around 60% -80% of the time. The utilisation of the stations can be increased by installing flexible stations for inspection of serviceable goods and disposition of unsearchable and identification of parts. In order to handle the demand of the coming years it is advised to acquire data form customers in advance to make repair orders. It the current operation is translated to the new situation in Hangar 14 the AS/RS system requires a minimum of 20 box stations and 4 pallet stations to handle the demand fluctuation conform the goal to handle components the same day. Furthermore the manpower requirements for the automated handling stations can be derived form the modelling study. Considering the same flow of components an indication was given on the amount of amount of skills (fte) required in two 6,5 hour (24/7) productive shifts are required given the repair orders are made after the component arrives (as is done in the current situation). As repair orders are generated in advance less positions are needed to obtain the same service level due to the reduced need of opening box is to acquire the attached documents. Less stations required when stations are flexible and can be used by multiple skills throughout the day. By increasing the level of proactive repair orders the resource requirements shifts from part ID skills to the logistic handler skill, as this skill is less knowledge intensive it is less expensive to buffer capacity in manpower requirements. By using the proposed configuration of skills the total handling time of all components in scope can be reduced to same day handling.

9

Conclusions & Recommendations

This chapter presents the conclusions and recommendations of this research. First, the answers to the research questions are given in Section 9.1. Next, the research objectives are elaborated. In Section 9.2 the contribution to literature is discussed, Section 9.3 elaborates the contribution to practice. Subsequently, the limitations to the research are discussed. Lastly recommendations and suggestions for further research are presented in section 9.5 Based on the results discussed in the previous chapters there are several conclusions to be drawn for all phases of the research project.

9.1. Conclusion

This research aimed on improving the performance of an aircraft MRO company providing component availability contracts to airline customers. The scope of the research was limited to the handling and reverse logistical processes within aircraft component supply chain. The research set out with with goal to redesign the current physical as well as the non-physical (administrative) processes in order to improve the overall supply chain performance. The main research questions was formulated;

How can the reverse logistic processes of a component MRO provider be redesigned in order to improve the performance from a integral supply chain perspective?

through the literature review presented in this research several conclusions can be drawn for companies providing component availability contracts for aircraft spare parts. First of all the majority of the academical research has been aimed at to novel availability models [65]. These studies have in common they are aimed at finding the right amount of stock given demand and a 'pipeline' time components are unavailable for stock, ignoring variation and queuing in the process performance. Although implementation of lean manufacturing in the MRO industry is still in its infancy, several studies have have been devoted to the production and use of process improvement theories within the production [70], [71], [41]. However a neglected part of the component MRO business is the reverse flow of and handling of components. The logistics and handling operations concerning the MRO field are unique due to the heavy regulatory obligations concerning the spare parts. Academical research that studies the the impact of new process designs of the (reverse) logistics flows and handling of components on the performance of a MRO provider in the component availability sector are scarce. For this purpose the MRO industry must look to broader research on reverse supply chains and the general (re)manufacturing industry. Literature describes several ways in which the (re)manufacturing industry is unique, including the requirement for a reverse logistics network, a need to balance returns with demands and highly variable, uncertain arrivals. No studies where found that are specifically aimed at redesigning and optimising the reverse logistic channel within the aviation MRO industry. Although some studies identify the need. Especially research aimed at understanding the impact of the variability in aircraft component turnaround times, and quantifying the value of having flex capacity to act as a 'shock absorber' in the system would be valuable to the commercial (and military) MRO sectors.
To answer the main research question the research followed a structured approach based on the lean six sigma methodology of define, measure improve and control. Instead of incremental improving the system this study took a business process redesign approach resulting in a redesign and evaluation phase (DMADE).

through conducting a theory analysis the best methodologies to guide the business process redesign using the DMADE structure where identified. Several process improvement theories and research methodologies where explored including; Lean Six sigma manufacturing, the theory of constraints, transaction cost theory, business process redesign and theories on operations and production management. In order to improve the processes with in the MRO process improvement theories can help with different aspects of the supply chain. In addition business process mapping methodologies and process modelling methods for evaluation where discussed. Based on the literature a business process redesign is desired in combination with the lean Six Sigma methodology. Although the goal and approach for bringing about change are different in these theories they do not exclude one another. Lean Six Sigma promotes incremental improvement on a continuous basis, BPR promotes fundamental rethinking and radical redesign. The define, measure and analyse phase of lean six sigma can be used in order to find the opportunities for a more radical redesign. To support the DMADE methodology a combination of improvement theories therefore is used to address the main research question. The review found that a number of methodologies tend to be more useful in relation to some phases than others. Therefore, a combination of different methodologies for a better result is proposed. The measurement phase is supported by a quantifying a combination of reverse logistic activities. Lean six sigma, business process mapping and transaction cost theory is used to analyse the target processes from the measurement phase. To support the methodology in the measure and analysis phase a combination of value stream mapping and swimlane maps is suggested. The classical VSM is useful for the identification of physical waste whereas cross function charts can complement the VSM on the information flow between departments and the associated (IT) transactions. In this research the VSM-I was put into practice by analysing an Boeing 737 component case study at KLM E&M. The value of the VSM-I here was the identification of the physical and non physical transactions. In addition to the mapping transactions cost theory should be included when analysing MRO supply chain. Transaction cost play an important role in aircraft component MRO. As one of the key characteristics of the The MRO industry is that it is subject to regulations and certifications of processes, assets and components due to government laws for safety of the customers making use of airlines [15]. In literature this is referred to as asset specificity. Transaction cot theory states high levels of asset specificity lead to higher transaction cost. The total cost of the component MRO supply chain which is subject to high levels of asset specificity should be taken into account then measuring and analysing its performance. Besides the above named theories variability is and important characteristic with a large impact on the supply chain and its performance. Especially in MRO where the demand (or supply of US components) is highly volatile. Theory on the effect of process variability should therefore always be included in MRO research.

As the research promotes a business process redesign methodology the design phase is more radical than incremental improvements gain from six sigma methodology. Testing the potential of more radical changes in a safe computer environment therefore is desired. Literature showed various analytic and statistical modelling approaches have been widely utilised in maintenance research. Queuing theory has been employed as an analytic instrument for various of these applications in production. Queuing models assume that the arrival and service times have particular distributions [56]. When modelling complex systems with queuing logic, it is however difficult to capture and represent complexity using analytic queuing theory, for such situation simulation is a more appropriate tool. Generally, simulation is recommended when problems are impossible or expensive to be solved by actual experimentation or when problems are highly complex to be treated analytically. In view of the fact that simulation considers the stochastic characteristics of a system, it can reproduce system behaviour with greater realism. Three main simulation techniques were discussed for the purpose of this study. Discrete event simulation (DES), system Dynamics (SD) and Agent-Based Simulation (ABS). Discrete event simulation (DES) and system dynamics (SD) are two modelling approaches widely used as decision support tools in logistics and supply chain management. According to Palma-Mendoza and Neailey [49] SD is mostly used to model problems at a strategic level, whereas DES is used at an operational/tactical level. For the purpose of this study a discrete-event simulation model Law et al. [40] is preferred for the evaluation different designs under different scenarios. Discrete event simulation modelling can be used to analyse the operational performance of a redesign of the handling area and is able to locate the bottlenecks, as it does offer the possibility to include stochastic variances over time and to run replications to perform sensitivity analysis and experiments under different circumstances. In the highly volatile MRO industry DES is therefore preferred over the other techniques.

The theories described where used to measure the performance of the reverse logistic processes of KLM E&M in a case study. Due to the large amount of (IT) systems used in the supply chain, no complete picture was readily available for analysis and was acquired through coupling of data for the individual systems. It can be concluded that the KLM E&M CS supply chain is performing substandard. The total reverse flow TAT of US components is 36 days for an in-house repair of a component, with a standard deviation of 26 days. By analysing each individual part of the supply chain according to the elements described by theory on reversed supply chains, it was concluded most of the waiting time occurs in the handling process of components. This includes the identification, inspection, sorting disposition and redistribution of the components.

Case study research using the described methodology showed waiting time is the largest contributor to the long lead times in the reverse supply chain. By analysing the root causes using a 4M analysis, identification of lean six sigma's TIMWOOD wastes on the physical flow and on the information flow several causes where identified. First of all, it was noted the demand pattern of components is highly erratic. Due to the erratic demand buffering occurs due to a imbalance of manpower related to the input. Furthermore, mapping analysis showed that there are many handovers and transactions necessary in the process that are subject to errors due to the manual entering of part and serial number. Also the repair order is made after the component has arrived, so the administration process is constraining the logistical flow. In addition, absence of component information causes rework for the customer interface department, requiring more transactions adding to the process time. Other types of waste where identified of the physical process. Handlers have difficulty matching the right components with the paperwork resulting in searching for the component in racks and extra handling time.

Following from the analyse phase the redesign of the reverse logistic supply chain of aircraft components consist of a redesign of the physical and the non-physical flow of components. The redesign was based on the identified need for automation in the physical handling to eliminate the need for manual identification, searching for components and unnecessary movements. For the physical redesign automation of the logistic handling of components can be done by separating between component size. For this purpose an automated AS/RS-workstation system is introduced. From the theory analysis followed that buffering of either (WIP) inventory, TAT or resource capacity is inevitable in highly volatile demand environments. Within the MRO industry capacity can be buffered in the repair shops, however this is expensive due to knowledge intensive tasks and certified labour. Buffering capacity in the reverse channel, and especially in handling is a more viable business model. When components can be pulled by shops can pulled based on there criticality less stock might be required. The key here is to get components 'shop ready' as fast as possible. In addition, non-physical administrative tasks concerned with aircraft components can be redesigned by proactive generation of repair orders before the component arrives at the logistics handling area, Furthermore, the process of repair order generation could be automated while on transport or shortly after the component arrives. The final question answered was how the new redesign handling area should be configured while subject to changes in the administrative process.

In order To answer this question a simulation model was constructed based on the proposed redesign scenarios. The performance of the handling and logistics was evaluated by running experiments with the model under different configurations optimising the required skill levels given a level of information flow known in advance to generate repair orders. In order to improve the supply chain performance resource capacity should be buffered. The optimisation of the amount of the be buffered capacity was evaluated using the goal of KLM E&M to handle components the same day. In addition the amount of resources required for lower service levels was illustrated using graphs obtained from the optimisation, offering the choice for different service level configurations.

9.2. Contribution to academic literature

This research contributes to academic literature in several ways. First of all the majority of the academical research has been aimed at to novel availability models [65]. These studies have in common they are aimed at finding the right amount of stock given demand and a 'pipeline' time components are unavailable for stock, ignoring variation and queuing in the process performance. Although implementation of lean manufacturing in the MRO industry is still in its infancy, several studies have have been devoted to the production and use of process improvement theories within the production [70], [71], [41]. A neglected part of the component MRO business is the reverse flow of components. This research contributes to academics by underlining the importance of being aware of the reverse logistic channel in the MRO organisation. By providing a structured approach and framework MRO organisation can use, days in the CLSC can be reduced. Until now, there was no academical research (to the best of the researchers knowledge) that studies the the impact of new process designs of the (reverse) logistics flows and handling of components on the performance of a MRO provider in the component availability sector. In addition, the most recent development in supply chain optimisation is the use of simulation based optimisation. Simulation based optimisation allows for detailed, and more complex representation of the supply chain. Studies on how to improve the performance of the MRO operations and redesign the logistical processes using simulation was lacking in MRO literature. This research furthermore aimed to create an understanding of the impact of the variability in aircraft component turnaround times, and quantifying the value of having flex capacity to act as a shock absorber. Furthermore, the addition of IT transactions into the classical VSM, can be considered to be of academical value. As studies in operations management, and especially theories around Six Sigma and Lean manufacturing tend to focus only on physical process flows. Studies in this field are focused to benefit to practice as well as academics, since the beginning of value engineering an description of processes at Toyota, academics and companies in the practical field have learned from each-other. This study builds on these shoulders of years of research by filling the gap in reverse logistics in the MRO industry using simulation.

9.3. Contribution to practice

As this research was a joint project with KLM E&M the research has a practical value for KLM E&M next to the contribution to science. Since the component services department is moving the operations form the logistic centre an the repair shops in building 425 to hangar 14 in the CS2.0 project, an opportunity rose to evaluate the potential for automating the handling of components. By analysing the complete reverse logistic chain on KLM E&M and coupling of data by the researcher an overview of the complete supply chain was acquired which was previously unknown. Especially the quantification of the TAT days lost between receiving components from the freight forwarder until a component is handled and ready for shop is of practical value to KLM E&M. The unavailability of measurements in the current KPI portals CBBSS and Spotfire make this process very difficult to manage. By using mapping sessions and incrementally improving on the model using various stakeholders form different departments of KLM E&M provided this understanding. In addition the sizing of the automated equipment required under different circumstances is considered of practical value. In addition the visualisation of the design model proved useful for showing the management and board of directors of KLM E&M the potential of the redesign and trade-off between TAT, inventory and used resources.

9.4. Limitations

Several limitation of the research can be identified. Firstly, the effect of disrupted flow is only party taken into account in the relationship between available repair administrator capacity and performance. As there where no measurements whether components where put on hold by the customer interface or by the repair administrators in the current logistic centre, no accurate quantitative data could be included in the model. In practice this does not have a effect on the workstation layout in the handling area, but it does so for the size of the AS/RS as disrupted flow is stored in that system. Additionally the on time performance is therefore higher than it would be in practice. For that reason it is advised to further analyse the effect of disrupted flow on the service level, and thus on the TAT and inventory levels. When looking at the link to the supply chain, it is limited to TAT reduction, this can be related to stocked inventory an thus monetary capital. It is advised to provide a more complex relationship between TAT and required stock. This particular problem as been part of research for many decades, but continues to the the holy grail in MRO organisations.

9.5. Recommendations & further research

In this section recommendations following from this research are presented. The recommendations are divided in academic and practical recommendations.

9.5.1. Scientific Recommendations

The logistic service level optimisation in the presence of highly variable inflow is analysed by evaluating the required capacity. This means the use of a prioritisation system is not necessary, since there will be sufficient flexibility in the process to handle almost all inflow scenarios. For the handling operations considered in this study only first in first out prioritisation was assumed. In practice components can be assigned different levels of priority based on the status of the stock levels. Further research could elaborate on differences between priorities of components. As this study uses only one case in the MRO industry it is advised to perform more studies on the effect of information distortion in the reverse supply chain of industries subject to high asset specificity. Further research should also focus on acquiring better customer data through loyalty or rewarding programs. Furthermore, developments around the vision of the Industry 4.0 in combination with the information flow within the MRO supply chain would be beneficial to the academic community. As innovations in the MRO processes historically have been moving in a slow pace, this might still just be a bridge to far although it can be considered of huge potential for the industry. Innovations around the industry 4.0 where all information is readily available for multiple users in the supply chain can have positive disruptive effects on the way to do business and need further investigating.

9.5.2. Recommendations for KLM E&M

Firstly, it is recommended to measure the performance of the reversed supply chain based on real time data. By actively monitoring the performance the process becomes easier to control. Several new KPIs should be introduced in the measurement of the service level performance of the logistics area. First of all the amount of components waiting for a repair order should be tracked. In addition the number of components on hold, components waiting to be dispatched and waiting to be received should be traced. In the current situation very little is tracked which makes the process difficult to manage. In addition it is recommended to implement the proposed design and start with the implementation process the process to build the automated handling area based on the results for the simulation model presented in this study. Another main recommendations is to start buffering in handling in terms of manpower capacity buffers. If not doing so, the WIP in handling and TAT days spent in handling will rise and will cause the overall supply chain performance to degrade. Investing in these buffers and in automated equipment is in this case a better idea than to invest in valuable components that are somewhere stuck in the reserved supply chain. Besides it is recommended to standardise the data input for the customers in a way components cannot be sent without the correct data or at least by knowing which data is missing while the component is on transport, so customers can be contacted for information when the lead time of the component is not yet critical. In addition, the impact of standardisation of contracts and the service provides should be researched. Currently sales departments in the MRO industry tend to make highly customised contracts for the provided service, this results in complex operations due to many IT systems required leading to higher transaction cost.

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A

Appendix A

A.1. input parameters

Input parameters used in the simulation model indicated in Figure A.1.

Input parameter	Distribution type	value [unit]
# US rotables internal repair arrivals/year	fixed value, varied in exp.	Table 8.2 [components/year]
# US rotables external vendor arrivals/year	fixed value, varied in exp.	Table 8.2 [components/year]
# US rotables internal CSP repair arrivals/year	fixed value, varied in exp.	Table 8.2 [components/year]
# US rotables internal CSP repair arrivals/year	fixed value, varied in exp.	Table 8.2[components/year]
# SE consumable arrivals/year	fixed value, varied in exp.	Table 8.2 [components/year]
# SE consumable CSP arrivals/year	fixed value, varied in exp.	Table 8.2 [components/year]
# SE consumable arrivals/year	fixed value, varied in exp.	Table 8.2 [components/year]
Box, Pallet, Oddsize ratio	Discrete distribution	Table 7.2 [%]
Mean arrivals week day	Normal distribution	mean:arrivals/weekday sigma:0.5*mean [components]
Mean arrivals weekend day	Normal distribution	mean:arrivals/weekend sigma:0.5*mean [comonents]
Interarrival time components before 12:00	Exponential distribution	mean: 1/arrivals per day [1/h]
Interarrival time components after 12:00	Exponential distribution	mean: 1/arrivals per day [1/h]
Shop request pulls per day box	Fixed value	(Components in box per year/weekdays per year) [components]
Time between pull requests box	Exponential distribution	mean: (1/ shop request pull per minute)) [minutes]
Processing time internal shop	Real input parameter	Input parameter distribution [minutes]
Repair administrator processing time Intern	Exponential	mean: 10 [minutes]
Repair administrator processing time Extern	Exponential	mean: 20 [minutes]
Repair administrator processing time CSP Intern	Exponential	mean: 40 [minutes]
Repair administrator processing time CSP Extern	Exponential	mean: 50 [minutes]
Trouble shoot time	Exponential	mean: 20 [minutes]
IIG processingtime consumable	Exponential	mean: 19 [minutes]
IIG processingtime rotable + rotable CSP	Exponential	mean: 7 [minutes]
Logistic handler time	Exponential	mean: 5 [minutes]
Time window shop pull	Fixed shifts	5 weekdays, 1 shift/day, 8,5 [h]
Work schedule Handling	Fixed shifts	24/7, 2 shifts/day, 6,5 [h]
Conveyor speed	Fixed shifts	5 [m/s]
AS/RS speed	Fixed shifts	10 [s]

Table A.1: Model inputs simulation model

A.2. Methodology framework

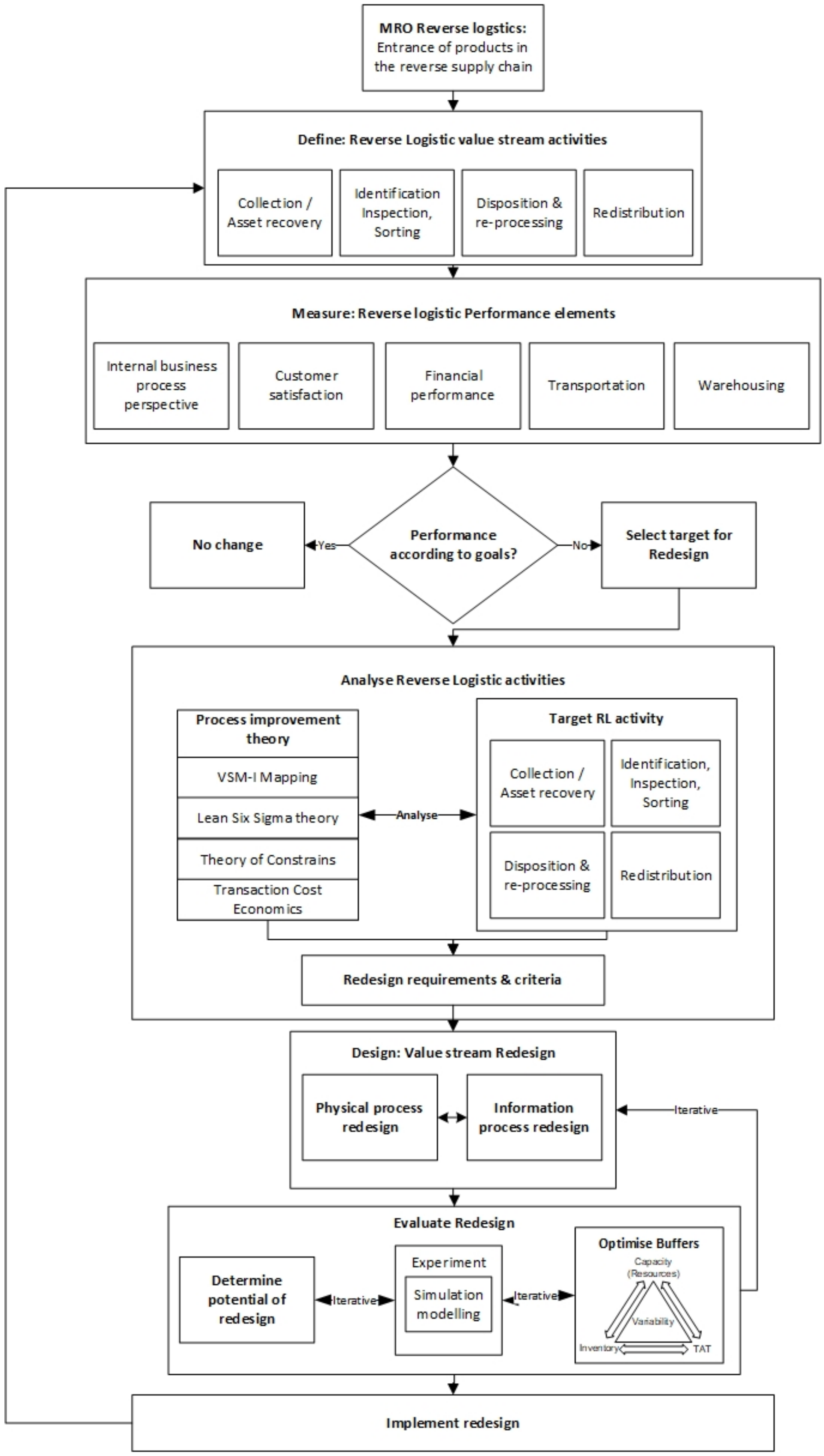

Figure A.1: Framework for reverse logistics in MRO

A.3. VSM-I charts

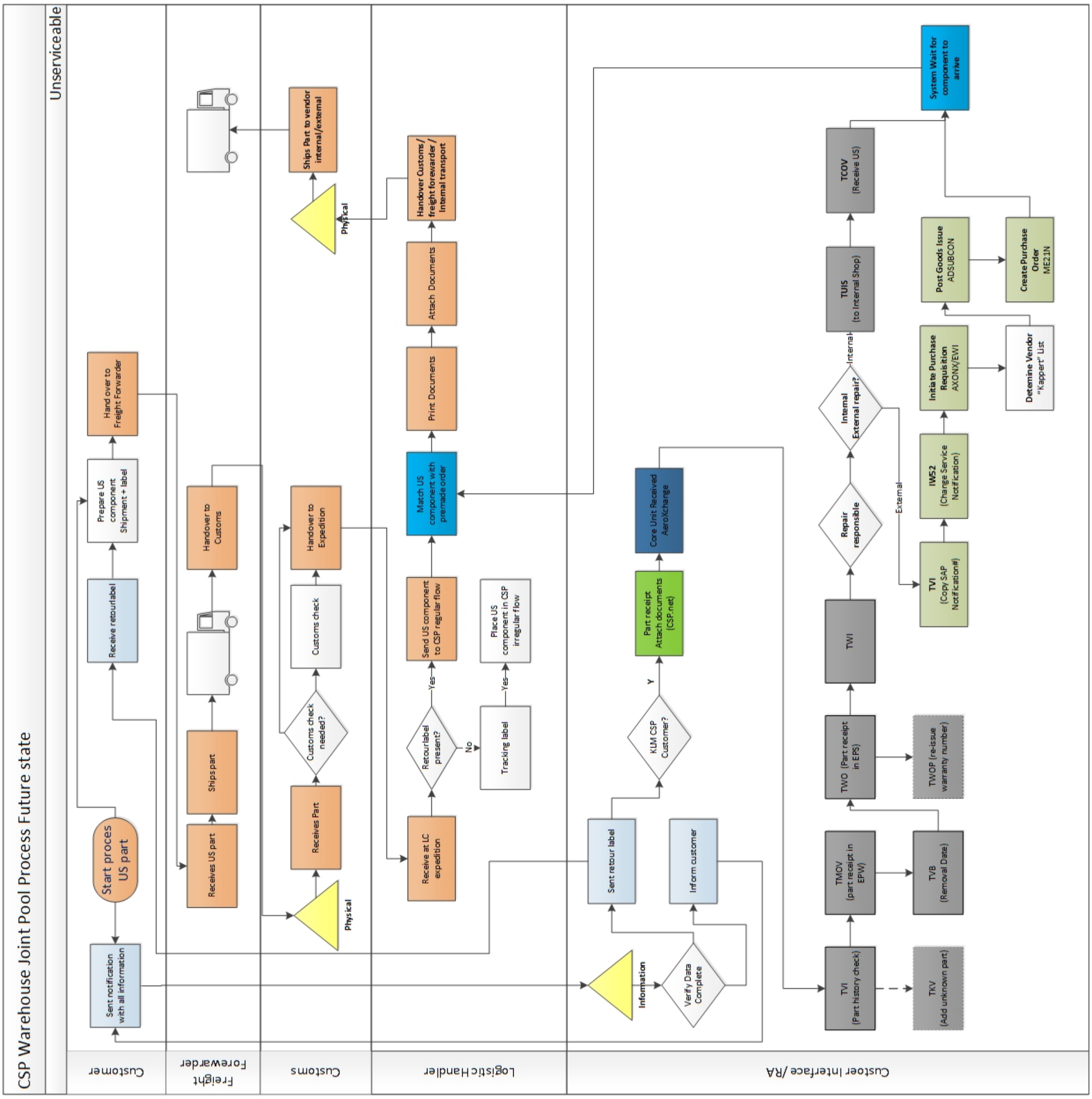

Figure A.2: Current State CSP VSM-I flow with detailed IT transactions

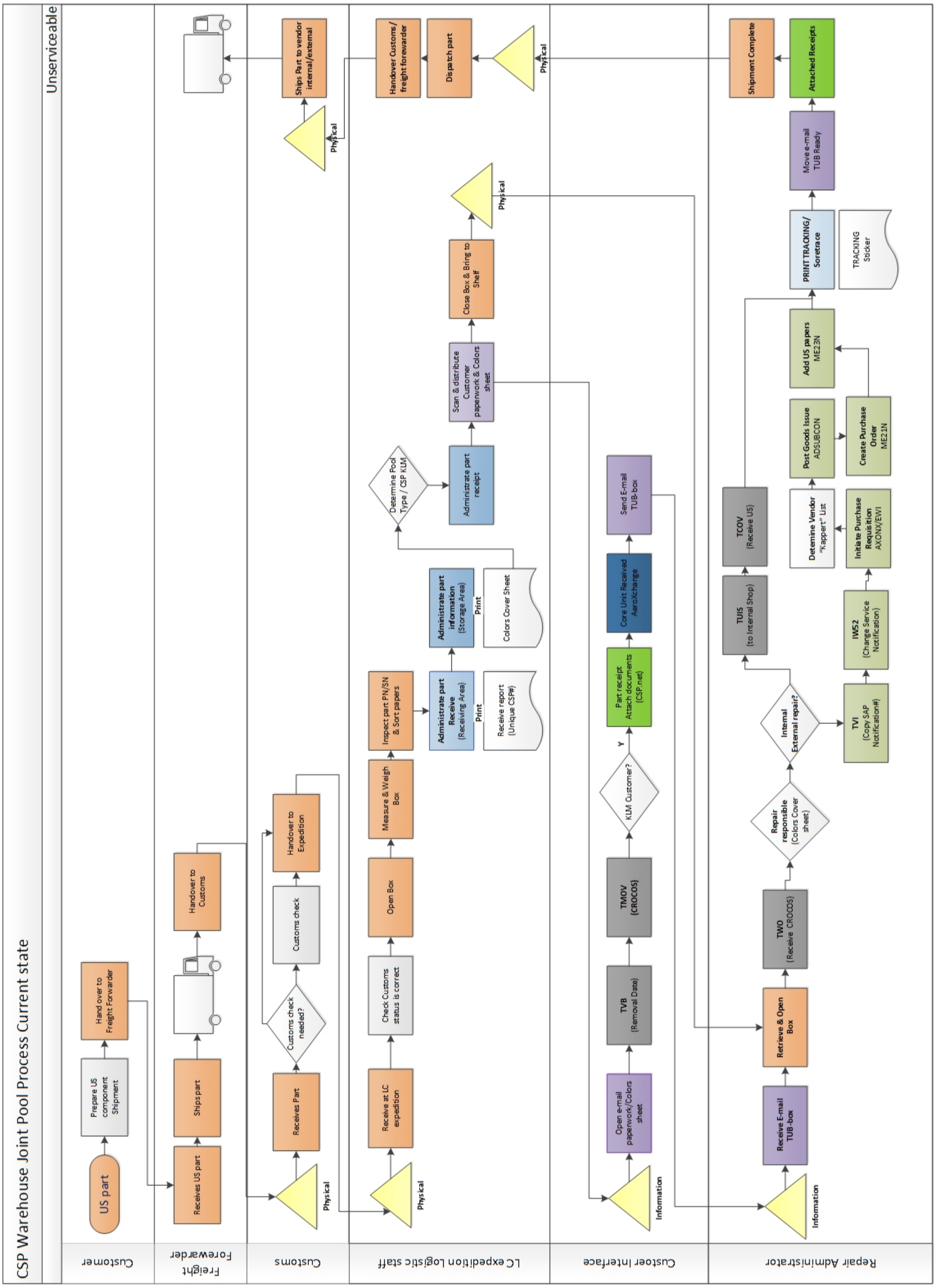

Figure A.3: Current State CSP VSM-I flow with detailed IT transactions

B

Appendix B

Optimisation graphs simulation model

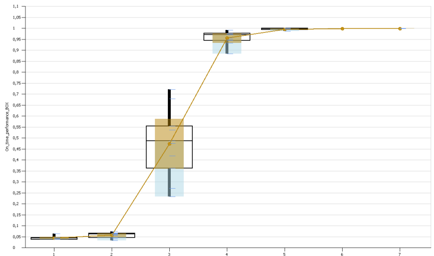

Figure B.1: current Box stations 80% proactive repair order

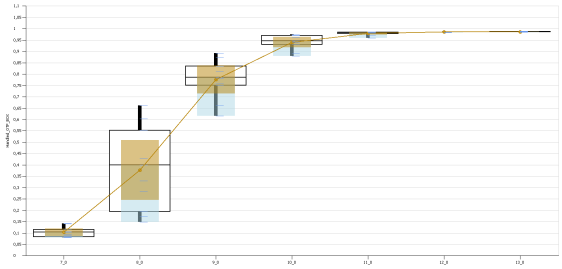

Figure B.2: Growth Box stations 80% proactive repair order

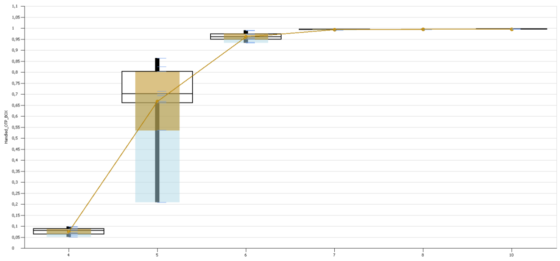

Figure B.3: Box stations current state 50% proactive repair order

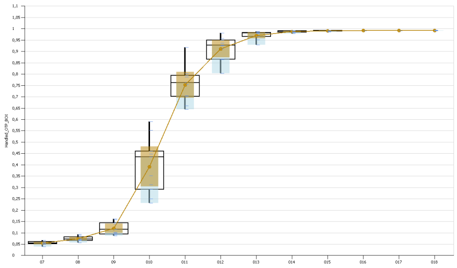

Figure B.4: Box stations growth scenario 50% proactive repair order

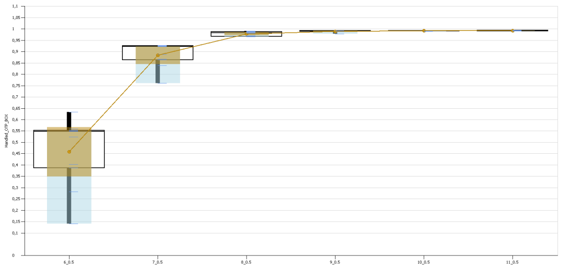

Figure B.5: Box stations current state 0% proactive repair order

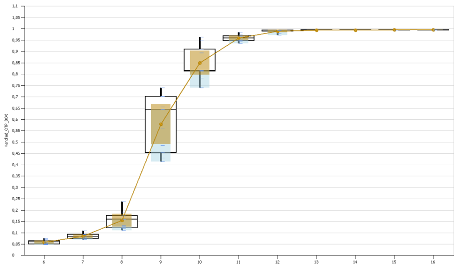

Figure B.6: Growth scenario Box stations 0% proactive repair order

C

Research paper

Modelling business process redesign strategies for improved reverse logistics: A case study in an aircraft component MRO supply chain

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Abstract

Within aircraft component MRO industry, companies providing availability contracts are challenged by inherently unpredictable demand patterns and complex time crucial operations. Most prevailing academic literature within the MRO industry has focused on availability models or operations management in repair shops in the past. This study focuses on one of the most critical, and often neglected parts of the MRO supply chain. The reverse logistic flow of aircraft components. A research methodology was constructed by integrating the adapted DMADE (Define, Measure, Analyse, Design, Evaluate) structure from Lean Six Sigma and a number of different business process improvement methodologies from the literature in combination with a simulation study. The aim of the study is to identify a methodology with practical design criteria on how to redesign the reverse logistical processes of a component MRO provider in order to improve the performance from an integral supply chain perspective. For this purpose a case study is performed and the current state of the closed loop supply chain of KLM E&M was measured and analysed. By analysing this current state, design criteria for redesign are determined. A new automated logistic handling area is introduced by separating the physical and administrative handling operations. The proposed redesign is evaluated using discrete event simulation. Through optimisation modelling the optimal balance between inventory, resources and time required to handle the volatile demand pattern to achieve a desired service level is determined. By optimising the capacity in handling the total time in the supply chain can be shortened. The redesign was evaluated using different levels of proactive repair order creation and skill configurations. Results from the case study showed the relationship between process efficiency, available capacity in terms of manpower, inventory, service level, and TAT. By separating the the physical from the administrative flow, reducing handovers and transactions, generating repair orders in advance and shifting from inventory buffers to capacity buffers the reverse logistic flow of component MRO providers can be drastically improved.

Keywords: MRO, Reverse logistics, Business Process Redesign, Discrete Event Simulation

1 Introduction

Maintenance, repair and overhaul (MRO) is the term used in aeronautical industry to describe continuous maintenance activities of aircraft. The purpose of MRO in aviation is to reverse the ageing and wear-out process of aircraft, components and sub-assemblies early in the operational life. MRO activities generality include inspection and testing to determine the condition of components, servicing, repair, modification, and overhaul [14]. Aircraft MRO is generally divided in line, engine and component maintenance. This research is performed within the field of aircraft component logistics. In the aviation industry, aircraft components are referred to as individual parts of an aircraft that make up the aircraft. A distinction can be made between repairable, 'rotable' components and expendables. Rotables are aircraft components which need to be 'rotated' at frequent intervals depending on a certain number of landings, flight hours or when (unexpected) damage is detected. Rotables can exchanged, repaired, overhauled (in-house or by a vendor) and put in pooled stocks to be used again. In the Aircraft MRO industry availability of aircraft rotable components is provided through availability contracts based on pooling stocks of components. Due to difference in failure rates of components and the typically extensive network of multiple customers around the globe, supply chains of aircraft rotable components are inherently unpredictable and associated with erratic and lumpy demand patterns [4] [23]. Especially the reverse flow of components, which considers the logistic and administrative handling processes required to retrieve components from customers to the MRO provider, suffers from high variation. The effectiveness the maintenance service strongly depends on the design of underlying spare part supply chain. Decisions made about the repair shop, logistic and administrative activities heavily influence the number of spare parts that are required; enabling more efficient processes by optimal design of the repair chain can mean less

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spare parts required to achieve the same service level. In order to assure high safety levels and high quality repairs, the MRO industry subjected to heavy regulations. Each repair method is standardised and requires certificated mechanics and procedures in order to make a unserviceable part serviceable again. Requirements to register the historic life cycle information of the components result in many inter- en intra-organisational transactions and complex processes. As competition in the MRO market rises, MRO providers continuously need to find ways to improve their operations. In addition there is a need to change business processes to support new innovations in automation and IT. The 'best' way to organise and carry out maintenance a decade ago is different from the 'best' way of carrying it out today, since there are now many things possible which were not technically or economically feasible, ten years ago [1]. The challenge is to determine the potential for improving the MRO business with today's technology as innovations are changing the rules of the game. Redesigning business processes is however challenging due to the complexity in operations and the MRO supply chain resulting in a need for new methodologies on how to improve and asses new strategies. A literature review on aircraft MRO was conducted and found that several different studies have been devoted to component service companies. The majority of the identified academical research has been devoted to novel availability models [22]. A few studies have been devoted to the production and use of process improvement theories within the production [26], [27], [17]. A neglected part of the component MRO business is the reverse logistic flow of components. In addition, supply chain management and operational excellence methodologies such as Lean six sigma manufacturing are still in its infancy within airline MRO [13] [3]. In the present day competitive MRO environment however, service providers need to continually identify ways to gain an advantage and invest to maintain leadership in the industry. The challenge is to minimise the TAT, manual labour and production wastes to aid the company's competitiveness in the global market. Furthermore, [11] states research aimed at understanding the impact of the variability in aircraft component turnaround times, and quantifying the value of having flex capacity to act as a 'shock absorber' in the system would be valuable to the commercial (and military) MRO sectors [11]. The research gap is filled by researching the potential for improving operations using the combination of operations management, innovations in automation and information technology and the practical application in the unique MRO environment. As academical research concerning the field of MRO supply chains is inherently linked to practical applicability in real life, this research uses a case study in order link academical methods and theory to practice. The case study is carried out in collaboration with KLM Engineering & Maintenance. KLM E&M is currently is moving its repair and logistic operations to a different location providing the opportunity to redesign the processes in a way the current waste in the chain is eliminated as much as possible. Based on the identification of the research problem consisting of the need to re-design business processes, a research question was elaborated; How can the reverse logistical processes of a component MRO provider be redesigned in order to improve the performance from a integral supply chain perspective?

2 Define: Theory & Methodology

Based on the identification of the challenges and main research question a literature review was conducted to find process improvement theories to support a business process redesign (BPR) study on the reverse logistic flow for aircraft components. The DMADE methodology by (Dr.W.W.A.Beelaerts van Blokland) is adapted and used to structure the research. DMADE stands for Define, Measure, Analyse, Design and Evaluate. This method is derived from proven DMAIC cycle originating from Lean Six Sigma theory (define, measure, analyse, improve, control). Where Lean Six Sigma promotes incremental improvement on a continuous basis, this research takes a more radical business process redesign approach. The improve and control phase are therefore replaced by design and evaluate phase. To support the methodology a combination of improvement theories is used. To address the main research question, a literature review was conducted to find the best methodologies to guide the business process redesign using the DMADE structure. The review found that a number of methodologies tend to be more useful in relation to some phases than others. Therefore, a combination of different methodologies for a better result is proposed. The measurement phase is supported by quantifying a combination of reverse logistic activities. Lean six sigma, business process mapping and transaction cost theory is used to analyse the target processes from the measurement phase. Next a redesign is proposed for both the the physical and administrative flow in the design phase. The design is evaluated using simulation modelling. The methodology is applied on the reverse logistic flow of rotable components of KLM E&M CS.

2.1 Process Improvement theory

The process improvement theories and research methodologies explored included; Lean Six Sigma manufacturing, the theory of constraints, transaction cost theory, business process redesign and theories on variation in operations and production management [31], [30], [7]. Although the goal and approach for bringing about change are different in these theories they do not exclude one another. Lean theory assist in finding (obvious) waste in the system by looking different aspects of the production system, using the TIMWOODS acronym waste within the system can be categorised and identified in transport, inventory, motion, waiting, over processing, overproduction, defects and skills. Six Sigma provides tools that compliment the Lean theory. Six Sigma is connected to Lean as both method both aim to reduce variability. However, Six Sigma is a methodology for variability reduction, not a general strategy for improvement (e.g., Six Sigma does not address obvious waste). BPR has its focus on process identification, process analysis and process change. These are similar to Lean Six Sigma approaches. However, the goals and approach for bringing about change are fundamentally different. Whereas Lean Six Sigma promotes incremental improvement on a continuous basis, BPR promotes fundamental rethinking and radical redesign. For this study the goal is to look for the more radical changes possible in the process as the logistics department and repair shops are moved to a new location the opportunity is there to use BPR thinking instead of incrementally improving the processes [12].

2.2 Reverse Logistics & Closed loop Supply chains

The key feature of aircraft MRO supply chains is that material flows occur in both directions [18]. This is in contrast to standard forward supply chain models of "consumable products" where there is a one-way flow of materials toward the customer. Physical flows of materials in the opposite direction towards the supplier are referred to as reverse logistics. These flows are rare in consumable product supply chains. However, in the MRO supply chain, there is an equal flow of unserviceable components from customer to supplier, with re-manufactured components flowing in the conventional downstream direction. The combination of the forward and reverse flow results in a closed loop supply chain, allowing the movement of rotable items [5]. This structure comes forth from the need to reduce the downtimes of aircraft. To prevent AOG situations unserviceable components are exchanged on site. The demand for service replacements associated with long lead times require spare parts stocking. In order for a company providing component availability to be competitive, the spare parts inventory level as well as the repair cycle should be optimised under consideration different performance aspects.

In the common manufacturing industry the majority of material flows consist of forward logistics, from suppliers to manufacturers to distributors to retailers. Forward logistics (FL) is therefore the focus of most research supply chain management (SCM) research. Literature which falls under the he general umbrella of reverse logistics and closed-loop supply chain is relatively new in academical literature although is has gained considerable attention in industry and academia over the past decade [29] [21] [10]. According to the American Reverse Logistics Executive Council, reverse logistics (RL) is defined as; *"The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal"* [21]. RL and Closed-loop supply chains open up a new and interesting issues [8]. When compared to forward logistics, RL presents more complicated operations due to the uncertainties inherent in product returns, complex nature of re-processing, and high implementation costs of RL systems. Hence, optimisation of RL supply chains, and development of efficient information management systems is essential. In literature several main activities in RL supply chain can be identified which are generally divided into four different levels. The first level is collection or asset recovery the second is the combined inspection / selection / sorting process, the third level is disposition and re-processing and the fourth level is redistribution [2]. According to [9] many firms use a silo approach to reverse supply chains, considering each activity in isolation without considering the integrated nature of reverse supply chains. Furthermore, companies tend to look at re-manufacturing as a technical operational problem: how to turn a returned product into a functioning product that satisfies all the quality requirements of a new product. This focus results in the fact companies often passively accept returns from the market or the channel. They do not actively manage the process of acquiring returns; hence, returns are uncertain in quality, quantity, and timing. Concentrating on the technical aspects of re-manufacturing, will result in ineffective reverse supply chains [9]. According to [15] there is no single reference model that all organisations can use to make their supply chains more efficient; each company must find a solution that best fits its specific situation. This research uses a combination of mapping techniques to define the physical flow simultaneously the information flow that characterises the Component MRO reverse supply chain. In addition places buffering of information and physical components occur throughout the supply chain are identified. A summary of the methodologies used is are presented in a Framework in Appendix Figure 6.

3 Measure

In the Measure phase all knowledge, information and data needed to analyse the current performance is acquired. Both the higher level processes as well as the processes that are necessary to execute single transactions are considered in this phase. The MRO supply chain consists of many different processes, it is therefore essential to identify the relevant supply chain processes present, and select a valid target for re-design. For this purpose, processes have to be mapped based on observations and work sessions with the involved stakeholders. This is done using a combination of the VSM and cross-functional chart (swimlane) map, the

VSM-I (where I stands for information). In order to identify and measure both the high level processes and lower level transactions, the scope is limited to several layers of detail. First, a high level MRO analysis was conducted presented. Next, using mapping sessions with the involved stakeholders, interviews and company data, the most critical processes and different flows are identified and presented using process mapping.Third, data is gathered from different sources in order to quantify current state performance of the component logistic and repair processes. According to [25] when optimising the performance of processes within a supply chain processes, three options can be identified:

- Global supply chain optimisation: assumes direct and cooperative relationship between all stages of the supply chain.
- Manufacturing facility optimisation: minimise cost from manufacturing only.
- Decentralised optimisation: individual optimisation of each of the supply chain entities.

The scope of global supply chain optimisation was considered too large for one research, limiting the in-depth analysis that makes a research valuable. The options named above does however not exclude one another. For that reason the choice was made to focus on the decentralised optimisation while still linking the results to the supply chain. Validating the choice for decentralised target for the redesign and its link to the supply chain are of major importance, especially in the MRO supply chain.

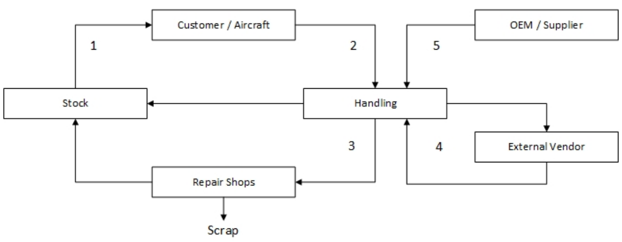

FIGURE 1: Closed loop supply chain MRO

This Figure shows that the component service supply chain essentially consist of five main steps:

1. Delivery of serviceable components to customers.
2. Reverse logistics flow of unserviceable components from customers.
3. Repair and maintenance and overhaul of unserviceable components.
4. Repair of US and return of SE components from external vendors
5. Procurement of serviceable components and materials from OEMs and other suppliers.

Delivery of serviceable components to customers. The delivery of SE components is a straightforward process which concerns the forward flow within the closed loop supply chain. This process starts when a customer places a request for a certain component at component availability department. In this request the customer states which component is required and when the component is needed. The notification for the request of a serviceable component can be sent in different ways depending on which system the customer uses. Aside from customers which have a direct link to the ERP system, a collaboration platform AeroXchange is used in most cases, however when a customer does not have a AeroXchange licence, notifications are send via Email. After receiving the request, the availability department acknowledges the request and when the part is on stock, it notifies the logistic department via the ERP system. Next, the component retrieved from the storage area and shipped via the third party logistics provider. On arrival the customer confirms the arrival and the demand is satisfied and the reverse flow can start.

Reverse logistics flow of unserviceable components The Reverse flow of components starts when a unserviceable component is removed from an aircraft during an aircraft maintenance check (usually an A- or C-check). After the part is removed the customer sends a notification to KLM E&M customer service. The component is then send either with the 3PL of KLM E&M or by using their own preferred logistic provider depending on the contract. On arrival the part is declared (if needed) by the customs agent. When the part is cleared by customs, the component is handed-over to the logistics expedition. The logistics expedition then has to identify the package and sort the components. After identification and sorting the expedition adds a tracking sticker for internal transport and the logistics department brings the package to the inbound buffer of the corresponding repair administrators (RA). On arrival the unpacks the component and starts administrative tasks and makes the repair order. Once the repair order is created, the component can be sent to a repair shop. The return flow of MRO components can be classified by: Differences in size, differences in information quality, uncertain arrival time and the status of components and packaging.

Repair and maintenance and overhaul of unserviceable components The MRO of the US components is done either in-house or components are outsourced to a vendor depending of the in-house capabilities. When a component is outsourced a repair order and proforma invoice is generated. These documents are attached to the part (box) and the component is sent to the vendor. If a component is repaired in-house only a internal repair order is generated using the ERP system and the component is sent to the shop. Several information systems are used in the supply chain. In order to accurately describe the transactions in the information systems in more detail the information flows where included in the VSM-I map. The results of the mapping of the case study are indicated in Figure 7.

Inbound flow of consumables & Servicable Rotables One of the necessary evils of component MRO is to check and update the documentation of attached to the components. One of these processes is called Inspect Incoming Goods (IIG), and is required to be performed if a component is to be installed into an aircraft (conform EASA Part-145 regulation). This process is required for the incoming flow off serviceable goods (i.e. from vendors) and for the incoming flow of consumables. For the consumable parts the IIG activity is straightforward and consists of mainly administrative actions in the internal systems. The inspection of serviceable rotables is more time consuming and includes a inspection of the part to guarantee the certification is done right which requires special skills. These processes are executed in the same warehouse as the inbound for US parts.

TABLE 1: Process performance

Action	Avg. Time [days]	Std.dev [days]
Time between removal and shipment from customer	5,3	50
Shipment from customer	4,3	4,8
"Handling time" (incl. sorting & repair order generation)	7,5	7,7
Buffer time internal repair	5,1	7,5
Repair time in-house repairs	13,2	18,9
Repair time external vendors (incl. quoting, shipping,dispatch)	40,9	33,4

The measurement phase in this study provided insight in the complete reverse logistic supply chain performance. From this phase it was concluded especially the handling and logistic operation in the current logistic centre was underperforming. Especially the reversed logistic supply chain of unservicable components suffers from high internal and external variation. The highly variable inflow of components results in backlogs, long turn around times (TAT), and causes high levels of WIP. Following from SCM theory, two main strategies can be identified in which MRO companies can deal with this variable demand. The MRO provider can either aim to reduce the variation in the supply chain, or design its processes in order cope with the variable demand. Reducing the variation is more difficult as one of the main sources of external variation is the failure rate of components. Hence the business model of Component Services is pooling of components to gain economics of scale and accommodate varying component failures customers themselves can not accommodate. The analysis phase is therefore focused on analysing the internal sources of variation and identifying ways to design the processes around the variable environment.

4 Analyse

The analysis phase investigated the reverse logistic processes in more detail. Both the physical flow of components as well as the information flow where mapped in the VSM-I. A case study for the flow with the largest number of transactions was chosen, namely the joint Boeing-KLM pool for which KLM E&M CS is repair responsible. In addition the performance of this perticular flow was considered to be underperforming. A VSM-I was constructed for this particular flow and presented in Appendix Figure 7.

The the analyses showed that administrative registration components and repair order generation and logistic operations of the reverse flow are the main constraining processes, with a handling time of 7 days on average and a similar standard deviation. The root cause of these constraints was determined using the TIMWOODS wastes from Lean manufacturing for the physical flow, next to this seven types of information waste as proposed by [28] were identified for the same case. The analyses identified that logistic and handling operations have several root causes. First of all, the demand can be classified as lumpy demand using Croston's method [24]. Due to the fluctuations in demand, buffering occurs due to a imbalance of manpower related to the input, and a sequence of physical and information buffers between repair administrators, customer interface and logistic handlers. Furthermore mapping analysis has shown that there are many handovers and transactions necessary in the process that are subject to errors due to the manual entering of part and serial number. Also the repair order is made after the component has arrived, so the administration process is constraining the logistical flow. Due to the entanglement of the logistic handling operation, the components are 'handled' based on the aircraft type in the current situation. Untangling the administrative flow and the physical flow enables to handle the components based on their size and thus making it more suitable for standardisation using automated equipment. Another observation was that is it difficult for the logistic department to identify packages as they do not have standardised labels so sometimes boxes have to be opened to determine what is destination should be. Defects in the process occur due to missing information from the customer (i.e. missing flight hours, cycles or reason for removal). A particular problem that occurs in reverse logistic flows [6]. Several different availability control and storage systems are required in the repair order process resulting in many transactions. In addition, Repair Administrators often are spending their time searching for right components. Furthermore analysis was performed to analyse the size of components and found distribution of 80%, 13%, 2% for box pallet and odd-sized unit loads.

5 Design

With the knowledge from the analysis phase several design criteria where developed on which the (re)design is of the inbound handling area in the new hangar facility is based. The first being the separation of the administrative process from the physical flow of components. This is enabled by skipping the part/serial number check in the logistics area (which was found an unnecessary during the mapping session as this also takes place in the repair shops). The redesign therefore consist of two separate parts. A redesign of the physical and of the (non-physical) information flow. For the information flow related to the reverse logistic processes of unservicable components, repair orders can be made in advance based on customer data. The physical flow is optimised using automated handling equipment. As the components now can be sorted based on their size (box, pallet, oddsize). The automation of the physical process consist of automated identification (scanner), automated transportation (roller conveyors) and automated storage (AS/RS system) for box flow. Together these elements for a miniload-workstation order picking system, divided into a miniload, workstations, and conveyors. For the redesign the handling activities of US, SE and consumable components are performed at the workstations. The administrative activities of SE rotables and consumables (Inspect incoming goods conform EASA part-145) remains the same.

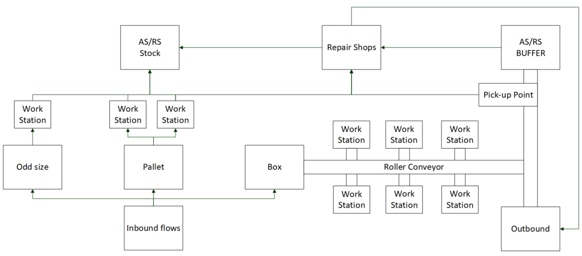

FIGURE 2: Physical configuration handling area (Schematic)

The layout of the work stations as indicated in Figure 2 consist of Incoming goods inspection for the SE flow and the consumable flow, logistic handling and a Part ID skill. The part ID skill new and is used for the trouble shoot flow of components that are not recognised by the automated scanner. Parts that are waiting for repair orders, overflow of components to be handled, and components ready for the internal shops can be stored in the AS/RS.

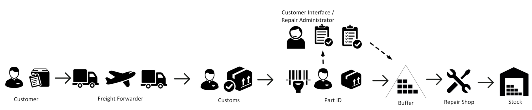

FIGURE 3: Reverse supply chain US flow component

For the information flow repair orders can be generated once all information necessary (aircraft registration, hours, cycles, reason of removal, part/serial number etc.). Currently this data is provided on paper and shipped with the component and communicated with customer interface through collaborating platform Aeroxchange. A future state VSM-I was constructed to visualise the redesign. The redesign resulted in less physical handovers and thus less locations where buffering can occur by changing the role of the repair administrator to only administrative tasks. In the redesigned scenario the customer is asked to provide the necessary data about the component in a shared information system. In the KLM E&M case this is done in the system AeroXchange. After filling the fields correctly the customers receives an message with a return-label which can be printed and attached to the component packaging. This can be done using a standard barcode (illustrated in Figure 3. A study by [19] investigated value of implementing RFID in the MRO supply chain, although concluded that here the biggest challenge lies in integrating the RFID technology with the legacy systems and data bases as well make the RFID technology accessible for customers and other business units within the company to fully leverage the benefits of the technology. For the ease of implementation a barcode is proposed in this study, if parts can not be identified a PN/SN check is still required and documents attached to the components scanned, and sent to the repair administrator. This is done by a new skill, Part ID as illustrated in Figure 4

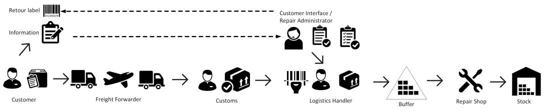

FIGURE 4: Reverse supply chain US flow proactive repair order

The next step is to evaluate the design. Here the goal is to accommodate the inflow variation using the right amount of resources. Conform [12], in the presence of variability, there are only three buffers available to synchronise demand and transformation with lowest cost and highest service level; capacity, inventory and time. If you cannot 'pay' to reduce variability, you will pay in terms of high WIP, under-utilised capacity, or reduced customer service (i.e., lost sales,long lead times, and/or late deliveries). This trade off is illustrated in Figure 5.

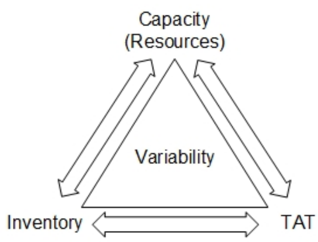

FIGURE 5: Trade off Capacity, Inventory, Time

The main driving principles of Lean manufacturing theory advocated the creation of flow in the process and the enabling of pull processes [31]. Pull is introduced in the reverse supply chain by using the AS/RS as a central buffer for shops from which components can be "pulled" by the repair shops. By buffering capacity in terms of handlers, part ID and IIG inspectors in the handling area, buffering anywhere but the central buffer is eliminated. As a benchmark the capacity in handling is set to physically handle 95% of components that arrive before 21:00h on the same day. The requirements for capacity and performance and configuration of the proposed redesign can be measured in three ways, namely analytic, with simulation or with physical experiments. As the redesign is more radical than classical Lean process improvements, testing the potential in a more safe computer environment is desired. As most complex, real-world systems with stochastic elements cannot be accurately described by a mathematical models which can be evaluated analytically [16] simulation is used. Discrete event simulation (DES) and system dynamics (SD) are two modelling approaches widely used as decision support tools in logistics and supply chain management. For the purpose of this study Discrete Event Simulation (DES) models are preferred above SD and agent based models (ABM) as DES models are better at capturing environments of high stochastic variation and can be used to find optimal configurations of resources on an operational level. Hence ,SD is mostly used to model problems at a supply chain level, whereas DES is used at an operational/process level [20].

6 Evaluate: Model & Results

The potential of the redesign is determined by evaluating the handling time (TAT) used resources and WIP. The DES model was constructed iteratively based on the concepts from the design phase. Simio LLC, Version: 9 (32 bit) was used as simulator as this allowed 2 and 3D modelling of the handling area and enabled the possibility of incrementally improving on the design involving stakeholders from KLM E&M. The aim and scope of the model was to evaluate the required capacity in terms of resources and equipment to handle components conform the stated On Time Performance (OTP) of same day handling. The model consist of entities (representing components (US, SE, consumable and repair order requests), several source objects for generating components and repair order request, server objects (workstations, AS/RS, repair administrator), and several sink objects marking the boundary of the model. The arrival of components in the model was based on the measurement phase, generating daily arrivals based on a normal distribution with a standard deviation set to half the mean value, and an exponentially distributed inter-arrival time based on this shifting mean. In the model the amount of repair orders which can be created in advance is varied as well as a growth scenario.
Results from the modelling study are presented in terms of manpower and equipment requirements in order to handle components the same day in Table 2. In addition requirements for the storage capacity was evaluated in the model. Based on historical times components components spend in repair and the pull behaviour of shops the amount of components in the central buffer is calculated. Resulting in a need for 830 positions in the current and 1652 positions in the growth scenario. Installing less manpower (and equipment) capacity than the required in the handling area the throughput through handling rises and the WIP of components in handling. generating repair orders in advance has a major impact on the need of newly introduced "part ID" skill, which has similar function as the repair administrator in the curret situation.

		Current 0% RO	Current 50% RO	Current 80% RO	Growth 0% RO	Growth 50% RO	Growth 80% RO
Dedicated stations	Box	11	8	7	20	15	13
	Pallet	4	4	4	4	4	4
	Odd	4	4	4	4	4	4
Flexibe stations	Box	10	8	6	19	14	11
	Pallet	2	2	1	4	3	2
	Odd	1	1	1	1	1	1
Total Skils	IIG SE	2	2	2	4	4	4
	IIG Consumable	4	4	4	7	7	7
	Part ID	5	3	2	10	5	3
	Handler	1	1	1	2	2	2
	RA	6	6	6	12	12	12

TABLE 2: Summary optimisation stations and skill resource capacity

7 Conclusion

This research aimed to answer the question; How can the reverse logistical processes of a component MRO provider be redesigned in order to improve the performance from an integral supply chain perspective? To answer the main research question several principles are suggested. Firstly; it is advised to use the DMADE methodology in the MRO environment. The Define phase is aimed to understand the business context, gaining knowledge about the sector in which the company competes and the way the company operates to satisfy its customers. Here the emphasis lies on identifying the current roles of supply chain management and IT technologies. In the measurement phase a complete picture of the supply chain in terms of TAT should be acquired for all reverse logistic activities (asset recovery, transport, identification, inspection, sorting and disposition). This in order to select a target for redesign. In the analyses phase a more detailed current state analysis can be performed using the VSM-I on transaction level. All possible improvements gained form the analysis phase form an input for redesign. This particular case showed the importance of separating the administrative from the physical flow which is essential for the MRO industry. This due to the fact all documentation should be correct before a repair can start. To achieve a more Lean process it is advised to reduce buffering in multiple stages by separating the physical and administrative processes. This allows for the components to be handled based on their size, enabling the opportunity to standardise and automate the process. By introducing a AS/RS-workstation

system the and optimising the capacity based on the volatile demand pattern, components could be handled and ready for shop in a single day. For the design of such a system with complex flows it is advised to use DES modelling to optimise the required demand give the availability of information. To conclude, results from the case study used in the MRO industry showed the total time components spend in the supply chain can be reduced through separating the physical from the administrative flow, reducing the number of transactions between departments and customers, acquiring data from customers the moment its generated, generating repair orders in advance and move from inventory buffers to capacity buffers. By introducing these principles the performance of the MRO supply chain can be improved from an integral perspective.
The case study in aviation MRO and the following results are company specific, the methodology does however have potential for other industries and companies, especially ones with high demanding information flows. Limitations of this research are found in the available data and the complexity of different flows. The case study used the most complex flow of KLM E&M as a base to represent all flows. More flows in MRO industry should be mapped using the VSM-I method from this study.
Further research in MRO should focus on acquiring more accurate data from airline customers by i.e. rewarding programs or better collaborating platforms. This is essential in order to reduce the information waste at the handling facilities down the reverse logistic supply chain. Furthermore, developments around the vision of the Industry 4.0 in combination with the information flow within the MRO supply chain would be beneficial to the academic community. As innovations in the MRO processes historically have been moving in a slow pace, this might still just be a bridge to far although it can be considered of huge potential for the industry. Innovations around the industry 4.0 where all information is readily available for multiple users in the supply chain can have positive disruptive effects on the way to do business and need further investigating.

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Appendix

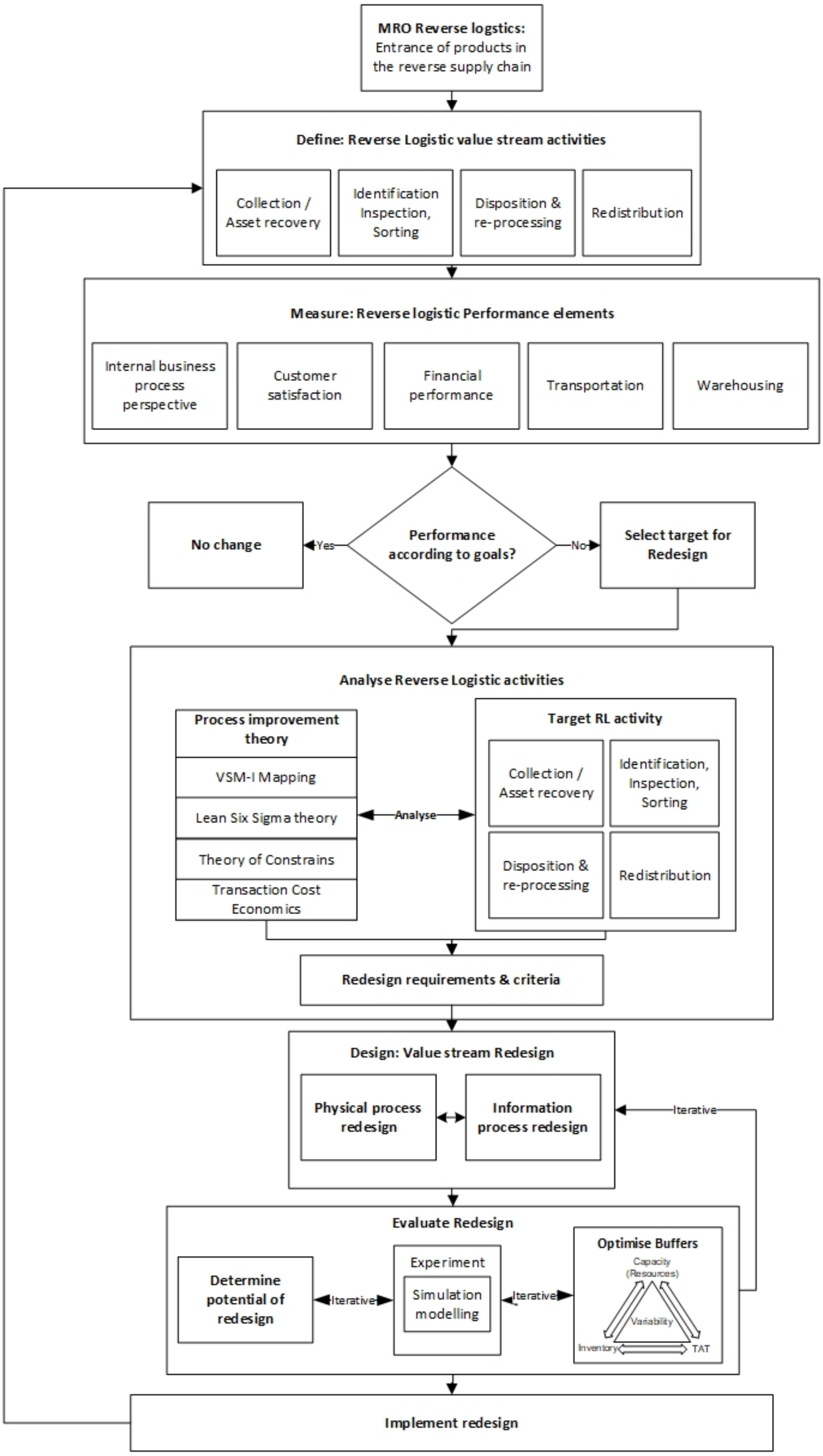

FIGURE 6: Framework for reverse logistics in MRO

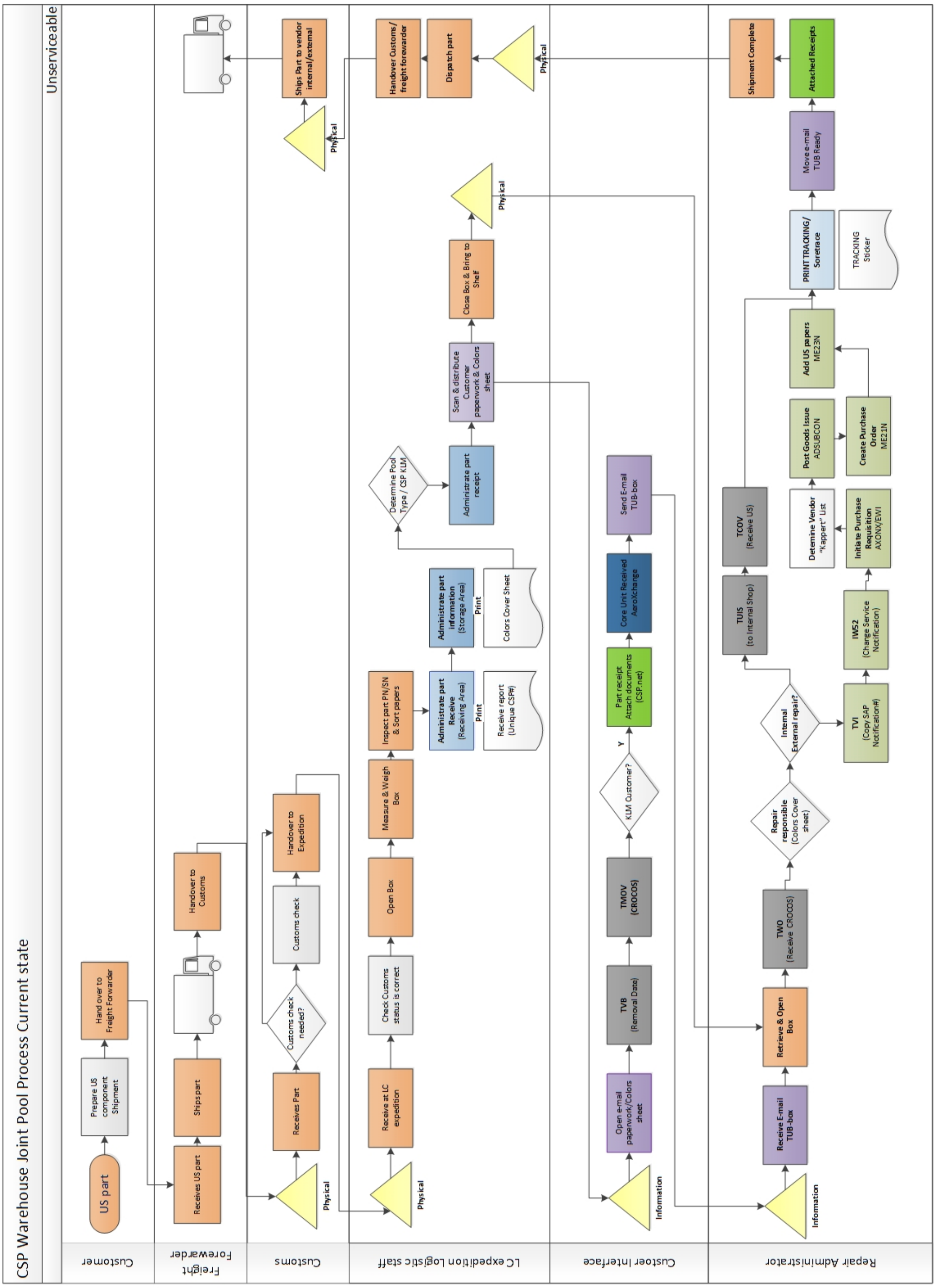

FIGURE 7: Current State CSP VSM-I flow with detailed IT transactions

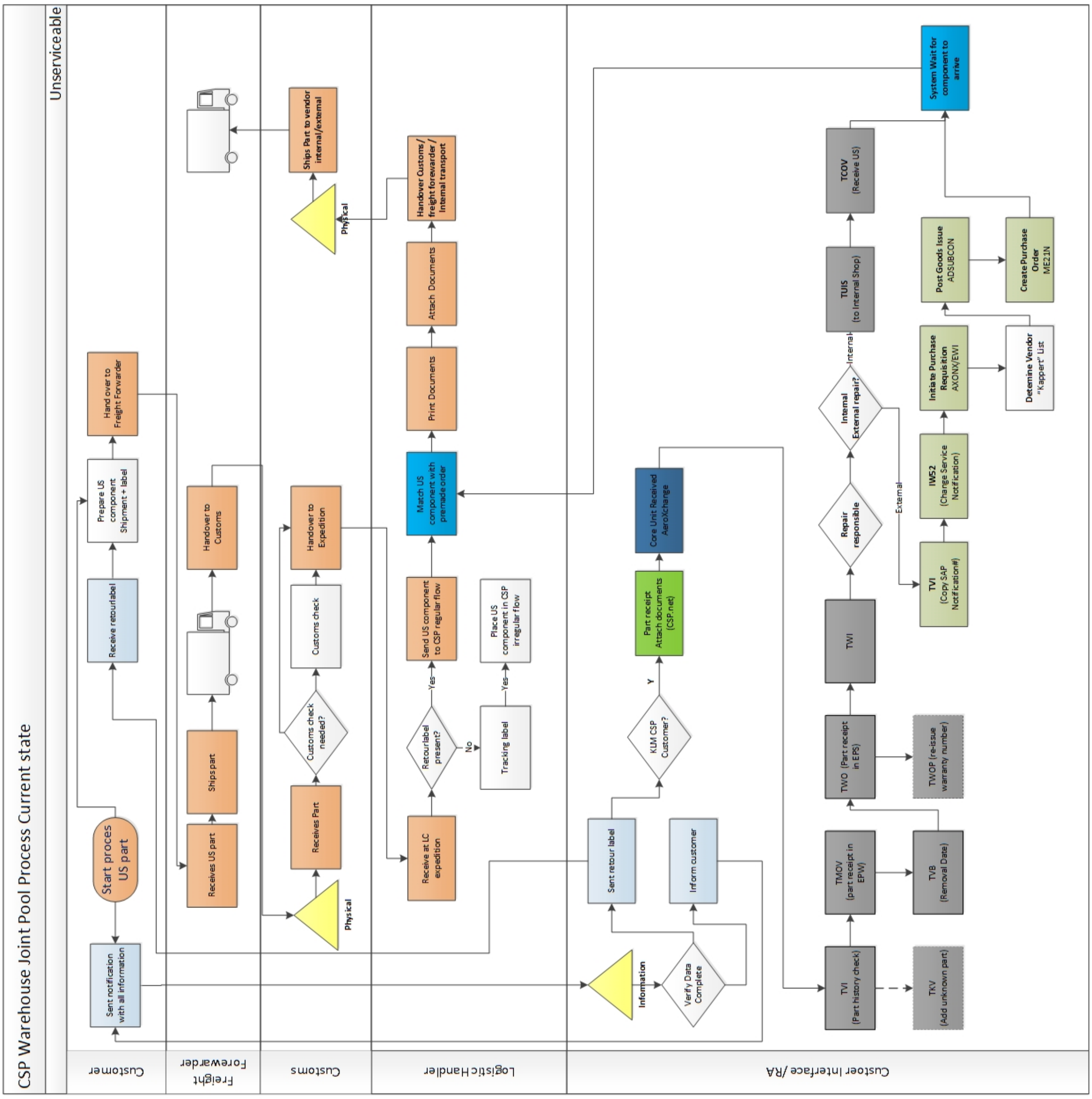

FIGURE 8: Future State CSP VSM-I flow with detailed IT transactions