Evaluating performance improvement strategies in a closed-loop supply chain

A case study at KLM E&M Component Services

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by

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Preface

This thesis is the final product to obtain my degree of Master of Science in Transport, Infrastructure and Logistics at the Delft University of Technology. The research is conducted as a collaboration between Delft University of Technology and KLM Engineering & Maintenance. During my time in Delft, I got the opportunity to develop myself in many areas and I made friends for life. Hence, I am looking forward to what my next journey will bring.

First of all, I want to thank my supervisor from KLM Engineering & Maintenance, Gijs van Schie. He has been extremely helpful and supportive during my entire internship, even when he switched jobs. In addition, he helped me to find my own way in a big and dynamic organisation.

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Last but not least, I want to thank my parents and brother for all the moral support. I particularly want to express my gratitude to my girlfriend for all the support and love she gave me when I needed it the most. Thanks to my friends from TIL for studying, complaining, eating and laughing together. Without your support writing my thesis would not be possible.

With pride I present to you my Master Thesis. Enjoy the read!

D.G.C. Munsters
Delft, July 2019

Summary

KLM Engineering & Maintenance Component Services (KLM CS) is responsible for ensuring spare part availability regarding its contracted customers. According to contracts with customers, KLM CS must fulfil 100% of the spare part requests. In 2018, a revenue of €910 million was gained from maintenance contracts. The supply chain of rotable spare parts is a so-called closed loop supply chain. Rotable spare parts are interchangeable and repairable aircraft spare parts. When a contracted customer requests a spare part, a serviceable (SE) component is shipped to the customer. In return, the customer ships the unserviceable (US) component to KLM Component Services. Then, the US spare part is shipped to the repair location, either in-house or outsourced, where the rotable spare is repaired and retrieves its SE status. Hereafter, the spare part is shipped to the logistics center (LC), where the spare part is restored at the Magazijn Logistiek Centrum (MLC) storage location. The demand for spare parts has a sporadic nature and consists of large zero demand periods. In order to increase the spare part utilisation rate and gain additional revenue, KLM CS introduced a loan service. The loan desk enables external customers (without contracts) to borrow a spare part against a predetermined fee. In 2018, a revenue of €1,5 million was gained by the providence of this additional service. However, the providence of this additional service should not negatively effect spare part availability regarding contracted customers. Especially, the back-order costs due to the providence of this service should be limited. As KLM CS must meet the supply obligations which are laid down in Service Level Agreements (SLAs), spare parts are back-ordered (borrowed or purchased) in case of unavailability. According to experts within KLM, there is an imbalance between both processes. In other words, KLM's loan desk negatively effects spare part availability regarding contracted customers. Accordingly, the objective of this research is to evaluate the potential performance improvement strategies to increase the contribution of the loan desk to the performance of KLM CS. In order to achieve this, the following research question was formulated:

"What strategic improvement option(s) should be employed in order to increase the contribution of KLM's loan desk to the performance of KLM Component Services?"

The researched system can be described as a closed-loop supply chain system where two demand types are fulfilled from a single inventory storage location. The causal relations and interactions of the system were determined by developing a causal diagram. It is important to understand complexity of systems in order to develop better operating policies and strategies, and guide effective change. When mapping the causal relations of the system, the interactions between subsystems were laid down. Orders from external customers decrease the on-shelf inventory level. As the Service Level (SL) regarding contracted customers is dependent on the on-shelf inventory level, external orders have a negative effect on spare part availability. This results in back-order costs and a lower profit. Therefore, it is important to find the right balance between total circulation stock level and spare part availability, to meet SLAs against the lowest costs. The state of the system is dynamic, which makes the availability decision at the loan desk regarding the acceptance of requests from external customers of high importance. Furthermore, the pricing method regarding external customers is related to the order acceptance rate of external customers. When investigating the procedures at KLM's loan desk: selection of requests, availability decision method and pricing method, it turned out that decision procedures are mainly based on feeling and experience. There is no clear nor standard procedure regarding the processes at the loan desk. Here, performance is monitored by solely tracking the monthly revenue generated by the loan service. Here, management set a monthly target of €200.000 which is met in approximately 17,5% of the months. Currently, the availability regarding external customers equals 21%. This low availability is due to zero or critical stock levels of the requested spare parts. The loss of potential income due to stock

issues is estimated on €175.000 per month. For KLM CS, the most important performance measure is service level, which represents the percentage on-time deliveries regarding contracted customers. According to SLAs, the average SL should equal 94,7%. Currently, the average SL equals 82%, which is rather poor. This resulted in back-orders in 14% of all contracted customer spare part request, which costs KLM roughly €500.000 per month solely for the B737 aircraft type. Moreover, there is no performance metric that is capable to assess the performance of KLM's loan desk while taking into account the back-order costs caused by this service.
The first step in Business Performance Management (BPM) should be to develop strategic goals by specifying objectives and Key Performance Indicators (KPIs). A five step method was used [29]:

1. Develop Supply Chain Strategic Roles
2. Identify/Prioritise Improvement Opportunities
3. Define Goals
4. Determine Performance Measures
5. Monitor Progress & Make Adjustments

The main goal of KLM CS is to provide spare part availability for its contracted customers against the lowest cost with high customer satisfaction. It is especially important that the right spare part with the right specifications is send to right customer and delivered at the right time. In addition, KLM is a profit seeking organisation and strives to increase its profitability, while meeting the contracted customer SLAs. In any case, the operation should be safe. In order to achieve this CS focuses on spare part turn around time (TAT) and inventory management improvement strategies. This study focuses on the latter. Here, KLM tries to maintain the lowest possible inventory level to meet the SLAs. The loan desk is introduced as a Strategic Business Unit (SBU). The main goal of introducing the loan desk is to contribute to the financial performance of CS in order to decrease the cost of providing spare part availability and increase profit. Based on the findings of the current state analysis, improvement areas were detected and prioritised. For this research, the following strategic improvement options were considered as top priority and were further elaborated and evaluated:

- *Spare part availability decision regarding external customers* - develop a rule/fact based decision methodology for KLM's loan desk that is able to make a trade-off between the opportunity of gaining additional revenue and the risk of back-ordering expenses due to component unavailability regarding contracted customers by offering the requested spare parts.
- *Increase the total circulation stock level* - increase the total circulation stock level to improve responsiveness of the loan desk in terms of availability for external customers.

To evaluate the most promising improvement strategies, a set of performance measures was introduced. The Key Performance Indicators are listed below:

- *Total result loan desk* - Benefits of the service in terms of revenue gained, subtracted by the back-order costs due to the providence of the loan service. In other words, profit.
- *Fill-rate contracted customers* - Percentage of contracted customer requests that were fulfilled at the same date as the request.
- *Availability rate external customers* - Percentage of external customer requests that were available and quoted to the external customer.
- *Marginal value of additional circulation stock* - The financial benefits of increasing circulation stock in terms of additional revenue gained from external orders and decrease in back-order costs, subtracted by the cost of increasing the circulation stock level. If the KPI has a positive value, increasing the circulation stock level is feasible.

In addition, one performance constraint was introduced, the *cost-benefit ratio* (CBR). The CBR constraints ratio between costs of the loan service in terms of back-orders caused by the loan service and the revenue generated by the loan service. Based on the criticality of spare parts, a different cut-off value of the CBR is used. By constraining the CBR, the effect of the loan desk on the availability service regarding contracted customers becomes manageable.
For the availability decision regarding external customer requests, two alternatives were specified. The first alternative is a *risk-based availability decision*. Here, risk refers to the risk of a shortage regarding contracted customers when loaning the spare part to an external customer. The risk of a shortage is calculated based on the state of the system. In case the calculated risk exceeds the maximum acceptable risk of a shortage, the spare part is not available. The second alternative is a *minimum on-shelf inventory level based availability decision*. Here, a cut-off value for the minimum on-shelf inventory level determines whether a spare part is available for an external customer. At KLM's loan desk, approximately 2000 different spare parts were requested during the first 44 weeks of 2018. For almost 80% of the requests, stock issues were reported. The strategic option to increase the circulation stock level of spare parts is evaluated by determining the marginal value of additional stock items.
It is often found that a small percentage of the SKUs contribute to the majority of the sales and revenue of a company. At KLM, no inventory classification is determined with respect to solely external demand. Based on: the demand size per spare part, the external customer hitrate and the average income per order, the demand value was estimated. It was found that 20% of the externally requested spare parts contributed to more than 80% of the total demand value at the loan desk. These spare parts were classified as class-A. For this research, 10 class-A spare parts were selected to evaluate the most promising improvement options. Based on characteristics such as demand, spare part value, repair location and criticality, a set of case spare parts with different characteristics was selected.
A single component simulation model was constructed in order to evaluate the developed strategies. For the availability decision, it was found that a risk-based availability is the most robust alternative. This alternative of the availability decision calculates the risk of shortage regarding contracted customers based on average yearly demand, repair location specific turn around time and the on-shelf inventory level. For each criticality level of spare parts, a cut-off value of the maximum risk of a shortage was determined. Based on the model results, the availability rate regarding external customers increases with 24%, which results in a revenue increase of €375.000 at the loan desk. Furthermore, it enables management to gain control over the effect of KLM's loan desk on the spare part availability service regarding contracted customers. For the increasing circulation stock strategy, it was found that for 7 of the 10 spare parts it is feasible within 5 years to increase the circulation stock level. Here, the decrease in total back-order costs contributed more to the marginal value of an additional stock item compared to additional revenue gained from the increase in external orders. However, due to poor inventory data quality, it was necessary to calibrate the circulations stock levels based on service levels for each case spare part. Therefore, it is recommended to improve data quality and reconsider the current inventory policy.

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1
Introduction

1.1. KLM company profile

Koninklijke Luchtvaart Maatschappij (or KLM) was founded in 1919 for the Netherlands and its former colonies. Since 2004 KLM has been part of the AIR FRANCE KLM group due to a merge between the two companies. In 2016, the KLM group operated worldwide flights with over 200 air crafts, generating €10 billion revenues and employing 32.000 staff from its Amsterdam basis. KLM consists of three core businesses, namely: Passenger Business, KLM Cargo and KLM Engineering & Maintenance (or KLM E&M) [27]. This master thesis is performed at KLM E&M Component Services.

KLM E&M is responsible for the Maintenance, Repair and Overhaul (or MRO) activities regarding aircraft spare parts and to ensure spare part availability for its customers. KLM E&M can be divided into three main maintenance units, namely: Air Frame, Component Services (or CS) and Engine Services (or ES). The provided spare part MRO services are mainly performed for contracted and POOL customers. In 2018, KLM E&M gained a revenue of €910 million from maintenance contracts [26].

1.2. Maintenance, Repair and Overhaul

MRO can be defined as follows: *"the arm of the aviation industry that is primarily responsible for the retaining or restoring of aircraft parts to a state in which they can perform their required design functions"* [1]. The MRO business sector can be characterised as a growing market in an intense global competition environment. This leads to an increasing pressure on MRO organisations. MRO service providers must increase profits whilst optimising and streamlining business operations [2]. Figure 1.1 shows the estimated world MRO spendings [32].

For MRO service providers it is important to adopt more flexible strategies since it is important to ensure spare part availability [15]. Therefore, spare part inventory control is a crucial factor. However, demand patterns differ per component and most are highly intermittent [39]. Intermittent demand is characterised by the fact that it tends to be random with large zero demand periods. The challenge remains to achieve high service level and low holding costs. In order to avoid sub-optimal performance, decision making must be intelligent [36]. However, this challenge remains hard and companies therefore outsource spare part MRO activities and start pooling [23]. Here, larger spare part MRO service providers manage a spare part pool from which contracted customers can request spare parts. MRO service providers have contractual agreements with customers regarding the minimum service level (or SL) that needs to be met.

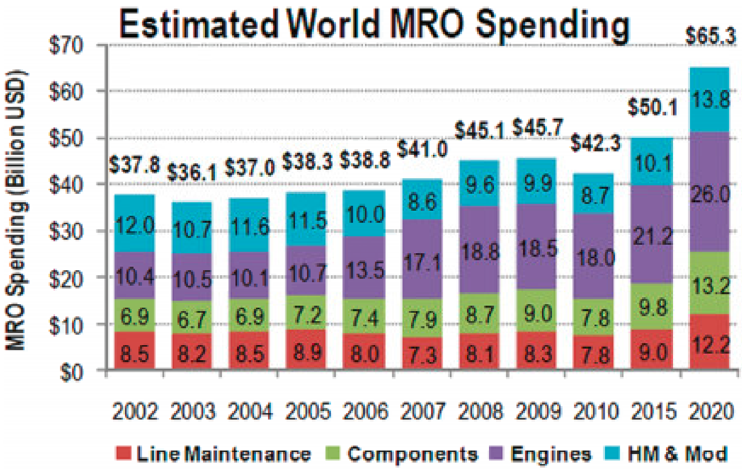

Figure 1.1: Estimated world MRO spendings [32].

1.3. Closed-loop supply chain at KLM E&M Component Services

In the MRO industry, there are mainly two types of spare parts, namely: rotable and consumable spare parts. Rotable spare parts are interchangeable and repairable, while consumables are not. This study solely focuses on the rotable spare parts. The supply chain of such parts can be classified as a so-called closed-loop supply chain. Figure 1.2 displays the closed-loop supply chain of KLM E&M Component Services. Rotable spare parts are stored at the Magazijn Logistiek Centrum (or MLC) at the Logistics Center (or LC) at Schiphol Oost. At this location, KLM manages a pool of components for contracted customers. Inventory pooling can be an effective strategy to improve component availability while reducing total costs [22]. Pooling refers to an arrangement where demand can be satisfied by using inventory from multiple stock owners, in this case airliners. Here, the POOL managing company ensures component availability for its contracted customers, so they can perform their aircraft MRO activities. In Figure 1.2, the physical flow of a rotable spare part is initiated after processing the spare part request from the contracted customer. At 1, the requested serviceable (or SE) component leaves the MLC storage location and is transported from the logistics center to the location of the customer. After receiving the SE spare part at 2, the customer returns an unserviceable (or US) spare part at 3. The US return unit is received at the LC at 4. Here, administration tasks are performed and the spare part is moved to the outbound expedition area of the LC. At 5, the spare part is transported to the corresponding repair location. Spare parts are either repaired in-house at KLM Repair Shops (or RS) or outsourced and repaired at a Vendor. The spare part arrives at the repair location at 6. Here, the spare part MRO activities are performed and the US spare parts retrieves its SE status again. At 7, the SE spare part is send to the LC where it is received at 8. At the LC, the spare part is inspected and restored at the MLC storage location. Here, solely SE spare parts are stored.
For this study, it is assumed that rotable components are endlessly repairable, so 0% of spare parts are scrapped. Therefore, the number of rotable spare parts in the closed-loop supply chain stays constant unless spare parts are purchased or sold.

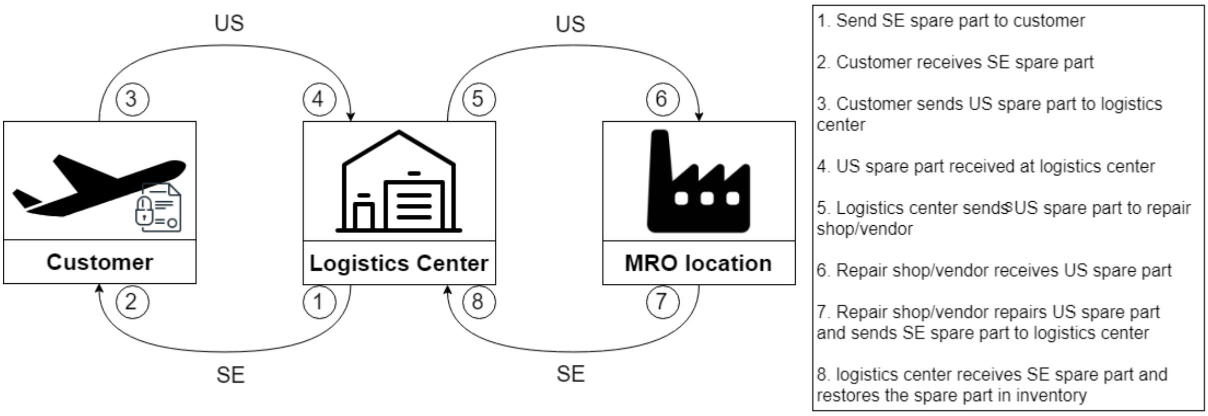

Figure 1.2: Closed-Loop Supply Chain of rotable aircraft spare parts

1.4. An additional loan and exchange service

Some large MRO service providers, like KLM E&M, offer an additional loan or exchange service besides ensuring spare part availability for POOL and contracted customers. At KLM, this service is managed by the so-called loan desk. The goal of this additional service is to gain additional revenues and improve the utilisation of spare parts. In 2018, the additional revenue gained by the loan desk equalled approximately €1,5 million. The demand for spare parts in order to perform aircraft MRO services has a sporadic nature and consists of large zero demand periods [15]. Due to the large variety of spare part components, this sporadic demand behaviour leads to high holding costs. This is the main reason for introducing a loan or exchange service. The loan desk enables external customers, non-POOL and non-contracted, to borrow a spare part from KLM. In return for this service, the external customer has to pay a predetermined loan fee. After the predetermined borrowing period, the borrowed component should be returned to the loan service provider, otherwise the customer has to pay an extra fee for each additional day. At KLM E&M, the same inventory source is used for the fulfilment of both contracted and external customer requests. In contrast to contracted customers, KLM has no supply obligation to external customers. At the loan desk, spare part requests from external customers are solely offered in case they are found to be available. This decision is of huge importance, as wrong decision could result in spare part unavailability for contracted customers. As KLM is obligatory to supply spare parts, a spare part is borrowed or purchased in case the, by the contracted customer, requested spare part is not available.
Besides increasing the utilisation rate of spare parts and increasing profitability, providing a loan service allows other airliners or brokers to adapt flexible strategies, as this service provides a back-up in case of a stock-out. Furthermore, loaning a spare part to an external customer who is in need of a component might improve the loyalty between the two companies. This could be important in future situations when KLM is in need for a particular spare part. If the relation between companies is good, the willingness to loan or exchange could be higher. In Figure 1.3 the closed-loop supply chain of rotable aircraft spare parts is presented. Here, the satisfaction of external demand is included.

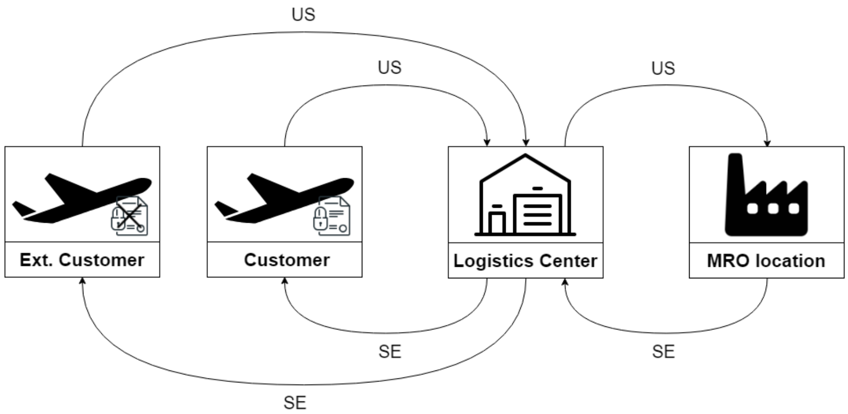

Figure 1.3: Closed-Loop Supply Chain of rotable aircraft spare parts including external customers

1.5. Problem description

The system investigated for this study consists of a single inventory source that satisfies two types of demands. The first demand category consist of *POOL and contracted* demand. KLM E&M is responsible for ensuring component availability for these customers according to contracts with customers, the so-called Service Level Agreements (or SLA). In SLAs criteria such as the minimum percentage of on-time deliveries, Service Level (or SL), are defined. In 2017, in total 10.223 requests from POOL and contracted customers were satisfied from the MLC storage location at Schiphol Oost, whereof 1.879 were not delivered on time according to the SLAs. This resulted in an average SL of 82% in 2017. The average target SL that should be achieved according to SLAs equals 94,7%. According to an interview with interviewee E (Appendix A.5), Boeing 737 supply chain specialist, this sub-optimal performance is mainly due to poor administration which leads to logistic delays and slow component turn around times. Moreover, in many situations, KLM was not able to supply requested spare parts from the POOL inventory. According to an interview with interviewee C (Appendix A.3), KLM Boeing 737 borrow specialist, in general when there is no inventory available at the requested date, the request is placed on hold for a period of maximum five days in which the requested spare part may become available. When the requested spare part is still not available, a component is borrowed, exchanged or purchased from a third party loan service provider. For the Boeing 737 aircraft type, this happened in 14% of all requests in 2017. Such situations are not desired as borrowing spare parts is highly expensive and therefore negatively effects profit. The second demand category that could be fulfilled from the POOL inventory is the demand from *external* customers, which is handled by KLM's loan desk. For this demand, KLM E&M has no supply obligation.

MRO service providers who offer an additional loan/exchange service must be aware of the unintended negative effect of this service on component availability regarding POOL and contracted customers. The negative effect on component availability should be minimised. Especially, the additional cost due to purchases and borrows caused by the providence of a loan service for external customers should be limited. On the other hand, a loan or exchange request is an opportunity to gain extra income and increase the utilisation rate of a spare part. Therefore, a well considered trade-off between: the risk of a shortage due to loaning or exchanging a spare part, and on the other hand the opportunity of gaining additional revenue should be made. In other words, the strategy of a loan desk should result into an operational balance between both processes in order to improve overall performance of KLM Component Services. Performance is in this case related to limiting the negative effect on component availability regarding POOL and contracted customers, more specific: the effect on SL and number of back-orders (borrow-in, exchange-in or purchase), and on the other hand increasing the profit generated by the loan and exchange service.

According to an interview with interviewee E (Appendix A.5), supply chain specialist at KLM E&M, there is an imbalance between both processes (contracted versus external customer demand satisfaction). In some cases, a shortage occurs due to loan and exchange orders at KLM's loan desk. This results in an increase in purchase and borrow expenses and a decrease in SL regarding POOL and contracted customers. In order to measure business performance, comprehensive Key Performance Indicators (or KPIs) are needed. According to literature, in many companies decisions are based upon the department's own constraints. By optimising locally within business departments, a global system optimum for the company cannot be achieved [18]. Therefore, there is a need for companies for an approach which enables integrated supply chain decision making. According to an interview with interviewee E (Appendix A.5), the currently used KPIs are not comprehensive to do so. Currently, no KPIs take into account the interactions between both processes.

1.6. Objective and research questions

The *objective* of this study is to evaluate potential performance improvement strategies for loan service providers. In addition, a recommendation should be provided for the loan desk of KLM Engineering & Maintenance Component Services. Strategies must aim to improve the contribution of KLM's loan desk to the performance of Component Services. Besides aiming to increase profitability, developed strategies should focus on controlling the interaction between both the fulfilment of contracted and external demand. More specific, the goal of a developed strategy should be to limit the negative effect on component availability that result in additional borrow or purchase expenses. To achieve this, the following *main research question* is formulated:

"What strategic improvement option(s) should be employed in order to increase the contribution of KLM's loan desk to the performance of KLM Component Services?"

In order to answer the main research question, the following *sub research questions* need to be answered:

1. What is the current state of KLM's loan desk and what are the characteristics of the system?
2. How can performance be defined regarding KLM's loan desk?
3. Which performance improvement strategies are most relevant to KLM's loan desk?
4. Which performance metrics should be used to evaluate potential improvement strategies?
5. What recommendations can be made regarding the developed strategies for KLM's loan desk?

1.7. Thesis methodology

To answer the presented research questions, a systematic methodology has been set up. The methodology is described below.

- *Problem description:* First, the problem and objective were identified. Furthermore, research questions are formulated and the project is scoped.
- *System description and performance:* The system description is determined to gain insight in the total system and sub-systems. System interactions are described by causal diagrams, and decision making procedures are presented. In addition, the loan and exchange market is explored, where demand and customer characteristics are presented. To complete the system description, the currently used performance metrics are described and current state performance is assessed.

- *Strategy exploration:* Based on the results of the previous step, improvement strategy direction are explored based on the goal and vision of the loan desk. Hereafter, the improvement strategy directions are evaluated. The most promising improvement strategy direction is chosen, which is elaborated in the next research stages. In addition, performance metrics are determined at this stage.
- *Strategy specification:* After re-scoping and selecting the most promising improvement strategy direction, strategies are specified. Before specifying strategies, spare part characteristics are discussed. These are used in the strategies.
- *Experiment and evaluation:* Next, an experiment is set up in order to evaluate the specified strategies. First, the system and strategies are conceptualised. Hereafter, a simulation model is constructed. The simulation results in combination with calculations are used to evaluate the most promising strategies.
- *Conclusion and recommendations:* The conclusion provides answers to the sub questions and main research question. Also, recommendations are provided regarding strategies and further research. Furthermore, an agenda for further research is presented.

1.8. Thesis outline

In Chapter 1, the problem and objective of this research are described and research questions are presented. In Chapter 2, the current state situation is described. Here, the system description is presented and the current state performance is assessed. Furthermore, this chapter provides a loan and exchange market exploration. In Chapter 3, potential improvement strategies are explored and evaluated. Here, the project is re-scoped and the most promising strategies are determined. In addition, in this chapter performance metrics in order to evaluate the strategies are developed. In Chapter 4, spare part characteristics are analysed and a cluster analysis is performed. After this, the selected strategies were specified. In Chapter 5, the system and strategies are conceptualised. Hereafter, the model implementation is presented as well as the verification and validation of the simulation model. In Chapter 6, the experimental plan for evaluating the developed strategies is presented. In addition, this chapter provides the model results. In Chapter 7, the conclusions are presented by answering the presented research question. In addition, limitations of the research and recommendations for KLM Component Services are presented as well as an academic and personal reflection.

1.9. Scope

This study aims to advice KLM about performance improvement strategies for KLM's loan desk. As the aim of the research is rather broad, the project is scoped. This research does not focus on lowering turn around times. Furthermore, solely rotable spare parts are taken into account for this research. As the number of spare parts is enormous, this study focuses solely on B737 spare parts. This aircraft type will be used in the future by KLM and has a large market share at KLM's loan desk. However, the proposed strategy should be applicable to all air frame types. As explained earlier, in Chapter 3, the thesis is re-scoped in Section 3.5. There are many improvement strategies possible, which makes it impossible to research all strategies. Therefore, improvement strategies are prioritised and the most premising options are further elaborated and evaluated. However, a research agenda is presented in the recommendations.

2
Current state situation

In this chapter, the current state situation of the closed-loop supply chain system, which satisfies multiple demands from a single inventory source, is discussed. First, the system description is presented in Section 2.1. Hereafter, the decision-making policy at the loan desk is described in Section 2.2. Furthermore, Section 2.3 explores the market KLM's loan desk is serving. In Section 2.4, the currently used performance metrics are discussed and performance is assessed.

2.1. System description

In this section, the researched system is described. First, some essential background information about the aviation industry is provided. Hereafter, the system is presented and discussed. Furthermore, the causal relations and interactions of the sub-systems are analysed.

2.1.1. Essential background information

In the aviation industry, all aircraft spare parts (or components) are identifiable by an unique combination of two numbers, namely; Part Number (or PN) and Serial Number (or SN). A PN identifies the part type, while the SN is the unique ID of a spare part. For example, two emergency doors may have the same PN but have a different SN.
Furthermore, aircraft spare parts can be divided in mainly two categories. The first category are rotable spare parts. These type of spare parts are maintained and re-used and are not consumed. However, the re-usability is limited to the component specific life cycle. For this research, the spare part life cycle is assumed to be infinity. The second category are the consumable spare parts. These spare parts are not repairable and can only be used once in an aircraft. An example of a consumable spare part is cabin carpet. As stated earlier, this study solely focused on rotable components. The underlying reason for this is that consumables cannot be borrowed by an external customer since they are not repairable. Consumables can only be sold to external customers.
Other essential background information that needs to be provided is about the status of a component. There are two possible conditions in which spare parts can be divided, namely; Serviceable (or SE) and Unserviceable (or US). Here, SE components are fully functional and can be installed on an aircraft. US components are components that need to be repaired or revised before they can be used in an aircraft. According to aviation regulations, when a rotable component is used in an aircraft, it should be inspected, and if necessary repaired, by doing so the component retrieves it SE status.
Lastly, some background information should be provided about the different types of customers. KLM E&M manages a so-called POOL of spare parts, which means that customers that are part of this POOL or have agreements with KLM share their inventory. In contracts,

agreements regarding supply obligations are laid down. For this study, customers that are not part of the POOL nor have agreements with KLM are called external customers throughout this report.

2.1.2. The closed-loop supply chain system

As stated earlier, the researched system is a closed-loop supply chain system. The system serves two types of demands: from contracted customers and from external customers. A flow chart of the system is presented in Figure 2.1. In this figure, a distinction is made between physical spare part flow and information flow. Here, physical spare part flow is indicated with a truck symbol. The boxes in the figure provide information about the processes at each stage of the closed-loop supply chain.

The first sub-system is about *the satisfaction of POOL and contracted spare part demand.* In the flow chart, this sub-system can be identified in the upper line in the system boundary box. This process starts with a request for a rotable spare part from a POOL or contracted customer. In case the, by the contracted customer, requested spare part is available at the storage location, the spare part is released form inventory and shipped to the customer. At KLM, the Magazijn Logistiek Centrum (or MLC) storage location is established at Logistics Center (or LC) at Schiphol Oost. Here, solely serviceable spare parts are stored. After KLM has supplied a serviceable spare part, the customer returns an unserviceable spare part to KLM. The returned unserviceable spare part is removed from the customer' aircraft while the received serviceable spare part is installed. The, by the customer returned, US spare part enters the LC via the expedition area. Here, the US spare part flow is distributed over the Repair Administrators (or RA) based on air-frame type. The RA inspects the returned component and performs some administration activities. Furthermore, the RA determines to which repair location the US component should be transported for the repair process. Hereafter, the component is moved back to the expedition area of the LC, where the component is temporary stored before it is shipped to the repair location. The transport duration is dependent on the repair location. About 50% of the spare parts is repaired at a Repair Shop (or RS), which are located at Schiphol Oost. For the other 50% of the spare parts the repair is outsourced and performed at a vendor. Vendors are located at various locations around the world, which increases transportation time. After transportation, the component arrives at the repair location where the component is repaired and receives its SE status again. After the repair process, components are send back to the LC where they are restored at the MLC storage location. Again, components enter the LC via the expedition area. SE components are now distributed to the corresponding Inspector Incoming Goods (or IIG) based on air-frame type. The IIG inspects the spare part and performs several administration tasks. When the component passes the inspection, it is restored at the MLC. Again, solely SE components are stored at the MLC. However, in some cases the requested spare part is not available at the storage location. According to service level agreements (or SLAs) a request of a contracted customer must be fulfilled as KLM has a supply obligation. According to an interview with interviewee C (Appendix A.3), KLM B737 borrow specialist, in general the request is fulfilled by back-ordering in case the requested spare part does not become available within five days after the request date. Back-orders are performed by KLM's borrow department. The requested spare part is borrowed or purchased from an external loan service provider. This results in back-ordering costs.

The second sub-system is about *the satisfaction of spare part demand from external customers.* In Figure 2.1, this demand can be identified in the middle line. KLM has no supply obligation nor SLAs with external customers. All requests from external customers are handled by KLM's loan desk. Here, employees decide whether the spare part request from an external customer can be fulfilled or not. At the loan desk, three types of requests are handled. The first request type is a *loan* request. Here, the customer borrows a spare part with a specific PN and SN for a predetermined time period. After the borrowing period, the customer must return the exact same spare part. In other words, the returned spare part should have the same PN and SN as the supplied spare part. The second request type is an *exchange* request. Here, the customer receives a spare part with requested PN and returns an US spare part with the same PN. So, the return unit does not have to have the same SN as the supplied spare part, in other words an interchange of spare parts takes place at the location of the customer. In general, lead time between supply of the SE spare part and receiving the US return unit is shorter for this order type compared to loan orders. The last request type handled by the loan desk is a *purchase* request. In this case, the external customer wants to buy a component from KLM. For this order type, the spare part does not return to KLM.

With the request types in mind, the second sub-system can be described. For the first two order types, loan and exchange, a SE spare part is released from the MLC and moved to the expedition area of the LC, where the component is temporary stored before it is shipped to the customer location. In case of a loan order, the spare part stays at the customer for a predetermined borrow period. After this period, the customer returns the exact same spare part, with the same PN and SN, to the LC. Here, the component is temporary stored at the expedition area of the LC. Hereafter, the component is moved to the Return After Loan (or RAL) desk, which is located at the LC. At this location, an employee inspects whether the returned US spare part has the correct PN and SN. In addition, some administrative tasks are performed. The employee places a repair order at the corresponding repair shop or vendor. Now, the component is moved to the expedition area again, where it temporary stored before being shipped to the repair location. At this point, the return after loan component flow has merged with the US return spare part flow from contracted customers. So, the same processes are executed from this point. The spare part goes through the repair process receiving its SE status again. Hereafter, the component is send to the expedition area at the LC. According to air frame type, the component is now send to the IIG, where the component is inspected and some administration tasks are performed. Next, the SE spare part is restored at the MLC. The same process steps are executed for exchange orders. However, in case of an exchange, the return spare part has the same PN but has a different SN compared to the supplied component. Again, in most cases the lead time between supply of a SE component and receiving an US component is shorter in case of an exchange. In order to clarify the processes at the logistics centre, Figure 2.2 graphically shows the physical component flow at LC.

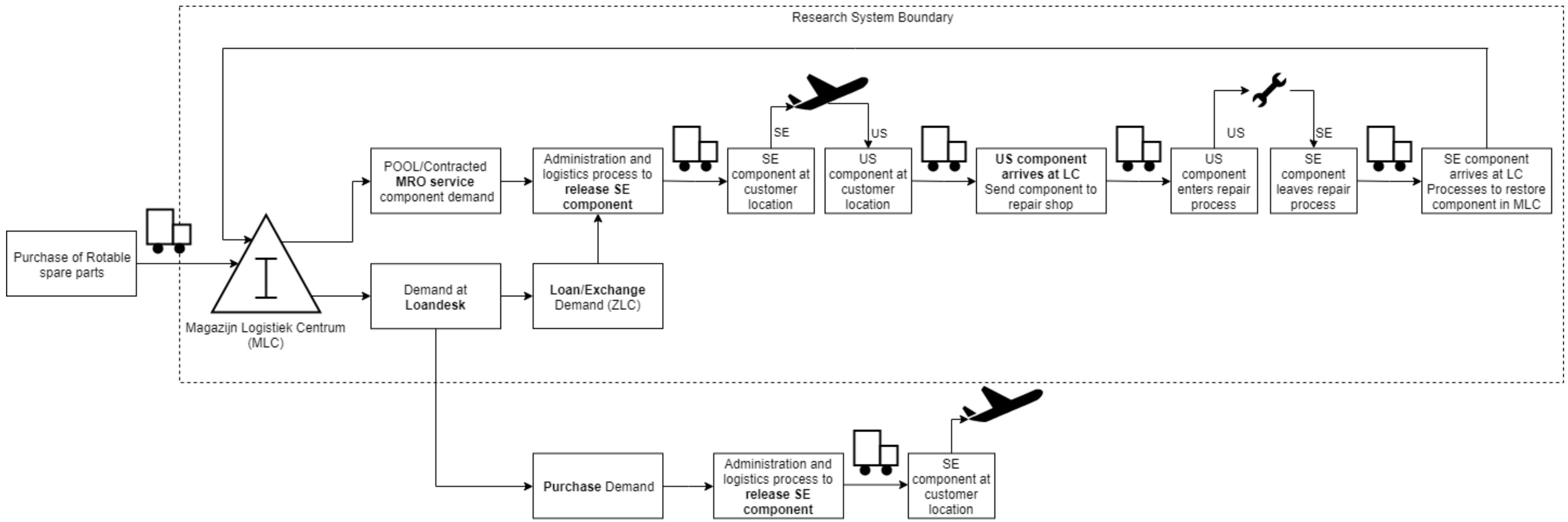

Figure 2.1: Rotable spare part flow

2.1.3. System boundaries

The aim of this research is to investigate possible improvement strategies for a loan service in a closed-loop supply chain system serving multiple demands from a single inventory location. Here, components are assumed to be endlessly repairable, which results in zero scrapped spare parts. Furthermore, the flow of purchased components by KLM is not taken into account for this research as well as sold components. In short, the total number of spare parts in the system is constant. The system boundaries are presented in Figure 2.1.

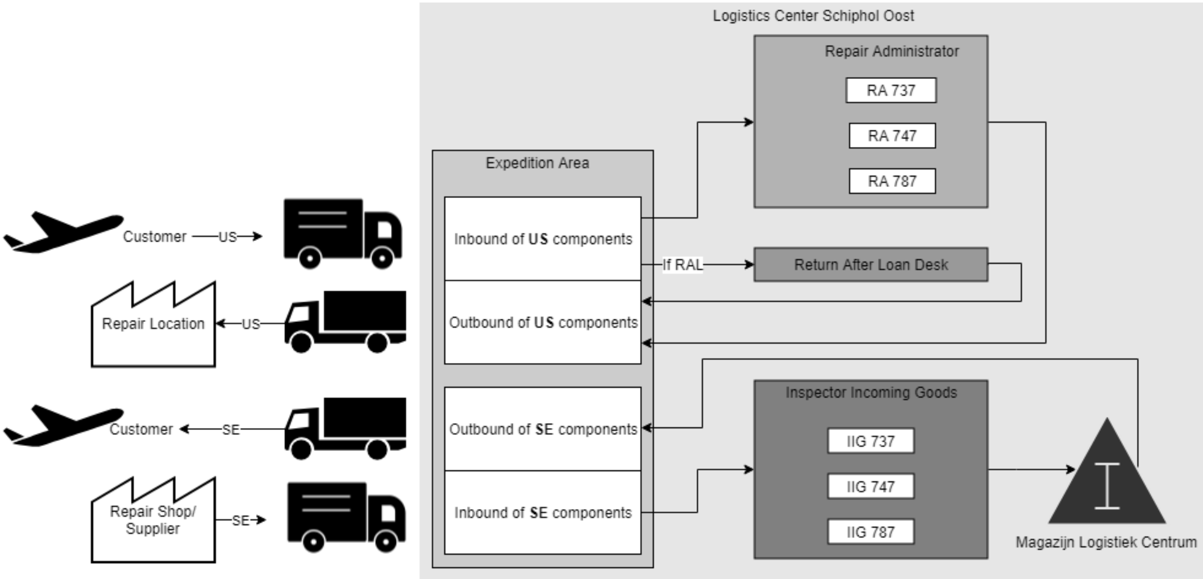

Figure 2.2: Physical spare part flow at the logistics center

2.1.4. Causal relations

In this section, the causal relations and interactions of the system presented in Section 2.1.2 are discussed. It is important to understand complexity of systems in order to develop better operating policies and strategies, which results effective change [46]. To make a complex system understandable, a causal relation diagram can help. Furthermore, causal maps can be used by managers to find the root cause of a problem, find critical control points and guide risk management [43]. Besides problem-structuring, causal maps are used to find a set of potential strategic options to improve a system [34]. A causal diagram consists of nodes and edges. Here, nodes represent variables and edges indicate relations between variables. In addition, the map has a structure of causes and effects [34]. An edge can either be positive or negative. A positive edge indicates that an increase in a variable results in an increase of the other variables as well, while a negative edge indicates that an increase in a variable results in a decrease of the other variable. There are only two basic methods for creating causal maps, namely: brainstorming and interviews [43]. Therefore, brainstorm sessions as well as interviews were organised in order to construct a causal diagram for the investigated system. Brainstorm sessions and interviews were organised with interviewee A, who is the Aircraft On Ground (or AOG) and loan desk manager of KLM. Additional interviews and brainstorm sessions were executed with interviewee E, who is supply chain specialist and responsible for ensuring component availability of the Boeing 737 air frame type. By including both interviewee A and interviewee E, sufficient expertise from both sub-systems is obtained in order to construct a causal diagram for the investigated system. In the first brainstorm round, the system variables were determined. During the second round, relations were indicated. And the last round was used to determine the sign of the edges. After each session, a discussion took place in order to evaluate the results and detect the important variables and relations. Besides validating results with interviewee A and interviewee E, literature is consulted to validate the obtained relations. In total, three causal maps were constructed.

The first causal map is about the satisfaction of POOL and contracted demand. This causal map is presented in Figure 2.3. First, the goal variables were determined which are: *profit* and *service level*. In the figure, the goal variables are displayed in bold. The first goal of the sub-system is profit maximisation. Besides aiming at maximal profit, the goal of this process is to meet the contracted SL. Next, the variables that have an effect on the goal variables were indicated. The first identified variable is *inventory level*. This variable has an effect on both goal variables. One can imagine that a higher inventory level results in less shortages and therefore an increase in SL. So, the relation between inventory level and service level is positive. However, a decrease in SL could result in a decrease in profit. This is due to the spare part supply obligation for POOL and contracted customers. In case a requested spare part is unavailable, KLM must borrow (back-order) a component in order to satisfy the demand. This increases back-order costs and has a negative influence on profit. Furthermore, an increase in inventory level results in higher holding costs, which has a negative effect on profit. Another identified variable is *spare part demand*. An increase in demand results in an increase in the number of *fulfilled orders* assuming there is sufficient inventory of the requested spare part. So, in case more demand is satisfied, *inventory level* decreases, while *profit* increases. By studying the causal diagram, it was found that the most important trade-off is made between holding sufficient inventory to satisfy demand and on the other hand minimising inventory to reduce holding cost. Now, other variables influencing *inventory level*, besides *fulfilled orders*, are determined. The first variable influencing inventory level is the *Turn Around Time* (or TAT) of a spare part. As explained in Section 2.1.2, the researched system is a closed-loop supply chain. So, each part that leaves the inventory, returns after the total TAT. In case the TAT of a spare part is lower, the moment a spare part is restored in inventory is earlier. Therefore, a decrease in *TAT* has a positive effect on *inventory level*. The second variable influencing *inventory level*, is the *purchase of spare parts*. Buying spare parts results in an increase in *inventory level*. However, buying spare parts costs money and therefore has a negative effect on *profit*.

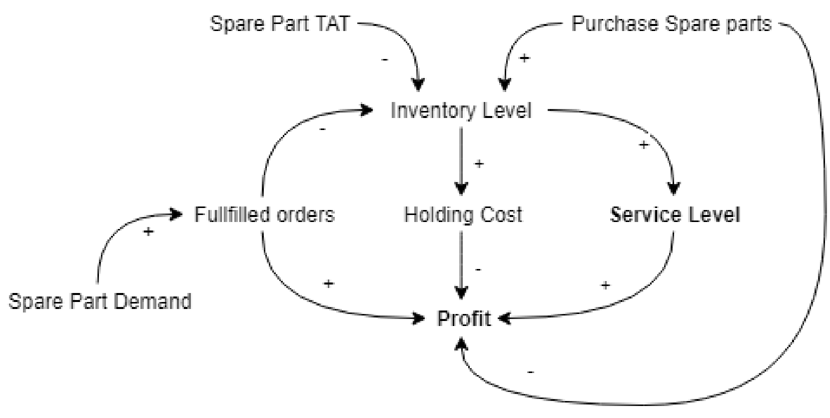

Figure 2.3: Causal map POOL/Contracted demand satisfaction

The second constructed causal map is regarding the satisfaction of loan/exchange demand from external customers. The causal map is presented in Figure 2.4. First, the goal variable is determined, which is *profit*. For this sub-system, the same variables related to *inventory* as for the POOL/Contracted demand satisfaction causal map were indicated, these are: *holding cost*, *purchase of spare parts* and *spare part TAT*. The cause effect relation of these variables is discussed earlier and therefore not explained in paragraph. However, in this causal map, *inventory level* is also related to the *responsiveness* of the loan desk. Responsiveness is about the ability of a company to positively and rapidly respond to customers' needs [17]. Here, responsiveness is about the ability of the loan desk to offer a spare part within a short amount time. At the loan desk, response time is important as there are multiple loan service providers around the globe, such as Lufthansa. The ability to be responsive is mainly related to the availability of spare parts or *inventory level*. An increase in on-shelf inventory level increases the responsiveness of the loan desk, while the probability of a stock out or critical stock situation decreases. Furthermore, an increase in *responsiveness* has a positive effect on the external customers' hitrate. This is the ratio between the number of orders and the number of requests quoted to the external customers. In other words, the quote acceptance rate of the external customer. Responsiveness in terms of reply speed by KLM's loan desk has a positive effect on the hitrate due to the fact that external customers urgently need a spare part. Customer would not use such expensive service in case the urgency is low. As the urgency is high, the customer is likely to request the spare part at different loan service providers, hoping for a fast reply. Therefore, the conclusion can be drawn that response speed is important. Furthermore, an increase in *responsiveness* could result in an increase in *demand*. It is likely that a customer returns when previous experiences with the service were positive. The variable *hitrate* is also related to the *quoted price* variable. The quoted price to the customer is a fee as percentage of the value of a component. Here, a lower price results in a higher probability of a quote being accepted by the customer, and therefore an increase in hitrate. In case the *hitrate* increases, the satisfied spare part demand from external customers increases, which results in a higher *profit*. Besides *hitrate*, the *price* a customer pays for a component is related to *profit*. A higher price paid for a component results in a higher profit.

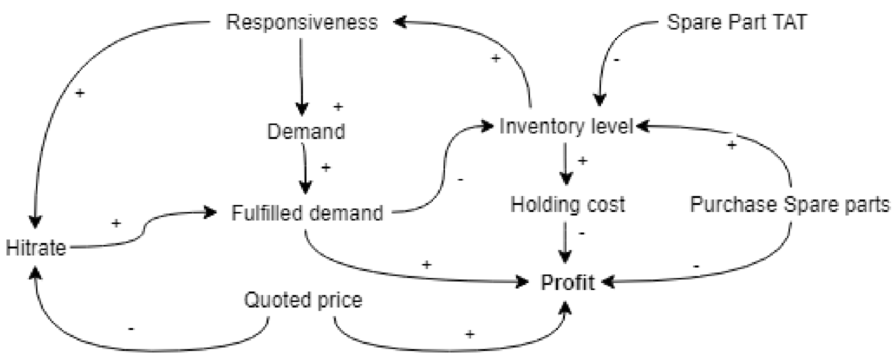

Figure 2.4: Causal map loan/exchange demand satisfaction

Based on the presented causal maps of both sub-systems, an integrated causal map for the total system is constructed. The causal map is presented in Figure 2.5. In the figure it is important to notice that both systems satisfy demand from the same inventory source. Therefore, satisfying demand from external customers could negatively effect SL. However, the satisfaction of demand of external customers has a positive contribution to the profit variable. To conclude, the decisions whether to loan a spare part and against which fee are of high importance.

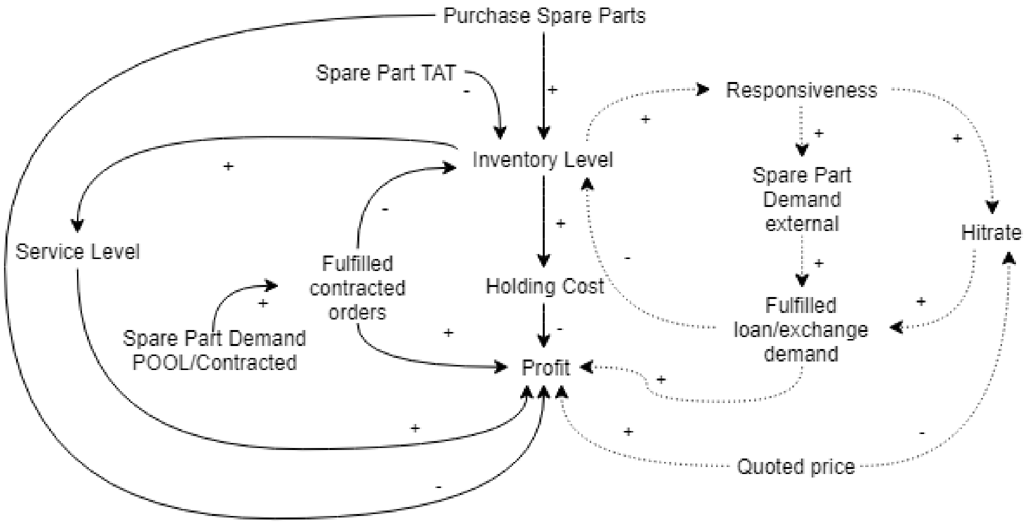

Figure 2.5: Causal map of a the total closed-loop supply chain system

2.2. Procedures and decision-making at KLM's loan desk

In this section, the loan desk is further explored and described. The focus lies on procedures and decisions made at the front office, where the requests from external customers are handled. At the loan desk, there are no general decision rules nor standard procedures when handling an external customer request. This makes it hard to understand the processes at the front office. Human decision making cannot be understood by researching final decisions. Human decision making is based on factors such as: perceptual, emotional and cognitive processes which in the end result into a decision [47]. A Verbal Protocol Analysis (or VPA) can be used to map complex decision making procedures [30]. The employees at the loan desk were asked to think aloud while performing their tasks. Based on the obtained empirical information retrieved from the employees, decision trees were constructed. A decision tree can be used to structure human decision making [37]. It enables to investigate which attributes and in what manner attributes influence the human decision.
At KLM's loan desk, mainly three procedures were detected: 1) request selection, 2) Component availability decision and 3) Pricing. The procedures are discussed throughout this section by presenting the decision trees. In the decision trees, actual decisions are indicated with a diamond shaped box, while steps in the procedure are indicated with a regular box.
Before discussing the procedures, some background information about KLM's loan desk needs to be provided.

2.2.1. Background information

KLM's loan desk enables external customers to borrow or exchange rotable spare parts. The front office, where all requests from external customers are handled, is located at the Operational Control Center (or OCC) at Schiphol Oost. The loan desk is open from 7:00AM until 11:00PM. At any moment during opening hours, there is at least one employee working at the loan desk. In Figure 2.6, a more detailed version of the system is presented. In the figure the information flow and physical spare part flow are separated. This section elaborates on the lower part of the information flow box of the figure. So, the interaction with external customers, spare part availability decision and the pricing methodology.

2.2.2. Request selection

On a daily basis, the loan desk receives about 100 requests. All requests are received in a central mailbox, where all employees at the front office have access to. The process at the loan desk starts by selecting a non-opened request from this mailbox.
The first factor that influences the selection of a request from the mailbox is *experience*. Based on previous experiences with customers, the employee has developed a preference for some customers. For example, requests from customers that regularly return to KLM's loan desk are more likely to be selected. Another influencing factor in selecting request are the employees of the Aircraft On Ground (or AOG) desk. In some cases, the employees at the loan desk asks whether the AOG desk has good experiences with the customer. The following airliners are in general perceived as good customers: Transavia Airlines, Delta Airlines, Cargolux Airlines, AirBridgeCargo Airlines and Atlas Air.

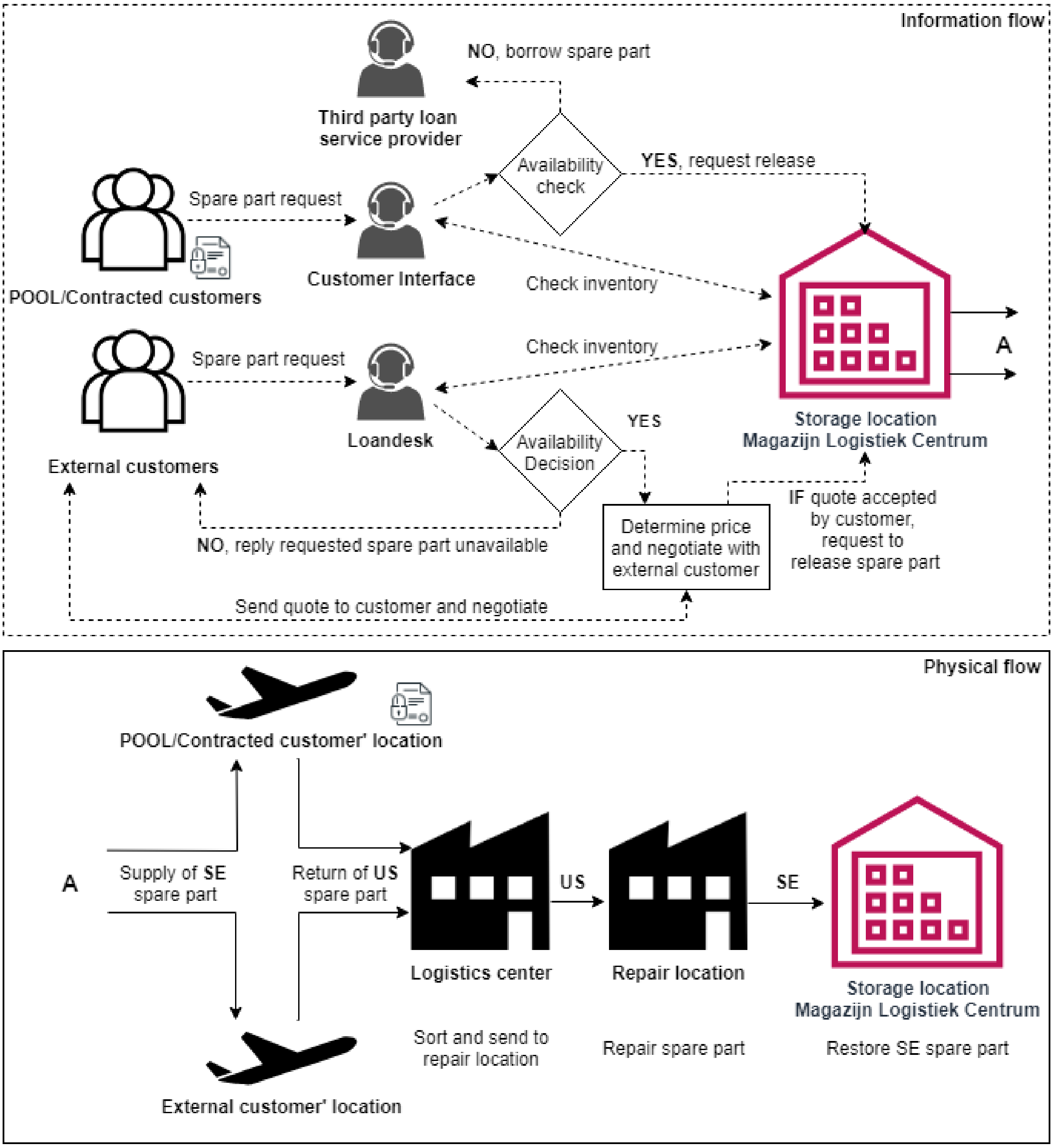

Figure 2.6: Detailed system description

Besides the feeling and experience an employee has with a particular customer, the employee takes into account whether the request is send to *solely KLM's loan desk* or to multiple loan service providers. Employees state that the probability that the spare part is ordered increases when the customer solely placed the request at KLM's loan desk. This is due to the fact that other loan service providers might react faster. Therefore, the demand might be satisfied before the loan desk has replied to the customer. So, priority is given to requests solely addressed to KLM. It could happen that based on the number of addressed service providers and past experiences with a particular customer, the employee rejects the request. In this case, the employee logs the characteristics, such as: PN, customer, date of the request. After selecting a request, the availability decision for the requested spare part is performed, this process is described in paragraph 2.2.3. Figure 2.7 shows the request selection procedure.

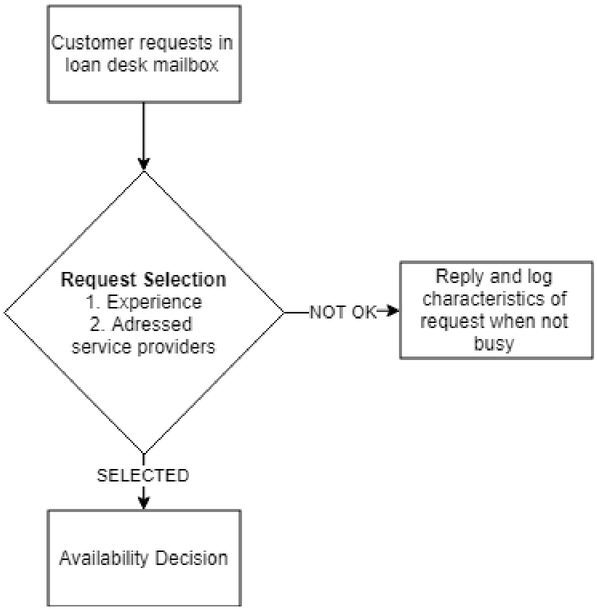

Figure 2.7: Request selecting procedure

2.2.3. Responsiveness and component availability

After selecting a request from the mailbox, the employee checks whether a component is available for loan or exchange. First, the employee checks whether the PN is know. In case a PN is unknown, KLM does not own such spare part and is therefore not available. In this case, the employee replies to the customer that the requested PN is not known and logs the characteristics of the request. In case the PN is known, a credibility check is performed in order to check whether the external customer has not exceeded its credit limit. When the customer does not pass the credit check, the credit department is contacted in order to check whether the credit limit for that customer can be increased. When the credit department does not agree with the request to increase the credit limit, a response is send to the customer to inform the customer that the credit limit is exceeded. Again, the employee logs the characteristics of the request. In case a new customer requests for a spare part, the credit department has to grant credit as well. When the customer passes the credit check, the actual availability decision takes place. For this decision, the following attributes are taken into account:

1. Planning number
2. On-shelf inventory level
3. Time in inventory
4. Component value
5. Number of cycles
6. Repair history

First, the *on-shelf inventory level* is retrieved by the employee. When there is zero stock of the requested PN, the employee replies that the component is not available and logs the characteristics of the request. In case there is SE stock available, the employee checks the *planning number*. This number indicates the advised total circulation stock of that particular spare parts, in order to satisfy POOL and contracted demand. This number is calculated once a year by KLM's supply chain team. Here, the ratio between inventory and planning is important in deciding whether a component is available or not. Based on experience, the employee interprets this ratio. This is the most influencing attribute in the availability decision. The empirical probability that the employee determines that a component is available increases when the on-shelf inventory level exceeds the planning number. However, currently there are

no decision-rules for the component availability decision. It is fully based on experience and feeling. In addition, when the employee doubts whether a component is available, the supply chain team is contacted for advice. The third attribute that influences the decision is the *time in inventory*. In case, the time period for which the SE spare part is in inventory is interpreted as long, the empirical probability for offering a spare part to the customer increases. While for components that are restored recently, the willingness to loan or exchange decreases. This line of reasoning is based on the thought that components that are stored for a longer period are less likely to be requested by POOL or contracted customers. Furthermore, the loan desk employee roughly estimates the *component value*. As the loan or exchange fee is based on the component value, and therefore increases for more valuable spare parts, the empirical probability of offering the spare part increases for more valuable components. The fourth and fifth availability decision influencing attributes are about the technical specifications of a spare part. First, the employee checks the *number of cycles* a spare part has made. In case the loan desk employee interprets the number of cycles low, the empirical probability of offering the component decreases. This is due to the fact that these components are relatively new, and may be bought with a POOL or contracted customer related purpose. Moreover, the repair history of the spare part is investigated. Here, employees especially pay attention to expensive repairs. In case a component is recently repaired for a, by the employee interpreted, large amount of money, the empirical probability of offering a spare part decreases.
The component availability procedure is presented in Figure 2.8. In addition, Figure 2.9 displays the decision influencing attributes and the relation to the empirical willingness to loan or exchange. Here, a plus indicates a positive contribution while a minus indicates a negative contribution to the willingness to offer a component. In Figure 2.6, the availability can be noticed in the lower line in the information flow box.

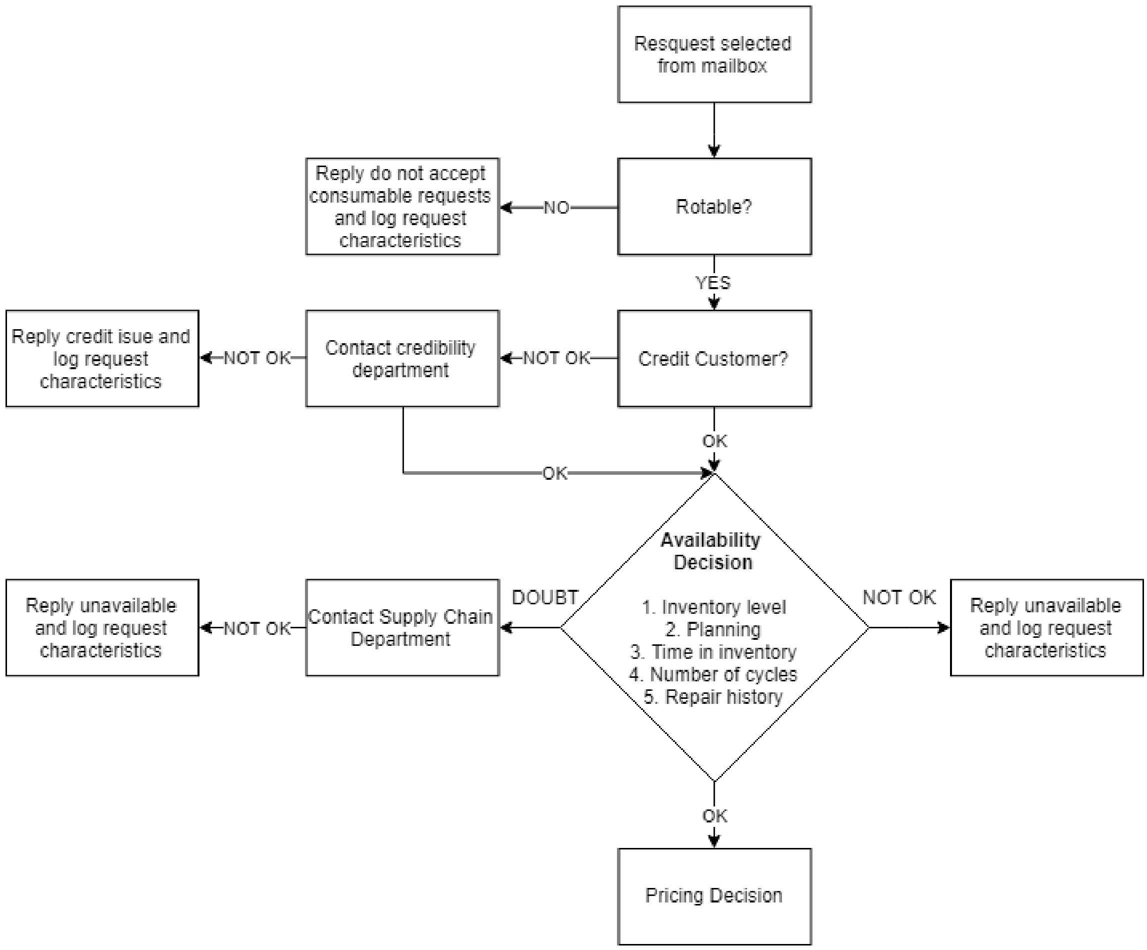

Figure 2.8: Component availability decision procedure

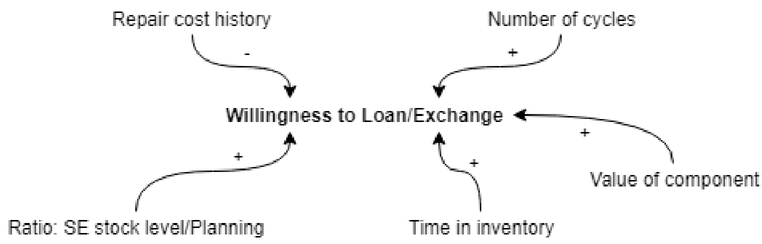

Figure 2.9: Causal effect map of availability decision influencing attributes

2.2.4. Pricing and spare part selection

When a spare part is found to be available for loan or exchange, the loan desk needs to determine the fee for the provided service. Furthermore, in case there are more than one components in inventory available for loan or exchange, a components should be selected to fulfil the demand. A component is selected based on the following attributes:

1. Repair history
2. Age of the component
3. Time in inventory
4. Number of cycles

Here, the employee has a preference for components that have no recent repair costs, are for a long time in inventory, are old and have made many cycles.
After selecting a component, the value of the component is estimated. This is done based on the Latest List Price (or LLP) and the price KLM paid for the component. Furthermore, an employee may increase the component value in case it is recently repaired for a large amount of money. For determining the loan or exchange fee, a distinction between external customers is made. Some external customers have agreements with KLM regarding these fees and have a Customer Support Manual (or CSM). For non-CSM customers, the loan desk employee can set the fee on any value. In general, loan fees are calculated according to a three stage (stage 1: 1-10 days, stage 2: 11-30 days and stage 3: 30+ days) pricing method, which is common in the industry. Formula 2.1 presents this method for loan orders.

$$f_{loan}(d) = \alpha + CP \cdot \frac{\sum_{n=1}^{3} \beta_n \cdot d_n}{100} \tag{2.1}$$

Here, CP presents the component price or LLP, α is the loan start-up fee, β represents the loan fee for loan stage n and d is the number of days of a loan in loan stage n. For exchange orders, the pricing method is different. Formula 2.2 presents the pricing method for exchange orders.

$$f_{exchange} = \alpha + CP \cdot \frac{\beta}{100} \tag{2.2}$$

Here, CP presents the component price or LLP, α is the exchange start-up fee and β represents the exchange fee.
After determining the price, a quote is send to the customer. The loan desk employee awaits the reaction of the external customer and starts working on another request. At the moment the customer replies and accepts the quote, the physical flow of the requested spare part is initiated. The component pricing and selecting procedure is presented in Figure 2.10.

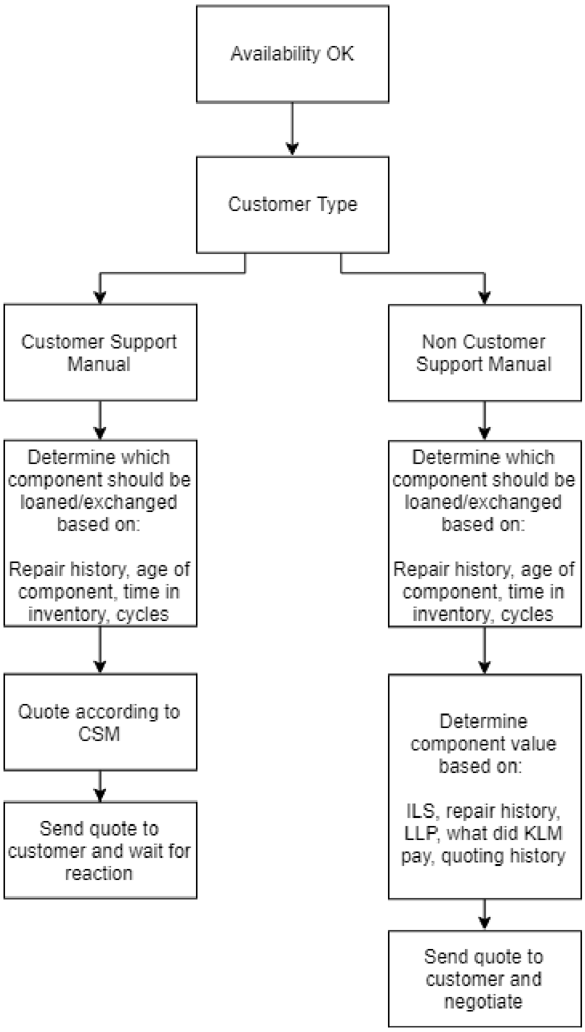

Figure 2.10: Component pricing and selecting procedure

2.3. Exploring the market KLM's loan desk is serving

This section explores the demand driven market in which loan/exchange service providers are operating. Market-oriented business units seem to achieve a higher level of performance. For service providers, like KLM's loan desk, quality of the service has a significant impact on performance. Service quality is found to be the most influential factor on performance [9]. For service providers, it is found that service quality has a strong effect on customers' loyalty to the company and a negative effect on the probability to switch from service providers [51]. Managing customer relations requires gathering adequate information from these customers for determining and implementing effective strategies. This highlights the importance of market research in service industries [3]. In the context of a loan service provider, customers' needs refer mainly to responsiveness as explained in Section 2.1.4. In this section, the market KLM's loan desk serves is orientated. First, some demand characteristics are presented. Hereafter, characteristics of the external customers are presented. Lastly, order characteristics are analysed and evaluated. For the performed analysis, several data sets provided by KLM are used. Throughout this section, the used data sets are indicated. A description of all data sets can be retrieved from Appendix B.

2.3.1. Market demand size

In this paragraph, the loan and exchange market demand is explored. This is done based on historical log data collected by the employees at KLM's loan desk. A description of this data set can be retrieved from Appendix B.1. First, the total weekly demand for rotable spare parts is investigated. Not all requested part numbers are known at KLM. Such requests are not 'useful' as these requests cannot be fulfilled. In addition, KLM's loan desk does not offer consumable spare parts. Therefore, these requests are also not 'useful'. So, after presenting the total demand size, the useful demand is investigated. In other words, the demand that could potentially be fulfilled by KLM's loan desk. Furthermore, the demand per air frame type is presented.

In week 1-44 of 2018, 13.688 requests were logged by employees at KLM's loan desk. As this study focuses solely on the loan and exchange service (so excluding purchases) the number of loan and exchange requests were counted. The total number loan and exchange requests equalled 10.148 for the observed period. From all loan and exchange requests, the requested PN was known in 4.600 cases. As explained earlier, KLM's loan desk solely provides a loan or exchange service for rotable spare parts. From the 4.600 requests of which the PN was known, 3.515 were regarding a rotable spare part. So, during the reviewed period, 26% of the requests were found to be 'useful'. In other words, 26% of all requests could potentially be fulfilled, depending on the availability of the spare part. Figure 2.11 graphically displays the number of useful requests per week for the observed period.

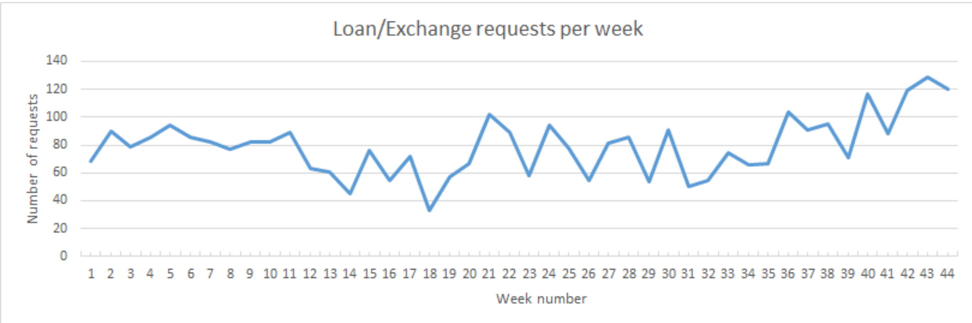

Figure 2.11: Number of request for rotable spare parts with known PN in week 1-44 of 2018

For the observed period, general statistics are generated in Excel. The minimum number of useful weekly requests equalled 33, while the maximum number of useful requests in a week equalled 129. Furthermore, the average demand size per week of useful requests equals 79,3 with a standard deviation of 21.
Next, the demand for spare parts is investigated for different aircraft types. This is done in order to identify differences in demand size per air frame type. Table 2.1 presents the total number of useful requests per aircraft type for the observed period. Note that the most demand is generated by the following aircraft types: B737, B747, B777 and B787. For these aircraft types, Figure 2.12 displays the weekly demand for week 1-44 of 2018.

Table 2.1: Number of rotable spare part requests for which the PN is known from week 1-44 of 2018

Aircraft type	Count request
A320	72
A330/A340	431
B737	757
B747	796
B757/B767	241
B777	497
B787	654

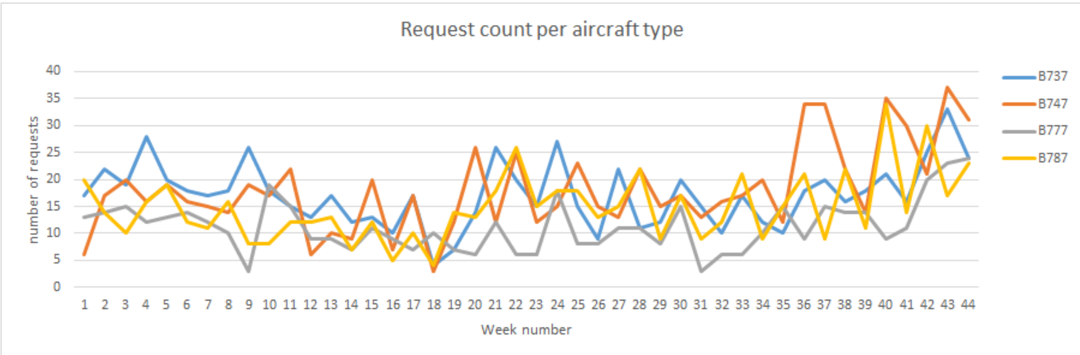

Figure 2.12: Number of request for rotable spare parts with known PN per aircraft type in week 1-44 of 2018

Furthermore, the frequency of the requests per PN is investigated. Most requested PNs, 2.571 of the 3.515, were only requested once during the reviewed period. However, 74 PNs were requested at least 5 times. So, the demand size differs per PN. Figure 2.13 displays the number of requests per PN for spare parts that were requested at least 5 times during the reviewed period.

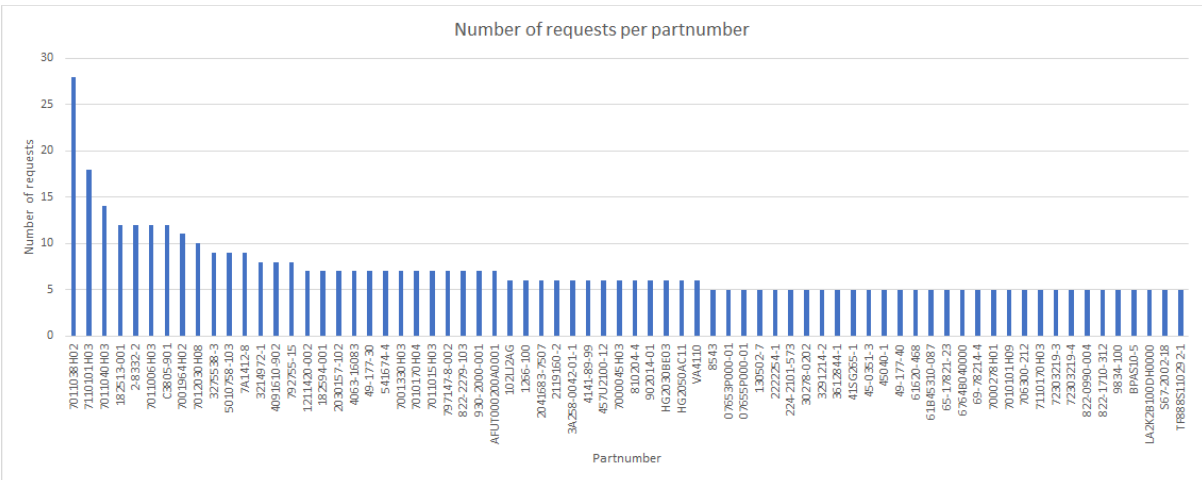

Figure 2.13: Total number of requests per PN in week 1-44 of 2018

2.3.2. External customer characteristics

Besides demand frequencies and demand trends, the characteristics of the external customers KLM's loan desk is serving are explored. First, this paragraph identifies the most important customers. Furthermore, some characteristics of the customers are calculated. First, the total number of requests per customer is counted based on the log data collected by the loan desk. Besides this, the number of requests that were quoted by the loan desk is counted and the total number of orders per customer is counted. In addition, the total income per customer is determined based on finance data from the controlling department, a description of this data set can be retrieved from Appendix B.3. The total income per customer is calculated for week 1-44 of 2018 in order to be able to compare the log data with the finance data. An overview of the obtained customer characteristics is presented in Table 2.2. The table presents: the total income, number of requests, number of requests quoted, number of orders, ratio of orders with respect to the number of quotes (customer hitrate) and the average income per order. Notice that 39 customers ordered a spare part for loan or exchange at KLM's loan desk. When investigating the characteristics of each customers, large variation between customers is detected. First, it seems that frequently returning customers spend less money compared to customers that occasionally request a spare part at KLM's loan desk. Furthermore, it seems that the order acceptance rate of some customers is higher compared to other customers. For example, the hitrate of Transavia Airlines equals 90%, which makes sense since Transavia Airlines is a subsidiary of AirFrance-KLM.

From the obtained results some general statistics were calculated in Excel. During the reviewed period, 39 customers spend a total of €1.336.439,70 for the loan and exchange services provided by KLM's loan desk. On average customers spend €13.499,39 per order, with a standard deviation of €30.347,14. So, there is a large variation in the amount of money customers spend at KLM's loan desk. The order characteristics are analysed into more detail in paragraph 2.3.3. Furthermore, for all customers, including customers that did not order in the reviewed period, 733 of the 3.515 useful requests were quoted and eventually 99 loan or exchange requests were ordered by the customer. Therefore, the percentage of lost potential orders equals almost 80%. Furthermore, the average probability of accepting a quote equals 13,5%, throughout this report this is often indicated by the term: *hitrate*. In order to find the underlying reasons why this percentage is low, an interview with interviewee C is executed, presented in Appendix A.3. Interviewee C is an employee of KLM's B737 borrowing department. Therefore, she is a customer of other loan and exchange service providers around the globe. She states that the probability of accepting a quote could increase when the response speed decreases. This is mainly due to the fact that customers requesting a spare part at a loan or exchange service provider most likely want to receive the requested spare part as soon as possible, which makes is likely that the customer places requests for the same component at multiple service providers. This is however depending on the urgency of the request. When the urgency is high, multiple service providers are contacted. Here, the service provider with fastest reply is often chosen. In such case, price is of subordinate importance. However, if the urgency is not high, the offered price is considered. Here, urgency refers in most cases to component unavailability that results in additional down time of an aircraft, which is highly expensive. When the urgency is low, a high price decreases the probability of the customer ordering the spare part while lower prices increase the probability of accepting the, by the customer of a loan or exchange service provider, received quote.

Table 2.2: External customer characteristics served by KLM's loan desk

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2.3.3. Order characteristics

Now, the characteristics of the orders from external customers at KLM's loan desk are explored. Four characteristics are analysed by visualising the log and financial data sets (Appendix B.1 and B.3), by means of a boxplot. From the log data set, week 1-44 of 2018 were used. For the financial data set, 2017 and 2018 were used. First, the lead time between ordering a spare part and receiving the return unit at the LC is analysed. In Figure 2.16, a boxplot is present regarding this lead time for both loan and exchange orders. From this figure can be concluded that in general, the lead time of a loan order is longer compared to an exchange order. The second investigated characteristic is the income generated by orders at KLM's loan desk. Figure 2.15 presents a boxplot for both the income from loan and exchange orders. Here the conclusion can be drawn that the income from loan order is greater than from exchange orders. This is mainly due to the fact the duration of a loan order is longer compared to an exchange order. Thirdly, the part unit price of the spare part for both order types is presented in Figure 2.14. Here, the part unit price for loan orders seems to be higher. However, in the boxplot regarding loan orders, one big outlier can be noticed. Lastly, Figure 2.17 presents the percentage of the part unit price the customer paid for the provided service. Again, the conclusion can be drawn that the percentage of the PUP that is earned from a loan order exceeds the income from exchange orders. In all boxplots, outliers are indicated by a star. Descriptive statistics regarding the order characteristics are presented in Table 2.3.

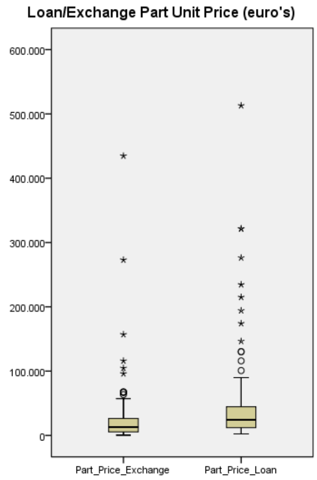

Figure 2.14: Boxplot of the part unit price in euro's

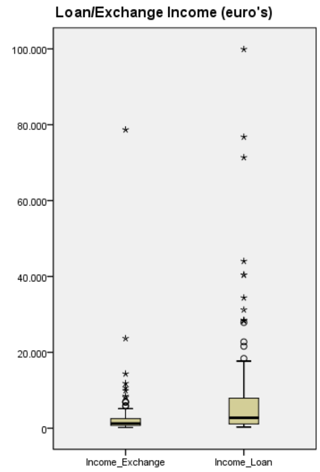

Figure 2.15: Boxplot of the income in euro's

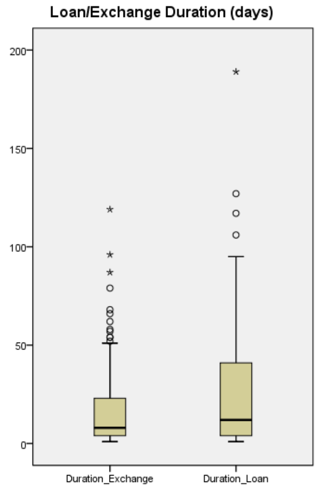

Figure 2.16: Boxplot of the duration in days

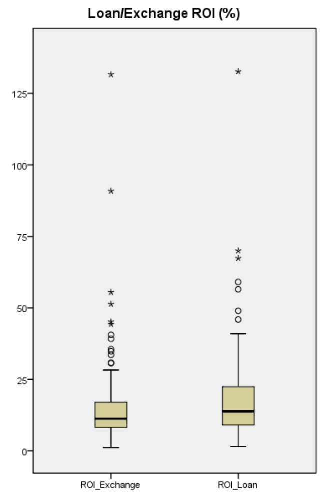

Figure 2.17: Boxplot of income as % of the Part Unit Price

Table 2.3: Descriptive statistics of loan/exchange orders based on 2017 and 2018

Request type	Variable	N	Mean	Standard Deviation
Loan	Duration (days)	106	26,61	32,98
	Income (euro's)	106	8.966,20	16.005,31
	Part Unit Price (euro's)	106	49.339,75	77.581,18
	Income as percentage of part unit price (%)	106	18,81	17,663
Exchange	Duration (days)	102	18,02	22,97
	Income (euro's)	102	3.250,05	8.266,01
	Part Unit Price (euro's)	102	28.408,53	54.369,10
	Income as percentage of part unit price (%)	102	16,47	17,490

2.4. System performance

In this section, the performance of the researched system is analysed. This is done by evaluating the Key Performance Indicators (or KPIs) of both sub-systems. The role of KPIs in the success of an organisation is of high importance. They affect strategic, tactical and operational planning and control. So, performance measurement play an important role in setting objectives, evaluating performance, and determine future strategic options [16]. First, the KPIs of each sub-system are described. Hereafter, the performance of both sub-systems is assessed. For the performance assessment of KLM's loan desk, all air craft types are taken into account, as KPIs are based on all aircraft types and cannot be interpreted for the solely for the Boeing 737 aircraft type. However, for the performance assessment of the satisfaction of POOL and contracted demand, solely the Boeing 737 spare part requests are taken into account.

2.4.1. Key performance indicators

At KLM's loan desk, one KPI is used in order to track performance, namely: *income generated* by the loan desk from loan and exchange fees. Here, management set a target of €200.000 per month. Besides the target revenue, it is interesting to investigate the responsiveness of KLM's loan desk. Currently, there is no KPI that measures this, however available log data (Appendix B.1) allows to investigate this. Here, responsiveness refers to the percentage of requests the loan desk was able to quote. In other words, spare part availability with respect to external customers.

For the fulfilment of POOL and contracted demand, there are multiple KPIs. However, as this study does not focus on improving the TAT of spare parts, there is only one KPI important to investigate for this research, namely: *service level* (or SL), the percentage of on-time deliveries to customers. However, according to an interview with interviewee E (Appendix A.5), supply chain specialist at KLM, SL is highly effected by logistical delays that are mainly caused by poor administration and transport delays. Therefore, for this research, performance of this sub-system is additionally measured by investigating the *costs of back-ordering* due to spare part unavailability. For the performance assessment, the financial data set is used. A description of this data set can be retrieved from Appendix B.3.

2.4.2. Performance assessment

First, the performance of KLM's loan desk is assessed. Currently, at KLM's loan desk solely one KPI is tracked, namely: income from loan and exchange orders. Based on financial data, the income from loan or exchange orders is analysed. Here, the income is calculated per month for January 2017 - November 2018 which is presented in Figure 2.18. In the figure, the target income of €200.000 per month is also displayed. From this figure, it can be concluded that either the target is set too high or the performance of KLM's loan desk is poor, as the target is only met in approximately 17,5% during the reviewed months.

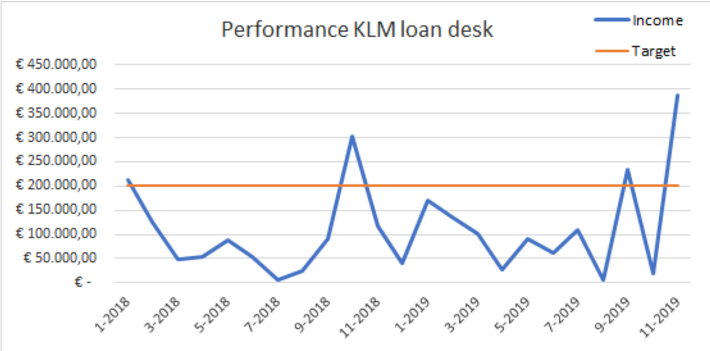

Figure 2.18: Income generated by KLM's loan desk versus target income

Besides income, the responsiveness in terms of component availability for external customers is researched. In order to investigate this, based on log data (Appendix B.1), the percentage of requests from external customers that were quoted, in other words: requests for which the requested spare part was available, is calculated per month. Furthermore, the percentage of requests that were ordered by external customers is calculated based on log data in combination with financial data. Both are calculated based on the number of useful requests, so rotable spare parts with a known PN. This resulted in an average, for the reviewed period January 2018 - October 2018, percentage quoted of 21% and percentage ordered of 3%. So, 79% of all useful requests were not quoted to customers. From the 2686 useful requests that were not quoted, 85% was due to stock issues, so zero or critical stock. The other 15% were not quoted due to other, non-specified, reasons. For quoted requests during the reviewed period, external customers accepted quotes and ordered in 13,5% of the quoted requests. In Figure 2.19, the responsiveness of KLM's loan desk is presented in terms of percentage quoted of the useful requests. In addition, the percentage of requests that were eventually ordered is presented.

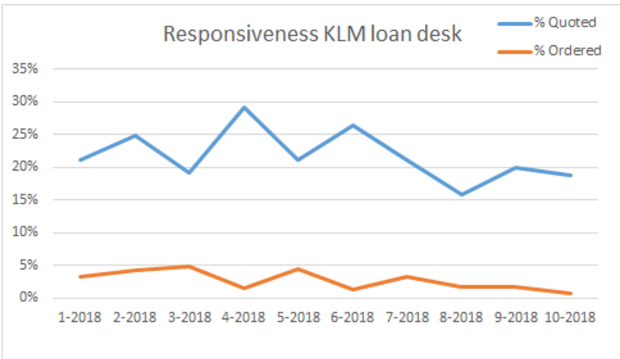

Figure 2.19: Responsiveness of KLM's loan desk

Based on the average income per order and the number of useful requests, the potential income of KLM's loan desk can be estimated. During the reviewed period, the number of useful requests equalled 3419, while the average income per order is €6.163,10. Based on these numbers, the potential monthly income of KLM's loan desk equals:

$$\frac{€6.163,10 \cdot 3419}{10 months} = €2.107.163,89/month \tag{2.3}$$

However, not all quoted orders result in actual orders. By multiplying the potential monthly income (in case all useful requests are ordered) with the average hitrate of 13.5%, the potential equals: €284.467,13. So, in case all requests could be quoted, this would be the estimated income.

Now, the performance of KLM Component Services' core business, the satisfaction of POOL and contracted demand, is assessed. This is done solely for the Boeing 737 air craft type. During the period: January 2017 - October 2018, 14.703 spare parts were requested by POOL and contracted customers. In 12.040 cases, KLM achieved to deliver the spare part on-time according to SLAs. This results in an average SL of 82%. The average target SL, or percentage on-time deliveries, that should be met according to SLAs is 94,7%. Here, one may draw the conclusion that, on average, the performance of KLM Component Services is poor. In Figure 2.20, the achieved average SL per month and the average target SL are presented.

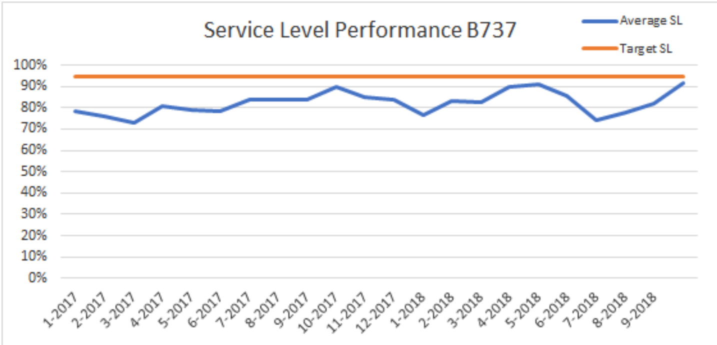

Figure 2.20: Service Level performance for B737

As stated earlier, in case a spare part is not available at the requested date, in general, the request is placed on hold for 5 days. When the requested spare part becomes available during this period, the demand is fulfilled with that spare part. However, if the requested part is not available after this period, KLM's borrow department makes sure the demand is fulfilled by borrowing, exchanging or purchasing the requested component from third party loan service provider. In Figure 2.21, the percentage POOL and contracted demand fulfilled by KLM's borrow department is presented. On average, the percentage demand fulfilled by KLM's borrow department equals 14%. Of course, KLM strives to keep the number of orders fulfilled by the borrow department as low as possible, as this decreases profit. When comparing Figure 2.21 with Figure 2.20, it can be seen that in case the percentage of borrows increases, SL decreases, which makes sense.

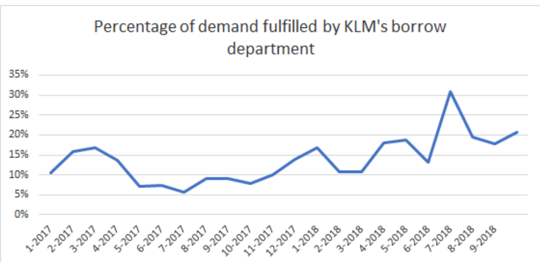

Figure 2.21: Percentage of demand fulfilled KLM B737 Borrow department

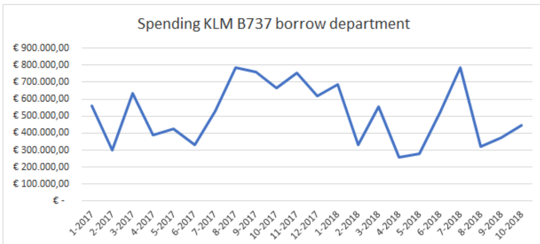

Figure 2.22: Total back-order cost of KLM B737 Borrow department

Next, the back-order expenses made by KLM's B737 borrowing department are investigated. Based on financial data from January 2017-October 2018, the cumulative costs per month are presented in Figure 2.22. One may expect that shape of the graph would look more or less identical to Figure 2.21. However, due to fluctuations in demand size per month, the results look rather different. On average the costs from borrowing and exchanging components roughly €500.000 per month.

2.5. Conclusion

The objective of this research is to investigate potential performance improvement strategies to increase the contribution of KLM's loan desk to the performance of KLM Component Services. While striving to improve the profitability of this service, strategies should limit the negative effect of providing a loan service on component availability regarding contracted customers. More specific, the number of back-orders caused by the providence of the loan service should be limited.

KLM CS is responsible for ensuring spare part availability for contracted customers. As the demand for rotable spare parts is intermittent, the utilisation rate of components is rather low. In order to increase the utilisation of rotables, an additional loan service for external customers is introduced. The researched system consists of a closed-loop supply chain with a single inventory source, serving both contracted and external customer demand. Rotable spare parts are interchangeable. When a customer requests a spare part, a serviceable spare part is shipped to the customer' location. In return, the customer ships an unserviceable spare part to the logistics center of KLM CS. From this location, the unserviceable spare part is send to the corresponding repair location where it is repaired and retrieves its serviceable status. Hereafter, the spare part is restored at the Magazijn Logistiek Centrum and is available for a new customer request.

When mapping the causal relations of the system, the interactions between subsystems were laid down. Orders from external customers decrease the on-shelf inventory level. As the service level regarding contracted customers is dependent on the on-shelf inventory level, external orders have a negative effect on service level. This results in back-order costs and a lower profit. Therefore, it is important to find the right balance between total circulation stock level and service level, to meet service level agreements against the lowest cost. The state of the system is dynamic, which makes the availability decision at the loan desk regarding the acceptance of requests from external customers is of high importance. Furthermore, the pricing method regarding external customers is related to the order acceptance rate of external customers.

When investigating the procedures at KLM's loan desk regarding the selection of requests, availability decision method and pricing method, it turned out that these procedures are mainly based on feeling and experience. There is no clear nor standard procedure regarding the processes at the loan desk.

At the loan desk, performance is monitored solely by tracking the revenue generated by the loan service. Here, management set a target of €200.000 which is met in approximately 17,5% of the months. Currently, the availability regarding external customers is 21%. This low availability is due to zero or critical stock levels of the requested spare parts. The loss of potential income due to stock issues is estimated on €175.000 per month. For KLM CS, the most important performance measure is service level regarding contracted customers. According to Service Level Agreements, the average service level should equal 94,7%. Currently, the average service level equals 82%, which is rather poor. This results in back-orders in 14% of all contracted requests, which costs KLM roughly €500.000 per month solely for the B737 aircraft type. Moreover, there is no performance metric that is able to assess the performance of KLM's loan desk while taking into account the back-order costs caused by this service.

3

Define potential performance improvement strategies

In this chapter, potential performance improvement strategies are defined and prioritised. Furthermore, comprehensive performance metrics are developed to enable management to track performance of the loan desk. In addition, the developed performance metrics are used to evaluate strategies. After exploring potential strategic options, the research is re-scoped. As not all possible strategies can be evaluated and tested, the most promising strategies are selected and further elaborated.

3.1. Theoretical background on strategy development

This section provides a theoretical background regarding performance metric development and business performance improvement strategies. Many companies rely on solely financial performance measures. However, relying on solely financial measures is not sufficient [21]. Financial measures lag indicators that track the outcomes from past actions or strategies. For this reason the Balanced Scorecard is introduced [21]. This approach contains financial measures but additionally measures on other drivers, the major indicators, of future financial performance are included. Currently, strategies for creating value shifted from tangible asset management to strategies that create and deploy an organisation's intangible assets [21]. These focus on: customer relationships, innovative services, high-quality and responsive operating processes, problem solving and improvement. However, companies were not able to measure and quantify their intangible assets. Intangible assets almost never result in a direct impact on profit. Improvement strategies regarding intangible assets effect financial performance by a series of cause-and-effect relationships. For example, better service quality leads to higher customer satisfaction. This does not directly affect performance, but does effect the loyalty of customers, which could result in increased revenues. Furthermore, many companies that are trying to implement local improvement options lack a sense of integration [20]. Performance metric are extremely useful to evaluate the effectiveness of alternative strategies [5]. Here, it is important to identify decision variables for which the values should be determined in order to achieve the desired performance level. Two categorises of performance measures are indicated (1) qualitative and (2) quantitative [5]. Here, qualitative measures are measures for which there is no direct numerical measurement. However, some aspects of these measures may be quantifiable. Quantitative performance measures can be directly described numerically. Furthermore, quantitative performance measures can be categorised by (1) objectives that are based on cost or profit and (2) objectives that are based on a measure of customer responsiveness. In order to optimise one or more performance measures, performance measures should be expressed as functions of one or more decision variables. The decision variables should be chosen in such way that the desired level of performance is

met. Here, it is important to set realistic goals.
The first step in Business Performance Management (or BPM) should be to develop strategic goals by specifying objectives and KPIs that are important to the organisation [14]. The key to improve the supply chain is to link supply chain strategies to the overall business strategy [29]. A seven-step methodology is proposed, the framework is presented in Figure 3.1.

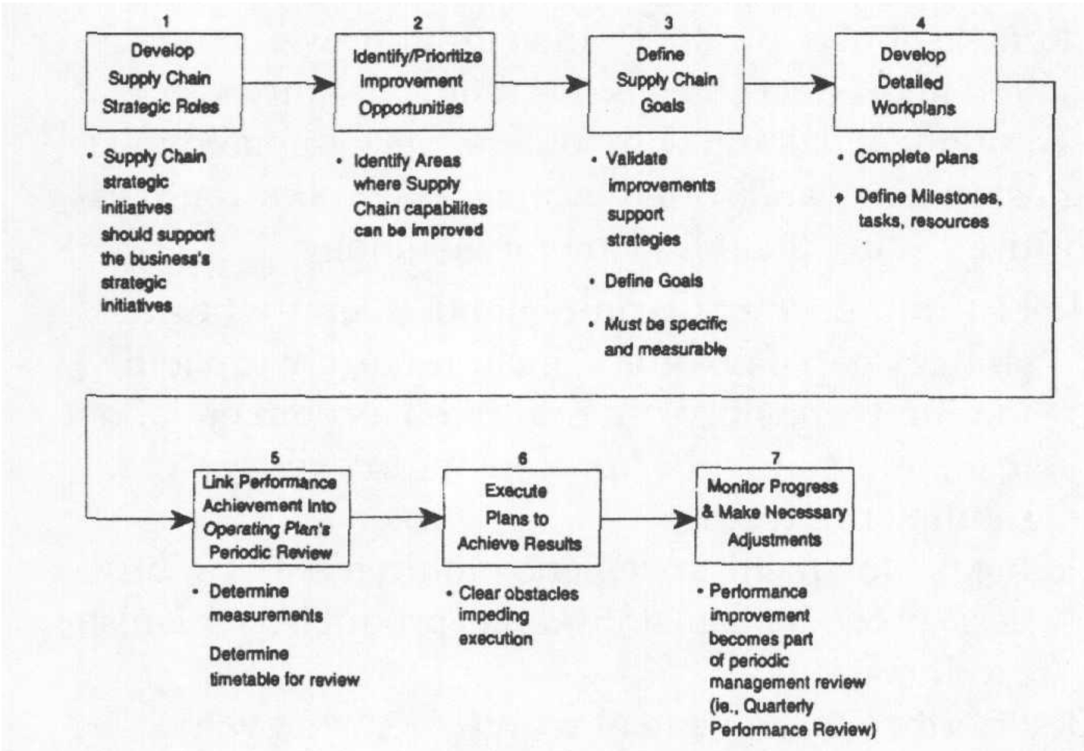

Figure 3.1: Supply chain strategic framework [29]

This research solely aims to advice KLM's loan desk regarding supply chain strategies, and not implement them (due to time limitations). Therefore, steps 1-3, 5 and 7 are more important to discuss. First, the supply chain role for achieving business strategies should be determined. Performance of a department should be measured by taking into account the effect on the total business performance [29]. Second, areas where supply chain capabilities can be improved should be detected. Here, companies must assure that the processes throughout the organisation are able to achieve the strategy. After detecting opportunities, measurable goals should be set. It is important to evaluate the developed strategies, not solely based on their performance, but also in terms of implementation possibilities. Next, performance metrics should be developed and review periods must be determined. Here performance metrics should be linked to the supply chain strategy. Lastly, the performance needs to be tracked and adjustments should be made if found necessary.

3.2. Goal and vision of KLM E&M Component Services

KLM strives to be a High Performance Organisation (or HPO). In literature, the definition of a HPO contains the following elements: good financial results, customer satisfaction, employee satisfaction, productivity and innovation, aligned performance measurement and strong leadership [10]. As KLM strives to be a HPO, all KLM businesses departments should contribute to this, including KLM E&M Component Services. Therefore, KLM E&M Component Services has set up several business improvement programs and introduced the Balanced Score Card (or BSCOR) to track performance. The BSCOR traditionally consists of 4 segments: Financial, Customer, Internal Business and Learning & growth [21]. In addition to these segments KLM CS introduced the safety segment. For each segment, performance measures are used to track performance. This is presented in Figure 3.2, which presents the simplified BSCOR of KLM CS.

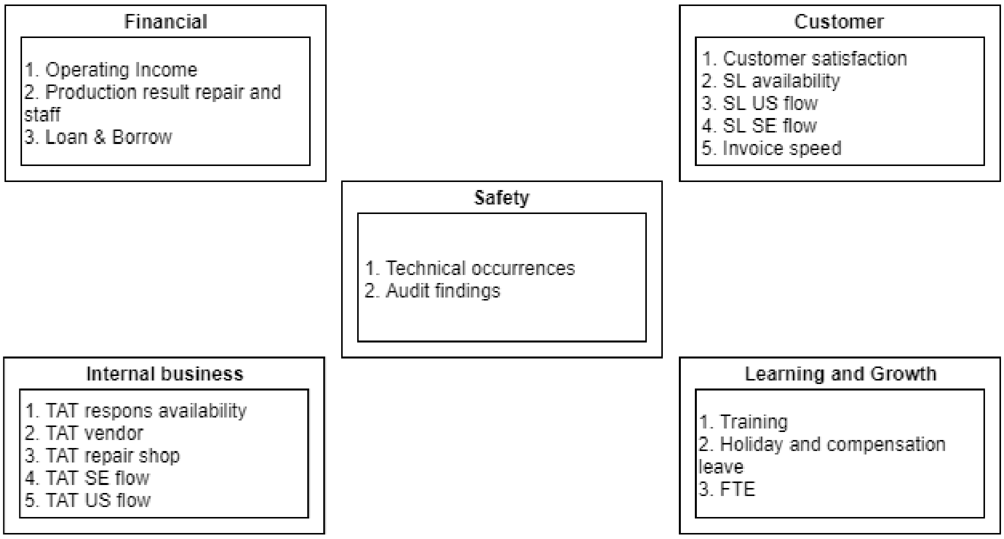

Figure 3.2: Balanced Scorecard KLM Component Services

The main goal of KLM CS is to provide spare part availability for its contracted customers and achieve high customer satisfaction. It is especially important that the right spare part with the right specifications is send to right customer and delivered at the right time. In addition, KLM is a profit seeking organisation and strives to increase its profitability, while meeting the contracted customer SLAs. In any case, the operation should be safe. In order to achieve this KLM CS focuses on spare part TAT and inventory management improvement strategies. This study focuses on the latter. Here, KLM tries to maintain the lowest possible inventory level to meet the SLAs. However, the demand for aircraft service parts is highly intermittent, i.e. random demand with a large proportion of zero values [50]. This makes the inventory control for service parts extremely difficult [6].

3.3. The loan desk as strategic business unit

This section explains the contribution of the loan desk to the vision and goal (KPIs) of KLM Component Services which is laid down in Section 3.2. In the BSCOR of KLM CS, the contribution of the loan desk to the KPIs of KLM CS can be found in the financial box. The loan desk is introduced as a Strategic Business Unit (or SBU). The main goal is to contribute to the financial performance of KLM CS, while not negatively affecting the spare part availability regarding contracted customers. Especially, the back-order costs due to the providence of the loan service should be limited. As stated earlier, back-orders are performed by the KLM borrow department in case of spare part unavailability. Therefore, the *goal* for the supply chain strategies is to increase the profitability of KLM Component Services by improving internal business processes regarding the loan desk. These should limit the effect on component unavailability regarding contracted customers that results in additional borrowing expenses, yet strive to increase the income generated by the loan desk.

3.4. Potential performance improvement strategies

In this section, areas where the supply chain capabilities regarding KLM's loan desk can be improved are identified. Furthermore, potential strategic options for each area are explored. The balanced scorecard framework is used to map the strategy of KLM's loan desk in order to accomplish the desired performance contribution with respect to KLM CS and to determine a coherent set of performance measures to evaluate performance.

3.4.1. Potential performance improvement opportunities

A strategy is a set of hypotheses about cause and effect [21]. In Section 2.1.4, the causal relations of the closed-loop supply chain system are presented. Here, areas that effect performance can be detected. In combination with the findings from Sections 2.2, 2.3 and 2.4, performance improvement opportunities are identified. When looking at Figure 2.5, one may notice that the *spare part TAT*, directly influences the on-shelf inventory level. In case the TAT decreases, spare parts are restored faster, which results in a higher average on-shelf inventory level. However, decreasing spare part TAT is not within the scope of this thesis. Therefore, this performance improvement area is not further discussed throughout the report.

The first identified performance improvement area is the *pricing method* at KLM's loan desk. In Section 2.2.4, the currently used pricing method is described. From this section, the conclusion was drawn that there is no rule-based nor standard pricing method. Employees determine the component value and fee based upon different criteria, and make decisions based on experience and feeling. Therefore, a more advanced and standard pricing method could increase the profitability of the loan desk. Here, the trade-off between the customer' hitrate or quote acceptance rate and the quoted price is of high importance in order to find the right balance between price and number of accepted orders in order to increase revenue. Furthermore, the risk of component unavailability by providing such additional service could be included in the pricing method.

Another potential supply chain capability improvement area identified in the figure is the *responsiveness* of KLM's loan desk. Interviewee D, loan desk employee, states that response time, the time between the request and the reply of the loan desk, is an important factor that influences the probability of a customer accepting the quote (Appendix A.4). This statement is verified by interviewee C, employee of KLM borrow, who is a customer of loan and exchange providers around the world (Appendix A.3). As explained earlier, this is due to high urgency to find a spare part in order to avoid or limit aircraft down times.

Furthermore, responsiveness refers to the availability of spare parts regarding external customers. In section 2.4, it was found that 79% percent of all useful requests were not quoted to external customers, mainly due stock issues, and is therefore identified as an opportunity to increase performance. Here, KLM could consider to buy additional circulation stock for frequently requested spare parts by external customers. This directly results in additional revenue as the availability regarding external customers increases. However, a trade-off between the additional costs, holding and purchasing, and the benefits of increasing the total circulation stock should well considered. Furthermore, by increasing the circulation stock, the responsiveness increases which could result in higher customer satisfaction and loyalty. When customers experience a loan and exchange service with high availability, the probability that the customer returns increases. This could result in an increase in external customer demand.

Lastly, in Section 2.2.3, it was found that the *component availability decision* for loan and exchange requests is vague and not rule based. This decision is of high importance as wrong decisions could result large back-ordering costs due to component unavailability regarding contracted customers. Here, a well-considered trade-off between the opportunity of gaining revenue and negatively effecting spare part availability regarding contracted customers should be made.

To conclude, in total three potential improvement areas were detected:

- *Total circulation stock strategy* - increase the total circulation stock to improve the responsiveness of the loan desk in terms of availability of spare parts regarding external customers.
- *Availability decision* - develop a rule/fact based decision methodology for KLM's loan desk that is able to make a trade-off between the opportunity of gaining additional revenue and the risk of back-ordering expenses due to component unavailability regarding contracted customers caused by loaning or exchanging spare parts to external customers.
- *Pricing method* - develop a pricing method that is enables to translate the potential risk of component unavailability regarding contracted customers into a price that is worth accepting the risk of additional back-ordering expenses. In other words, a pricing method that takes into account the risk of a shortage regarding contracted customers, while striving to increase the revenue of KLM's loan desk.

3.4.2. Strategy map

The balanced scorecard provides a framework to organise strategic objectives in four different perspectives [21]:

1. *Financial* - strategy for profitability.
2. *Customer* - strategy for creating customer value from the customer perspective.
3. *Internal Business* - strategies for various business processes that create customer and financial satisfaction.
4. *Learning and Growth* - strategies to create a climate that supports the organisational change, innovation and growth.

Based upon the scorecard, a framework for describing the strategy of a company is developed, the strategy map [21]. A strategy map is developed to present the strategy of KLM's loan desk, which contributes to the performance of KLM CS. In the strategy map, the improvement areas detected in Section 3.4.1 are displayed. In addition, the strategy map helps to detect additional improvement areas that were not yet detected. It is a top-down representation of the loan desk's mission and strategy. It helps to focus on improvement areas. It presents the crucial elements of the strategy. The strategy map is build from top to down, starting with the objective. The two top layers of the strategy map answer the question: "What do we want to achieve?". while the two bottom layers of the strategy map provide an answer to the question: "How are we going to achieve this?". For this research, a strategy map is developed that presents the goal and vision about how the loan desk should contribute to an overall performance improvement of KLM Component Services. By interviewing interviewee A, loan desk manager, and interviewee B, direct support leader, the strategic objective and vision of KLM Component Services and in particular the goal of introducing KLM's loan desk were determined. The interviews can be retrieved from Appendix A.1 and A.2. Companies increase economic value trough two approaches: revenue growth and productivity [20]. Revenue growth strategies are about gaining revenue from new markets, products and new customers. Furthermore, it aims to increase the number of sales by increasing customer loyalty by offering excellent service. Productivity strategies are about improving the cost structure of an organisation. It aims to utilise both employees and material assets.
The loan desk SBU, can be considered as both a revenue and productivity growth strategy from a financial perspective. The loan desk serves new customers at a new market, external customers at the loan/exchange market. Moreover, as the loan desk uses the same inventory source, the asset utilisation rate increases, by using the same inventory for additional revenue gaining purposes. In order to increase the revenue generated by the loan desk, two strategies are proposed: *increasing the customer value* and *expanding revenue*. The first strategy is about increasing the profit margin per customer. The second strategy aims to expand the

revenue opportunities, by increasing the number of orders at KLM's loan desk. From a productivity growth perspective, the utilisation of the spare part inventory POOL KLM manages, is increased by using these spare parts for additional purposes, namely: providing a loan and exchange service. However, the back-ordering costs as result of this additional service should be limited.
The core in every business strategy is customer value proposition [21]. This is about the right mix of product, price, service and the relationship that a company offers to its customers. For this research, this concept is discussed into more detail for external customers, as these are the target group for gaining additional revenue. For customer value proposition it is key to understand the customers' needs. External customers served by KLM's loan desk are looking for a fast loan/exchange service with high availability. In many cases, external customers are urgently looking around for spare parts. The down time of an aircraft is extremely costly. Therefore, according to interviewee C, KLM borrow employee, customers do not care that much about the price for the loan or exchange service, as they want to get their aircraft in the air as soon as possible (Appendix A.3). Furthermore, the strategy of KLM's loan desk should focus on *customer loyalty*. When the customer satisfaction is great, the probability that the customer uses the service again in the future increases. This eventually results in a greater revenue.
Once it is clear what the customer and financial perspectives are, the company should determine how the perspectives can be achieved. The internal business perspective includes the most important organisational activities to achieve the financial and customer perspective, which can be split into four categories [20]:

1. *Built the franchise* by developing new products and services to penetrate new markets.
2. *Increase customer value* by expanding relationships with existing customers.
3. *Achieve operational excellence* by improving supply chain management, asset utilisation, resource-capacity management and other processes.
4. *Become a good corporate citizen* by establishing effective relationships with external stakeholders.

A decrease in costs from an increase in operational efficiencies results in short-term benefits. Revenue growth by improving customer relationships is on the mid-term time scale. Innovation results in long-term returns. In order to achieve the goals stated in the customer and financial perspective, some potential improvements regarding internal business process are explored. These improvements are based upon the described potential performance improvement areas, and are in this section linked to the above described vision of KLM Component Services. In particular the contribution of the loan desk to the performance of KLM Component Services is laid down.
First, the internal business strategic options in order to achieve the financial perspectives are discussed. To meet the goal of limiting the back-ordering costs due to the loan desk, the current operations management strategy needs to improved. Especially the *availability decision* needs improvement. In this decision, the risk of back-ordering costs should be incorporated. In addition, the *inventory strategy* should be reconsidered as it might be beneficial to increase the total circulation stock for some spare parts to limit the number of back-orders. Both above mentioned strategic options could also contribute in achieving the second financial perspective, which is: expanding revenue opportunities. For achieving this financial perspective, the *availability decision* should be a well considered trade-off between the opportunity of gaining additional revenue and the risk of component unavailability that results in back-ordering costs. The strategic option to increase the *total circulation stock level* for high potential spare parts that were, in many cases, not offered to external customers due stock issues, i.e. zero or critical stock, the feasibility of increasing the circulation stock should be evaluated. The last financial perspective, increasing customer value, refers to the increase of customer profitability. Here, strategic internal business options are improving the *pricing method* or improving the customer service by providing *additional services*. For example, the customer satisfaction could increase when a track and trace service is provided and therefore the willingness to pay

for the provided service could increase.
Now, the strategic internal business options in order to meet the goal regarding the external customer perspective are discussed. As stated earlier, external customers are looking for a spare part with high urgency. Therefore, external customers desire a *fast* and reliable service with *high availability*. Here, the *price* is of secondary importance, but is definitely considered by the customer. These attributes effect the customer satisfaction. Improving on these attributes could increase the customer loyalty, as stated earlier this results in additional revenue on the mid-term time scale. Moreover, increased *customer loyalty* and a better customer relation could be beneficial in case KLM needs a spare part from a third party loan/exchange provider. The willingness to provide this service against a better price increases if the relation is good. Besides improving on operations management, i.e. price and availability, providing *additional services* could improve customer satisfaction and customer loyalty.
The bottom layer of the strategy map presents the learning and growth perspective, which is the base of any strategy. Here, the capabilities and skills of employees, technology, and the company climate are defined that are needed to successfully implement a strategy. First, when the availability and pricing decision are improved, specified and standardised, a *Decision Support Tool* should be developed. However, before this can be achieved, the *information capital* or data warehousing must be improved. KLM is doing this with the so-called KLM digitising project. Furthermore, it is important that the employees at the loan desk gain an *integrated view* of KLM Component Services, as their actions influence the system. Furthermore, the awareness should be increased about the *customers' needs*. In order to achieve this, brainstorm sessions should be organised with the KLM borrow department, as they are customer of other loan or exchange service providers around the world. Lastly, the *knowledge and skills* of employees at the loan desk should be aligned with new technologies, such as a decision support tool. Moreover, *development programs* about the systems the employees use can be very useful to improve efficiency.

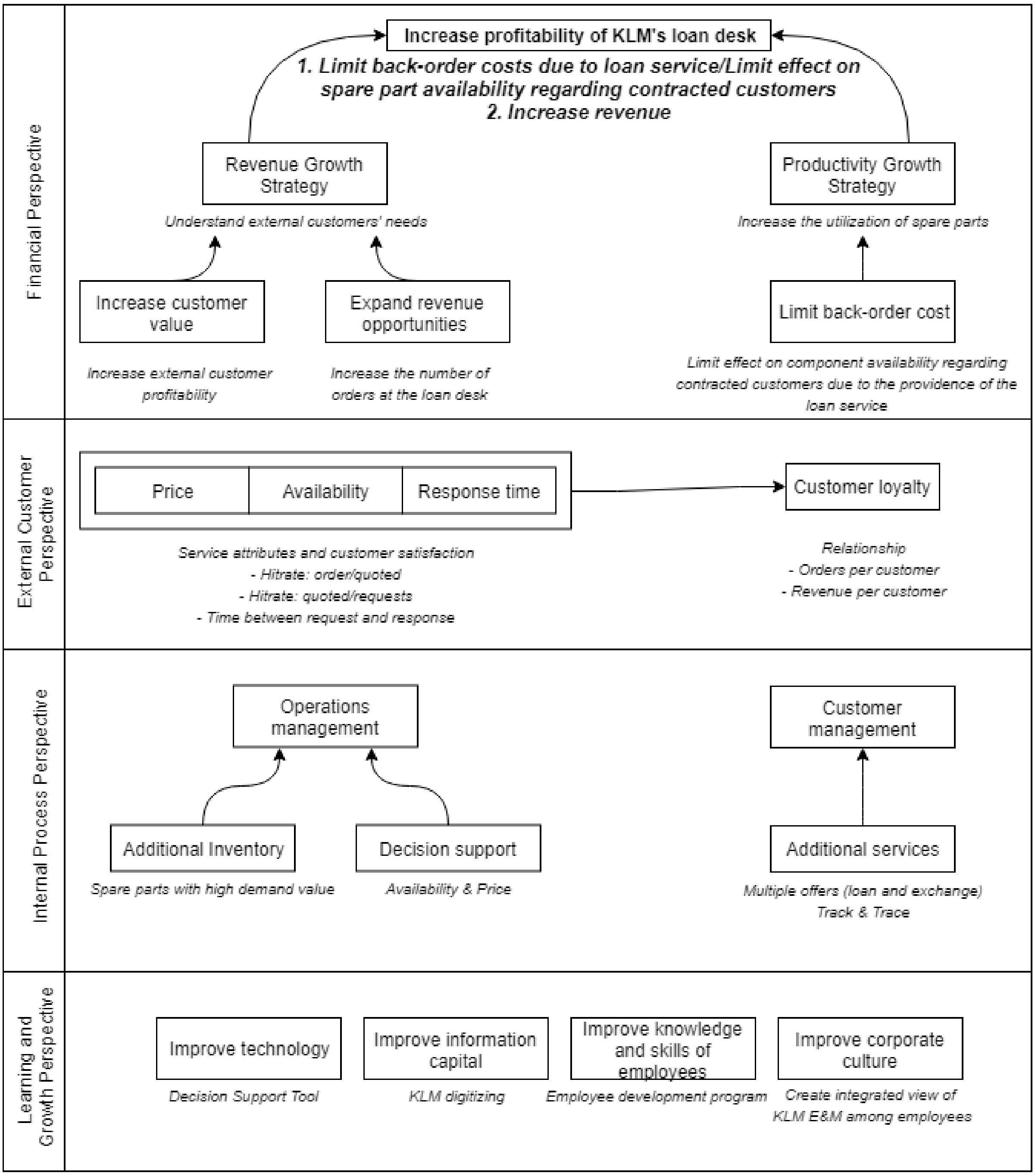

Figure 3.3: Strategy Map: the contribution of KLM's loan desk to the performance of KLM Component Services

3.5. Evaluation of strategic options and re-scope

Now the strategic options to achieve the goal and vision are determined, a prioritisation about the options should be made. Analysing all strategic options is not achievable due to time limitations. However, an agenda for further research regarding strategic improvement options is provided. Hence, this thesis focuses solely on **internal business improvement options**, which are evaluated below.
As the goal of KLM CS' management is to limit the back-ordering expenses due to the service provided by the loan desk, yet increasing revenue generated from this service. The **availability decision** is considered as top priority, and is therefore analysed into depth in the following chapters. Furthermore, currently 79% of the requests form external customers were not offered due to stock issues, i.e. zero or critical stock. As management wants to improve profitability of the loan desk, the availability decision could play an essential role. Here, employees might be too careful in some cases while taking to much risk in other situations. This again confirms the high priority for investigating the possibilities to improve the availability decision method. As currently 79% of the requests could not be offered due to stock issues, increasing the **total circulation stock level** is also considered as important strategic option and is further analysed in the following chapters. Here, an analysis should be performed in order to determine whether increasing the circulation stock of spare parts is feasible. Feasibility refers to the balance between costs of increasing the total circulation stock and the benefits gained due to the additional stock items. Additional costs are for example: holding cost and purchase cost, while benefits are: additional revenue from external orders and a decrease in back-order expenses.

Pricing strategies are not further investigated for this research. The first priority is to gain control over the availability decision before considering advanced pricing methods. Furthermore, there is no data available that can be used in order to asses the customers' behaviour. Without data that enables to statistically analyse the choice behaviour of customers, such as the willingness to pay for additional services, no comprehensive analysis can be performed. As it is known that customers prefer a fast service with high availability, the availability decision and inventory strategies to increase availability have a higher priority. Moreover, in case the availability decision can be made faster, by for example applying standard decision rules, it is likely that the percentage of quotes accepted by the external customers will increase. In addition, as currently the availability for external customers is poor, providing additional services should not be the point of attention. Before aiming to increase the demand size by improving customer satisfaction and increasing the customer loyalty, availability of the service must be improved.

3.6. Performance metrics and constraints

In this section, performance metrics are developed in order to evaluate the strategic options. Figure 3.4, presents the Balanced Scorecard that corresponds to the strategy map presented in Figure 3.3. As not all strategic options are further researched, the performance metrics that are not related to the researched strategic options are not elaborated on. The performance metrics that are related to the strategic options are explained into more detail and displayed in bold.

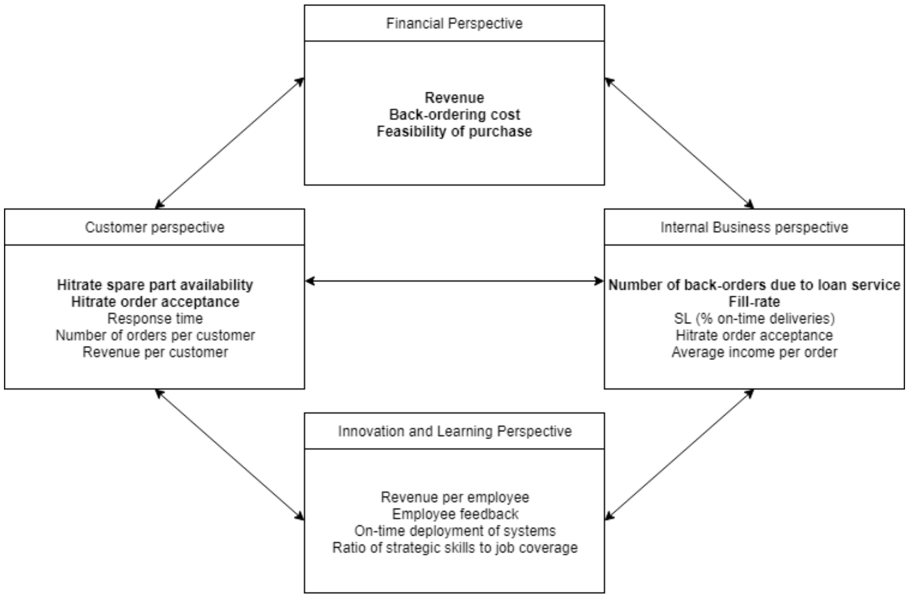

Figure 3.4: KLM loan desk's Balanced Scorecard

The first performance metric to track performance and to evaluate the strategic internal business improvement options is the *Availability ratio* (or AR). The AR is the percentage of the total external demand that was available for an order. In other words, the percentage of requests from external customers that is quoted. The AR is calculated according to formula 3.1.

$$AR = \frac{\sum Q}{\sum R_{external}} \cdot 100\% \tag{3.1}$$

In this formula, Q represents the number of requests for spare parts that were available for loan or exchange, and thus quoted to the external customer. $R_{external}$ indicates the total number of requests received by the loan desk from external customers. The maximum value of the AR equals 100%, in this case all requested spare parts were available and quoted to the customers. This performance metric enables to monitor the responsiveness in terms of spare part availability to external customers.

The second performance metric is the *Fill-Rate* (or FR). The FR is the percentage of requests from contracted customers that could directly be supplied from stock. The maximum value for the FR equals 100%. The FR is calculated according to formula 3.2.

$$FR = \frac{\sum H}{\sum R_{contracted}} \cdot 100\% \tag{3.2}$$

In this formula, H represents the number Hits, or the number of requests for spare part that were directly supplied from stock. In other words, were not placed on hold or back-ordered. $R_{contracted}$ indicates the total number of requests from contracted customers. This performance metric enables to monitor the responsiveness to contracted customers. In addition, the effect of different internal business improvement options on the FR can be evaluated by this performance metric.

The third performance indicator is the *Total Result* (or TR) generated by the loan desk. This performance metric presents the financial contribution of the loan desk. TR equals the *Total Income* (or TI) subtracted by the *Total Cost* (or TC). Here, TI is the total income from external orders, which is calculated according to formula 3.3. Here, n is the number of external orders, while I indicates the order specific income. TC equals the total back-order cost due to the providence of the loan service in order to meet supply obligations regarding contracted customers. This is calculated by multiplying the number of back-orders (k) due to the loan service by the cost of back-ordering (C). This is presented in formula 3.4. To calculate TR, TI is subtracted by TC as presented in formula 3.5.

$$TI = \sum n \cdot I \tag{3.3}$$

$$TC = \sum k \cdot C \tag{3.4}$$

$$TR = TI - TC \tag{3.5}$$

To evaluate the financial effect of business improvement strategies, the *Total back-ordering cost* (or TBC) are tracked. This performance measure is calculated by multiplying the total number of back-orders (z) with the back-order specific cost (C). This is presented in Formula 3.6.

$$TBC = \sum z \cdot C \tag{3.6}$$

For the evaluation of the second improvement option, increasing the total circulation stock, some additional performance evaluation measures are needed. The feasibility of purchasing an additional spare part is determined by calculating the *marginal value of an additional stock item* (or F). By subtracting the total benefits of increasing the circulation stock level with the additional costs of increasing the circulation stock level, the marginal value of a stock item is calculated. Here, the benefits consist of: decrease in total back-order cost (or ΔTBC) and additional income (or ΔTI) generated by the loan desk. The additional cost consist of: purchasing cost (or PC) and holding cost (or HC). For this research, the marginal value of a stock item is calculated over a 5 year time period. Formula 3.7 presents how the marginal value of a stock item is calculated in order to evaluate the feasibility of increasing the circulation stock.

$$F = \Delta TI + \Delta TBC - PC - HC \tag{3.7}$$

In addition to the performance measures, one performance constraint is introduced, the *Cost-Benefit Ratio* (CBR). This is the ratio between the total income generated by the loan desk and the back-order costs due to the providence of the loan service. Business improvement strategies are constraint to a maximum value of the CBR. Here, the value of the CBR differs per spare part type, which is explained in following chapters. The CBR is calculated according to formula 3.8.

$$CBR = \frac{\sum TI}{\sum TC} \tag{3.8}$$

By introducing this performance constraint, the effect of the loan service providence on the availability service regarding contracted customers becomes manageable. Constraining the CBR to a maximum value enables to control the effect on the availability service per spare part type. As spare parts own different characteristics, the value of the CBR should be determined based on spare part characteristics. If the CBR exceeds 1, the back-order costs caused by the loan desk exceed the benefits from the service. This should be avoided in any case. To determine which characteristics should be taken into account for the maximum value of the CBR, and what the maximum value of the CBR should be, an interview with Direct Support Leader, interviewee B, is executed (Appendix A.2). The maximum value of the CBR per spare part type are discussed after the spare part characteristics analysis presented in Section 4.1.

3.7. Conclusion

The main goal of KLM Component Services is to provide spare part availability for contracted customers and achieve a high level of customer satisfaction. The costs of providing the spare part availability service should be limited in order to increase profitability. Therefore, KLM Component Services introduced the loan desk to increase spare part utilisation and gain additional revenue. However, the effect of the providence of this additional service on spare part availability regarding contracted customers should be limited. Especially, the back-orders needed in order to meet supply obligations regarding contracted customers as a result of spare part unavailability due to the providence of the loan service should be limited. In order to achieve this, two strategic improvement options are proposed, which are specified and evaluated for this thesis:

- **Spare part availability decision** - Introduce a spare part availability decision method that enables to make a well-considered trade-off between the opportunity of gaining additional revenue and the negative effect on spare part availability regarding contracted customers.
- **Circulation stock level** - Determine whether increasing the circulation stock level is feasible. Here, a trade-off between the benefits and the costs of increasing the circulation stock should be made.

In order to evaluate the proposed strategic options, 7 performance metrics are determined, whereof 4 are Key Performance Metrics. These are the following:

- *Total result loan desk* - Benefits of the service in terms of revenue gained, subtracted by the back-order costs due to the providence of the loan service.
- *Fill-rate contracted customers* - Percentage of contracted customer requests that were fulfilled at the same date as the request.
- *Availability rate external customers* - Percentage of external customer requests that were available and quoted to the external customers.
- *Marginal value of additional circulation stock* - The financial benefits of increasing circulation stock in terms of additional revenue gained from external orders and decrease in back-order costs, subtracted by the cost of increasing the circulation stock level. If the KPI has a positive value, increasing the circulation stock level is feasible.

In order to enable management to gain control over the effect of the loan desk on the availability service regarding contracted customers, one performance constraint is introduced, the cost-benefit ratio. This is the ratio between the revenue gained and back-order costs due to the providence of the loan service. Based on spare part characteristics, the maximum cost-benefit ratio should be determined.

4

Specifying most promising strategic improvement options

In this chapter, the most promising strategic internal business improvement options selected in Chapter 3 are specified and further elaborated. Prior to specifying the strategic options, characteristics of spare parts are analysed. This is important as some characteristics could be of high importance when specifying the strategic options. Therefore, this chapter provides an analysis of spare part characteristics, such as but not limited to: demand patterns, inventory classification and criticality. Strategies should be able to cope with different spare parts and their characteristics. After analysing and discussing spare part characteristics, the strategic improvement options are specified and explained. In the following chapters, the strategic options are modelled, tested and evaluated.

4.1. Spare part characteristics

In this section, spare part characteristics are analysed and described. First, a spare part demand classification is performed. Furthermore, the inventory classification of spare parts is discussed. Also, this section provides characteristics about the repair process of spare parts, especially the difference between in-house and outsourced repairs is discussed. Finally, relevant characteristics the cost structure are discussed.

4.1.1. Demand classification

The demand for aircraft spare parts has a sporadic nature [39]. Demand forecasting is therefore is considered as one of the most crucial issues in inventory management of aircraft components. These parts are vital to operations and unavailability can result in excessive down time costs. The nature of spare part demand can be divided into mainly four categories [39]:

- *Smooth Demand* - No great variation in the inter-demand intervals and quantities.
- *Intermittent Demand* - No extreme variation in quantity but many zero demand periods.
- *Erratic Demand* - No grate variation in the inter-demand intervals but many variation in demand sizes.
- *Lumpy Demand* - Random demand with many zero demand periods and many variation in demand sizes.

Before investigating demand patterns into more depth, the total demand for spare parts is analysed. Based on removal data (Appendix B.4), the total weekly demand for B737 spare parts for October 2017 - December 2018 is calculated in Matlab. The Matlab script developed to do this, is presented in Appendix C. Figure 4.1, presents the obtained result.

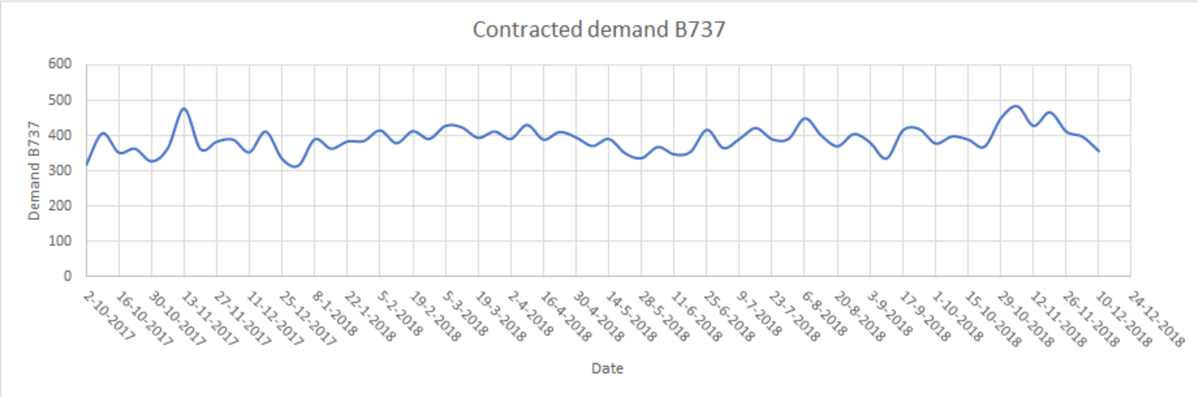

Figure 4.1: Contracted demand trend B737 for period: October 2017 - December 2018

During the reviewed period, the total contracted demand size equalled 25.106, with a weekly average of 369. From the figure can be concluded that the total demand size is stable. However, when investigating the demand per part number, large differences in demand size were found. In total 1.326 different PNs were requested during the reviewed period. The demand per PN fits a Pareto distribution, as 20% of the PNs were responsible for 80% of the total demand. Now, the demand patterns of spare parts are analysed into more depth. Traditionally, the demand characteristics of sporadic demand are derived based on the average inter-demand interval (or ADI) and the coefficient of variation (or CV). ADI indicates the average number of time periods between demands, while CV represents the standard deviation of the demand size divided by the average inter-demand interval time. The formula to calculate CV is presented in equation 4.1.

$$CV = \frac{\sqrt{\sum_{i=1}^{n}(\epsilon_{ri} - \epsilon_a)^2/n}}{\epsilon_a} \tag{4.1}$$

Here, n is the number of periods, ϵ_{ri} is the component demand in period i, and ϵ_a is the average inter demand interval for all periods. The cut-off values for the demand parameters that distinguish different categories of demand are: ADI = 1,32 and CV^2 = 0,49 [48]. The result of the demand categorisation cluster analysis for Boeing 737 spare parts is presented in Figure 4.2. As can be seen in the figure, most parts can be categorised as intermittent, which is verified in literature [11]. The same analysis is performed for the demand at KLM's loan desk. For all requested spare parts, the demand was classified as either intermittent or lumpy.

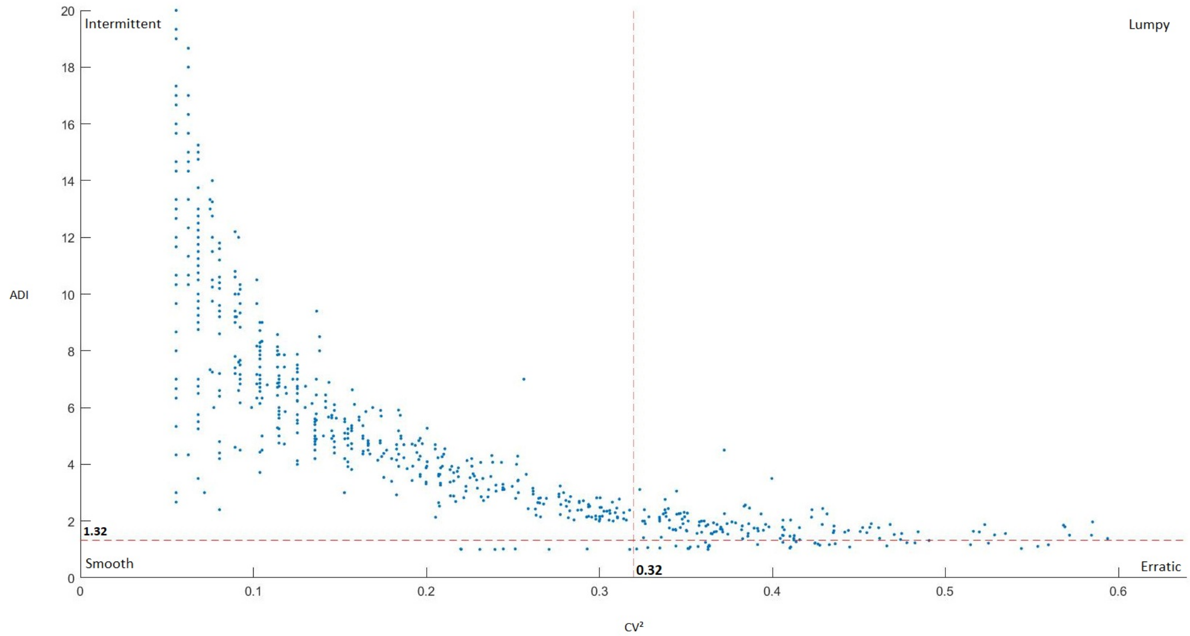

Figure 4.2: Contracted demand classification of B737 parts

4.1.2. Inventory classification

ABC inventory classification is one of the most broadly employed inventory classification techniques in companies [38]. This classification technique is based on the Pareto principle. Items are classified based on the annual use value. This is calculated by multiplying the demand by the unit price. Class A spare parts are relatively few in number but contribute large to the annual use value. Class C are items that are relatively large in number, but have a relatively small contribution to the annual use value. Class B is the group components in between the A and C class spare parts. So, class A spare parts have to be controlled tightly. At KLM E&M, the inventory classification is based on this method.

In addition to the ABC inventory classification method, spare parts are classified based on their criticality. This is indicated by the Essentiality Code (or ESS) code, which are determined by the International Air Transportation Association (or IATA). The ESS code (ESS1, ESS2 or ESS3) indicates the degree to which failure of the subsystem affects the ability of the system to perform its intended mission [28]. Aircraft components are divided into three categories:

- ESS 1 : “NO GO” item
- ESS 2 : “GO IF” item
- ESS 3 : “GO” item

If an ESS1 component fails, the affected aircraft cannot take off (NO-GO). In case of an ESS2 component failure, the aircraft can take off under certain conditions (GO-IF). Only in case of an ESS3 component failure, the component exchange can be delayed and the aircraft may take off (GO).

4.1.3. Repair characteristics

The repair of rotable spare parts is either performed in-house at a KLM Repair Shop (or RS) or outsourced and performed by a Vendor (or VEN). When analysing repair data (Appendix B.5), large differences in repair time were detected. Here, repair time is the time between the arrival date of the (US) spare part at the repair location (either RS or VEN) and the date the repaired (SE) spare part is received at the logistics center of KLM at Schiphol Oost. Figure 4.3 presents a boxplot of the repair time for both repair shops and vendors.

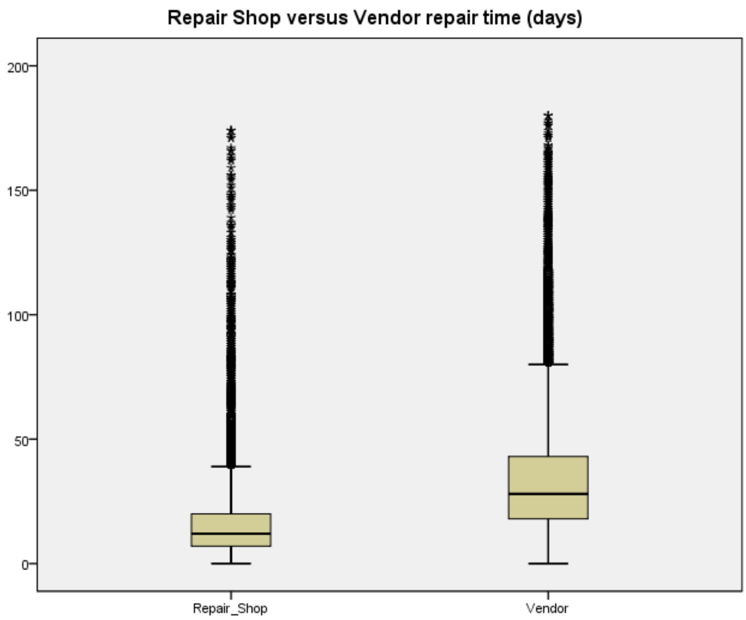

Figure 4.3: Boxplot of repair time of repair shops and vendors

At repair shops, the average repair time equals 17 days, and for vendors 35 days. So, a large difference in average repair time is observed. This difference can partly be explained by one reason. Available data does not allow to calculate the time between arrival and leave of a spare part at a repair shop. Therefore, the transportation from the repair location to the logistics center is incorporated in the presented repair times. Again, the displayed repair times are the time between arrival of the US spare part at the repair location and arrival of the SE spare part at the logistics center. In general, repair shops are located at Schiphol Oost. Therefore, the transportation time is short compared to vendors, which are located around the globe. For repair shops, the transportation time is approximately 1 day and for vendors 3 days. So, there remains a large gap between repair times when comparing in-house repairs to outsourced repairs. Some additional descriptive statistics are presented in Table 4.1.

Table 4.1: Repair time characteristics for in-house and external vendor repairs

Repair type	N	Min duration (days)	Max duration (days)	Mean repair time (days)	Std. deviation mean (days)
In-house repair shop	20738	0	174	17,16	17,45
External vendor	18579	0	180	34,87	25,51

4.1.4. Cost structure

The cost of an availability service consist mainly of three elements: inventory holding, ordering and back-order costs [7]. Here, back-order costs are divided into loan-in and waiting costs. In addition, interference cost are identified [24]. This represents the annual fixed costs for maintaining relationships between the cooperating parties in the POOL. Inventory holding costs are the cost of capital and storing spare parts. Regardless of the spare part inventory size, there will be back-order costs by borrowing required spare parts from external loan providers resulting in loan-in costs [24]. In case of spare part unavailability, there is risk of a flight

delay, this results in additional down time costs.
The annual holding costs are 17% of the market value of a spare part [23]. Back-ordering costs are derived from financial data (Appendix B.3), and presented in Table 4.2. In this table, the back-ordering costs are presented as percentage of the part unit price. From this table can be concluded that 10% of the back-orders are loan-in/borrow while 90% are exchange-in. Furthermore, it can be concluded that the back-order costs from exchange are approximately 15 percent points higher compared to loan-in back-order costs.

Table 4.2: Back-order costs as percentage of the Part Unit Price

Back-order type	N	Min percentage of CP	Max percentage of CP	Mean percentage of CP	Std. deviation mean
loan-in/borrow	123	1,13%	482,67%	24,10%	50,56%
exchange-in	1107	0,60%	1190,79%	39,38%	55,21%

4.2. Specification of the strategic improvement options

In this section, the in Section 3.5 selected strategic business improvement options are further elaborated and specified. As stated earlier, these are: spare part availability decision regarding external customers and increasing the total circulation stock level.

4.2.1. Availability decision

In this paragraph, two alternatives for the availability decision are discussed. The first alternative is a risk-based availability decision. Here, risk refers to the risk of a spare part shortage regarding contracted customers when loaning the spare part to an external customer. The second alternative is a minimum on-shelf inventory level based availability decision. Here, a cut-off value for the minimum on-shelf inventory level determines whether a spare part is available for an external customer.

Risk of a shortage based availability decision
This alternative calculates the risk of a shortage based on the state of the system. In other words, the probability that a spare part shortage regarding a contracted customer occurs when loaning the spare part to the external customer. According to literature, the Poisson distribution is a good approximation for the removal pattern for aircraft spare parts [11] [23]. According to interviews with interviewee E and interviewee F (Appendix A.5 and A.6), at KLM, the removal pattern of spare parts is estimated according to a Poisson distribution. The risk of a shortage during the spare part turn around time is calculated according to formula 4.2.

$$p(I_{on-shelf} - 1 < k) = \sum_{k=I_{on-shelf}-1}^{\infty} \frac{D_{TAT}^{k} \cdot e^{-D_{TAT}}}{k!} \tag{4.2}$$

In this formula, $p(k > I_{on-shelf} - 1)$ represents the risk of a shortage, where the probability is calculated whether the number of removals regarding contracted customers k is bigger than the on-shelf inventory level when offering the spare part ($I_{on-shelf} - 1$). And D_{TAT} represents the expected number of removals during the TAT of the spare part, which is calculated via equation 4.3.

$$D_{TAT} = \frac{D_{year} \cdot TAT}{365} \tag{4.3}$$

In this equation, D_{year} indicates the average yearly demand, which is based on historical data (Appendix B.4). The TAT, is the estimated turn around time of the spare part based on the repair location (in-house or outsourced). For this research, the spare part TAT is split into three stages due to the structure of available data. The TAT equals the sum of the following lead times (or LTs):

1. *Lead time customer* - time between the supply date of a serviceable spare part and the receive date of the unserviceable return spare part at the logistics center.
2. *Lead time logistics* - time between receiving the unserviceable spare part at the logistics center and the arrival date of the unserviceable spare part at the repair location.
3. *Lead time repair* - time between the arrival date of the unserviceable returned spare part at the repair location and the date the repaired serviceable spare part is restored at the Magazijn Logistiek Centrum storage location.

The total spare part turn around time as well as the presented lead times is visualised in Figure 4.4.

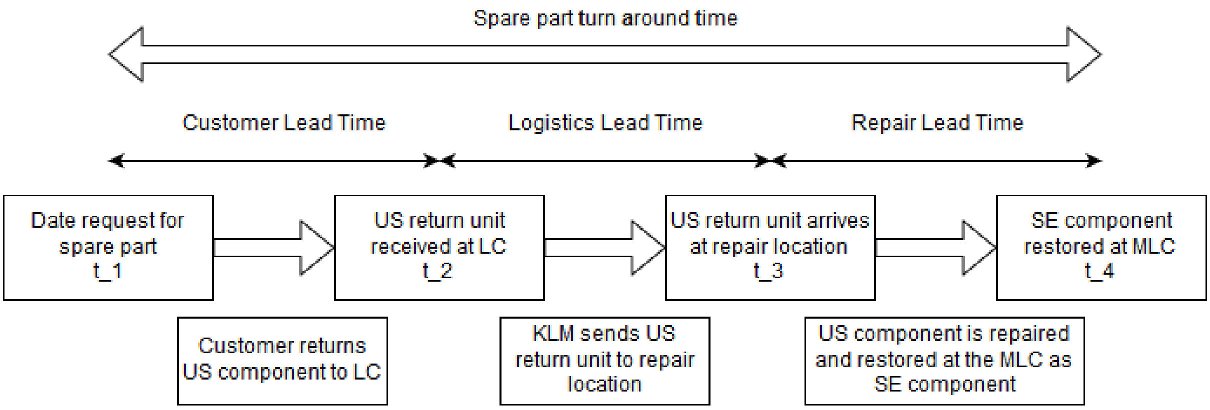

Figure 4.4: Phased spare part turn around time

For the estimation of the TAT, a distinction between spare parts that are repaired in-house and are outsourced is made. Here, a different LT logistics and LT repair are used. The estimate for the LT customer is the same for both repair types. Table 4.3 provides the descriptive statistics of the lead time input parameters for spare parts that are repaired at repair shops and vendors. For estimating the TAT for both spare part types, the rounded averages are used. For the LT logistics regarding spare parts which are repaired at a repair shop, no data was available. According to an interview with interviewee E (Appendix A.5), the LT logistics equals 1 day for these spare parts.

Table 4.3: Descriptive statistics of lead times

Lead time	Repair location	N	Mean (days)	Std. Deviation (days)
Customer	RS/VEN	26.092	8,84	6,64
Logistics	RS	-	1	-
	VEN	18.579	3,24	3,27
Repair	RS	20.738	17,16	34,87
	VEN	18.579	34,87	25,51

Based on the calculated risk, a decision is made whether the spare part is available for the external customer. So, a cut-off value for the maximum risk of a shortage should be determined. In case the calculated risk exceeds the cut-off value, the spare part is not available. As spare parts own different characteristics, the cut-off value should differ per spare part. The cut-off values are determined in the following chapters.

Minimum on-shelf inventory level based availability decision
This alternative is less complicated compared to the risk-based availability decision. For this alternative, the on-shelf inventory level at the moment an external customer places a request determines whether the spare part is available or not. In case the minimum on-shelf inventory exceeds the on-shelf inventory level at the moment a request is placed, the spare part is available. Here, the cut-off value for the minimum on-shelf inventory level differs per spare part type. The cut-off values for this availability decision alternative are determined in the following chapters.

4.2.2. Total circulation stock level

This paragraph discusses the second strategic business improvement option: increasing the total circulation stock level. At KLM's loan desk, approximately 2.000 different spare parts were requested during the reviewed period of 44 weeks (week 1-44 of 2018). For many requests, stock issues were reported as reason for not offering the spare part to the external customer. An option to solve this, is to increase the total circulation stock level of spare parts. Here, the feasibility of purchasing additional circulation stock should be well considered. As explained in Section 3.6, feasibility refers to the difference between the financial benefits and additional costs of increasing the total circulation stock (marginal value of a stock item). One way to manage large number of Stock Keeping Units (or SKUs) is to classify them into groups, and develop an inventory policy per group [33]. The most widely used inventory grouping, is the ABC classification method, which is also used at KLM. It is often found that a small percentage of the SKUs contributes to the majority of the profit, which led to the 80-20 rule [35]. The top 20% of the items are classified as A, the next 30% as B and the bottom 50% the C classification. At KLM, no inventory classification is determined based on solely external demand. Based on the demand size per spare part, the external customer hitrate and the average income per order, the demand value per spare part regarding the loan desk is estimated. The demand value equals the product of the aforementioned variables. In Figure 4.5, the cumulative demand value for all requested spare parts at the loan desk is presented. Here, 100% availability regarding external customers is assumed.

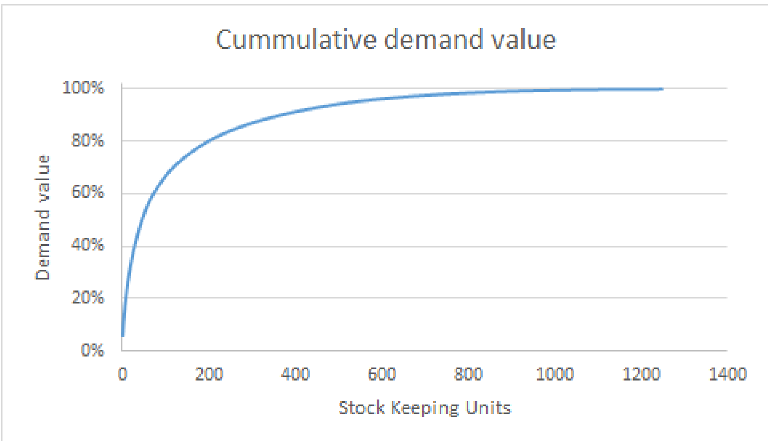

Figure 4.5: Cumulative demand value of requested SKUs at KLM's loan desk

Table 4.4: Characteristics of the ABC classes regarding KLM's loan desk (based on the first 44 weeks of 2018)

Class	SKUs count	Estimate revenue contribution (euro)
A	296	€ 3.614.139,04
B	444	€ 544.585,78
C	740	€ 155.248,89
Total	1480	€ 4.313.973,71

The result of classifying the spare parts according to the aforementioned ABC classes is presented in Table 4.4. As can be seen in the table and figure, a Pareto distribution is found. For this research, 10 case spare parts are selected from this category. For these spare parts, the availability decision strategies and increasing total circulation stock strategy are modelled and evaluated in the following chapters.

4.3. Conclusion

Strategic improvement options regarding KLM's loan desk should be able to cope with different spare part characteristics. For most spare parts, the demand of contracted customers can be categorised as intermittent, no extreme variation in quantity but many zero demand periods. Besides the traditionally used ABC inventory classification, spare parts are classified based on their criticality. This refers to the ability of a system to perform its intended mission. Besides differences in demand characteristics and inventory classification, large differences in terms of repair times were observed. For spare parts for which the repair is outsourced and are repaired at a vendor, on average the repair time takes 18 days longer compared to spare parts that are repaired in-house at repair shops. Furthermore, characteristics of the cost structure of providing the availability service are analysed. These consist of inventory holding cost (17% of component value per year), ordering and back-ordering cost. It was found that the back-order costs are on average 38% of the spare part value per back-order.
With these characteristics in mind, the in Section 3.5 selected strategic improvement options regarding KLM's loan desk were specified. For the first strategic option, improving the availability decision, two alternatives are specified: 1) risk-based availability decision, and 2) minimum on-shelf inventory level based availability decision. For the risk-based alternative, the probability of a shortage regarding a contracted customer is calculated. In case the estimated risk is lower than the maximum acceptable risk, the spare part is offered to the external customer. For the second availability decision alternative, minimum on-shelf inventory level based, a request from an external customer is accepted when the on-shelf inventory level is greater than the minimum on-shelf inventory level. The cut-off value for the maximum acceptable risk and the minimum on-shelf inventory level are determined by setting up an experiment, which is presented in the following chapters.
In order to analyse whether it is feasible to increase the circulation stock of spare parts, an ABC spare part classification analysis regarding the demand from external customers is performed. It turned out that the cumulative demand value of spare parts at KLM's loan desk follows a clear Pareto distribution. Based on this analysis, 10 A-class spare parts are selected, with different characteristics regarding: demand frequency and repair location. For these spare parts, the feasibility of increasing the total circulation stock is investigated by performing an experiment in the following chapters. The same case spare parts are used to evaluate both availability decision alternatives for KLM's loan desk.

5

Modelling most promising strategies

The objective of evaluating the behaviour of the performance metrics under the different strategic improvement options, as explained in Chapter 4, can be accomplished through the use of a simulation study. Due to its modelling flexibility, simulation is often used for supporting decision making in supply chain management [49]. It enables researchers to estimate the effects of different strategies and configurations. There are several types of simulation models. For this research, Discrete Event Simulation (or DES) is used. It is defined as: *"a simulation in which the state variables change only at those discrete points in time at which events occur"* [4]. Discrete event simulation is used to evaluate the behaviour of the performance indicators under different strategy configurations in different scenarios.
In this chapter, the model is conceptualised. Here, the scope, assumptions, assumptions, model inputs and model outputs are described. Hereafter, the model is implemented, verified and validated. The experimental plan and results are presented and discussed in Chapter 6.

5.1. Model conceptualisation

In this section, the conceptual model is presented. A conceptual model is defined as follows: *"a non-software specific description of the computer simulation (that will be, is or has been developed), describing objectives, inputs, outputs, content, assumptions and simplifications of the model"* [40]. To construct a conceptual model, the framework presented in Figure 5.1 is proposed.

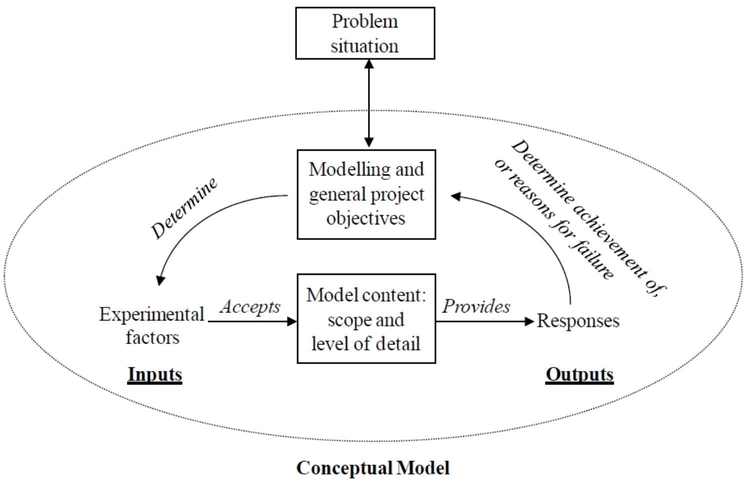

Figure 5.1: A framework for conceptual modelling [40]

According to the framework, five activities should be performed in order to obtain a complete conceptual model: 1) understand the problem situation, 2) determine the modelling and general objective, 3) identify the model outputs, 4) identify the model inputs, 5) determine the model content and identify any assumptions and simplifications. The listed activities are performed and presented throughout this section.

5.1.1. Model scope

The scope of the simulation model is to evaluate the, in Chapter 4, developed business improvement strategies, which are the following:

1. *Risk-based availability decision* - the risk of a contracted/POOL shortage is calculated based on the state of the system. The model is used to evaluate the effect on performance metrics for different values of the maximum risk of a shortage cut-off value configuration variable.
2. *Minimum on-shelf inventory level based availability decision* - the serviceable on-shelf inventory level is used to determine whether or not to accept a request from an external customer. Here, the minimum on-shelf inventory level is the configuration variable for which the effect on the performance metrics is evaluated.
3. *Circulation stock level* - determining the circulation stock level (total of on-shelf inventory level and pipeline inventory), to increase the availability for both contracted and external customers. Here, the feasibility of increasing the circulation stock level is analysed based on the model results.

The first two strategies are regarding the availability decision that takes place at KLM's loan desk. This decision can be seen in Figure 5.2 in the lower line.

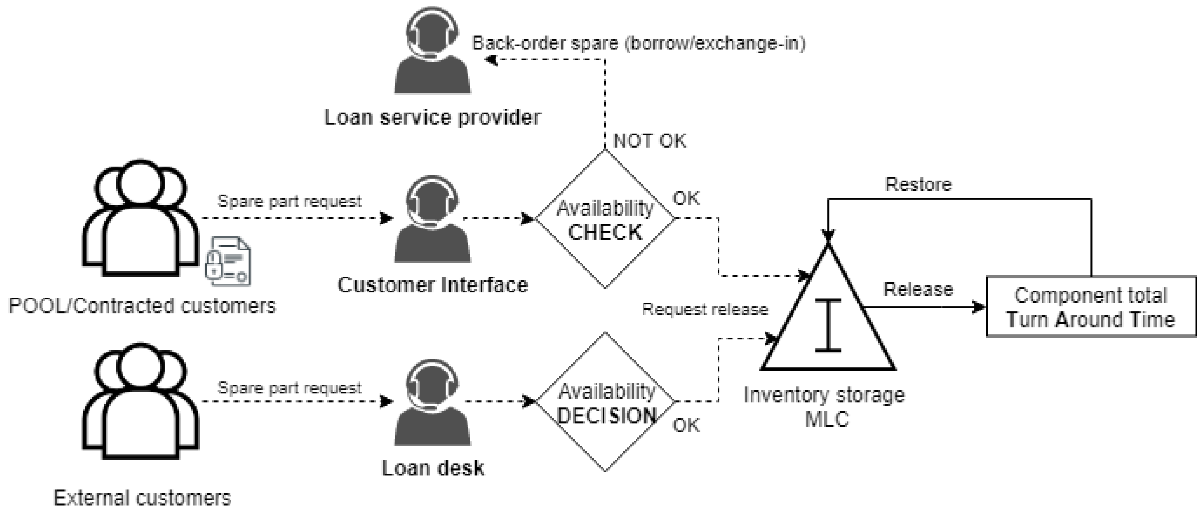

Figure 5.2: Simplified system flowchart

The model is developed to evaluate performance of different configurations of the presented strategies. It uses different configuration variables to obtain values for the performance indicators in order to evaluate the aforementioned strategies. The configuration variables are stated in Table 5.1. The developed performance metrics and constraint, described in Section 3.6, are presented in Table 5.2. As this research does not aim to model the interactions between components in the system, a single component simulation model is proposed. In order to test the suitability of strategies and different strategy configurations, 10 case study components are selected to evaluate the strategies. In Section 4.2.2, the spare part classification with respect to external demand is executed. All selected case components are class A components, as these are the most useful to research.

Table 5.1: Definition of the configuration variables

Strategy	Variable	Unit	Detail
1	Maximum risk of a shortage	-	The maximum acceptable level of shortage risk regarding contracted demand, in case the external demand is fulfilled.
2	Minimum on-shelf inventory level	[# of spares]	The minimum number of SE on-shelf inventory level for which the external demand can be accepted.
3	Circulation stock level	[# of spares]	The number additionally purchased spares in the system.

Table 5.2: Definition of the performance indicators and constraint

Performance Indicator	Unit	Objective	Detail
Total Income loan desk (TI)	[€]	↑	Income generated by orders from external customers.
Total back-order Cost due to loan desk (TC)	[€]	↓	Back-order cost due to the providence of the loan service.
Total back-order cost (TBC)	[€]	↓	All back-order costs in order to meet the supply obligation regarding contracted customers.
Purchase Cost (PC)	[€]	↓	Cost for purchasing spares (only strategy 3).
Key Performance Indicator	Unit	Objective	Detail
Total Result loan desk (TR)	[€]	↑	Result generated by KLM's loan desk (TI-TC).
Fill-Rate contracted customers (FR)	[%]	↑	Percentage of contracted customer requests fulfilled at the same date as the request date.
Availability-Rate external customers (AR)	[%]	↑	Percentage of external customer requests that were available and quoted.
Marginal value of additional stock items (F)	[€]	↑	The difference between the benefits and costs of increasing the total circulation stock level (only strategy 3).
Performance Constraint	Unit	Objective	Detail
Cost-Benefit Ratio	[-]	↓	Ratio between back-order costs due to the providence of the loan service and the benefits from the service.

5.1.2. Assumptions

In order to simplify the real system to a model, assumptions are made. It is important to treat these with care as wrong assumptions could lead to incorrect results and a wrong understanding of the how the system works. Therefore, the assumptions are reviewed in the validation part of this experiment. For this research, three types of assumptions are made: model, data and parameter assumptions.

The following **data** assumptions are made:

1. *Demand:* In literature regarding stock sizing in the MRO industry, the assumption of a constant failure rate is adopted [8]. The Poisson distribution is a good approximation for the stock sizing of spares [11] [23]. This means that the inter demand interval function for the demand for aircraft spares is exponentially distributed. So, for both demand types: contracted and external, the inter arrival rate is assumed to be exponential. Here, the inter arrival rate is based upon available historical demand data. An explanation of the data can be found in Appendix B.4. Also, interviewee E, supply chain specialist B737, confirms that the Poisson model is suitable to model the removals. The interview can be found in Appendix A.5
2. *Lead times:* For this research, the total Turn Around Time (or TAT) is split into three stages (or lead times). For the first LT, customer lead time, three distributions are fitted. For contracted customers, the LT distribution is fitted based on the data set presented in Appendix B.6. For external customers, a distinction in request type made, for both

loan and exchange orders a different distribution is fitted based on the financial data set, presented in Appendix B.3. For the second lead time, repair logistics lead time, a difference is made between spares that are repaired at a vendor and spares being repaired at repair shops. For repair shops, the assumption is made that this LT equals 1 day, which is based on an interview with interviewee E (Appendix A.5). For the logistic LT of repairs that take place at a vendor, a distribution is fitted based on the data set presented in Appendix B.5. For the last lead time, repair LT, a part specific LT distribution is fitted based on the data set presented in Appendix B.5.

The following **parameter** assumptions are made:

1. *Hitrate:* The hitrate of external customers, the percentage of quoted requests that result in an actual order, is fixed on 13,5%. This is based on historical log data collected by KLM's loan desk (Appendix B.1).
2. *Income:* The income from external orders, both loan and exchange, are based upon historical data (Appendix B.3). For loan orders, the income per day is 2% of the component's latest list price (or LLP). For exchange orders, the income per day equals 3% of the LLP. The latest list prices are obtained via Boeing.
3. *Holding cost:* For the third strategy, *increasing the circulation stock level*, holding cost are taken into account to evaluate the feasibility of holding additional inventory. As KLM could not provide data regarding holding cost, the annual holding cost are set to 17% of the LLP [23].
4. *Back-orders:* The back-order costs are set to 38% of the LLP per back-order. This is based on historical data (Appendix B.3). In case a component is unavailable at the date of the request, the request is placed on hold for maximum 5 days. In case the requested spare does not become available during this period, a back-order is placed. This is based on an interview with interviewee C (Appendix A.3).

Table 5.3: Model parameters

Model constant	Value	Source
Income loan order	2% of LLP per day	Historical data KLM (Appendix B.3)
Income exchange order	3% of LLP per day	Historical data KLM (Appendix B.3)
Hitrate external customers	13,5%	Historical data KLM (Appendix B.1)
Max time window before back-order	5 days	Interview with interviewee C (Appendix A.3)
Back-order cost	38% of LLP	Historical data KLM (Appendix B.3)
Annual holding cost per spare	17% of LLP	Kipli, 2004

The following **model** assumptions are made:

1. *No scrapped spares:* It is assumed that the scrap rate of spares is zero. Therefore, the total number of spares in the system is constant.
2. *24/7 operations:* There are no work schedules included in the model. However, all lead times are based upon historical data. Therefore, this assumption does not result in unrealistic outputs. For example, the repair lead time distribution is fitted based upon an actual start and end date. Therefore, factors such as capacity and work schedules are indirectly taken into account. So, no buffers are modelled and the capacity of repair locations is set to infinity.

As explained in Section 3.6, a cut-off value for the cost benefit ratio must be determined as well as a multiplier penalty per demand class for the CBR constraint. The *Cut-off values for the Cost-Benefit Ratio (or CBR)* is determined in an interview with the Direct Support Leader, interviewee B (Appendix A.2). The maximum CBR value to which each level of essentiality (ESS) of a spare is is constrained is determined. This value corresponds to the maximum effect the loan desk has on the availability service regarding contracted customers. For ESS 1

(NO-GO) spare parts, the CBR should be less or equal to 10%, for ESS 2 (GO-IF) 25% and for ESS 3 (GO) 50%. In addition, a penalty by which the CBR is multiplied per *Demand class* is assumed. As explained in Section 3.6, the CBR is multiplied with a penalty factor per demand class. As all demand is modelled with an exponential inter-arrival distribution, the in Section 4.1.1 determined demand characteristics are lost in the model. Therefore, for evaluating the CBR for different strategy configurations the CBR is multiplied by a penalty of 1 for smooth demand, 1,25 for erratic demand, 1,25 for intermittent demand and 1,5 for lumpy demand. The penalty factors are determined in an interview with interviewee F who is supply chain engineer at KLM (Appendix A.6). This constraint must be taken into account when evaluating the strategy configurations.

Table 5.4: Multiplier penalty cost benefit ratio per demand class

Demand Class	Multiplier Cost Benefit Ratio
Lumpy	1,5
Erratic	1,25
Intermittent	1,25
Smooth	1

Table 5.5: Maximum cost benefit ratio per ESS class

Essentiality	Maximum value of the cost benefit ratio
GO (ESS 3)	0,5
GO-IF (ESS 2)	0,25
NO-GO (ESS 1)	0,10

5.1.3. Model input

As explained earlier, a single component simulation model is constructed for this research. Therefore, some model inputs differ per case spare part. A selection of 10 spare parts is made based upon different component characteristics. The selected components differ in inter demand rates (for both contracted and external demand) and demand class (intermittent, smooth and lumpy), in repair location (repair shop or vendor), component value and criticality. Moreover, solely components classified as A component were selected, as these have the highest potential in terms of performance improvement. The characteristics of the case study components are presented in Tables 5.6, 5.7 and 5.8.

Table 5.6: A summary of contracted demand characteristics

No.	Component Description	Part Number	ADI (week)	CV^2	Average Demand (year)	Demand categorisation
1	TRIM AIR PRESSURE REG VALVE	3214972-1	1,54	0,37	46,4	Intermittent
2	AIR SEPERATION MODULE	2030157-102	2,44	0,34	24	Intermittent
3	RAM AIR ACTUATOR	541674-4	1,06	0,33	196,8	Smooth
4	RADAR TX/RX	930-2000-001	4,69	0,21	15,2	Intermittent
5	ADF ANTENNA	2041683-7507	11,00	0,03	1,6	Intermittent
6	AIR DATA INERTIAL REFERENCE UNIT	HG2050AC11	2,40	0,33	32	Intermittent
7	BLEED AIR VALVE APU 73N	3291214-2	3,05	0,24	19,2	Intermittent
8	LANDING LIGHT	45-0351-3	1,59	0,44	51,2	Intermittent
9	REAR POSITION LIGHT ASSY LH	72303219-3	2,52	0,38	32	Intermittent
10	REAR POSITION LIGHT ASSY	72303219-4	2,17	0,29	24	Intermittent

Table 5.7: A summary of loan/exchange demand characteristics

No.	Component Description	Part Number	ADI (week)	CV²	Average Demand (year)	Demand categorisation
1	TRIM AIR PRESSURE REG VALVE	3214972-1	5,17	0,03	9,45	Intermittent
2	AIR SEPERATION MODULE	2030157-102	5,00	0,22	8,27	Intermittent
3	RAM AIR ACTUATOR	541674-4	4,25	1,35	8,27	Lumpy
4	RADAR TX/RX	930-2000-001	9,00	0,01	8,27	Intermittent
5	ADF ANTENNA	2041683-7507	6,33	0,67	7,09	Lumpy
6	AIR DATA INERTIAL REFERENCE UNIT	HG2050AC11	6,00	0,01	7,09	Intermittent
7	BLEED AIR VALVE APU 73N	3291214-2	10,00	0,01	5,91	Intermittent
8	LANDING LIGHT	45-0351-3	1,33	0,15	5,91	Intermittent
9	REAR POSITION LIGHT ASSY LH	72303219-3	8,50	0,37	5,91	Intermittent
10	REAR POSITION LIGHT ASSY	72303219-4	6,00	0,26	5,91	Intermittent

Table 5.8: A summary of general component characteristics

No.	Component Description	Part Number	LLP (euro)	Total circulation stock	Essentiality code (ESS)
1	TRIM AIR PRESSURE REG VALVE	3214972-1	€ 12.835,88	20	1
2	AIR SEPERATION MODULE	2030157-102	€ 69.997,92	6	3
3	RAM AIR ACTUATOR	541674-4	€ 5.702,56	57	2
4	RADAR TX/RX	930-2000-001	€ 106.418,28	7	1
5	ADF ANTENNA	2041683-7507	€ 12.697,62	5	2
6	AIR DATA INERTIAL REFERENCE UNIT	HG2050AC11	€ 452.618,64	16	1
7	BLEED AIR VALVE APU 73N	3291214-2	€ 78.512,95	8	2
8	LANDING LIGHT	45-0351-3	€ 31.220,00	10	1
9	REAR POSITION LIGHT ASSY LH	72303219-3	€ 5.971,05	15	1
10	REAR POSITION LIGHT ASSY	72303219-4	€ 5.971,05	24	1

The input for both contracted and external demand consists of an exponential distribution with a component specific inter arrival rate. Here, the inter arrival rate is calculated by taking the inverse value of the average demand.
As explained earlier, the total TAT is split into three stages: lead time customer, lead time logistics and lead time repair. The sum of these LTs equals the total TAT. For the *lead time contracted customers*, a distribution function is fitted for each individual case spare part. For the *lead time external customers*, probability distribution functions are fitted based on the order type, so loan or exchange. Here, the distribution is not spare part specific, but assumed to be the same for all components. Next, the *logistics lead time*, which is the same for components that are used by either contracted or external customers as both component flows are merged at this stage. This LT is the time between the, by the customer, returned US unit is received at the Logistics Center at Schiphol Oost and the moment the US return spare part is received at the repair location. For components that are repaired at a repair shop (in-house), the logistical lead time is set to 1 day, as there was no available data regarding this lead time. This assumption is made in consultation with interviewee E, supply chain specialist at KLM (Appendix A.5). For the last lead time, the *repair lead time*, a probability function is fitted for all case spare parts.
All distribution functions were fitted by using the EasyFit software. This software enables to fit a continuous distribution and presents three types of Goodness of Fit (or GoF) measures, namely: Kolmogorov Smirnov, Anderson Darling and Chi-Squared. The Kolmogorov Smirnov test is based on the maximum difference between an empirical and a hypothetical cumulative distribution [31]. This test was used to rank the fitted distributions. However, the other two GoF measures were interpreted as well when deciding which distribution to chose. In addition, EasyFit allows researchers to generate a number of plots of the fitted distributions in order to visually inspect the GoF [44]. For example, a PP plot shows the percentiles of one distribution versus the percentiles of another [13]. This plot is used in this research to interpret the GoF of the possible distributions. The lead time distributions per case component are

presented in Table 5.10. As stated earlier, for the *lead time external customers* a non spare part specific distribution is fitted. For this LT, a distribution function for both order types, loan and exchange, are fitted. These distribution functions are presented in Table 5.9. As can be noticed in both tables, most fitted distribution functions were significant even at the highest confidence level of α = 0,01. In 3 cases, no distribution was found to be significant. Here, a triangular distribution is fitted.

Table 5.9: Lead time distribution functions (* significant at α = 0,01)

Lead Time	n	Distribution function (days)	Kolmogorov-Smirnov statistic
External customer loan	102	loglogistic(1.1808, 11.304)	0.093*
External customer exchange	106	loglogistic(1.3745, 8.6744)	0.066*

Table 5.10: Lead time distribution functions (* = sign. at α = 0,01)

No.	Lead Time	n	Distribution function (days)	Kolmogorov-Smirnov statistic
1	Contracted Customer	29	exponential(10)	0.112*
	Repair	21	weibull(1.8735, 31.419)	0.097*
	Logistics	-	Internal repair, set to 1	-
2	Contracted Customer	26	weibull(0.8938, 7.0363)	0.160*
	Repair	23	weibull(1.9797, 37.177)	0.167*
	Logistics	23	loglogistic(6.7536, 4.252)	0.359*
3	Contracted Customer	134	loglogistic(1.0839, 2.8143)	0.133*
	Repair	104	weibull(2.4731, 19.4)	0.066*
	Logistics	-	Internal repair, set to 1	-
4	Contracted Customer	18	uniform(1.4076, 13.926)	0.122*
	Repair	13	loglogistic(3.6217, 16.173)	0.176*
	Logistics	13	uniform(0.5174, 5.1749)	0.164*
5	Contracted Customer	9	exponential(23)	0.182*
	Repair	5	triangular(19, 36, 66)	/
	Logistics	5	uniform(2.3026, 6.0974)	0.352*
6	Contracted Customer	3	triangular(6, 6, 40)	/
	Repair	11	triangular(1, 14, 21.171)	0.106*
	Logistics	-	Internal repair, set to 1	-
7	Contracted Customer	29	loglogistic(1.2056, 7.3044)	0.101*
	Repair	16	triangular(4, 23, 37)	0.123*
	Logistics	16	triangular(0, 1, 3)	/
8	Contracted Customer	29	exponential(13.4)	0.905*
	Repair	21	lognormal(2.7706, 0.61865)	0.082*
	Logistics	-	Internal repair, set to 1	-
9	Contracted Customer	15	lognormal(3.1377, 0.87779)	0.178*
	Repair	21	lognormal(3.3645, 0.56026)	0.990*
	Logistics	12	uniform(2.5229, 5.4771)	0.171*
10	Contracted Customer	15	loglogistic(3.7964, 21.558)	0.162*
	Repair	12	lognormal(4.0784, 0.59501)	0.136*
	Logistics	11	uniform(2.2705, 7.3659)	0.296*

Besides demand and lead time distributions, the *total circulation stock* is a case component specific input parameter. The total circulation stock is the sum of the on-shelf inventory level and the spares in the system (at repair shops, in transport and at a customer). The total circulation stock per case spare part is presented in Table 5.8.

All aforementioned model inputs are the same for the all three strategies. However, for all strategies, the configuration variables differ. Moreover, some additional parameters are used per strategy. For each strategy additional model inputs are needed. These are explained in the following paragraphs.

Risk-based component availability decision model input
For this strategy, the first model input is the *cut-off value for the maximum acceptable shortage risk* for which the external request can be accepted. In addition, to calculate this risk, two additional spare part specific parameters are used as input. These are the *average yearly demand* and the *estimated total TAT*, which is based on the repair location. These inputs are explained into more detail in Section 4.2.1.

Minimum on-shelf inventory level based availability decision model input
For this strategy, only one additional input variable is required, namely: *minimum on-shelf inventory level*. As explained earlier, this configuration variable refers to the minimum SE on-shelf inventory level for which external requested spare part can be offered.

Circulation stock level model input
For this strategy, also one additional input variable is required, namely *additional circulation stock*. This configuration variable presents the number of additionally purchased spares. The feasibility of increasing the circulation stock level is evaluated by calculating the marginal value of the additional stock items.

5.1.4. Model output

The model should be able to obtain input values for the, in Section 3.6 developed, performance metrics and constraint, which are summarised in Table 5.2. For the total income of the loan desk, the model output should be the duration of each loan/exchange order. Based on the income parameters presented in Table 5.3 and the latest list price of the spare part, the income can be calculated. For the total back order costs due to the providence of the loan desk, the model must be able to count the number of back-orders that is placed during the time a spare part is on loan or exchange. By multiplying this number with the back-order cost parameter presented in Table 5.2 and the latest list price, the value for this performance metric can be obtained. For the total back-order cost performance metric, the model must be able to count all back-orders. This number is multiplied by the back-order cost parameter and the latest list price of the spare part. For the purchase cost (only applicable in the third strategy), the number of additionally purchased spares needs to be counted. By multiplying this with the latest list price of the spare part the value of this performance metric is obtained.

For the first KPI, total result of the loan desk, the total income generated by the service is subtracted with the total back-order costs due to the providence of the service. So, no additional model output is needed for this KPI. For obtaining a value for the second KPI, fill-rate contracted customers, the number of hits needs to be counted as well as the total number of requests from contracted customers. As explained earlier, a hit is a request that could be fulfilled at the same date as the request was placed. For the last KPI, availability rate external customers, the number of spare part requests that were offered must be counted. In addition, the total number of requests from external customers must be tracked. The value for this KPI is calculated by dividing the number of requests that were available by the total number of requests.

For the performance constraint, cost benefit ratio, no additional model outputs are needed. This constraint is calculated by dividing the total back-order costs due to the providence of the loan service by the income generated from the service. As stated earlier, for the evaluation of the strategies, the value of the CBR is multiplied by a penalty factor depending on the demand classification of the spare part. The penalty factors can be found in Table 5.4. In addition, the maximum value of the CBR per essentiality spare part class is presented in Table 5.5.

5.1.5. Conceptual simulation model

In Figure 5.3, the conceptual simulation model logic is presented. It is a representation of the model logic to be simulated. It highlights the model concepts, relations, spare part and information flow. The conceptual simulation model is based on the system description, presented in Figure 2.6. In this figure, a distinction between two flows is made, information and physical flow. In Figure 5.3 spare part requests from both contracted and external customers can be noticed. Here, the information flow is initiated.
For contracted customers, spare part requests are send to customer interface, where the availability of the requested spare is checked based on the on-shelf inventory level, this step can be found in the figure as the decide block in the top line. In case the on-shelf inventory level is greater than zero, the component is send to the customer. At this point, the physical flow of the component starts. The spare part is released from the storage location and send to the customer. Now, the customer returns the unserviceable spare part. The time between the request of the customer and the date the return unit is received at the logistics center, is the LT contracted customer. Hereafter, the spare part is send to the repair location. The time between the date the spare part is received at the logistics center and the date the spare part arrives at the repair location can be found in the figure as the LT logistics. Now, the component goes through the repair process and is eventually restored at the MLC storage location. This can be found in the figure as the LT repair. For spare part requests that could not be fulfilled at the date of the request, the request is placed on hold for a maximum of 5 days. During this review period, the on-shelf inventory level is scanned and in case a spare part becomes available, the request is fulfilled. However, if no spare part becomes available during this period, a back-order is placed.
For external customers, spare part requests are send to the loan desk, where the availability decision takes place. This is the decision block where different configurations of strategy 1 and 2 (availability decision) are implemented. In case the requested spare part is available, the spare part is ordered or not, depending on the customer' hitrate. In Table 5.3 can be seen that this parameter is set to 13,5%. In case the spare part is ordered by the external customer, the spare part is released from the storage location and send to the customer. The time between the request of the external customer and the moment the return component is received at the logistics center can be seen in the figure as the LT exchange order or LT loan order, depending on the order type. In the model, 51% of the orders is a loan order while the other 49% are exchange orders, this is based on historical data (Appendix B.3). Hereafter, the flow of spares merges at the logistics center. The, by the external customer returned spare part, is send to the corresponding repair location where they are repaired. Hereafter, the spare parts is restored at the storage location.
In addition, all capacities of servers and decision blocks are set to infinity. As this study does not focus on investigating buffers, LTs are modelled by fitting a distribution. Therefore, realistic LTs are obtained. In addition, spare parts are allowed to overtake each other. For example, in case one spare part arrives at a server with a LT of 25 days and another spare part arrives at the same server the next day and has a LT of 15 days, the second spare part leaves the server earlier than the first spare part.

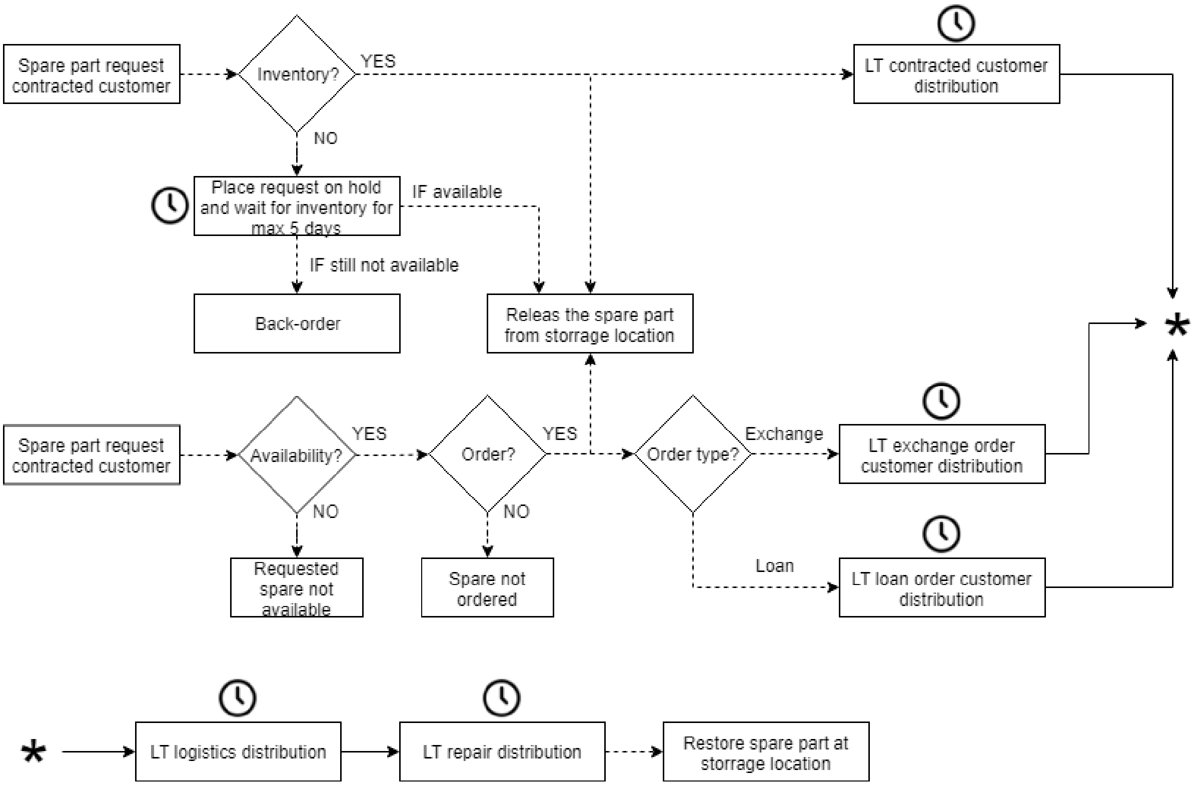

Figure 5.3: Conceptual simulation model logic

5.2. Model implementation

The conceptual simulation model presented in Section 5.1.5 is implemented in the Simio simulation software version 9.158.15009. Figure 5.4 shows a screenshot of the constructed simulation model. The model is explained into detail in Appendix D.

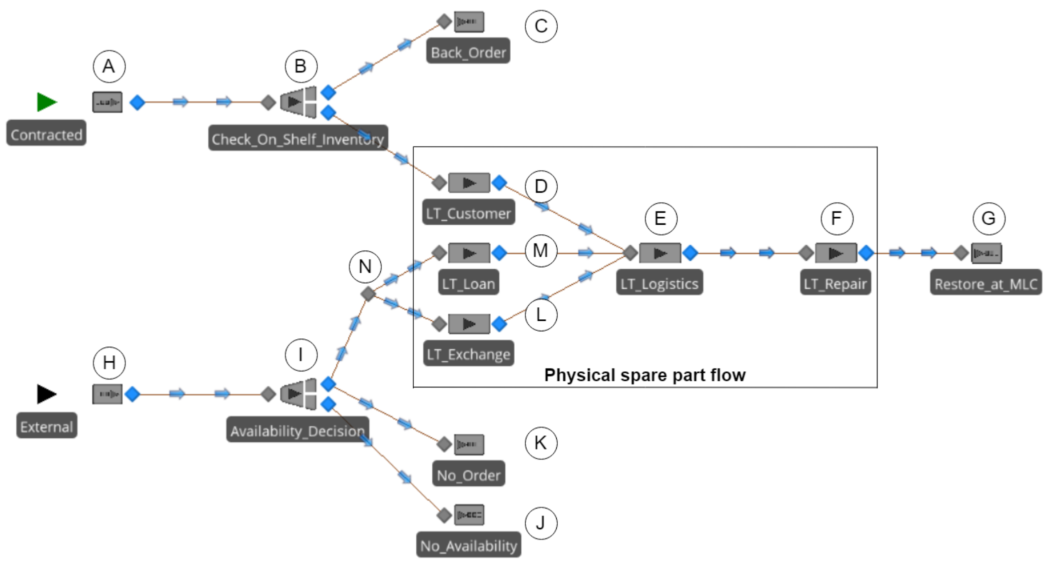

Figure 5.4: Simio simulation model

5.3. Verification and validation

Simulation models are increasingly being used to research decision-making. As these models are used to develop new policies, the correctness of models is of high importance. Verification and validation address the concern of a model being correct [42]. Here, *verification* is about understanding whether the model is built correct according to the specifications. As the model is developed for a specific purpose, the validity should be determined with respect to that purpose. *Validation* is concerned with determining whether the model is an accurate representation of the system.

5.3.1. Verification

In this section, the verification of the model is presented. Model verification can be defined as: *"ensuring that the computer program of the computerised model and its implementation are correct"* [42]. The following verification checks are executed when building the simulation model:

1. *Model correctness:* The simulation model is build in steps. After adding a process or object in the model, the results were directly inspected and checked whether this was expected or not. The model was constantly de-bugged when an error was detected. As the model became bigger, add-on processes were built separately (modular design) and implemented in the overall model after testing and checking the correctness. Furthermore, a top down building approach was used, where a 'rough' model was built first and detail was added later.
2. *Balance checks:* By creating status labels at each model object, balance checks were performed. In addition, the pivot grid of Simio was used to inspect the number of created and destroyed entities. Here, the number of created entities should always equal the sum of the number of entities in the system and the number of destroyed entities. Furthermore, the number of created entities was compared to the inter arrival distribution model input.
3. *Event tracing:* Simio enables researchers to trace entities through the model by the step function. In this manner, the model logic is tested and adjusted in case an error was found.
4. *Run time visualisation:* To inspect whether the behaviour of the simulation model was correct, status labels and counters were included at every model object. By changing input variables, the behaviour (causal relations) of the model was inspected and verified.

Besides the performed verification checks, verification runs are performed. An *extreme condition test* is performed, where extreme cases are tested; input values of 0, 1 or ∞ [12]. The first test is with respect to total circulation stock level input parameter (I_MLC). Two runs were setup, the first with $I\_MLC = 0$ and a second with $I\_MLC = \infty$. It is expected that in the first scenario, the fulfilled demand is zero. Therefore, no entities should arrive at the servers. For the second scenario, it is expected that all created entities at source A (contracted demand) arrive at the servers, in other words: all demand is satisfied (no back-orders). The results are presented in Table 5.11.

Table 5.11: Results of extreme condition test regarding different total circulation stock level

Scenario	Total demand	Demand fulfilled	Number of back-orders
I_MLC = 0	146	0	146
I_MLC = ∞	146	146	0

Next, an extreme condition test is performed regarding the availability decision (separator I) for external demand. For both strategies: risk-based and minimum on-shelf inventory level based, the test is performed. For the risk-based strategy, two scenarios were created. The maximum shortage risk cut-off value was set to 1 and 0. For 1, it is expected that all external requests are fulfilled (are available). While for 0, no requested spares by external customers should be available. For the minimum on-shelf inventory level based availability decision, also two scenarios were tested. The minimum on-shelf inventory level cut-off value was set to 0 and ∞. For 0, it is expected that all spare part requests are available for an external order, while for ∞ no request from external customers could be fulfilled due to unavailability. In both scenarios, the starting inventory level was set to infinity, so inventory was always available. The result are presented in Table 5.12. From both tables can be concluded that the model behaves as expected.

Table 5.12: Results of extreme condition test regarding different availability decision configurations

Scenario	Total demand (external)	Total available	Total unavailable
Prob_shortage_max = 1	89	89	0
Prob_shortage_max = 0	89	0	89
Minimum_shelf_stock_external = 0	89	89	0
Minimum_shelf_stock_external = ∞	89	0	89

Besides the extreme condition test, another verification run is performed in order to check whether the number of spares in the system does not exceed the total circulation stock. This should not be possible as there cannot be more spares in the system than the total circulation inventory level of that particular part. The results of the verification run are presented in Figures 5.5 and 5.6. Here, the total circulation stock level was set to 4. As can be seen in the figures, the sum of the number of spares in system and the on-shelf inventory level equals 4 at all time steps.

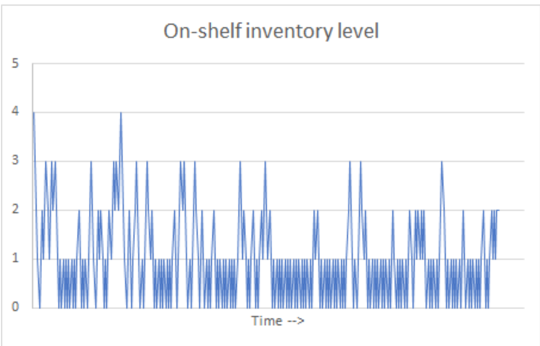

Figure 5.5: On-shelf inventory level

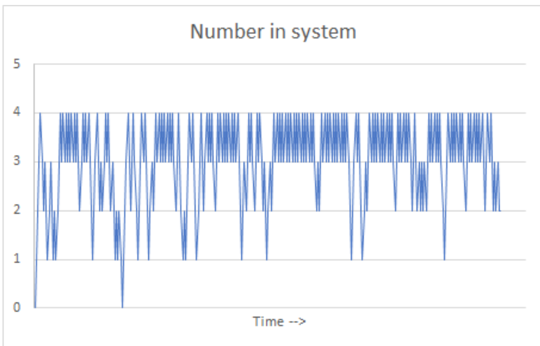

Figure 5.6: Number of spares in the system

5.3.2. Validation

In this section, the validation of the model is presented. Validation is defined as follows: *"substantiation that a computerised model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model"* [42]. However, 100% proof for validation does not exist [12]. The validation is split into structural validation, data validation, model calibration and performance validation.

Structural validation
After the model is verified, the next step is to determine whether the model represents the real world accurately enough to research the objective. If this is not the case, real world decisions should not be supported by the model. Here, the goal is to evaluate the performance

of different availability strategies regarding external customers. In addition, the goal is to investigate the effect and feasibility of increasing the circulation stock. One common technique to determine whether a model is valid or not, is to use the experience of stakeholders. Knowledgeable individuals about the system were asked whether the model and its behaviour are reasonable [42]. This technique is called *face validation*. Individuals that are involved, know the behaviour and structure of the system. Two experts of KLM involved in the system were consulted. In collaboration with the experts, interviewee A and interviewee C, the system description presented in Figure 2.6 was evaluated. Both experts agreed upon the presented system description. Hereafter, the structure and behaviour of the simulation model was presented. By looking at the model behaviour at different configurations, it was concluded that the model was sufficient in order to research the objectives.

Data validation

Now the model structure is validated, the next step is to validate the data. When comparing the model output to historical data, large differences were noticed. In Table 5.13, the fill rates obtained by the model and fill-rates obtained from historical (Appendix B.6) data are presented. Here, the run length was set to 30 weeks with 300 replications as run-time was no issue. Again, the fill-rate is the percentage of contracted demand that could be fulfilled directly from stock at the requested date. To find the reason for the performance inequality, interviews with interviewee A and interviewee E were executed (Appendix A.5 and A.1). They state that the CROCOS data base (Appendix B.2) is highly polluted. From this data set, the total circulation stock levels for all case spare parts were retrieved, which are presented in Table 5.8. It occurs in many cases that scrapped spare parts are not removed from the data. Therefore, the presented circulation stock levels are often to high.

Table 5.13: Case fill-rate versus model fill-rate

No.	Fill-rate case	Fill-rate model
1	93%	100%
2	72%	94%
3	90%	100%
4	89%	100%
5	78%	100%
6	83%	100%
7	77%	98%
8	91%	100%
9	87%	98%
10	60%	100%

Model calibration

In the previous paragraph it was found that the total circulation stock levels are invalid. Therefore, a solution is proposed. Based on the fill-rates obtained from the valid CBSS data set (Appendix B.6), the total circulation stock levels are calibrated according to the spare part specific fill-rates. Calibration is defined as: *"the estimation and adjustment of model parameters and constants to improve the agreement between model output and a data set"* [41]. In order to do this, an experiment is set up. In the experiment, the total circulation stock is used as a configuration variable. Here, the configuration variable is increased by 1 in each scenario, starting at 0. The total circulation stock level is set to the closest value of the fill-rates obtained from historical data (Appendix B.6). In the experiment, the run time was set to 300 weeks with 300 replications. This experiment is performed for all case spare parts. The result for spare part no. 8 is displayed in Figure 5.7. Here, the total circulation stock level is plotted against the fill-rate obtained from the model. For all model outputs (fill-rates) the maximum half width equalled 2, at a confidence level of 95%. The results for all case spare parts are presented in Appendix E.1.

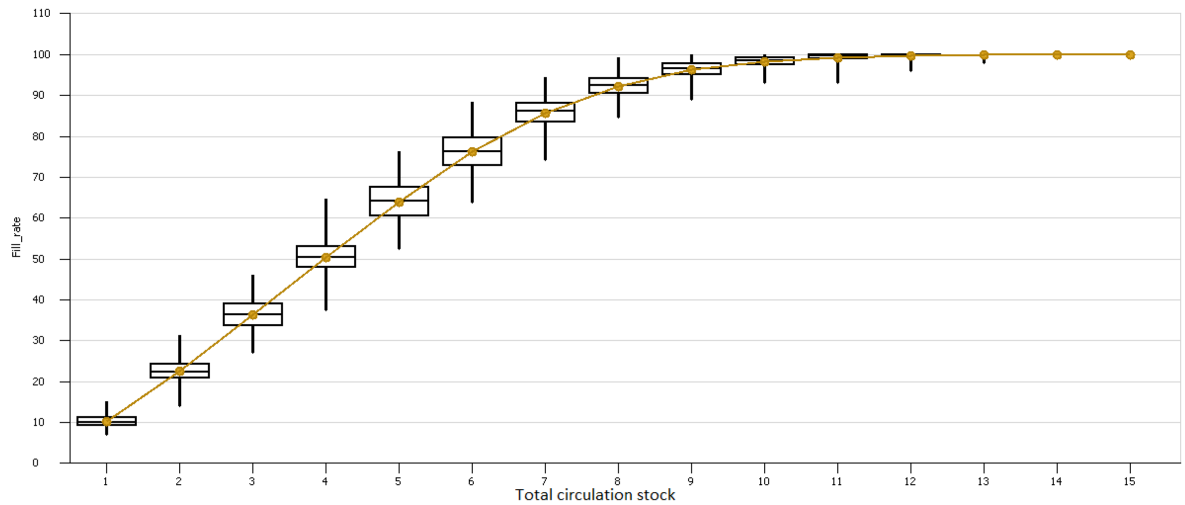

Figure 5.7: Fill-rate versus total circulation stock level case spare part no. 8

Performance validation

By calibrating the model, new circulation stock levels for each case component are determined. Now, the performance is validated by comparing the model results with the historical data. Here, a comparison is made between fill-rates and the number of back-orders. The result is presented in Table 5.14. From the table can be concluded that the model results are close to the values obtained from historical data. Hereby, the performance of the model is validated.

Table 5.14: Validation run result with determined total circulation stock levels

	Total circulation stock	Fill rate		Back-orders (yearly average)	
No.	Model	Model	Case	Model	Case
1	9	95%	93%	1	0
2	4	76%	72%	4	5
3	19	90%	90%	4	3
4	3	90%	89%	1	2
5	1	80%	78%	0	0
6	4	78%	83%	1	0
7	3	77%	77%	0	0
8	8	92%	91%	2	2
9	8	88%	87%	1	1
10	5	62%	60%	7	9

6
Experimental plan & results

This chapter provides the experimental plan where treatment specifications (i.e. warm-up period, run-length and replications) are defined. Hereafter, the run configurations are described and the results are presented. For both availability decision strategies, the best strategy configuration is determined for each specific spare part. Hereafter, a generic availability decision strategy is chosen and specified. Based on the generic availability decision rule, the feasibility of increasing the circulation stock is investigated.

6.1. Experimental plan

In this section the simulation parameters: warm-up period, run length and replications are defined. In addition, the run configurations are described.

6.1.1. Warm-up period

A warm-up period is the time after which the statistics of the run are cleared. This is done in order to remove the atypical system conditions. With respect to this study, especially for fast moving components, the on-shelf inventory does not equal the total circulation stock. Therefore, a warm-up period is used for this research. This start-up period is determined based on the spare with the highest demand (case spare part no. 3). By plotting the number in system, the warm-up period is graphically determined. This is displayed in Figure 6.1. In the figure can be seen that a warm-up period of one month is needed. Therefore, the warm-up period is set to *one month* in all experiments.

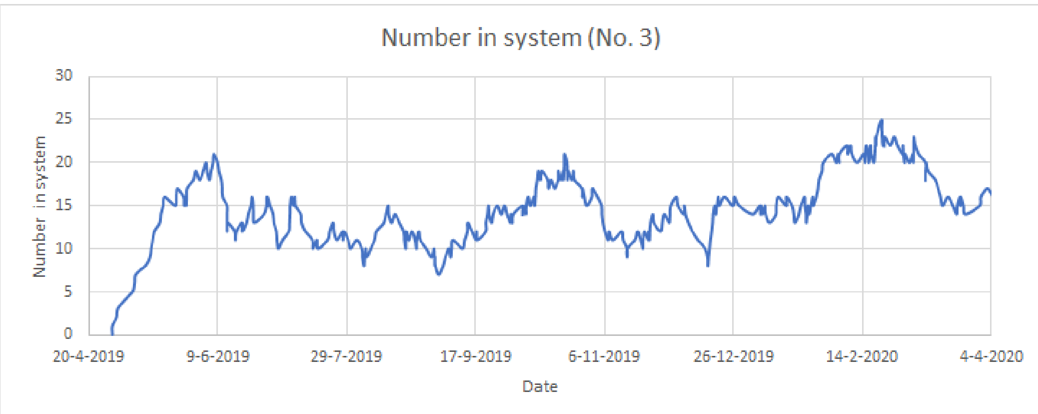

Figure 6.1: Number in system for case component no. 3

6.1.2. Run-length and replications

Once the model has warmed up, the run length has to be determined. As the demand for some spares is rather low, a long run length is needed in order to gain sufficient information about the responds of the system to the strategies under different conditions. Therefore, the run-length, excluding the warm-up period, is set to *5 years*. Now, the number of replications needs to be determined. A replication is a simulation that uses the experiment's logic and data but its own unique set of random numbers [45]. By doing this, the statistical results are generated. By testing different number of replications, the outcome of the model, the KPIs, are compared. Here, the error margin or half width of the 95% confidence interval of a KPI should be below 5% [19]. By checking this for the fill rate KPI, this level of significance can be achieved at *250* replications. The simulation parameters used for all experiments are presented in Table 2.4. When running the model and evaluating the KPIs, it turned out that the half width of some KPIs was not less or equal to 5% of the average. This occurs in situations that were observed less frequently. For example, in an experiment where the fill-rate of a spare part is low and threshold to offer a spare part to an external customer is high (i.e. when the on-shelf inventory level >90% of the total circulation stock), a spare part is almost never offered to an external customer. Due to the low number of observations in such scenario, the half width exceeds 5% of the average. For all situations where the desired half width was exceeded, the number of replications was increased.

Table 6.1: Simulation parameters

Warm-up period (weeks)	Run-time (weeks)	Number of replications
4	260	250

6.2. Availability decision strategies

In this section, the run configurations for both availability decision strategies are discussed. Hereafter, the best strategy configuration for both availability decision strategies is determined per case spare part based on the model results. For both strategies, the robustness of the strategy is tested by running different scenarios where the input parameters are varied. Finally, a generic availability decision strategy is determined based on the obtained simulation results.

6.2.1. Case spare parts

As explained earlier, 10 case spare parts are selected to evaluate the proposed strategies. In Section 4.2.2 an ABC analysis regarding the demand value at KLM's loan is presented. As class A spare parts are the most interesting to research, 10 spare parts from this class were selected. In Section 4.1, spare part characteristics were analysed. As strategies must be able to cope with all spare part types, spare parts with different characteristics were chosen. Table 6.2 presents the selected case spare part with some important characteristics.

Table 6.2: Characteristics of the case study spare parts

No. 1	Total circulation stock	Essentiality class	Demand class	Repair location	Average TAT (days)	Average yearly contracted demand	Fill-rate	Max CBR
1	9	NO-GO	Intermittent	Vendor	35	46,4	93%	0,1
2	4	GO	Intermittent	Repair shop	43	24	72%	0,5
3	19	GO-IF	Smooth	Vendor	24	196,8	90%	0,25
4	3	NO-GO	Intermittent	Repair shop	35	15,2	89%	0,1
5	1	GO-IF	Intermittent	Vendor	44	1,6	78%	0,25
6	4	NO-GO	Intermittent	Repair shop	18	32	83%	0,1
7	3	GO-IF	Intermittent	Repair shop	29	19,2	77%	0,25
8	8	NO-GO	Intermittent	Vendor	25	51,2	91%	0,1
9	8	NO-GO	Intermittent	Repair shop	43	32	87%	0,1
10	5	NO-GO	Intermittent	Vendor	78	24	60%	0,1

6.2.2. Run scenarios

Scenarios are used in order to test the robustness of a solution [25]. For this research, the robustness of both availability alternatives is tested by running the scenarios presented in Table 6.3. By interpreting the changes in the values of the KPIs, the robustness of both availability decision alternatives is evaluated.

Table 6.3: Run scenarios

Input	Δ Input
Contracted Demand	+10%
Contracted Demand	-10%
External Demand	+10%
External Demand	-10%
Repair Time	+10%
Repair Time	-10%

6.2.3. Run configurations

This paragraph presents the run configurations for both availability decision strategies: the risk-based and minimum on-shelf inventory level based availability decisions. The values for the configuration variables and input parameters for the availability decision strategies are presented.

Risk-based component availability decision
For the first availability decision strategy, the risk of a shortage is calculated based on the state of the system at the moment a request from an external customer is received at KLM's loan desk. To calculate the risk of a shortage, some input parameters are needed. These are specified and presented in Table 6.4. In Section 4.2.1, the risk of a shortage calculation is explained. In short, based on the repair location of a spare part (in-house or outsourced), the spare part turn around time is estimated. This is used to estimate the expected demand during the TAT. Based on the on-shelf inventory level and the expected demand during the spare part TAT, the risk of a shortage is calculated. In other words, the probability that the number of expected removals is greater than the on-shelf inventory level during the estimated spare part TAT.

Table 6.4: Risk of shortage calculation input parameters

Risk of shortage input value	Value	Unit	Source
D_{year}	Spare part specific (Table 5.6)	[#spares/year]	Historical data (Appendix B.4)
LT customer	9	[days]	Historical data (Appendix B.6)
LT logistics	Repair shop 1; Vendor 3	[days]	Historical data and interview (Appendix B.5, A.5)
LT repair	Repair shop 17; Vendor 34	[days]	Historical data (Appendix B.5)

Again, a request from an external customer can be accepted in case the cut-off value is greater than calculated shortage risk. For each case component, 5 runs were executed where the configuration variable (maximum risk of a shortage) is varied from 0 to 1, with a step-size of 0,2. For each case spare part, KPIs are plotted against each value of the configuration variable, the results are presented in Section 6.2.4.
After evaluating the results and choosing the best strategy configuration for each spare part, the robustness of the strategy is tested as explained in Section 6.2.2.

Minimum on-shelf inventory level based availability decision
In this strategy, the availability decision is based upon the on-shelf inventory level at the moment a request is received by the loan desk. Here, a request is accepted in case the on-shelf inventory level is greater than the configuration variable: minimum on-shelf inventory level. For each case component the configuration variable is varied from 0 up to the total circulation stock level with step size 1. So, in case the configuration variable equals 0, all requests are offered to the external customer. For each case spare part, KPIs are plotted against each value of the configuration variable, the results are presented in Section 6.2.4.
After evaluating the results and choosing the best strategy configuration for each case spare part, the robustness of the strategy is tested, as explained in Section 6.2.2.

6.2.4. Model results

In this section, the model results regarding the availability decision strategy alternatives are presented. The best configuration for both strategies is determined per case spare part based on the values of the KPIs and the maximum cost benefit ratio constraint. For each case spare part, 3 graphs were obtained. First, a plot that presents the availability for both contracted and external customers against the value of the configuration variable. As explained earlier, for the risk-based availability decision the configuration variable is the maximum risk off a shortage. For the minimum on-shelf inventory level based availability decision, the configuration variable is the minimum on-shelf inventory level. In addition, a plot is obtained in which the financial KPIs are presented for each value of the configuration variable. Lastly, the cost benefit ratio is plotted for each strategy configuration.
Hereafter, the robustness of each strategy is evaluated by exploring the results of the run configurations presented in Table 6.3. In addition, the most important spare part characteristics of the case items can be found in Table 6.2.

Risk-based component availability decision
Based on the resulting KPIs and the cost benefit ratio constraint, the best strategy configuration for each case spare part is determined. The maximum value to which the CBR is constrained, depends on the essentiality of the spare part. As explained in Section 6.2.3, an experiment is performed where the configuration variable: *maximum risk of a shortage* is varied from 0 to 1.
First, the effect for each strategy configuration with respect to the spare part availability is obtained. The result for spare part no. 1 is presented in Figure 6.2.

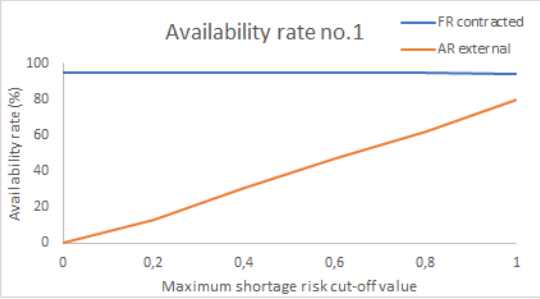

Figure 6.2: Availability versus maximum risk of a shortage

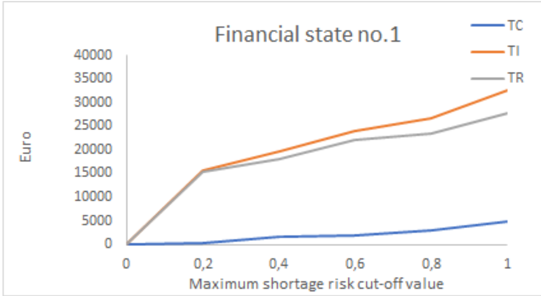

Figure 6.3: Financial KPIs versus maximum risk of a shortage

In the figure can be seen that the fill-rate regarding contracted customers varies from 94,3% to 94,9%, when the maximum risk of a shortage value decreases from 1 to 0. So, when the configuration variable is set to 1, the spare part is available for an external customer in case the on-shelf inventory is greater than 0. It can be seen that an increase in the configuration variable results in an increase in availability regarding external customers. The availability results for all case spare parts can be retrieved from Appendix E.2.
Next, the financial performance is presented. The financial results for case no. 1 are displayed in Figure 6.3. Here, TI indicates the total income generated from external orders, while TC indicate the back-order costs due to the providence of the loan service. By subtracting TI with TC, the total result (TR) is calculated. The figure shows that the TI and TC increase while the value of the configuration variable increases. In the figure can be seen that the TR is at its maximum when the risk of a shortage equals 1. In this strategy configuration, the TR for case no. 1 equals €28.709,55. However, to determine whether this is the best configuration for this spare part, the CBR constraint needs to be checked. It turns out that the CBR equals 0,18 in this configuration. As explained earlier, the maximum CBR is dependent on the essentiality of the spare part. Spare part no. 1 is a "NO-GO" (or ESS1) item, for which the maximum CBR is constrained to 0,1. In Figure 6.4 the CBR is presented for each strategy configuration. It can be seen that for a value of 0,6 of the configuration variable, the CBR constraint is met. In combination with the financial results, it can be concluded that this is the best strategy configuration for case no. 1. In this configuration the TR equals €22.012,58.

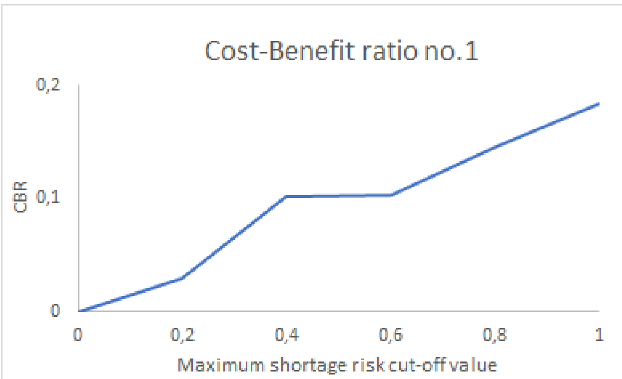

Figure 6.4: Cost benefit ratio versus maximum risk of a shortage

In addition, when looking at the availability results, the fill-rate of contracted customers equals 94,9% and the availability rate for external customers 47,4%. This shows that this strategy configuration, results in a negligible effect on the contracted customer fill-rate, which should be the case as it is a "NO-GO" item.
The same approach in order to find the best strategy configuration for the other case spare parts. The resulting KPIs are presented in Figure 6.5. The confidence intervals of the obtained KPI values are presented in Tables 6.5 and 6.6. In the tables, the optimal value for the con-

figuration variable is presented per case spare part. The results per case spare part for each strategy configuration are presented in Appendix E.2.

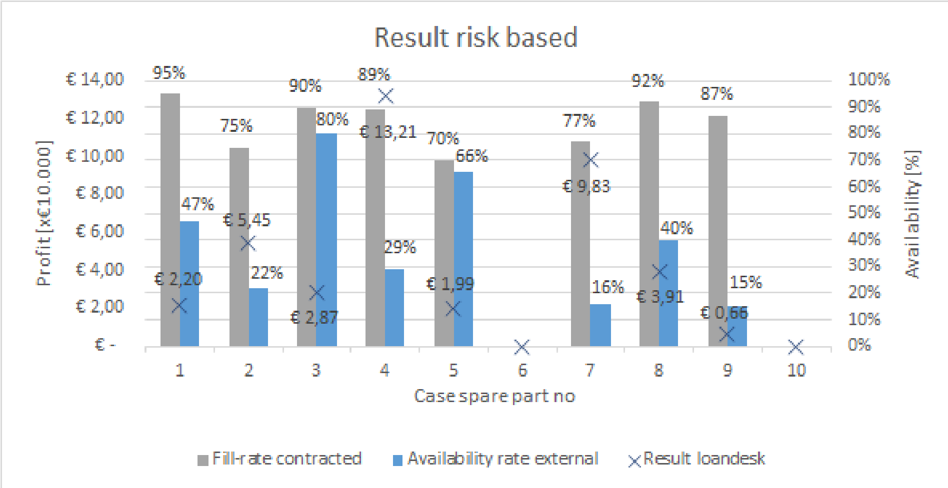

Figure 6.5: Model results risk-based availability decision in best strategy configuration per case spare part

Table 6.5: Model results availability KPIs for maximum risk of a shortage based availability decision at optimum value for configuration variable

No.	Configuration variable result	Fill-rate contracted			Availability rate external		
		Average	low 95%	High 95%	Average	low 95%	High 95%
1	**0,6**	94,8%	94,7%	95,0%	47,7%	47,2%	48,3%
2	**0,8**	75,2%	74,8%	75,5%	75,2%	74,8%	75,5%
3	**1**	89,5%	89,3%	89,7%	79,0%	78,6%	79,4%
4	**0,4**	89,4%	89,1%	89,6%	28,8%	28,3%	29,3%
5	**1**	69,7%	68,7%	70,7%	65,6%	65,0%	66,2%
6	**0**	78,8%	77,6%	79,0%	0,0%		
7	**0,6**	76,8%	76,4%	77,1%	15,8%	15,3%	16,2%
8	**0,4**	92,0%	91,8%	92,2%	40,6%	40,0%	41,2%
9	**0,4**	87,2%	86,9%	87,5%	15,6%	15,1%	16,0%
10	**0**	62,5%	61,8%	63,1%	0,0%		

Table 6.6: Model results financial KPIs for risk of a shortage based availability decision at optimum value for configuration variable

No.	Configuration variable result	Total income loan desk			Total back-order cost due to loan desk		
		Average	Low 95%	High 95%	Average	Low 95%	High 95%
1	**0,6**	€23.500	€22.000	€25.500	€2.000	€1.750	€2.250
2	**0,8**	€86.000	€77.000	€95.000	€23.000	€20.500	€25.500
3	**1**	€40.000	€38.000	€41.000	€9.500	€9.000	€10.000
4	**0,4**	€134.500	€123.000	€145.500	€12.000	€10.000	€13.500
5	**1**	€22.000	€21.000	€23.500	€3.750	€3.500	€4.000
6	**0**	€0	€0	€0	€0	€0	€0
7	**0,6**	€98.500	€82.500	€114.500	€8.500	€7.000	€10.000
8	**0,6**	€44.500	€40.500	€48.000	€3.500	€3.000	€4.000
9	**0,4**	€7.000	€6.000	€8.000	€400	€300	€500
10	**0**	€0	€0	€0	€0	€0	€0

To test the sensitivity of the performance indicators and to evaluate the robustness of the strategy, different scenarios were simulated. To do so, the value of some input parameters are varied. The run scenarios are presented in Table 6.3. The average change in the value of the KPI values per run scenario are presented in Table 6.7. It can be concluded that the performance indicators are sensitive in some situations. However, the responds are in the expected direction. For example, when the repair time increases, it is logical that the availability decreases for both contracted and external customers. In addition, the results show that the strategy performs as it should, as the availability for external customers decreases when the demand of contracted customers increases.

Table 6.7: Robustness of the risk-based availability decision

Input	Δ Input	Δ Fill-rate contracted customers	Δ Availability rate external customers	Δ Result loan desk
Contracted Demand	+10%	-4%	-11%	-12%
Contracted Demand	-10%	+4%	+15%	+4%
External Demand	+10%	0%	-1%	0%
External Demand	-10%	0%	+0%	-5%
Repair Time	+10%	-2%	-7%	-11%
Repair Time	-10%	+2%	+10%	+1%

Minimum on-shelf inventory level based availability decision

Based on the resulting KPIs in combination with the cost benefit ratio constraint, the best strategy configuration is chosen for each case spare part. As stated earlier, the maximum CBR is dependent on the essentiality of the spare part. For all case spare parts, the configuration variable: *minimum on-shelf inventory level* is varied from 0 up to the total circulation stock of that particular spare part.

First, the effect of each strategy configuration with respect to spare part availability is obtained. The results for spare part no. 1 are presented in Figure 6.6.

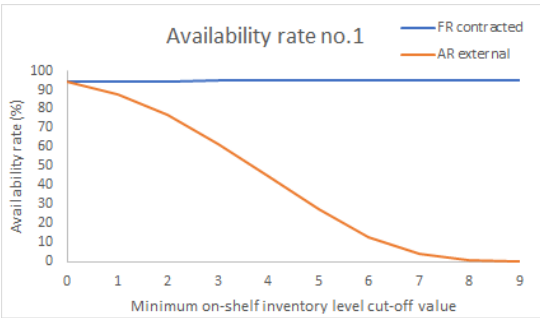

Figure 6.6: Availability versus minimum on-shelf inventory level

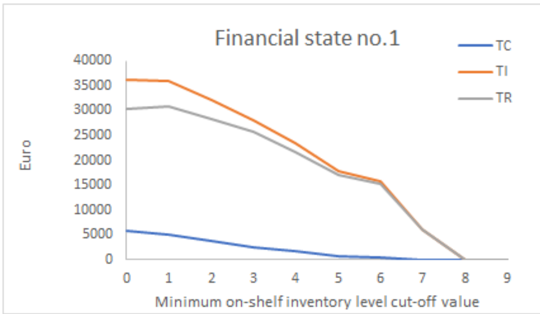

Figure 6.7: Financial KPIs versus minimum on-shelf inventory level

In the figure can be seen that the fill-rate regarding contracted customers varies from 93,3% to 94,9% when the minimum on-shelf inventory level value increases from 0 to 9. In addition, in case the minimum on-shelf inventory level is set to 0, the availability for external customers is at its maximum value (94,2%). Logically the availability decreases if the value of the configuration variable increases. The availability results for all case spare parts can be found in Appendix E.3

Next, the financial KPIs are investigated. The results for case spare part no. 1 is presented in Figure 6.7. In the figure, TI represents the total income generated from external orders. TC indicates the back-order costs due to the providence of the loan service. By subtracting TI with TC the total result (TR) is obtained. In the figure can be seen that the income decreases when the minimum on-shelf inventory level cut-off value increases. Also, it can be noticed that the back-order cost due to the loan service decrease when configuration variable increases. It appears that, for case spare part no. 1, the total result is at its maximum when the minimum on-shelf inventory level cut-off value equals 1. In other words, when an external request is offered to a customer in case the on-shelf inventory level is at least 2. In this configuration, the total result is at its maximum of €30.804,69. However, to determine whether this is the best configuration of this strategy the CBR needs to be inspected. The CBR for each strategy configuration for case spare part no. 1 is presented in Figure 6.8. Case spare part no. 1 is a “NO-GO” (or ESS1) item, so the value of the CBR should be less or equal to 0,10. From the figure can be concluded that the minimum on-shelf inventory level for this spare part should be greater than 3. With this in mind, the financial KPIs are inspected again. It turns out that the best strategy configuration for this spare part, when taking into account the CBR constraint, is at a minimum on-shelf inventory level value of 3. In this configuration the TR equals €25.703,97.

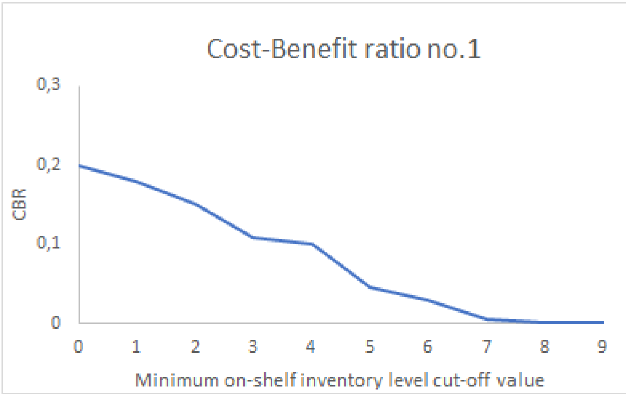

Figure 6.8: Cost benefit ratio versus minimum on-shelf inventory level

When inspecting this configuration in the availability plot, Figure 6.6, it turns out that the fill-rate regarding contracted customers equals 94,1% and the availability rate for external customers 61,4%. This shows that when using this strategy configuration, the effect of the loan service is negligible, as the fill-rate regarding contracted demand only drops by 0,1%. This should be the case as this case spare part is classified as a “NO-GO” item.
By applying the same approach, the optimum configuration variable is determined for all case spare parts. The KPI results are presented in Figure 6.9. The confidence intervals of the KPIs can be retrieved from Tables 6.8 and 6.9. These tables also provides the optimum value for the configuration variable for each case spare part. In addition, the results per case spare part for each strategy configuration can be retrieved from Appendix E.3.

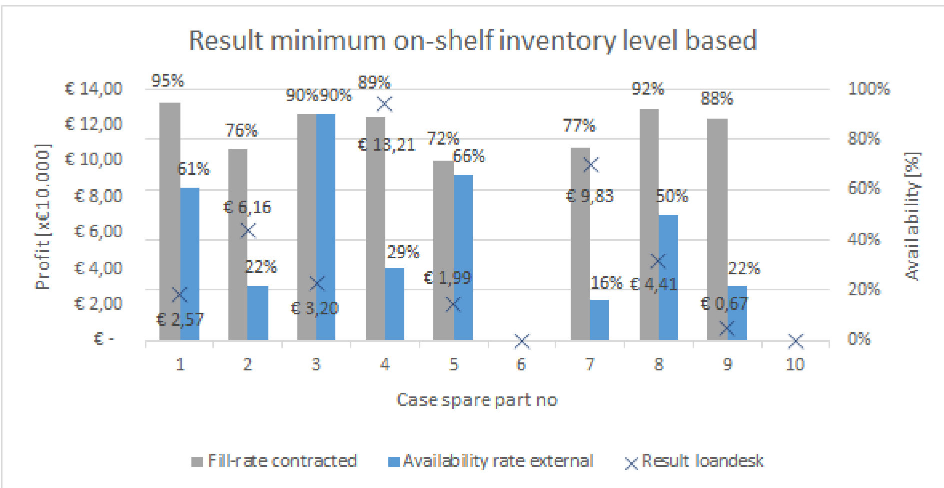

Figure 6.9: Model results minimum circulation stock level based availability decision

Table 6.8: Model results availability KPIs for minimum on-shelf based availability decision at optimum value for configuration variable

No.	Configuration variable result	Fill-rate contracted			Availability rate external		
		Average	low 95%	High 95%	Average	low 95%	High 95%
1	**3**	94,9%	94,8%	95,0%	61,7%	61,1%	62,3%
2	**2**	75,7%	75,4%	76,1%	22,7%	22,1%	23,2%
3	**0**	89,6%	89,5%	89,8%	89,5%	89,2%	89,8%
4	**2**	89,5%	89,2%	89,8%	28,8%	28,3%	29,3%
5	**0**	72,2%	71,3%	73,1%	65,6%	65,0%	66,2%
6	**4**	78,8%	77,6%	79,0%	0,0%	0,0%	0,0%
7	**2**	77,1%	76,8%	77,4%	15,8%	15,3%	16,2%
8	**3**	92,1%	91,9%	92,3%	50,8%	50,1%	51,5%
9	**4**	87,5%	87,2%	87,8%	22,0%	21,4%	22,6%
10	**4**	62,5%	61,8%	63,1%	0,0%	0,0%	0,0%

Table 6.9: Model results financial KPIs for minimum on-shelf based availability decision at optimum value for configuration variable

No.	Configuration variable result	Total income loan desk			Total back-order cost due to loan desk		
		Average	Low 95%	High 95%	Average	Low 95%	High 95%
1	**3**	€27.000	€26.000	€28.000	€2.400	€2.300	€2.500
2	**2**	€84.500	€76.000	€93.500	€22.500	€20.000	€25.000
3	**0**	€44.000	€42.500	€45.500	€10.500	€9.500	€11.500
4	**2**	€134.500	€123.000	€145.500	€12.000	€10.000	€13.500
5	**0**	€22.000	€21.000	€23.000	€3.750	€3.500	€4.000
6	**4**	€0	€0	€0	€0	€0	€0
7	**2**	€98.000	€82.000	€103.500	€8.500	€7.000	€10.000
8	**3**	€47.000	€43.500	€50.500	€4.000	€3.500	€4.500
9	**4**	€7.000	€6.000	€8.000	€500	€400	€600
10	**4**	€0	€0	€0	€0	€0	€0

To check the sensitivity of the performance indicators and to evaluate the robustness of the strategy, different scenarios are modelled, where the value of the input parameters is varied. These scenarios can be found in Table 6.3. The average change in the KPIs for different scenarios is presented in Table 6.10. It can be concluded that in some situations the KPIs are sensitive. However, from the results can be concluded that the strategy behaves as expected. For example, the results show that in a case the contracted demand increases, the availability for external customers decreases, which should be the case. In addition, it can be noticed that changes in demand from external customers do not effect the KPIs, this is due to the fact that in general the demand from contracted customers is much greater than from external customers.

Table 6.10: Robustness of the minimum on-shelf inventory level based availability decision

Input	Δ Input	Δ Fill-rate contracted customers	Δ Availability rate external customers	Δ Result loan desk
Contracted Demand	+10%	-6%	-13%	-19%
Contracted Demand	-10%	+4%	+15%	+4%
External Demand	+10%	-1%	0%	+0%
External Demand	-10%	0%	-1%	-8%
Repair Time	+10%	-4%	-5%	-15%
Repair Time	-10%	+2%	+10%	+0%

6.2.5. Towards a generic availability decision

This research aims to improve the performance of KLM Component Services, which could be achieved by improving the availability decision at the loan desk. Ideally, standard decision rules are developed for the availability decision regarding external customers. This enables employees to respond faster yet well-considered. In this subsection, the possibilities of a generic availability decision rule are investigated.
For all three criticality classes, the cost-benefit ratio constraint has a different maximum value. For this research, 10 spare parts were selected as a case study, with different criticality classes. This makes it hard to define a generic decision rule per spare part class as the amount of case studies is limited. Therefore, all 10 case spare parts are treated as GO, GO-IF or NO-GO when defining the generic availability decision rule per criticality class. By doing so, for each criticality class, 10 spare parts with different characteristics are used to test strategy configurations.
When trying to determine a generic availability decision rule based on the minimum on-shelf inventory level strategy, it turned out that the value of the configuration variable varies a lot. This mainly due to one reason. The total circulation stock level differs a lot per spare part, which makes it nearly impossible to determine a generic availability decision rule. The risk-based availability decision does not cope with this problem. Based on the model results of this strategy, a maximum risk-off a shortage value could be determined per criticality class. These are presented in Table 6.11.

Table 6.11: Generic decision rule: maximum risk of a shortage per criticality class

Essentiality level	Maximum risk of a shortage
GO	0,8
GO-IF	0,6
NO-GO	0,2

Now, the model results when implementing the maximum risk of a shortage cut-off values are presented per criticality class.
For the first category, “NO-GO” items, the model results are presented in Table 6.12. Here, a cut-off value of 0,2 was selected. By doing so, the CBR does only exceed the maximum value of 0,1 once. However, this is an exceptional case as the total circulation stock for this item is only 1. To motivate why it is acceptable for this item to accept the exceeded maximum CBR, the total number of back-orders is investigated. It turns out that the total number of back orders increases only by 0,52 back-orders over a 5 year period, when comparing a maximum risk acceptance of 0,2 to 0 (when a spare part is not available in any situation). The financial impact of this is almost zero and therefore acceptable for this case spare part.

Table 6.12: Model results for maximum risk of a shortage: 0,2

No.	Fill-rate contracted [%]	Availability rate external [%]	Total back-order cost due to loan desk	Total income loan desk	Total result loan desk	Cost benefit ratio
1	94,9	12,9	€500	€ 15.500	€ 15.000	0,03
2	75,3	0,0	€0	€0	€0	0,00
3	90,3	0,0	€0	€0	€0	0,00
4	89,3	0,0	€0	€0	€0	0,00
5	69,6	65,9	€ 3.500	€ 23.500	€ 20.000	0,20
6	78,5	0,0	€0	€0	€0	0,00
7	77,1	0,0	€0	€0	€0	0,00
8	92,2	5,1	€ 500	€ 30.000	€ 29.500	0,03
9	87,6	3,1	€0	€0	€0	0,00
10	61,6	0,6	€0	€0	€0	0,00

For the second category, “GO-IF” items, the model results are presented in Table 6.13. For this category, the cost benefit ratio should not exceed 0,25. By using 0,6 for the maximum risk of a shortage, this can be achieved, except for case spare part number 2. Therefore, the results for this case spare part are investigated into more depth by inspecting the total number of back-orders (not only due to the loan desk). It was found that the total number of back-orders increases with 0,06 over 5 years, when comparing a maximum risk acceptance of 0,6 to 0 (when a spare part is not available in any situation). Therefore, this decision rule can be accepted.

Table 6.13: Model results for maximum risk of a shortage: 0,6

No.	Fill-rate contracted [%]	Availability rate external [%]	Total back-order cost due to loan desk	Total income loan desk	Total result loan desk	Cost benefit ratio
1	94,9	47,4	€2.000	€24.000	€ 22.000	0,10
2	75,2	22,1	€23.500	€78.000	€54.500	0,30
3	90,3	0,6	€0	€0	€0	0,00
4	88,5	64,0	€30.500	€192.000	€161.500	0,20
5	69,6	65,9	€3.500	€23.500	€20.000	0,20
6	78,4	26,4	€78.500	€327.000	248.500	0,24
7	76,7	15,6	€9.000	€107.500	€98.500	0,11
8	92,0	40,1	€3.000	€42.000	€39.000	0,09
9	87,6	32,1	€1.000	€7.000	€6.000	0,14
10	61,1	15,6	€ 1.000	€5.500	€4.500	0,23

For the last category, “GO” items, the model results are presented in Table 6.14. For this category, the CBR is constrained to a maximum value of 0,5. This can be achieved for all case spare parts when applying a maximum risk of a shortage cut-off value of 0,8.

Table 6.14: Model results for maximum risk of a shortage: 0,8

No.	Fill-rate contracted [%]	Availability rate external [%]	Total back-order cost due to loan desk	Total income loan desk	Total result loan desk	Cost benefit ratio
1	94,6	61,8	€3.000	€26.500	€23.500	0,15
2	75,2	22,1	€23.500	€78.000	€54.500	0,37
3	90,2	3,1	€500	€20.000	€19.500	0,02
4	88,5	64,0	€30.500	€192.000	€161.500	0,20
5	69,6	65,9	€4.000	€23.500	€19.500	0,20
6	78,0	52,7	€190.500	€661.500	€471.000	0,36
7	76,4	46,0	€30.000	€132.000	€102.000	0,28
8	91,9	57,8	€5.500	€46.500	€41.000	0,15
9	87,5	50,0	€1.500	€8.000	€6.500	0,23
10	61,1	15,6	€2.000	€5.500	€3.500	0,50

The average results of the case spare part mix for each strategy configuration are presented in Figures 6.10, 6.11 and 6.12. From these figures can be concluded that the effect of the loan desk drastically increases when the maximum acceptable risk of a shortage exceeds 0,8.

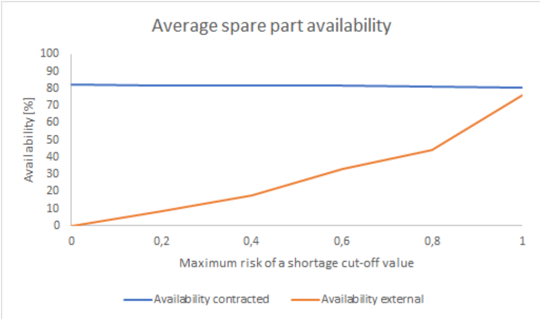

Figure 6.10: Average availability case spare parts versus maximum risk of a shortage cut-off value

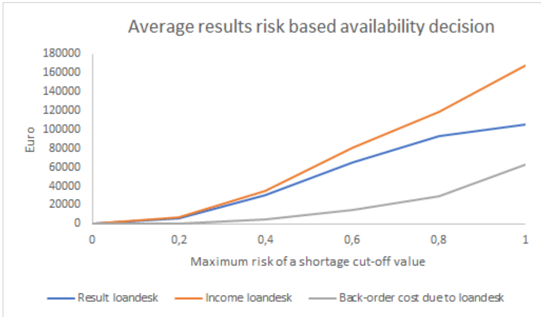

Figure 6.11: Average financial results case spare parts versus maximum risk of a shortage cut-off value

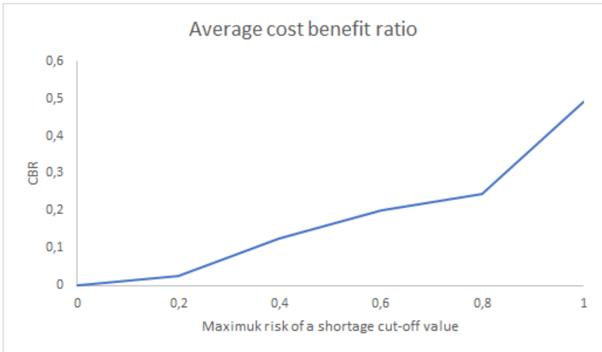

Figure 6.12: Average CBR case spare parts versus maximum risk of a shortage cut-off value

6.3. Circulation stock level

In this section, the run configuration for the third strategy: increasing the total circulation stock level is presented. Hereafter, the model results are discussed.

6.3.1. Run configuration circulation stock level

This section presents the run configuration for the circulation stock strategy. In Section 6.2.5, a generic availability rule is determined. The presented generic availability decision rule (Table 6.11) is used in all runs. Again, the value cut-off value for the maximum risk of a shortage is dependent on the essentiality class of the spare part.
For this strategy, the *total circulation stock level* is the configuration variable. For each case spare part, 5 configurations are modelled. Here, the configuration variable is incremented by 1 in each configuration, starting at the total circulation stock levels presented in Table 5.14. The same input and simulation parameters were used as for the availability decision, which is explained in Sections 5.1 and 6.1.

6.3.2. Model results circulation stock level

In this section, the model results of the circulation stock level strategy are presented and discussed. For each case spare part, the marginal value of an additional circulation stock item is calculated according to formula 3.7. Here, the marginal value (F) of additional stock items n is calculated by subtracting the benefits of the additional spares with the costs of the additional spares. As the run length is set to 5 years, the marginal value is calculated for the same duration. In other words, when the obtained outcome for the marginal value is positive, the purchase of the additional spares is feasible within 5 years. The *benefits* consist of Δ total back-ordering costs, which is the decrease in total Back-Ordering Cost (so not solely the back-order cost due to the providence of the loan service) and TI, which is the Total Income generated by the loan desk. The costs that are taken into account are: Purchase Cost (or PC) which are calculated by multiplying n with the latest list price; and Holding Cost (HC). The HC are calculated by multiplying the annual holding cost (17% of LLP) by the LLP over a time span of 5 years.

For each spare part the marginal stock value is plotted against the total circulation stock level, starting at the current circulation stock value. For case no. 2, the results are presented in Figure 6.14. In the figure can be seen that the total cost linearly increase. The benefits of increasing the total circulation stock also show an increasing pattern. However, the increase of the benefits stagnates as the total circulation stock increases. At a certain point, the fill-rate approaches 100% and no back-order costs are made. When this point is reached, the benefits still increase until the availability rate regarding external customers equals 100%. Hereafter, no additional benefits are gained. The effect on the availability regarding both contracted and external customers are presented in Figure 6.13. The model results for all case spare parts can be found in Appendix E.4.

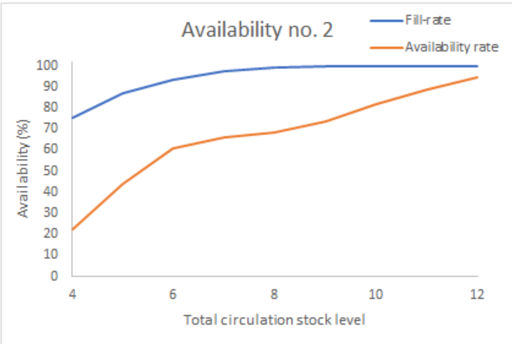

Figure 6.13: Availability versus total circulation stock level case no. 2

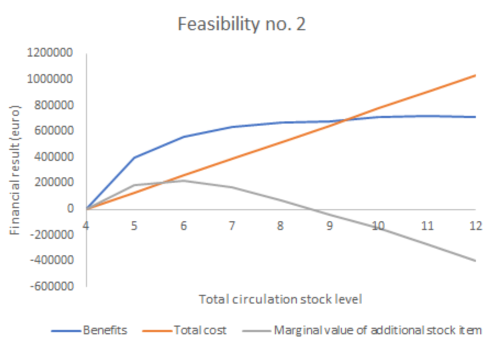

Figure 6.14: Marginal value of stock item versus the total circulation stock level of case no. 2

In the figure can be seen that an increase of 4 spares (from 4 to 8) is the maximum increase that is still feasible. So, increasing the circulation stock with 1,2 or 3 is also feasible. In this situation, when the circulation stock is increased with 4 stock items, the total back-order cost decrease from €544.539,02 to €13.406,00. In addition, the total income generated by the loan desk increases from €77.829,41 to €135.940,76. The result for all case spare parts is presented in Table 6.15.

Table 6.15: Results increasing circulation stock strategy

No.	Additional circulation stock	Δ Fill-rate contracted (percent points)	Δ Availability rate external (percent points)	Δ Total income loan desk	Δ Total back-order cost	Δ Holding cost	Purchase cost	Marginal value of additional stock items
1	**0**	-	-	€0	€0	€0	€0	€0
2	**4**	23,9	46,1	€58.000	- €531.000	€238.000	€280.000	€71.500
3	**3**	7,0	1,4	€0	- €33.000	€14.500	€17.000	€1000
4	**1**	7,5	28,2	€120.500	- €147.000	€90.500	€106.500	€70.500
5	**0**	-	-	€0	€0	€0	€0	€0
6	**5**	21,5	63,4	€802.500	- €3.420.500	€1.923.500	€2.263.000	€36.500
7	**3**	21,7	53,7	€128.000	- €437.000	€200.000	€235.500	€129.000
8	**0**	-	-	€0	€0	€0	€0	€0
9	**2**	8,6	17,6	€8.000	- €20.000	€10.000	€12.000	€6.000
10	**8**	38,0	75,5	€10.500	- €81.000	€40.500	€48.000	€3.000

6.4. Evaluation of the model results

This section evaluates the results presented in this chapter. First, the performance of the generic availability decision rule is evaluated. This is done by comparing the performance of the current state situation with the model results of this strategy. Furthermore, the results of increasing the total circulation stock strategy are evaluated and discussed.

6.4.1. Generic spare part availability decision

Currently, the average availability rate regarding external customers equals: *21%*. For the generic availability decision rule, the average availability rate per essentiality class are presented in Table 6.16.

Table 6.16: Average availability rate per essentiality level of generic availability decision rule

Essentiality level	Availability rate [%]
GO	9%
GO-IF	33%
NO-GO	43%

From the log data collected by KLM's loan desk (Appendix B.1), the demand share per criticality class are obtained and presented in Table 6.17.

Table 6.17: External demand share per criticality class

Essentiality level	Share of requests [%]
GO	7,7%
GO-IF	59,7%
NO-GO	32,6%

When taking the demand share per essentiality class into account, the average availability rate equals *26%* for the generic availability decision rule. So, on average **the availability rate regarding external customers increases with 24% or 5 percent points**. Based on the above presented tables, the difference in revenue between the current state situation and the generic availability decision rule can be estimated. Here, the hitrate is assumed to remain at 13,5% (explained in Section 2.3.2). Furthermore, the average income per order remains €13.499,39 (Table 2.2). As explained in Section 2.4.2, during the first 44 weeks of 2018, 3.419 useful requests were received by KLM's loan desk. Based on this, the estimated revenue generated by KLM's loan desk, when implementing the generic decision rule, increases from €1.336.439,70 to €1.653.422,53, so **the revenue increases with €375.777,85 per year**. Unfortunately, no data historical data allows to investigate the number of back-orders due to the providence of the service provided by the loan desk. However, when using the generic availability decision, the level of risk KLM is willing to take is adjustable for each criticality class. Furthermore, from the simulation results the increase in back-order cost due to the providence of the service can be estimated and are presented in Table 6.18. Most importantly, by using the generic availability decision rule, the cost-benefit ratio constraint is met.

Table 6.18: Total back-order cost for each maximum risk of a shortage configuration

Maximum risk of a shortage	Δ total back-order cost
0	0%
0,2	1%
0,4	1%
0,6	2%
0,8	3%
1	9%

6.4.2. Circulation stock level

From the results presented in Table 6.15, the conclusion can be drawn that for most case spare parts it is feasible to increase the total circulation stock level. Especially, the decrease in back-order costs contributes to the feasibility of increasing the circulation stock. When inspecting solely the increase in income generated by the loan desk, increasing the total circulation stock is not feasible in any case for all case spare parts. However, the finding that the total back-order cost can be decreased drastically by increasing the total circulation stock is of huge importance. Currently, KLM strives to keep the total circulation stock as low as possible, which results in huge back-order expenses. Therefore, the inventory management policy at KLM should be reconsidered. Moreover, the circulation stock levels are not known at this moment. Therefore, it is important to gain insight in inventory levels before actual decision can be made.

7

Conclusions and recommendations

In this chapter, the conclusions are presented by answering the research questions in Section 7.1. Furthermore, this chapter provides the research discussion in Section 7.3. Here, research limitations and assumptions are discussed. In addition, this chapter presents the recommendations for KLM Engineering & Maintenance Component Services and for further research in Section 7.2. Finally, an academic and personal reflection is provided in Section 7.4.

7.1. Conclusion

The goal of this research is to provide an answer to the main research question formulated in Section 1.6:

"What strategic improvement option(s) should be employed in order to increase the contribution of KLM's loan desk to the performance of KLM Component Services?"

To provide an answer to the main research question, the sub-questions are answered. These narrower research questions were formulated to structure the thesis and make the research manageable. Hereafter, the answer to the main research question is presented.

1) What is the current state of KLM's loan desk and what are the characteristics of the system?

KLM Component Services is responsible to ensure spare part availability for the contracted customers of KLM Engineering & Maintenance. In 2018, KLM E&M gained a revenue of €910 million from maintenance contracts. According to Service Level Agreements, KLM Component Services must fulfil 100% of the requests from contracted customers. In case of unavailability, the requested spare part is borrowed or purchased from a third party service provider. This study focuses solely on rotable spare parts, which are interchangeable and repairable spare parts. The supply chain of such spare parts is characterised as closed-loop. When a contracted customer requests a rotable component, KLM Component Services ships a serviceable (or SE) spare part to the location of the customer. Here, the SE component is interchanged with the unserviceable (or US) component, which is returned to the logistics center of KLM Component Services. The US spare part is send to the right repair location, either in-house or outsourced, where the spare part MRO takes place. The spare part now retrieves its SE status and is shipped to the logistics center where the SE component is restored. This is the so-called closed-loop supply chain. The removal pattern of rotable spare parts is sporadic with large zero demand periods, which results in a low spare part utilisation rate. To increase the utilisation rate of spare parts, KLM Component Services introduced the loan desk. Here, spare part requests from non-contracted or external customers are handled. This enables external customers to borrow a spare part from KLM against a predetermined fee. Both demands,

contracted and non-contracted, are supplied from the same inventory source, the Magazijn Logistiek Centrum. In short, the system can be characterised as a closed-loop supply chain, serving both contracted and external customers from a single inventory source.
At KLM's loan desk, the procedures regarding the availability and pricing decisions are rather vague. Decisions are made based upon feeling and experience instead of standard or rule-based. Currently, the loan service negatively influences spare part availability of contracted customers. This effect should be limited, especially the back-order costs caused by the providence of an additional loan service should be minimised. Both the availability and pricing decisions directly influence the number of external orders, which results in additional revenues gained from this service. However, this also effects spare part availability regarding contracted customers.
At the loan desk, performance is monitored solely by tracking the revenue generated by the loan service. In 2018, the revenue gained from this service equalled €1,3 million. Management set a monthly revenue target of €200.000 which is met in approximately 17,5% of the months. Currently, the availability regarding external customers equals 21%. This low availability is due to zero or critical stock levels of the requested spare parts. The loss of potential income due to stock issues is estimated on €175.000 per month. For KLM Component Services, the most important performance measure is Service Level regarding contracted customers, the percentage on-time deliveries. According to Service Level Agreements, the average service level should be 94,7%. Currently, the average service level equals 82%, which is rather poor. This results in back-orders in 14% of all contracted requests, which costs KLM Component Services roughly €500.000 per month solely for the B737 aircraft type.

2) How can performance be defined regarding KLM's loan desk?
The reason for introducing the loan desk is to increase the utilisation of rotable spare parts. By serving external customers, additional revenues are gained which should contribute to the profit of KLM Component Services. However, the providence of the loan service could result in additional back-order costs, which decreases the profit of KLM Component Services. Therefore, from a financial perspective, performance refers to: increasing the revenue gained from external customers while limiting the effect on spare part availability regarding contracted customers.
Performance from an external customers perspective refers to: a service with high availability, fast response and good price. Achieving this results in an increased customer satisfaction and customer loyalty, which indirectly increases the number of orders.

3) Which performance improvement strategies are most relevant to KLM's loan desk?
Two strategic improvement options are most relevant to improve the contribution of KLM's loan desk to the performance of KLM Component Services:

- *Spare part availability decision* - Introduce a spare part availability decision method that enables to make a well-considered trade-off between the opportunity of gaining additional revenue and the negative effect on spare part availability regarding contracted customers.
- *Circulation stock level* - Determine whether increasing the circulation stock level is feasible. Here, a trade-off between the benefits and the costs of increasing the circulation stock should be considered.

The spare part availability decision regarding external customers is considered as top priority. Before considering advanced pricing methods or providing additional services such as track and trace, the availability decision must be under control as wrong availability decision could result in a large financial impact. Two availability alternatives are determined:

- *Risk-based availability decision* - The risk of a contracted/POOL spare part shortage is calculated based on the state of the system. In case the calculated risk of a shortage exceeds the maximum acceptable risk of a shortage cut-off value, the spare part is not available.

- *Minimum on-shelf inventory level based availability decision* - The serviceable on-shelf inventory level is used to determine whether or not to accept a request from an external customer. If the on-shelf inventory level is lower than the minimum on-shelf inventory level cut-off value, the spare part is not available.

The second proposed strategic improvement option is to increase the total circulation stock for high potential spare parts. At the loan desk, 79% of the requests could not be fulfilled due to zero or critical stock levels. In addition, 14% of spare part requests from contracted customers are fulfilled by back-ordering (borrow, exchange-in or purchase) a spare part. Increasing the circulation stock increases spare part availability for both contracted and external customers. The feasibility of purchasing additional spare parts should be evaluated.

4) Which performance metrics should be used to evaluate potential improvement strategies?
In total, 7 performance metrics are developed in order to evaluate the proposed strategies, whereof 4 are Key Performance Indicators. These are the following:

- *Total result loan desk* - Benefits of the loan service in terms of revenue gained, subtracted by the back-order cost due to the providence of the loan service. In other words, profit.
- *Fill-rate contracted customers* - Percentage of contracted customer requests that were fulfilled at the same date as the request.
- *Availability rate external customers* - Percentage of external customer requests that were available and quoted to the external customer.
- *Marginal value of additional circulation stock* - The financial benefits of increasing circulation stock in terms of additional revenue gained from external orders and decrease in back-order costs, subtracted by the cost of increasing the circulation stock level. If the KPI has a positive value, increasing the circulation stock level is feasible.

In addition, one performance constraint is introduced: the *cost-benefit ratio*. This is the ratio between the revenue gained and back-order costs due to the providence of the loan service. Spare parts can be categorised based on their criticality (GO, GO-IF and NO-GO). These levels indicate whether or not a component failure affects the ability of the system to perform its intended mission. The financial consequences of spare part unavailability differ per criticality class. Unavailability for a NO-GO component could result in aircraft downtime which is extremely costly. Therefore, the cost-benefit ratio should be constrained per criticality class. The cost-benefit constraint allows to control the level of risk that can be taken when specifying the configuration variables of the availability decision alternatives. The configuration variables of each alternative are: maximum acceptable risk of a shortage and minimum on-shelf inventory level.

5) What recommendations can be made regarding the developed strategies?
When evaluating the robustness of both availability decision alternatives, it turned out that the risk-based availability decision outperforms the minimum on-shelf inventory level based availability decision. Moreover, this alternative is more suitable to determine generic availability decision rules. Therefore, the risk-based availability decision is considered as the best alternative and is recommended. This availability decision alternative calculates the risk of a shortage based on: expected yearly spare part demand, in-house or outsourced repair turn around time and the on-shelf inventory level. Based on the experimental results of a case study consisting of 10 spare parts with different characteristics, the maximum risk of a shortage cut-off values are determined. For all three criticality classes (GO, GO-IF and NO-GO), a different maximum risk acceptance level is specified, these are respectively: 80%, 60% and 20%. Results show that the availability rate regarding external customers increases with *24%*. This results in an estimated revenue increase of approximately €375.000 per year for the complete product mix. In addition, this availability decision method enables to gain control over the spare part flow initiated by the loan desk. Hence, the effect on spare part availability regarding contracted customers becomes manageable.

For the second strategic option, increasing the circulation stock level, some conclusions can be drawn. First, for the case study spare parts, it is not feasible to increase the circulation stock when only considering the additional revenue from external orders. However, when taking into account the effect on total back-ordering costs, it turns out that, for 7 of the 10 case spare parts, increasing the total circulation stock level is feasible within 5 years. Therefore, it is recommended to reconsider the current inventory management policy.

Based on the provided answers to the sub-research questions, the main research question can be answered. KLM Component Services should employ a risk-based spare part availability decision at KLM's loan desk. This strategy calculates the risk of a shortage regarding contracted customers during the spare part turn around time based on: average yearly demand, estimated spare part turn around time (in-house or outsourced) and the on-shelf inventory level. Based on the criticality of the requested spare part, a different level of risk is accepted when determining availability. Applying this strategy increases the availability regarding external customers with 24%, which results in approximately €375.000 additional revenues for the complete product mix. In addition, this availability decision method enables to control the spare part flow initiated by the loan desk, which makes the effect of the loan desk on spare part availability regarding contracted customers manageable. In addition, KLM Component Services should reconsider the current inventory management policy.

7.2. Recommendations

This section presents practical recommendations for KLM Engineering & Maintenance Component Services as well as recommendations for further research.

7.2.1. Recommendations for further research

After determining potential improvement strategies for the loan desk, the thesis was re-scoped. A solution for gaining control over the availability decision regarding external customers is proposed. As the rotable spare part flow regarding external customers is now controllable, new research field can be explored.

In this research, it was found that the pricing method regarding external customers can be improved. The possibilities of a standard pricing method, based on, for example: the risk of a shortage, customer characteristics and market trends should be addressed in further research. Eventually, a decision support system should be developed, which supports the decisions regarding availability and price to achieve operational excellence. Such system enables to limit the effect on spare part availability, yet aiming to increase revenue by making a trade-off between risk and opportunities while offering the best price. Besides these benefits, it enables to respond faster to external customers, which is likely to positively effect the probability of an external order being accepted. Therefore, it is also interesting to further research the effect of response speed on the behaviour of external customers. Currently, the order acceptance rate equals 13,5%. It is expected that this rate could increase drastically when the response speed decreases. A hitrate increase of 10 percent points would result in roughly €1.000.000 additional revenue at the loan desk per year, assuming that the availability regarding external customers does not decrease. If positive effects of response speed on the number of orders are proven, the feasibility of introducing a platform where external customers can request and automatically get a response should be researched, as this decreases the response time to zero. Furthermore, this research showed that a large part of the customers at the loan desk tend to shop, as they request spare parts at multiple loan service providers. Especially for these customers, an online platform would be a great solution which could increase the number of orders drastically at KLM's loan desk.
To achieve this, data should be collected. First and most importantly, it should be tracked whether a back-order is placed due to unavailability as a result of an external order at the

loan desk. By doing so, the effect of the loan desk on the availability service regarding contracted customers becomes track-able. This enables to further develop and configurate the availability decision. Next, to research the effect of response time on the order acceptance rate, the response time should be tracked for each request. Currently, employees at the loan desk log characteristics of external customer requests. Here, a column should be added where the response time is logged. This is the difference between the moment the loan desk replies to the customer and the moment the request from the external customer entered the central mail box. Lastly, the data quality regarding circulation stock levels should be improved, as stated earlier, the quality of this data is currently rather poor. This can be achieved by implementing RFID technology, which could be used for many purposes such as a track and trace service. Introducing RFID enables to track spare parts over the entire supply chain, which is extremely valuable in decision-making. For example, in case of spare part unavailability regarding a contracted customer, a borrow employee can simply track the spare part and determine whether a back-order is needed or not. RFID could contribute to faster and improved decision making.

In addition, when the operation at the loan desk are under control, improving the provided service should be the aim. Research should focus on external customer satisfaction. Topics such as, the willingness to pay for additional services should be investigated, for example: track-and trace.

Furthermore, the effect of the providence of the loan service on the average spare part TAT should be investigated. It is expected that this currently does not significantly effect the TAT as the contracted rotable spare part flow is much larger compared to the external flow. However, when the spare part flow share of the loan desk increases, such effects should be researched in order to improve TAT capabilities.

In general, the circulation stock level for a particular spare part is calculated by an iterative probability calculation, based on: the mean time between removals, turn around time, quantity per aircraft, number of hours flown by the aircraft of the same air frame and the target service level. However, such inventory policy does not incorporate demand from external customers. Research should be performed to evaluate the performance of the currently used inventory policy and provide a solutions to cope with additional removals for external customers. In addition, the traditional method to calculate the total circulation stock level does not incorporate the relative cost of a spare part. It makes more sense to delay an aircraft for a €100.000 spare part than for a €1.000 euro spare part. Further research should address this problem. In order to do so, it is important that the quality of the circulation stock data improves, as this data set is currently highly polluted.

7.2.2. Recommendations for KLM Component Services

A generic availability decision rule is developed for KLM's loan desk, which increases the availability rate with 24% regarding external customers, which results in an estimated additional revenue of €375.000 per year. Besides employing this decision rule, it is recommended to introduce additional KPIs to track the performance of the loan desk. These focus on 1) the interaction between the availability service of contracted customers and the additional loan service, and 2) the responsiveness of the loan desk. Besides revenue, the cost-benefit should be tracked for each criticality spare part class. This allows to evaluate whether the loan desk can take more risk or not, which also helps to further configurate the maximum risk acceptance cut-off values. For this research, the CBR is used as a performance constraint but it is recommended to use this ratio as supportive performance indicator in the future. In addition, the responsiveness should be tracked by means of the availability rate regarding external customers.

It is recommended to test the generic availability decision for the case spare parts. In order to do this, the borrow department should be involved closely. In case a back-order was necessary due to an external order at the loan desk, this should be logged. By doing so, the resulting cost-benefit ratio can be evaluated. After validating the simulation results with the real world scenario, the generic decision rule should be implemented on a large scale, for example for one air frame type. For the implementation of the generic availability decision rule as it is presented in this research, no additional data needs to be collected. However, it is recommended to update and re-estimate the input parameters on a yearly basis. As stated earlier, to be able to validate the results and to further configurate the maximum acceptable level of risk per spare part type, the borrow department should track whether back-orders are the result of an external order at the loan desk or not.

This research showed that for 7 of the 10 case study spare parts, it is feasible to increase the total circulation stock level. However, the circulation stock levels used in the simulation model were determined by model configuration, as the CROCOS inventory data set is highly polluted. Therefore, it is necessary to increase data quality. Afterwards, the inventory policy should be researched as the currently used policy results in large back-order expenses and a low service level. Hence, this research classified loan spare parts based on the annual demand value. For A-class spare parts, it is recommended to increase the circulation stock in case the availability regarding customers is low. For A-class components with a lower value (or latest list price), the risk of purchasing additional spare parts is considered as low. Especially for A-class spare parts for which the service level regarding contracted customers is poor.

Besides inventory data, it is extremely useful to track the total turn around time of spare parts. When sufficient TAT data is collected for spare part, the proposed availability decision can be improved. Instead of an estimated TAT based on repair location (repair shop or vendor), a spare part specific TAT can be estimated and used as input for the availability decision. This allows to calculate the risk of a shortage with higher precision and reliability.

As it is expected that response time is of high importance with respect to the order acceptance rate, employees must focus on responding fast. Furthermore, as loan requests are handled by the AOG desk during nights, it is recommended that one AOG desk employee focuses on loan requests. Currently, AOG desk employees do not consider handling loan requests as priority. However, if there are no AOG requests, loan requests should be answered by AOG employees as this decreases the average response time drastically.

As KLM's borrow department is a customer of other loan service providers, these employees know the needs of a customer of a loan service provider. Therefore, it is recommended to organise a session in which the loan desk employees and borrow department come together to brainstorm about the needs of external customers. Understanding the customer helps to improve contributes to increase the performance of the loan desk.

Lastly, it was found that the revenue gained from non-frequently returning customers is substantially higher compared to customers that frequently order a spare part at the loan desk. Loan desk employees should be aware of this and take this in mind when selecting a request from the central mailbox.

7.3. Limitations

In this section, the limitations and shortcomings of the research are discussed. These are important to recognise before the employment of the proposed strategic improvement options.

First, due to unreliable inventory data, it was necessary to perform a model configuration step in order to determine the circulation stock level which results in realistic results in terms of service level and number of back-orders. However, with data experts of KLM it was found that this was the best option in order to be able to test the strategic improvement options. Due to the lack of inventory data, no concrete recommendation regarding increasing circulation stock level could be provided. However, based on back-order data and simulation results the recommendation to reconsider the current inventory management policy could be made. Data unavailability also caused issues when defining the problem, as the number of back-orders due to the providence of the loan desk is currently not known. Therefore, the effect of the loan desk on the spare part availability service was not quantifiable.

Furthermore, for determining the configuration of the availability decision 10 case spare parts were used. It is recommended to add more case spare parts to further detail and configurate the maximum risk of a shortage values.

Demand is modelled as a distribution with an inter arrival rate, which removes demand characteristics such as fluctuations. In order to take this into account when specifying the availability decision configuration, the cost benefit ratio is penalised based on demand classes.

The turn around time of spare parts is modelled by fitting distributions and setting server capacities to infinity. Therefore, the effect of demand fluctuations on the turn around times are not present in the model.

In the simulation model, the effect of response speed is not modelled. A hitrate parameter is introduced, which is based on historical data, to model the order acceptance of external customers.

In the model, it is assumed that in case of contracted customer spare part unavailability a back-order is placed after 5 days. In reality, the priority differs per request, which results in different request holding times. However, when comparing the back-order results from the model, no large differences were detected when comparing to historical data.

7.4. Thesis reflection

In order to evaluate performance improvement strategies in a closed-loop supply chain, a case study at KLM Engineering & Maintenance Component Services has been performed. The aim of the case study was to increase the contribution of the loan desk to the performance of KLM Component Services. Research questions were formulated to structurally achieve the stated objective. Developing strategic improvement options is a challenging and complex topic. Therefore, a structured approach was necessary.

The first step in this thesis consisted of understanding the current state situation. During this stage, interviews with employees and performing verbal protocol analyses were extremely valuable. Especially due to data unavailability and in some cases poor quality, the employees helped to understand and map the current state situation at KLM Component Services and its loan desk. Understanding the current state at KLM Engineering & Maintenance was a time consuming task as it consists of many complex processes. Prior to understanding the current state situation, the challenge to scope the thesis so it provided scientific contribution, was great. However, after describing the current state situation and performing literature research, it became clear that no previous research is performed regarding the interactions between an aircraft spare part availability service and an additional loan service.

With the current state situation described, the next step was to identify performance improvement areas and to develop performance improvement strategies. Determining improvement options and prioritising them is an extremely challenging task. The supply chain strategic framework [29] was used to tackle this task. During this process, interviews were exceeded with management to determine the role of KLM's loan desk within KLM Component Services. In addition to the supply chain strategic framework, the balanced scorecard methodology [21] was used to link improvement strategies to performance. Developing a strategy map helped in detecting additional strategic options. As a large number of improvement areas were detected, the project was re-scoped and internal business improvement areas that are considered as top priority were elaborated into depth. Due to the limited amount of literature regarding the specific subject, some innovative solutions were used gain control over the loan process. Introducing the cost-benefit ratio performance constraint enabled to control the financial impact of the loan service on the overall performance of KLM Component Services.

After specifying the strategic improvement options, a single spare part simulation model was constructed. During the validation phase, a large setback was experienced. The simulation model results were invalid. By consulting data experts within KLM, it was found that the data set from which circulation stock levels were retrieved was highly polluted. After brainstorming with TU Delft supervisors, a model calibration step was proposed to resolve this problem. After the model configuration step, the model was found to be sufficiently valid to test the developed improvement strategies.

This thesis provided a solution to gain control over the spare part flow initiated by the loan desk. It showed an innovative way of using the cost-benefit ratio in order to gain control over the flow and impact of an additional loan service on spare part availability regarding contracted customers. In previous research, the cost-benefit ratio is used as evaluation measure rather than performance constraint. By constraining the ratio between the benefits from this service and the costs caused by the service, the spare part flow initiated at the loan desk becomes manageable and makes the balance within such closed-loop supply chain system consolable. Furthermore, this research provided a solution for the availability decision regarding external customers. The risk-based availability has high potential, and should be further elaborated. Soon KLM will arrive at a digital era were lots of data will be collected and stored, the risk of a shortage can be estimated with high precision with the presence of big data. This research proved the usability of such availability decision and showed its potential.

However, many challenges remain and further research is needed in order to further improve the performance of the loan desk. The next priority is to increase responsiveness, especially in terms of response time. Research should focus on the effect of response time on the order acceptance rate of external customers. The goal for KLM´s loan desk should be to increase the hitrate of external customers. If KLM succeeds to achieve this the loan desk could substantially contribute to the financial performance of KLM Component Services.

Personal reflection

During my academic career I did not follow an internship program. This made the choice of performing my master thesis at a company easy. KLM Components Services was a great place to put my TIL tool kit into practice. Due to circumstances, my KLM supervisor was not able to provide guidance during the first phase of my thesis. I have learned a lot during this period, as I had to find my way in a big company. I organised meetings with management and talked to the employees on the floor to identify challenges and develop the research proposal. During this period I experienced that it takes a lot of time and effort to find the right people in such a large organisation. When my supervisor returned, I presented my findings and updated him about the progress I made. He confirmed the problems and challenges I identified during the first two months, which was a big relief for me. Besides learning a lot by experiencing such a dynamic environment, I learned a lot about the aircraft industry, developing strategies and the managerial aspects in large companies. Moreover, I had never performed a simulation during my study. Learning how to build a comprehensive simulation model was a big challenge, which took some time. In the end, I am happy that I made the choice to do this as it is such a powerful tool to support supply chain decision-making nowadays.

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APPENDICES

Contents

A
Interviews

Throughout the report, a number of assumptions is made based on interviews with experts within KLM Component Services. In addition, the experts were helpful in validating the structure of the model. Below, a summary of the interviews and brainstorm sessions held is presented.

A.1. Interviewee A - Aircraft On Ground Desk Leader

What does KLM's loandesk do?
The loandesk is introduced in order to provide a service for non-contracted customers. It enables external customers to loan or borrow a rotable spare part from KLM. In return, the customer has to pay a predetermined fee for this service. In addition, the customer pays for the repair of the return unit. By providing this service, KLM gains additional revenues and the utilisation rate of spare parts increases.

Can you provide some context about the system the loandesk is part of?
As the loandesk only offers rotable spares, it is part of the closed-loop supply chain of KLM. KLM manages a POOL of spares for contracted customers, for which there is supply obligation. Furthermore, KLM has service level agreements with these customers about minimum service level that should be met. So, both types of customers, contracted and external, are supplied from one inventory source, the Magazijn Logistiek Centrum. Here, spare part requests from contracted customers must be fulfilled and spare part request from external customers can be fulfilled if possible. So, for external customers there is no supply obligation nor service level agreements. After supplying a rotable spare part to a customer, the customer returns an unservicable spare part which is repaired by either a repair shop or a vendor. Hereafter, the spare part is restored at the MLC.

What is the challenge or problem the loandesk is facing?
At this moment, it is hard to track performance as there are no performance metrics besides income. However, employees at the loandesk log all request characteristics which provides useful information about the market in which the loandesk is situated. Moreover, information about the responsiveness of the employees can be retrieved from this data. But first, comprehensive KPIs are needed to track and define performance. The challenge the loandesk is facing is that management set goals in terms of income the loandesk should generate. However, the supply chain team, who are responsible for component availability regarding contracted customers have contradictory goals. They want to keep the availability as high as possible. In the end, the supply chain team is responsible for the decision whether a spare part is available for an external customer or not. The challenge remains to find the right balance between fulfilling both demands. So, increasing the income from the loan service while ensuring component

availability for contracted customers.

A.2. Interviewee B - Direct Support Leader

What is the strategic vision of KLM's loandesk
The main goal is to gain additional revenues, by providing the additional loan service. However, it is important to limit the effect on component availability regarding contracted customers. Especially, the back-order costs due to the providence of the loan service should be limited. It does not make sense to earn money by providing the loan service and spending the earned money in another department, borrow department, to meet supply obligations.

What should be the maximum risk that can be taken by the loandesk when considering to offer a spare part?
This depends on the spare part. Some spare parts are more essential than others. In terms of essentiality, spare parts can be divided into mainly three groups: ESS 1 (NO-GO), ESS 2 (GO-IF) and ESS 3 (GO). For ESS 1 spares, the cost of back-ordering should be less or equal than 10% of the income generated by the loan service providence. For ESS 2 this should be less or equal to 25% and for ESS 3 less or equal to 50%.

A.3. Interviewee C - Borrow Specialist B737

What does the borrow department do?
The borrow department makes sure that in case a spare part is not available, the requested spare is borrowed at an external loan service provider. This is done to meet the supply obligation regarding contracted customers.

When is a back-order placed?
It depends on the urgency of the request. But, in most cases, a back-order is placed in case the requested spare is not available 5 days after the request is placed.

What important for customers at a loan service provider?
In many cases, the urgency of borrowing a spare part is high. The MRO service of an aircraft is on a tight time schedule and component unavailability could result in additional aircraft downtime. Therefore, customers of a loan service provider are looking for a quick respond with high availability. Here, the costs of the service are of secondary importance as the cost of downtime of an aircraft out weights the costs of a back-order.

A.4. Interviewee D - Loandesk Employee

What do you think customers are looking for in a loan service?
I think it is important that customers can count on the loandesk. In other words, I think that customers return to KLM's loandesk if the availability is high. In addition, the response time should be low. The price of a spare part is mostly not of high importance. However, this plays a more important role if the external customer is a broker.

What is the challenge the loandesk is facing at this moment?
The availability decision is often to slow. The supply chain team needs to be consulted in many cases and there are no clear decision rules. Most decisions are based based upon feeling and experience.

Verbal Protocol Analysis
In addition to interviews, the researcher asked B. Kooijman to walk through the process of handling requests at the loandesk. Here information regarding the availability decision, component pricing and the selection of a spare part was gathered. When a request from an external customer entered the mailbox, B. Kooijman informed the researcher. Every step that was taken to handle a request was pronounced out loud, so that the researcher could map the process.

A.5. Interviewee E - Supply Chain Specialist B737

Which air frame has the largest market share at KLM?
Currently, the B737 and B787 have the largest market shares. These air frames will also be used in the next years.

What is the reason why the service level is low?
The systems at KLM are outdated and the administration is poor. This leads to logistic delays. In addition, KLM tries to hold as less inventory as possible. The stock sizing calculations are based upon the TAT of a component. At this moment, the TAT of spares is to long.

What is the lead time of a component between an unservicable spare part is received at the logistics center and the moment the spare part arrives at the repair shop?
Repair shops are also located at Schiphol Oost. In our calculations a period of 1 day is used for this lead time. In many cases, the component is delivered at the repair shop the same date it arrived at the logistics center.

What is currently the problem with respect to the loandesk?
Currently, there is an imbalance between both processes, full-filling both contracted and external demand. It happens too often that a spare part is needed for a contracted customer and it turns out that the component is at an external customer. This results to a decrease in service level and an increase in borrowing expenses. In measuring the performance of the loandesk, the effect on the fulfilment of contracted demand should be taken into account.

How is the spare part removal pattern modelled at KLM?
We estimate the number of removals based on a Poisson distribution.

A.6. Interviewee F - Supply Chain Engineer B737

In the simulation model, all demand categories are modelled as Poisson. How can the effect of intermittent and lumpy demand be taken into account when determining the best availability decision policies?

At KLM, we estimate removals based on a Poisson distribution. By evaluating Cost Benefit Ratio KPI in the simulation, it might be an option to include a penalty for each demand class. For smooth demand this is not necessary. For intermittent and erratic demand the CBR should be multiplied by 1,25 and for lumpy demand by 1,5. By doing so, the risk factor (CBR) in order to evaluate the availability strategy configurations incorporates an effect of demand classes. The exact values for these penalty factors is hard to estimate, but it is important to incorporate these penalties in the evaluation of the strategies.

B

Data

Several data were are used for this research. All data sets were provided by KLM. In this appendix, the used data sets are explained.

B.1. Log data loan desk

This data set contains log data collected by the front office employees at the loan desk. An Excel template is used to log the characteristics of all requests. This data set contains all requests from external customers from week 1-44 of 2018. In the first column, the request date is logged. The second column indicates shift which handled the request, which can be either day or evening. In the third column, the name of the customer is filled out. In the fourth column, the customer type is logged, this can be either an airliner or broker. In the fifth column the request type is logged, this can be either: loan, exchange or sale. In column six, the aircraft type is logged. In column eight, the part number is logged. In column nine is indicated whether the part is a rotable or consumable component. In the tenth column is indicated whether the component was available or not, so whether the request was answered by the loan desk and a quote was send. Column eleven shows the reason for not quoting the request, if this was the case. Here, the following reasons for unavailability are possible: part number unknown at KLM, consumable spare part (cannot be loaned nor exchanged), critical stock level, zero stock and lastly other, non-specified, reasons. In the last column is indicated whether the request resulted in an order.

B.2. CROCOS data

In the CROCOS data base, general information about all spare parts that KLM manages are stored. First, the part number is stored in the first column. in the second column a key word is provided that indicates the part. In the next four columns the: length width height and weight of the column are presented. Also, the manufacturer of the spare part is presented. Next the ESS code of the column is shown. Also, the total circulation stock is presented in a column. Furthermore, the latest list price, provided by the manufacturer, is presented in a column. The ABC inventory classification is also presented in a column. Lastly, the quantities of that part per aircraft is shown as well as the owner of the spare part.

B.3. Financial data

This data set contains the financial data from 2018 and 2019. Here, both income from external order and the back-order (or borrow) expenses are presented. The first column presents the creation date of a request. Next, the document number of the request and company code number are stored. In the next column, the transaction type is logged. Here, the following options are possible: exchange in, borrow, exchange out and loan. The first two are costs of back-ordering while the last two are income from external orders. In addition, the destination airport of the spare part is stored in a column as well as the name of the trading partner. Next, the open and close date of the order are presented. Also, the part unit price used that was used in the invoice is presented in a column. The next columns consist of the fees and the invoice total. Also, the invoice number is presented as well as the part number.

B.4. Removal data

This data set contains all component removals of the last 15 months. For this research, the data set from October 2017 - December 2018 is used. Each row in represents a removal. The first two columns consist of the part number and serial number. The next columns shows the removal date and week number. Lastly, the reason for removal and aircraft type are presented.

B.5. Repair data

This data set is split into two data sets: vendor and repair shop data. Vendor repair data was available from July 2018 - January 2019 while repair shop data was available from January 2018 - January 2019. In both data sets each row represents a repair. In the first two columns the part number and serial number of the repaired part are presented. The third column presents the repair location. Also, the service order number is presented in a column. The rest of the columns consist of time stamps. For this research, the overlapping time stamps of the repair shop data and vendor data are used. The first time stamp used is: the date the return unit of the customer is received at the logistics center at Schiphol Oost. The second time stamp that is present in both data sets is: the date the return unit was received by the vendor or repair shop. The last time stamp that was available in both data sets is the date the repaired return unit was restored at the Magazijn Logistiek Centrum.

B.6. CBBSS data

This data set contains information regarding the service level. The data set presents all requests from contracted customers of 2017 and 2018. The first column presents the name of the customer. The second column indicates the request date, and the third column shows whether the spare part was available at the requested date. For each request the corresponding service level that should be met is presented. Furthermore, the requested part number is presented. Furthermore, many time stamps are logged in this data set. However, only one other time stamp was needed for this research, the date the return unit of the customer arrives at the logistics center.

C

Matlab scripts

C.1. Demand classification script

```
clear all; close all; clc

%rename and select needed data
data = dataclustervend;
data = data(2:end,:);

%create vector with all unique PN and codenr
PN = unique(data(:,2));
PN = table2cell(PN);
PN = cellstr(PN);
Codenr = unique(data(:,1));
Codenr = table2cell(Codenr);
Codenr = cellstr(Codenr);

%count demand per week for each PN
clear n counter counter_start data_new

n = 1;
counter = 0;
counter_start = 1;
data_new = strings([length(PN),68]);

for i = 1:size(data,1)
    for i = 1:size(data,1)
        if data.Period(i) == n
            counter = counter +1;
        end
    end
    if n > 68
        break;
    end
    data_new(1:(counter - counter_start+1),n) = data.Partnr(counter_start:counter);
    counter_start = counter + 1;
    n = n+1;
end
```

```
%create output matrix
for i = 1:68
    x = data_new(:,i);
    y=unique(PN,'rows');
    for k=1:size(y,1)
      freq(i,k)=sum(ismember(x,y(k,:),'rows'));
    end
end

out=[cellstr(y) num2cell(freq')];

%export to excel
xlswrite('output.xls',out)
```

D

Discrete event simulation

The model constructed consists of 13 objects which are connected through paths. There are four different object types: A source (A and H), a separator (B and I), a server (D, M, L, E and F) and a sink (C, G, J and K). All objects are discussed throughout this section.

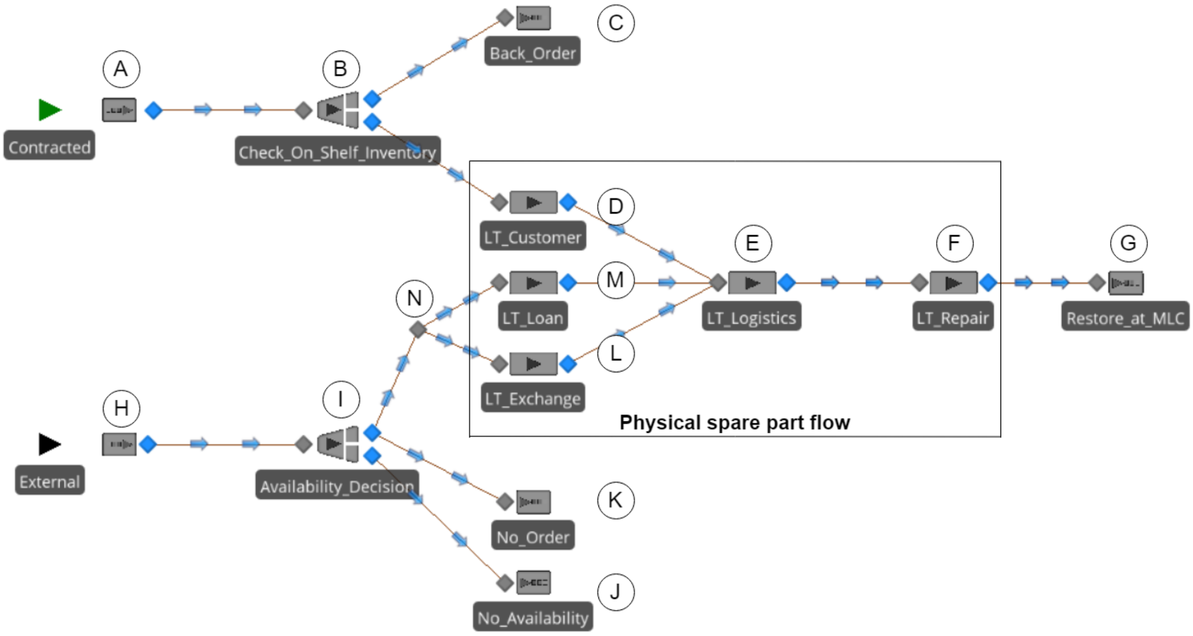
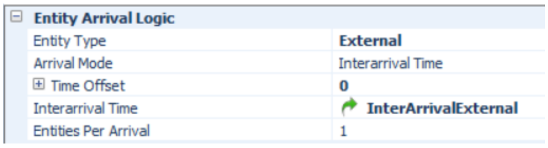


Figure D.1: Facility of the Simio simulation model

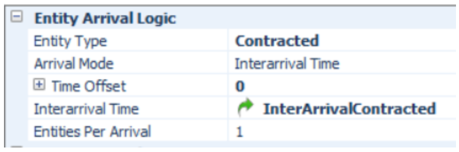
D.0.1. Source

The constructed simulation model contains two source nodes, A and H. At A, arrivals of contracted customers are generated, which represent a request for a spare part. The entities that are generated from this source are: Contracted. At H, the arrivals of external customers are generated. The entities generated from this source are: External. For the creation of both entity types, an exponential distribution with an average inter-arrival rate is used, as the demand distribution is assumed to be Poisson. The model is a single component simulation model, thus different inter-arrival rates are used for each case study component. In order to be able to change the inter-arrival rates easily, two model properties are created, namely: *InterArrivalContracted* and *InterArrivalExternal*. Figures D.2 and D.3, shows the implementation of the properties into the arrival distribution. Properties can be changed in the control window, which is presented in Figure D.4.



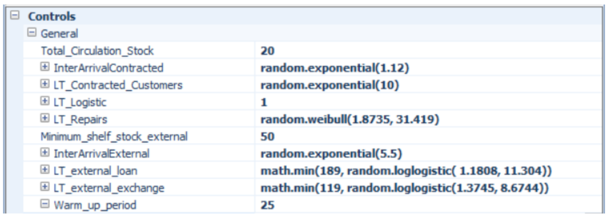
Entity Arrival Logic	
Entity Type	External
Arrival Mode	Interarrival Time
Time Offset	0
Interarrival Time	InterArrivalExternal
Entities Per Arrival	1

Figure D.2: Implementation properties external customer arrival distribution



Entity Arrival Logic	
Entity Type	Contracted
Arrival Mode	Interarrival Time
Time Offset	0
Interarrival Time	InterArrivalContracted
Entities Per Arrival	1

Figure D.3: Implementation properties contracted customer arrival distribution



Controls	
General	
Total_Circulation_Stock	20
InterArrivalContracted	random.exponential(1.12)
LT_Contracted_Customers	random.exponential(10)
LT_Logistic	1
LT_Repairs	random.weibull(1.8735, 31.419)
Minimum_shelf_stock_external	50
InterArrivalExternal	random.exponential(5.5)
LT_external_loan	math.min(189, random.loglogistic(1.1808, 11.304))
LT_external_exchange	math.min(119, random.loglogistic(1.3745, 8.6744))
Warm_up_period	25

Figure D.4: Simulation control inputs

D.0.2. Separator

In the model, two separators can be identified, B and I. At separator B, contracted entities arrive and are send to either the parent or member output based on an Add-On process. In this process, the on-shelf inventory level is checked. In case inventory is directly available, the on-shelf inventory level is subtracted by 1 and the entity is assigned to the member output of the separator (connected to D). If there is no on-shelf inventory, the request entity is delayed for a period of maximum 5 days. Each day, the on-shelf inventory level is checked. If, during this period, inventory becomes available, the on-shelf inventory level is subtracted by 1 and the entity is send to the member output. Entities that are longer than 5 days in separator B are send to the parent output of the separator (connected to C). The capacity of the separator is set to infinity. The explained Add-On process is presented in Figure D.5.

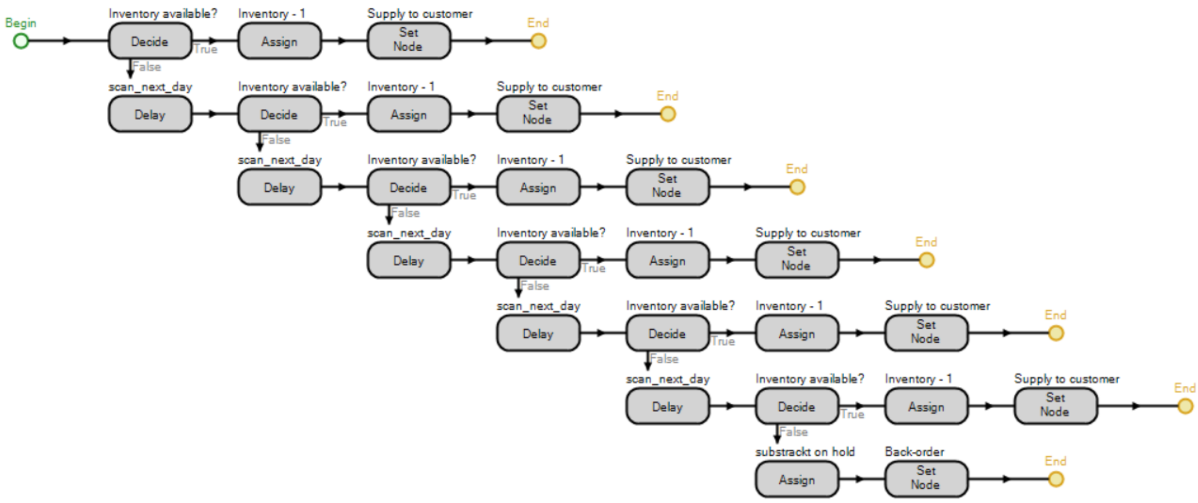


Figure D.5: Add-On process separator B (check inventory)

At separator I, both availability decision strategies are modelled. First, the **minimum on-shelf inventory level based** availability decision is discussed. At separator B, external entities arrive are send to either the member output (connected to J) or the parent output (connected to N) of the separator based on the availability decision. Here, the availability decision is implemented in the separator as an Add-On process, presented in Figure D.6, and Figure D.7 presents the decision logic. In the decision block, the input parameter, *Minimum_shelf_stock_external* is compared to the system variable *I_MLC*. In case the the on-shelf inventory level (*I_MLC*) is greater that the *Minimum_shelf_stock_external*, and the spare is thus available for the external request, the entity is send to the parent output of the separator. As explained earlier, the hitrate of external customers is 13,5%. Therefore, 13,5% of the entities leaving from the parent output are send to node N (order), while 86,5% is send to the sink node K (no order). This is done by changing the routing logic to link weight based and setting weights for both links. At N, the order type is specified. Here, 49% of the entities is send to node L (exchange order), while 51% of the entities is send to node M (loan order). Now, the physical spare part flow starts. For spare part requests that were determined to be not available, the entity is send to the member output connected to sink node J (not available).

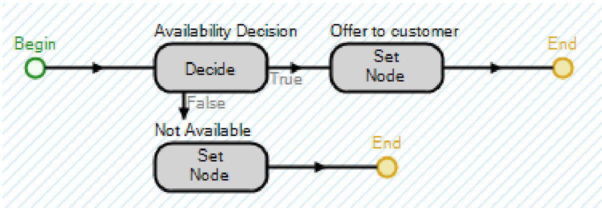


Figure D.6: Add-on process of the minimum on-shelf inventory level based availability decision strategy decision

Basic Logic	
Decide Type	ConditionBased
Condition Or Probability	**I_MLC > Minimum_shelf_stock_external**

Figure D.7: Decision block of the minimum on-shelf inventory level based availability decision strategy

For the second availability decision strategy: **Risk-based component** availability decision, the configuration of separator I is different. Here, the risk of a shortage is calculated based on the following inputs: *I_MLC* (on-shelf inventory level) and *D_TAT* (estimated demand during TAT). Here, the risk of a shortage is the probability that the number of removals during TAT is greater than the on-shelf inventory level. The cumulative risk is calculated for the scenario in which the external order is accepted, therefore, the on-shelf inventory is subtracted by 1. In case the calculated risk exceeds the *Prob_shortage_max* (cut-off value maximum acceptable risk), the entity is unavailable and send to the member output (connected to J). In case the calculated risk does not exceed the cut-off value *Prob_shortage_max*, the requested spare is available and send to the parent output of the separator. After the entity is send to the parent output, the same steps are performed as explained above (From I to K,N and from N to M,L). The implementation of the availability Add-on process is presented in Figure D.8, and Figure D.9 presents the decision block. This figure shows the availability for an entity that arrives when the on-shelf inventory equals 3.

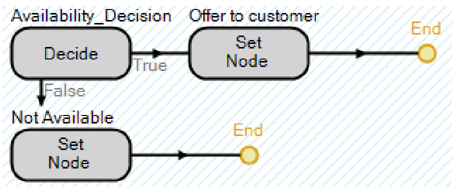


Figure D.8: Add-on process of the risk based availability decision strategy

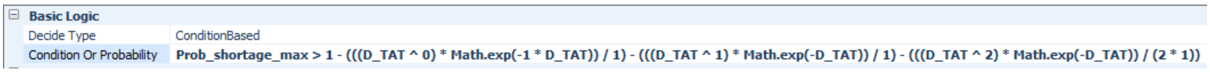


Figure D.9: Decision block of the risk based availability decision strategy

D.0.3. Server

In the Simio simulation model, 5 servers can be identified. As stated earlier, the first LT represents the customer lead time, the time between the request date and the date the US return spare is received at the LC. In the simulation model, each order type has a separate LT, where: LT contracted is D, LT external loan is M and LT external exchange is L. As explained earlier, the capacity of the servers is set to infinity. The customer LT distributions for external orders are modelled as non spare part specific, while the LT distribution contracted customer is variable per spare part. In Figure D.1, the LT customer servers are: D, M and L. After the LT customer servers, the flow of entities merges in the server E, LT logistics. After exiting from the last server LT repair (F), the on-shelf inventory state variable *I_MLC* is incremented by 1 and the entity is send to sink G, which is the end of the process.

D.0.4. Sink

In the model, 4 sink nodes can be identified. All sinks are used to destroy entities and collect statistics. If an entity enters sink C, the number of back-orders is incremented by 1. In addition, in case an entity is located in the physical spare part flow box shown in Figure D.1, the number of back-orders due the providence of the loan service is incremented by 1. At K, the number of spare part requests that were available yet not ordered is counted. At J, the number of requests for spare parts that were found to be not available is counted.

E
Results

E.1. Determine circulation stock level

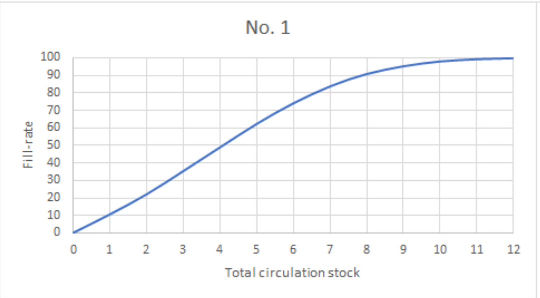


Figure E.1: Fill-rate versus on-shelf inventory level no. 1

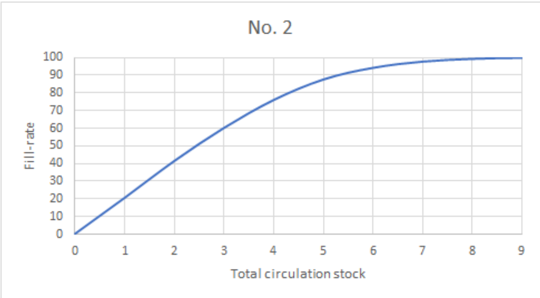


Figure E.2: Fill-rate versus on-shelf inventory level no. 2

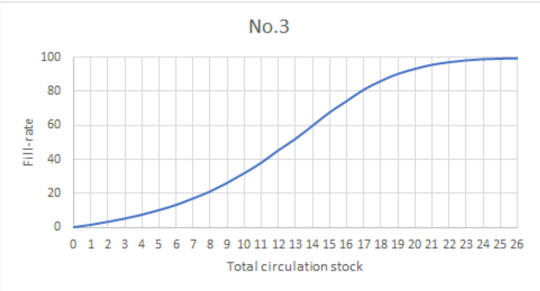


Figure E.3: Fill-rate versus on-shelf inventory level no. 3

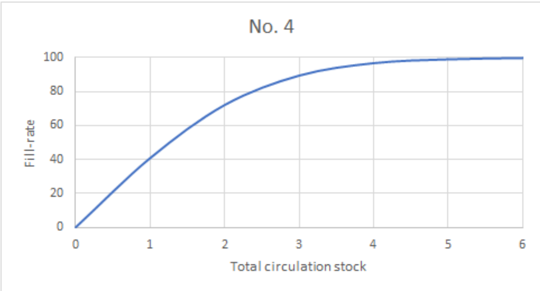


Figure E.4: Fill-rate versus on-shelf inventory level no. 4

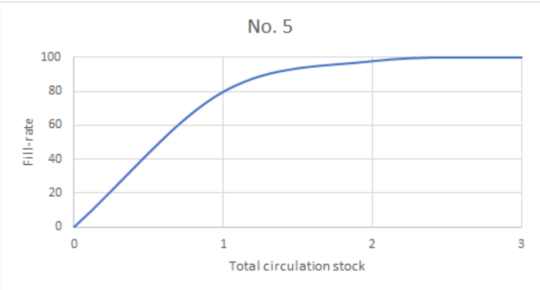


Figure E.5: Fill-rate versus on-shelf inventory level no. 5

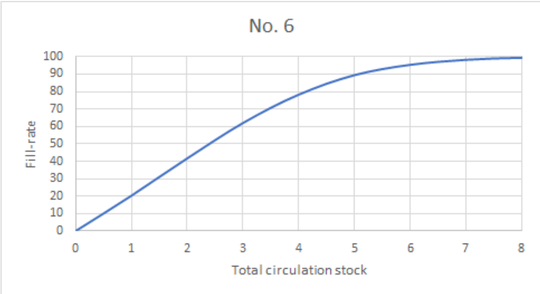


Figure E.6: Fill-rate versus on-shelf inventory level no. 6

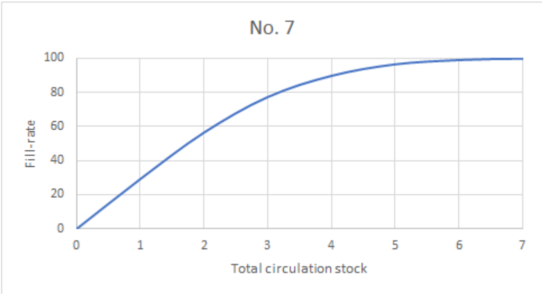


Figure E.7: Fill-rate versus on-shelf inventory level no. 7

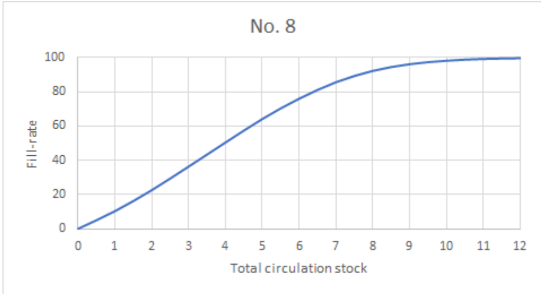


Figure E.8: Fill-rate versus on-shelf inventory level no. 8

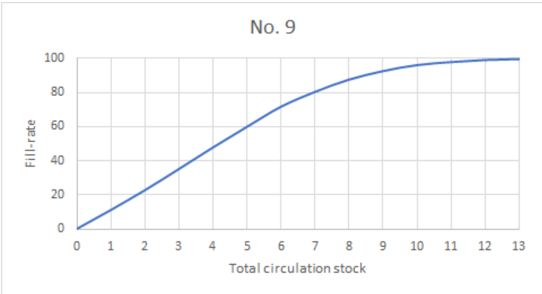


Figure E.9: Fill-rate versus on-shelf inventory level no. 9

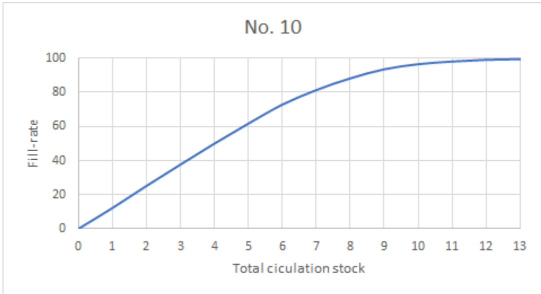


Figure E.10: Fill-rate versus on-shelf inventory level no. 10

E.2. Risk-based availability decision

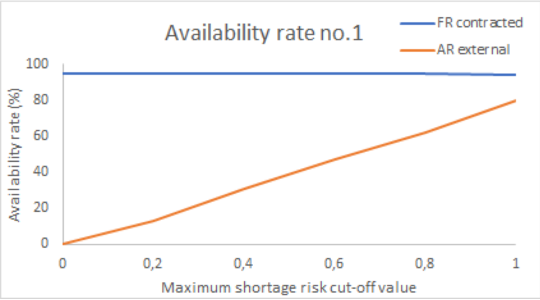


Figure E.11: AR vs max risk of a shortage no. 1

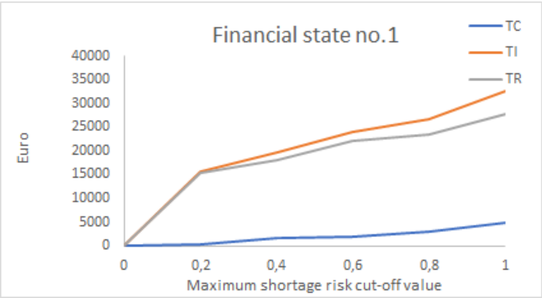


Figure E.12: Financial state vs max risk of a shortage no. 1

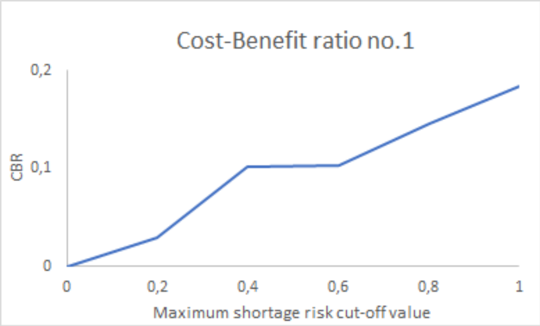


Figure E.13: CBR vs max risk of a shortage no. 1

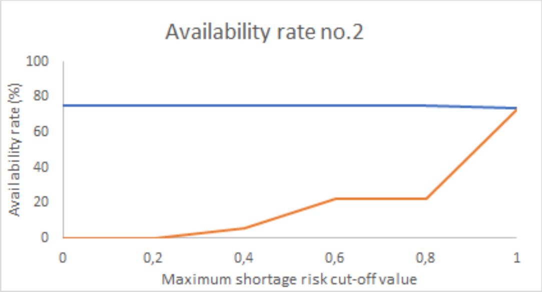


Figure E.14: AR vs max risk of a shortage no. 2

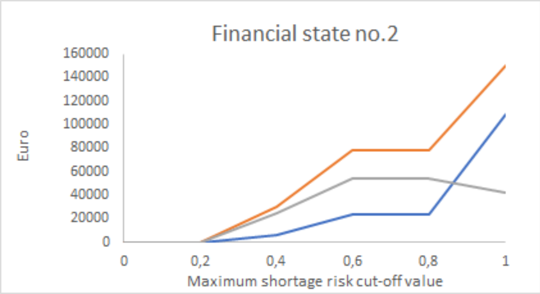


Figure E.15: Financial state vs max risk of a shortage no. 2

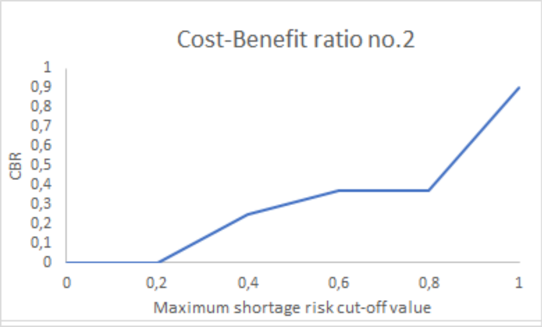


Figure E.16: CBR vs max risk of a shortage no. 1

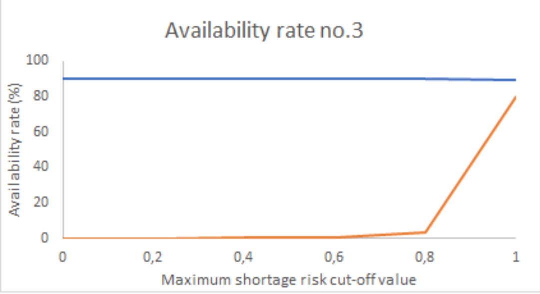


Figure E.17: AR vs max risk of a shortage no. 3

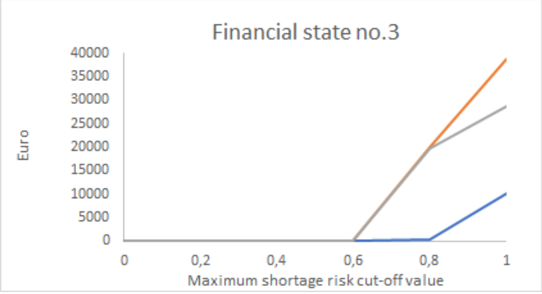


Figure E.18: Financial state vs max risk of a shortage no. 3

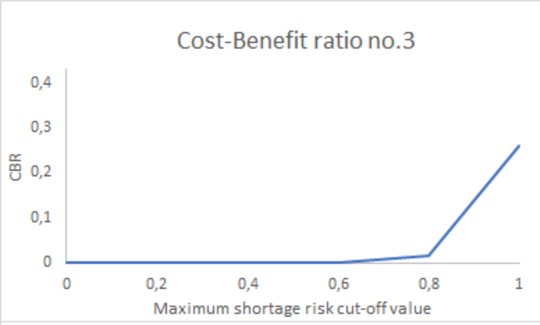


Figure E.19: CBR vs max risk of a shortage no. 3

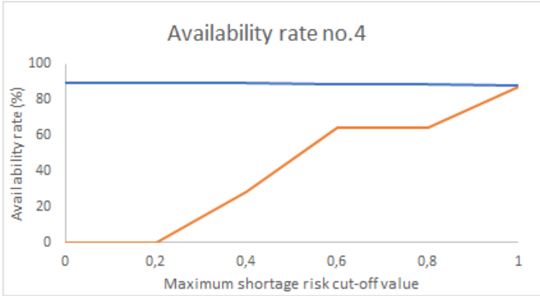


Figure E.20: AR vs max risk of a shortage no. 4

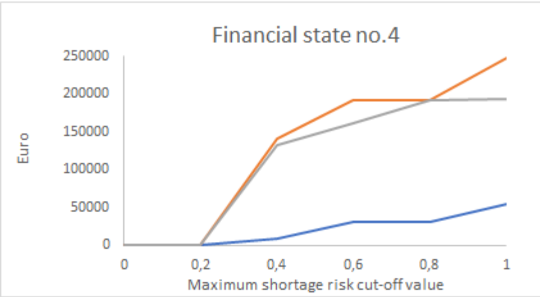


Figure E.21: Financial state vs max risk of a shortage no. 4

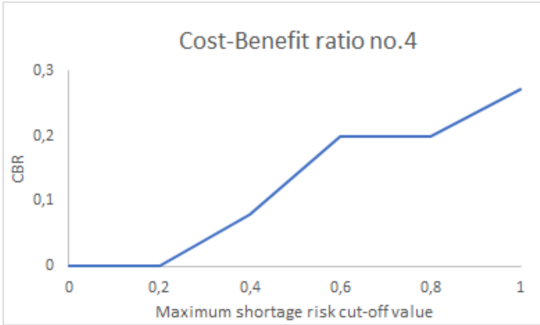


Figure E.22: CBR vs max risk of a shortage no. 4

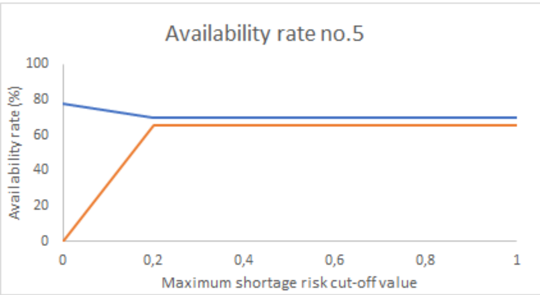


Figure E.23: AR vs max risk of a shortage no. 5

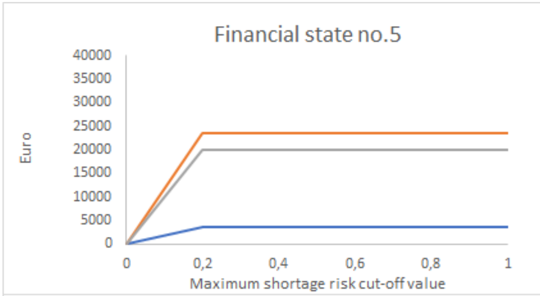


Figure E.24: Financial state vs max risk of a shortage no. 5

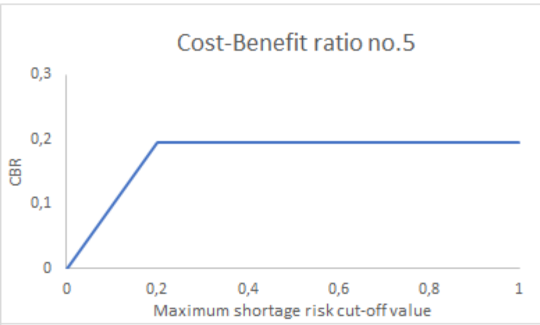


Figure E.25: CBR vs max risk of a shortage no. 5

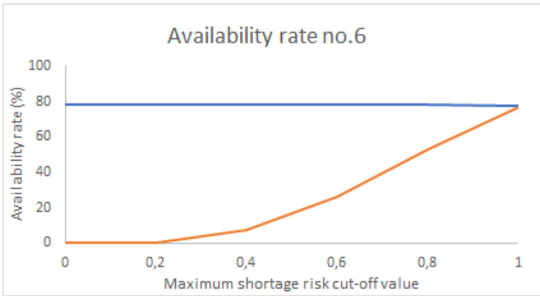


Figure E.26: AR vs max risk of a shortage no. 6

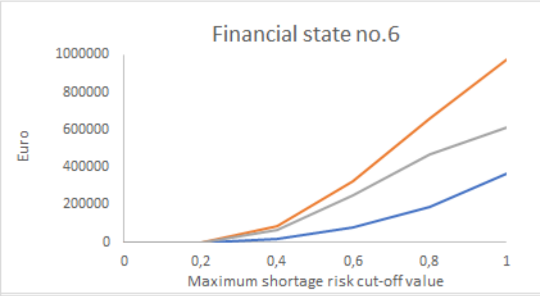


Figure E.27: Financial state vs max risk of a shortage no. 6

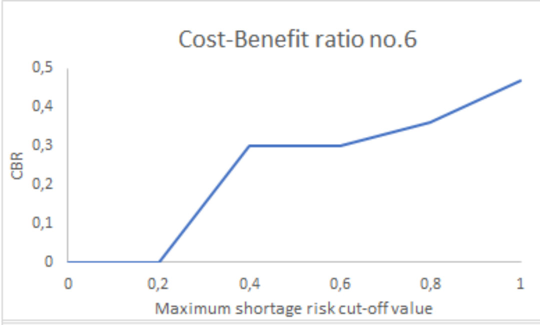


Figure E.28: CBR vs max risk of a shortage no. 6

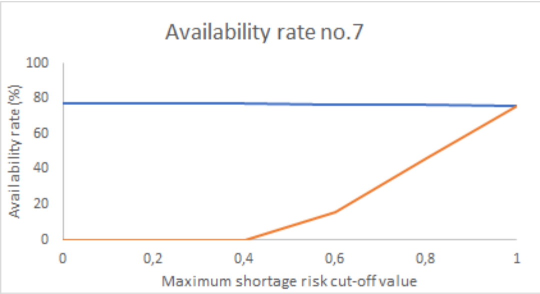


Figure E.29: AR vs max risk of a shortage no. 7

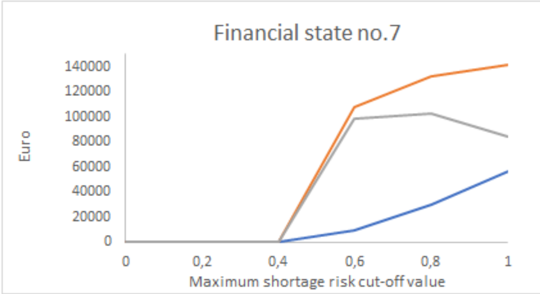


Figure E.30: Financial state vs max risk of a shortage no. 7

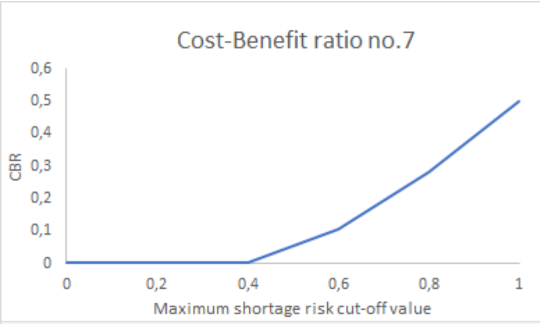


Figure E.31: CBR vs max risk of a shortage no. 7

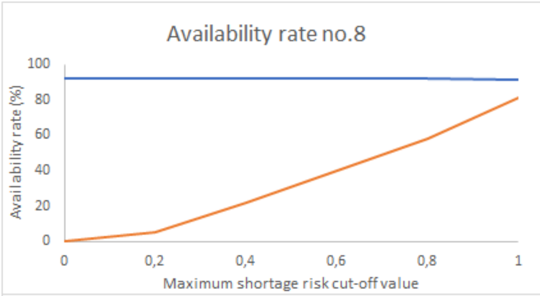


Figure E.32: AR vs max risk of a shortage no. 8

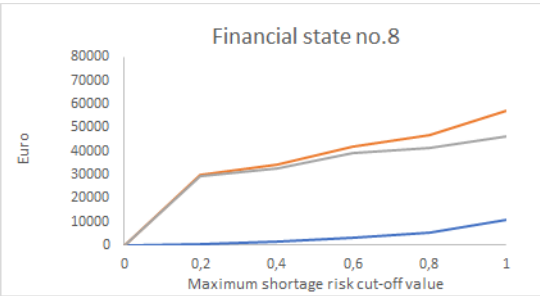


Figure E.33: Financial state vs max risk of a shortage no. 8

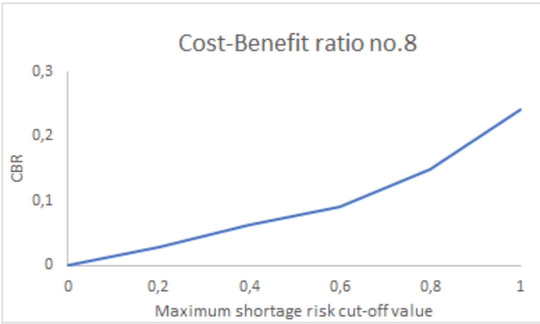


Figure E.34: CBR vs max risk of a shortage no. 8

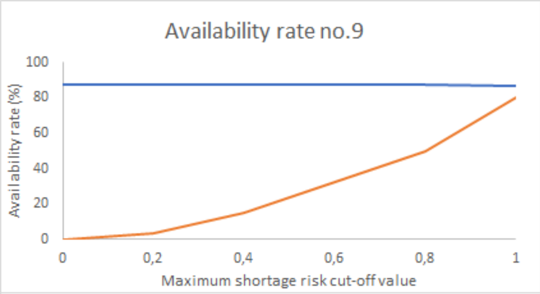


Figure E.35: AR vs max risk of a shortage no. 9

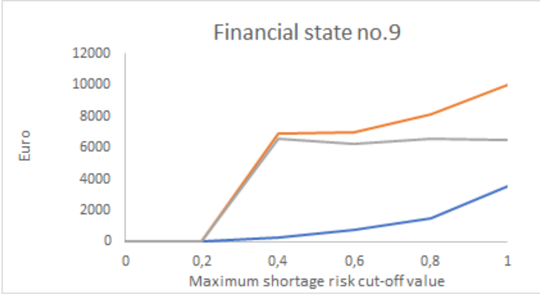


Figure E.36: Financial state vs max risk of a shortage no.91

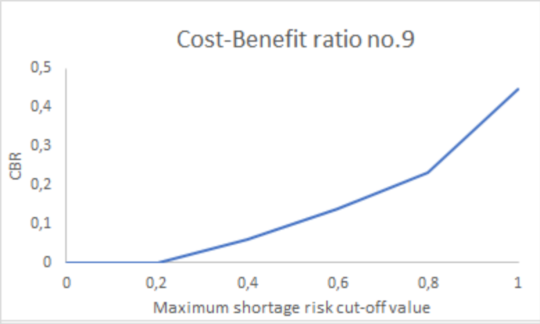


Figure E.37: CBR vs max risk of a shortage no. 9

Figure E.38: AR vs max risk of a shortage no. 10

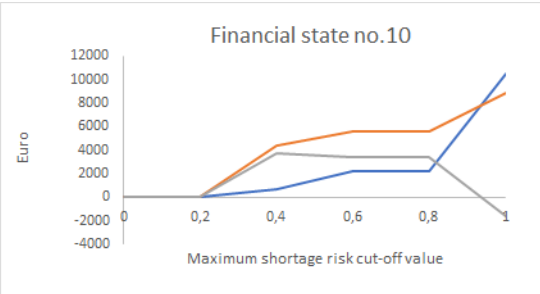


Figure E.39: Financial state vs max risk of a shortage no. 10

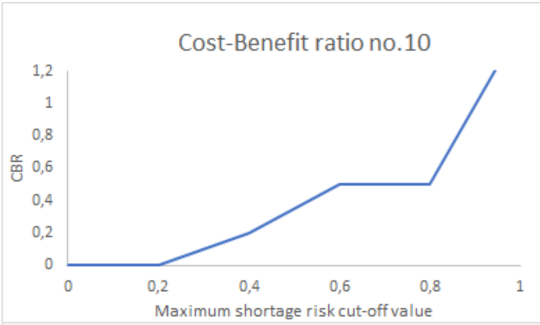


Figure E.40: CBR vs max risk of a shortage no. 10

E.3. Minimum on-shelf inventory level

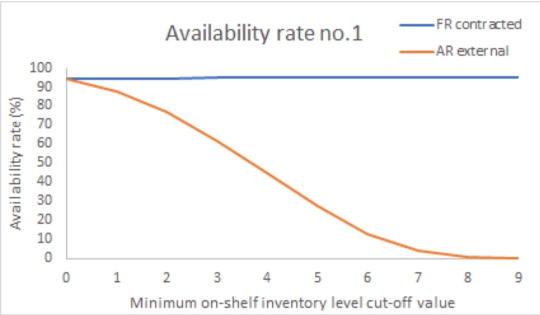


Figure E.41: AR vs min on-shelf inventory level no. 1

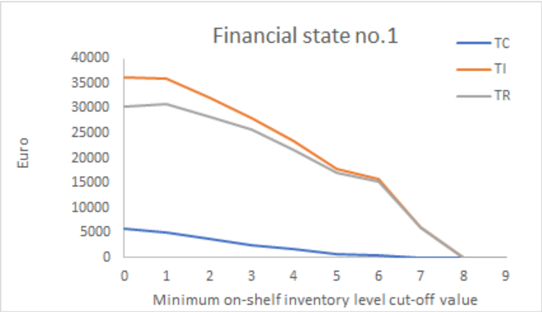


Figure E.42: Financial state vs min on-shelf inventory level no. 1

Figure E.43: CBR vs min on-shelf inventory level no. 1

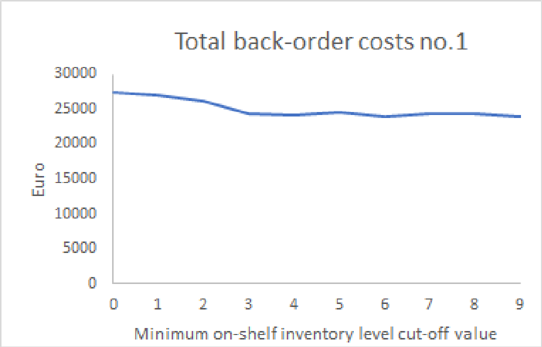


Figure E.44: Total back-order cost vs min on-shelf inventory level no. 1

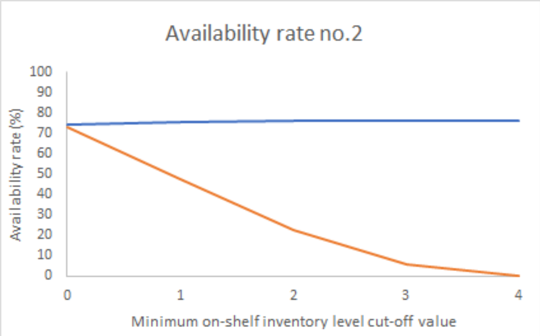


Figure E.45: AR vs min on-shelf inventory level no. 2

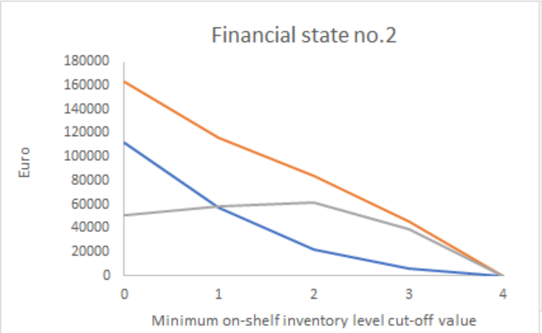


Figure E.46: Financial state vs min on-shelf inventory level no. 2

Figure E.47: CBR vs min on-shelf inventory level no. 1

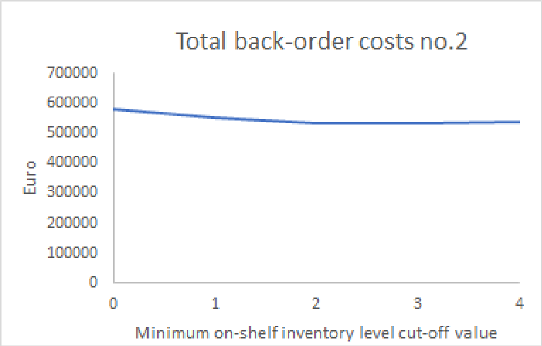


Figure E.48: Total back-order cost vs min on-shelf inventory level no. 2

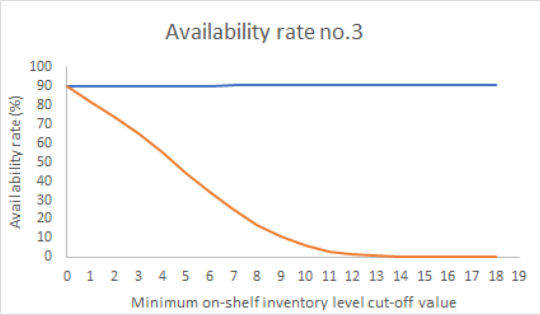


Figure E.49: AR vs min on-shelf inventory level no. 3

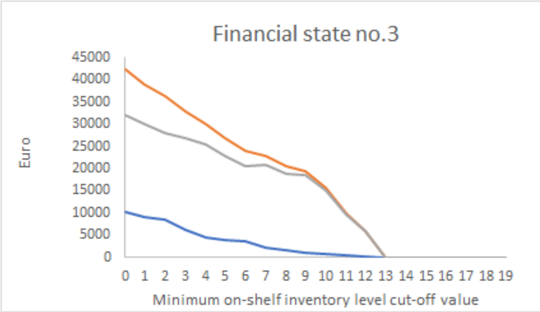


Figure E.50: Financial state vs min on-shelf inventory level no. 3

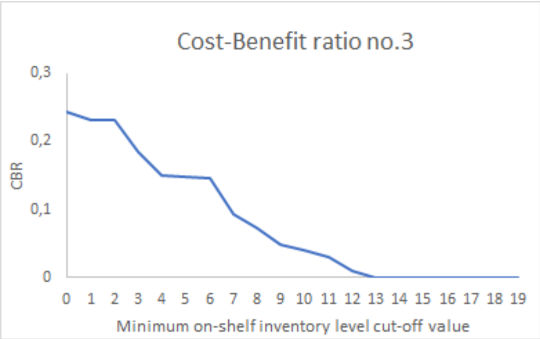


Figure E.51: CBR vs min on-shelf inventory level no. 3

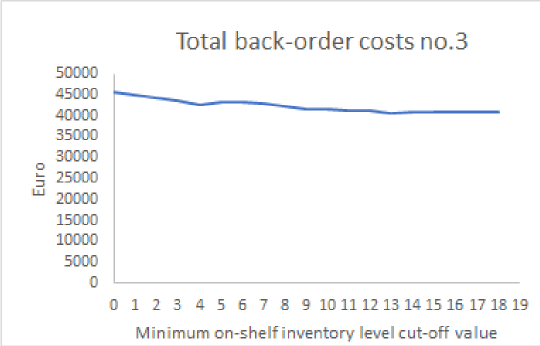


Figure E.52: Total back-order cost vs min on-shelf inventory level no. 3

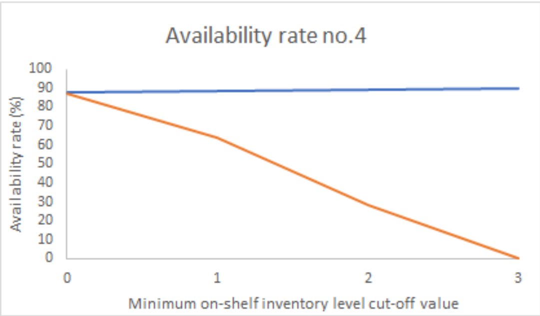


Figure E.53: AR vs min on-shelf inventory level no. 4

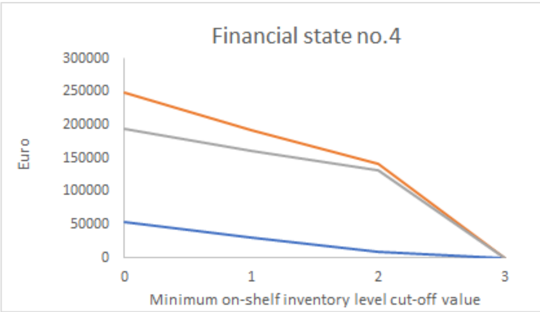


Figure E.54: Financial state vs min on-shelf inventory level no. 4

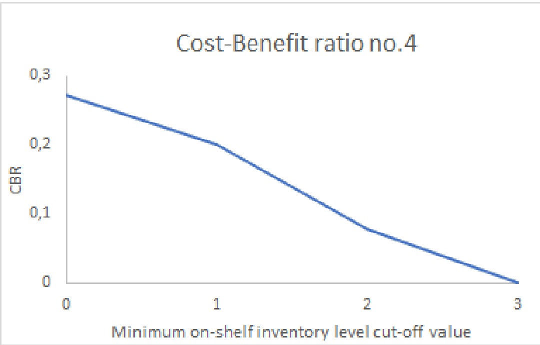


Figure E.55: CBR vs min on-shelf inventory level no. 4

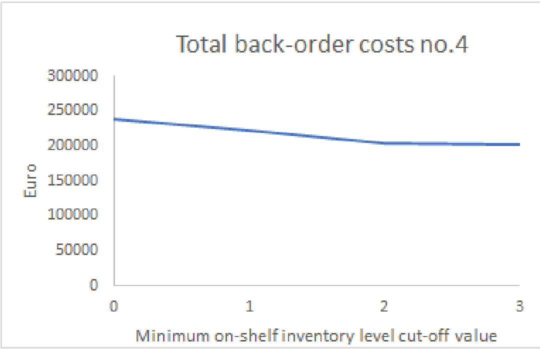


Figure E.56: Total back-order cost vs min on-shelf inventory level no. 4

Figure E.57: AR vs min on-shelf inventory level no. 5

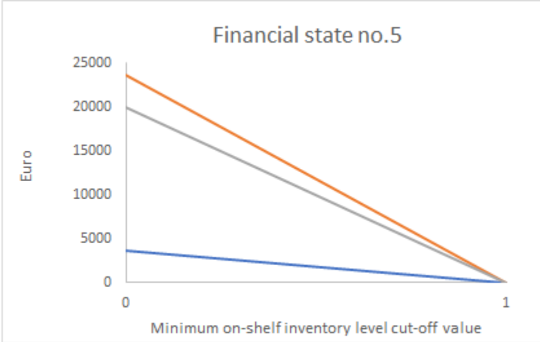


Figure E.58: Financial state vs min on-shelf inventory level no. 5

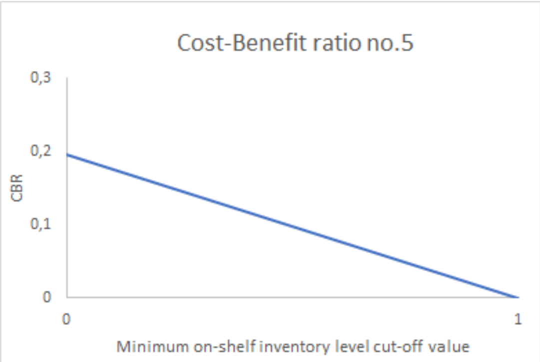


Figure E.59: CBR vs min on-shelf inventory level no. 5

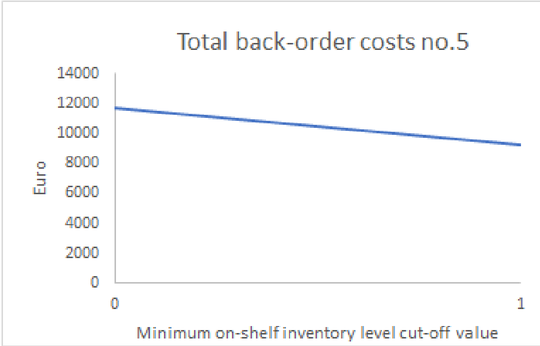


Figure E.60: Total back-order cost vs min on-shelf inventory level no. 5

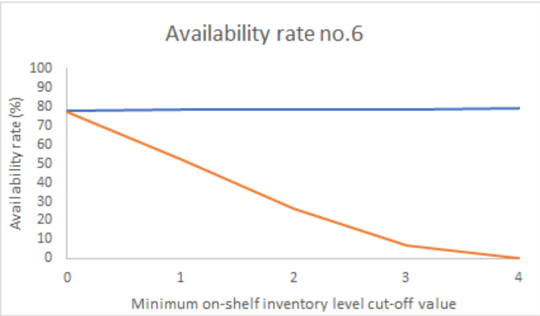


Figure E.61: AR vs min on-shelf inventory level no. 6

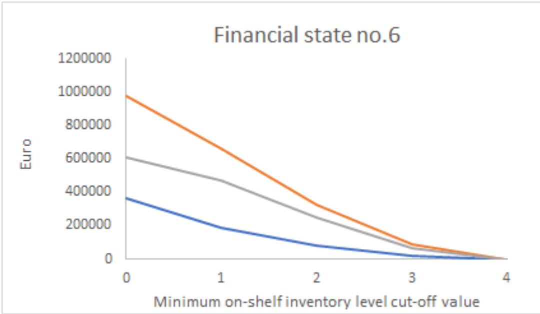


Figure E.62: Financial state vs min on-shelf inventory level no. 6

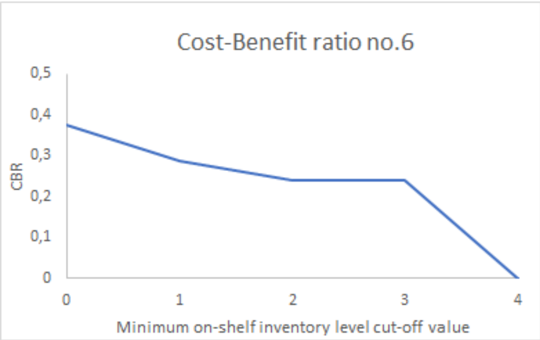


Figure E.63: CBR vs min on-shelf inventory level no. 6

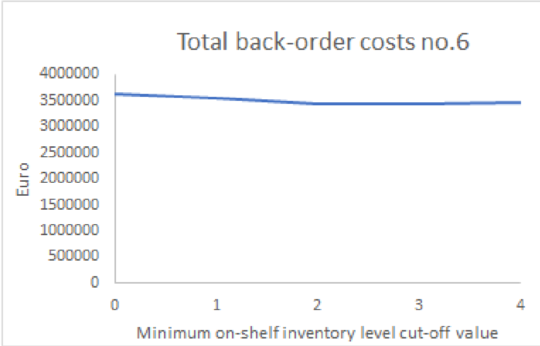


Figure E.64: Total back-order cost vs min on-shelf inventory level no. 6

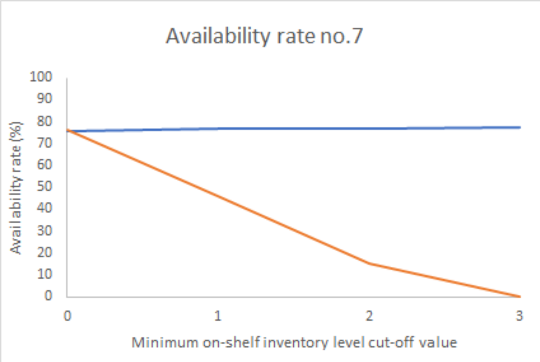


Figure E.65: AR vs min on-shelf inventory level no. 7

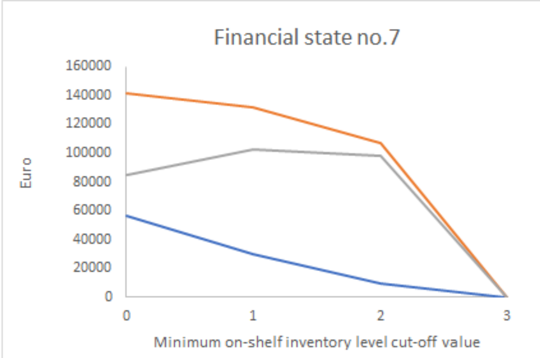


Figure E.66: Financial state vs min on-shelf inventory level no. 7

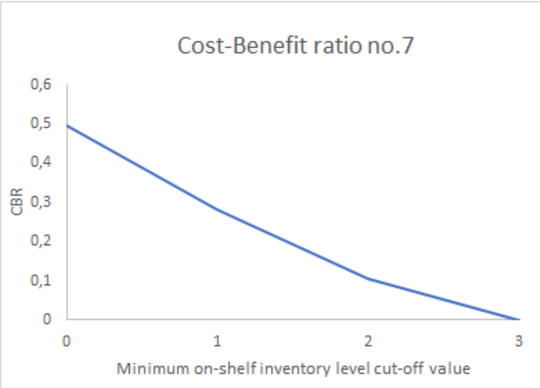


Figure E.67: CBR vs min on-shelf inventory level no. 7

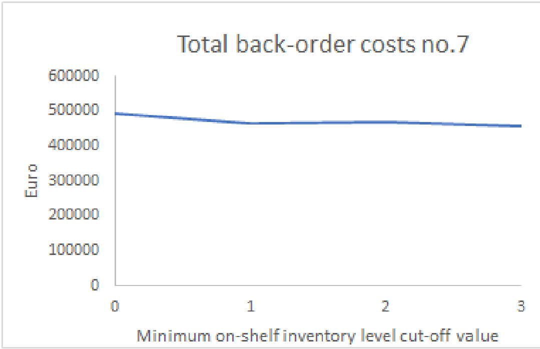


Figure E.68: Total back-order cost vs min on-shelf inventory level no. 7

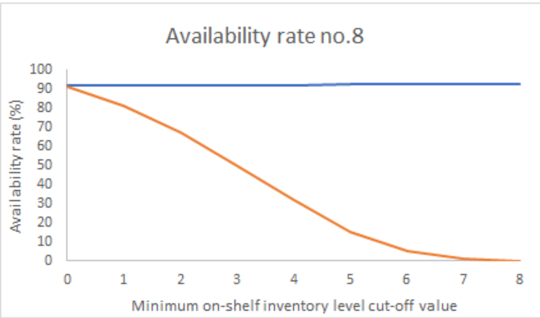


Figure E.69: AR vs min on-shelf inventory level no. 8

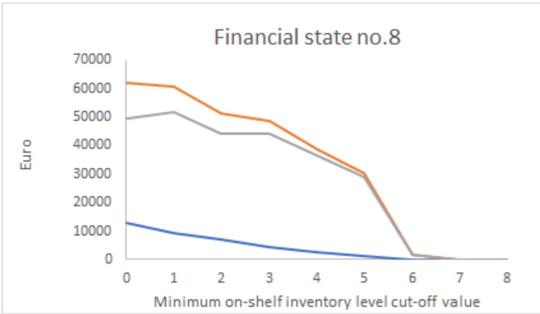


Figure E.70: Financial state vs min on-shelf inventory level no. 8

Figure E.71: CBR vs min on-shelf inventory level no. 8

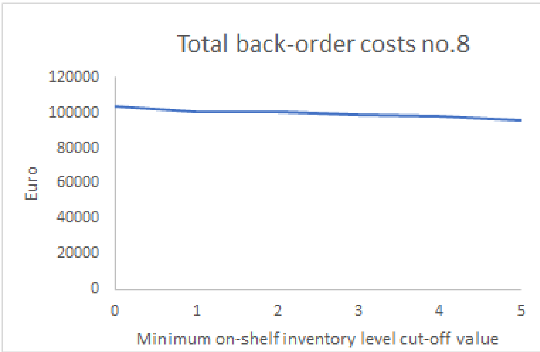


Figure E.72: Total back-order cost vs min on-shelf inventory level no. 8

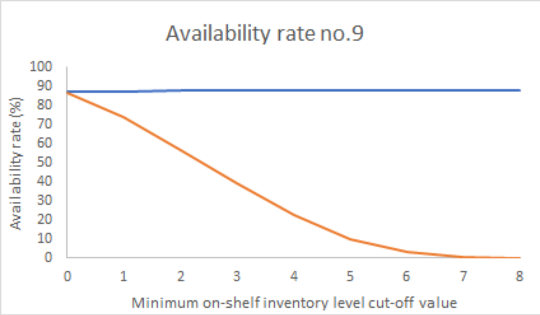


Figure E.73: AR vs min on-shelf inventory level no. 9

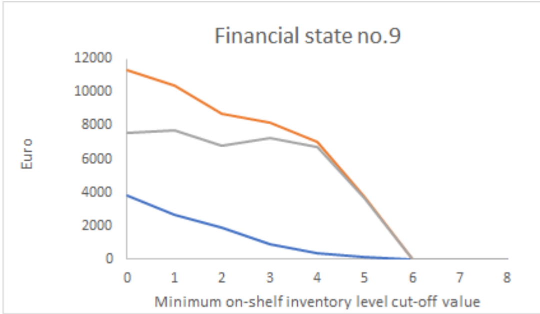


Figure E.74: Financial state vs min on-shelf inventory level no.91

Figure E.75: CBR vs min on-shelf inventory level no. 9

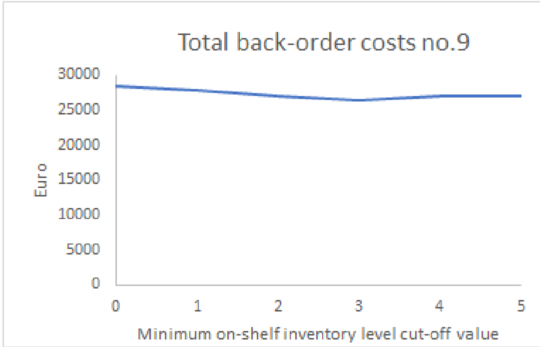


Figure E.76: Total back-order cost vs min on-shelf inventory level no. 9

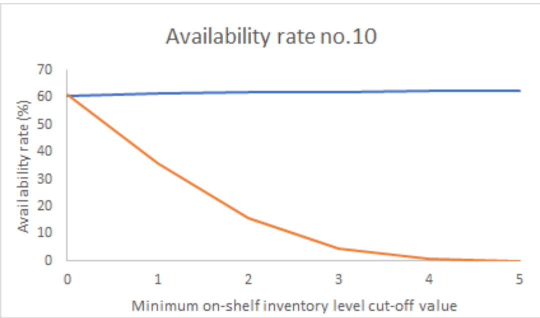


Figure E.77: AR vs min on-shelf inventory level no. 10

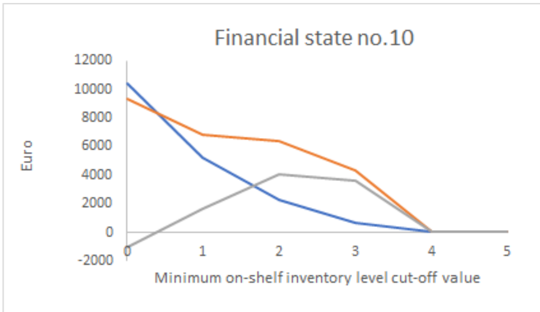


Figure E.78: Financial state vs min on-shelf inventory level no. 10

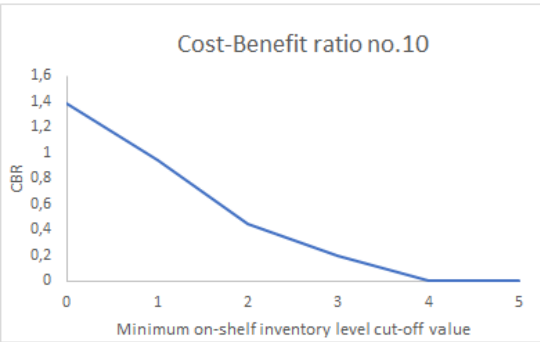


Figure E.79: CBR vs min on-shelf inventory level no. 10

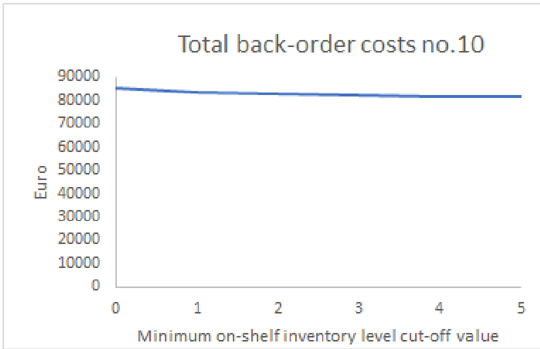


Figure E.80: Total back-order cost vs min on-shelf inventory level no. 10

E.4. Feasibility increasing circulation stock

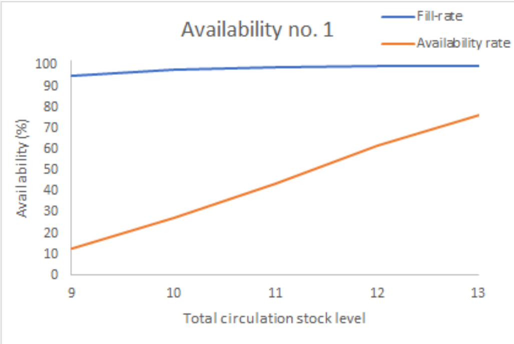


Figure E.81: Availability vs total circulation stock level no. 1

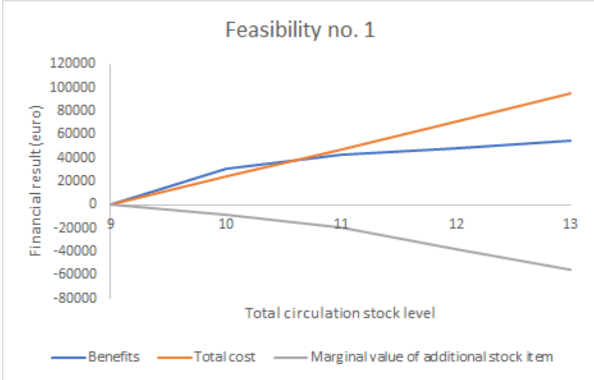


Figure E.82: Marginal value of additional stock item vs total circulation stock level no. 1

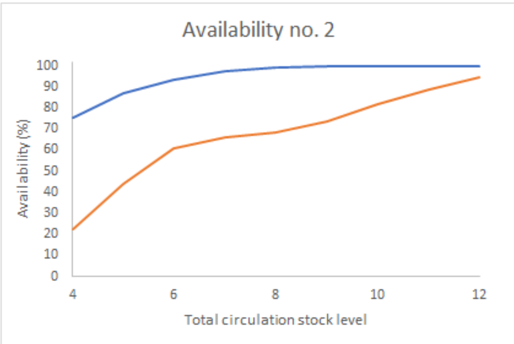


Figure E.83: Availability vs total circulation stock level no. 2

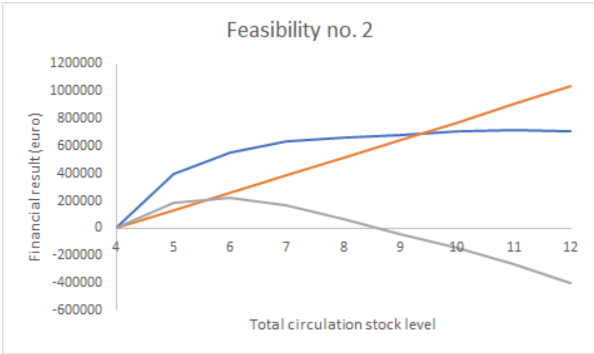


Figure E.84: Marginal value of additional stock item vs total circulation stock level no. 2

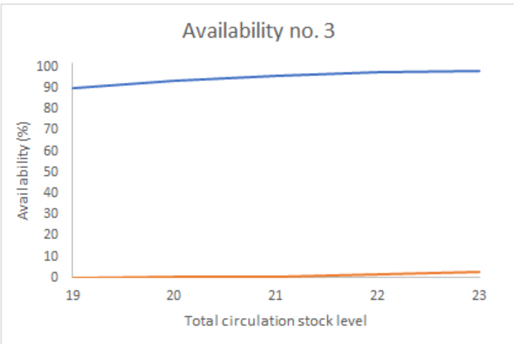


Figure E.85: Availability vs total circulation stock level no. 3

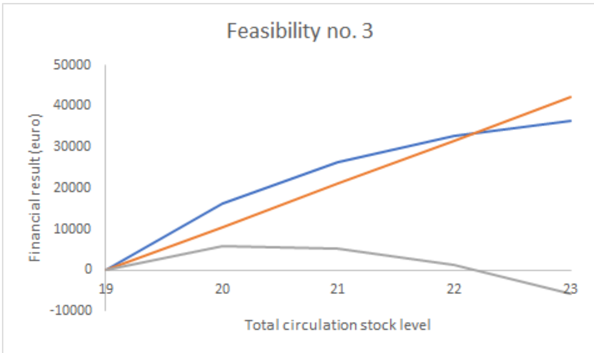


Figure E.86: Marginal value of additional stock item vs total circulation stock level no. 3

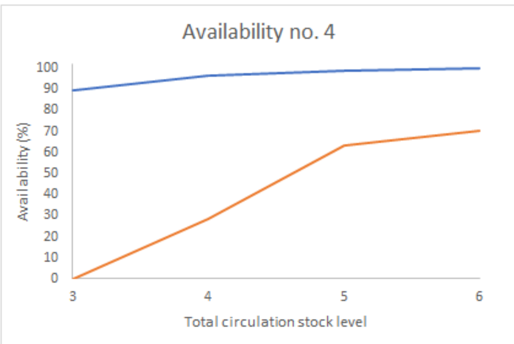


Figure E.87: Availability vs total circulation stock level no. 4

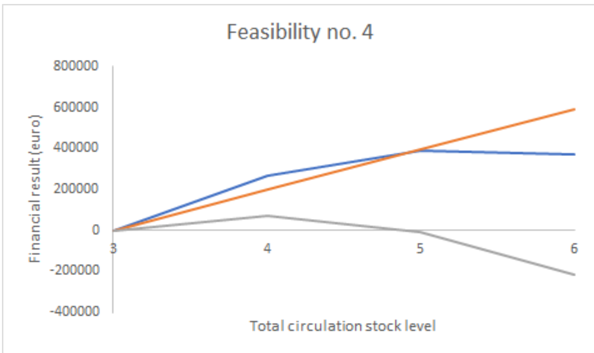


Figure E.88: Marginal value of additional stock item vs total circulation stock level no. 4

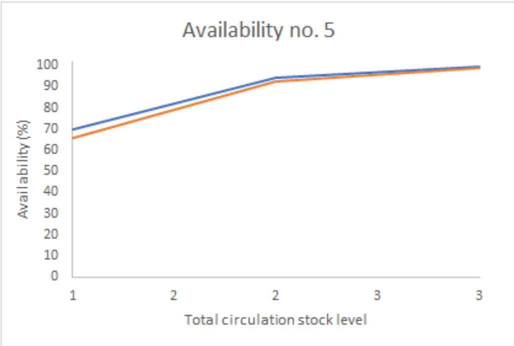


Figure E.89: Availability vs total circulation stock level no. 5

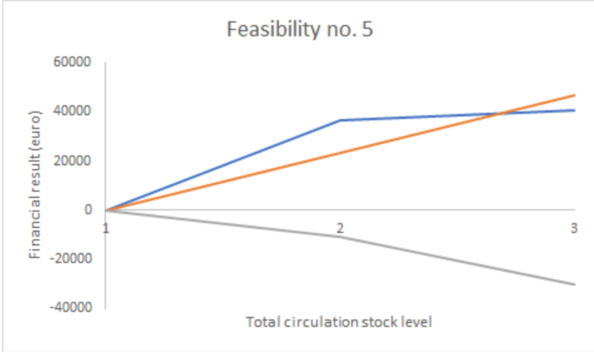


Figure E.90: Marginal value of additional stock item vs total circulation stock level no. 5

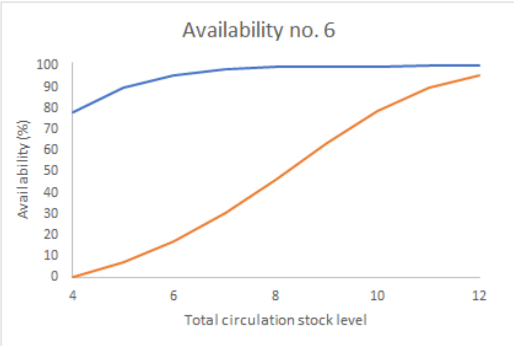


Figure E.91: Availability vs total circulation stock level no. 6

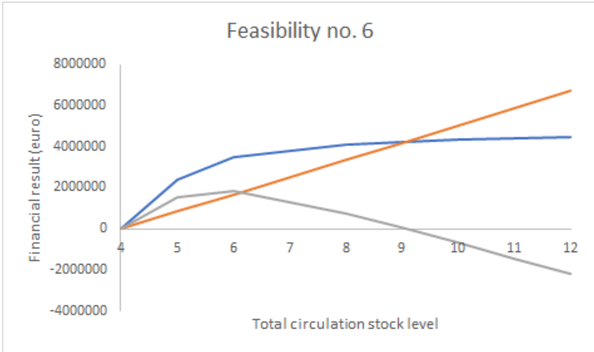


Figure E.92: Marginal value of additional stock item vs total circulation stock level no. 6

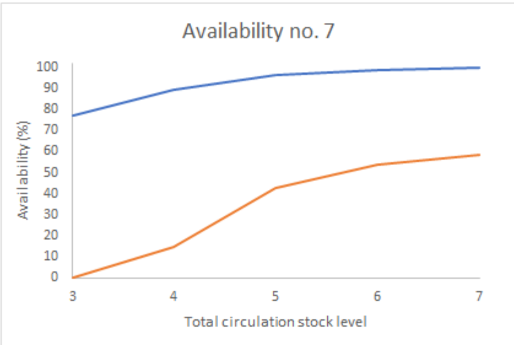


Figure E.93: Availability vs total circulation stock level no. 7

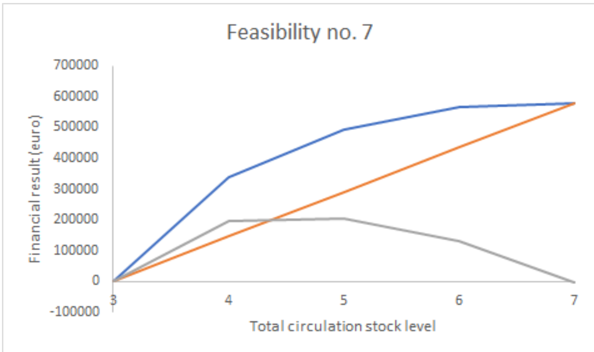


Figure E.94: Marginal value of additional stock item vs total circulation stock level no. 7

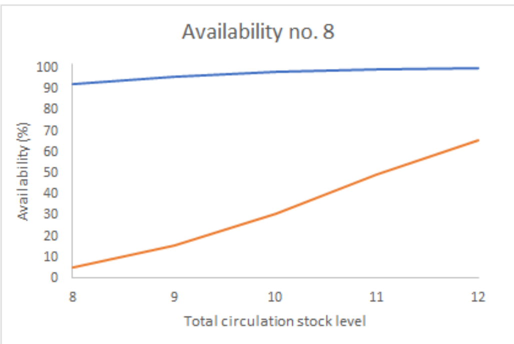


Figure E.95: Availability vs total circulation stock level no. 8

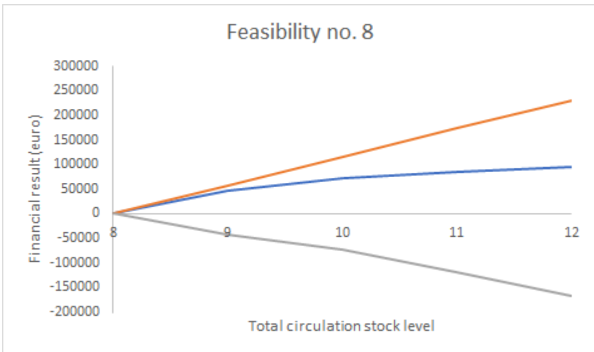


Figure E.96: Marginal value of additional stock item vs total circulation stock level no. 8

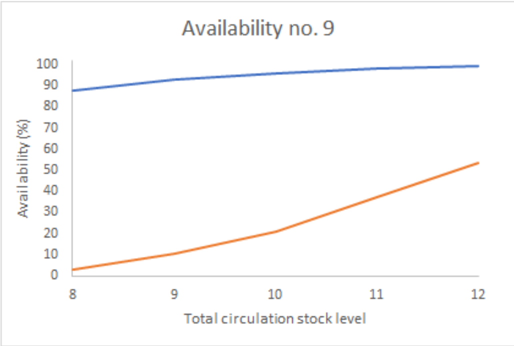


Figure E.97: Availability vs total circulation stock level no. 9

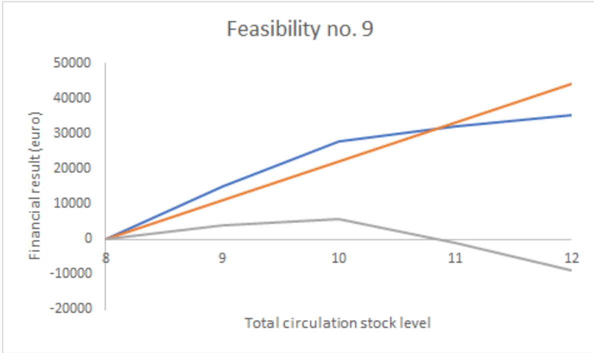


Figure E.98: Marginal value of additional stock item vs total circulation stock level no. 9

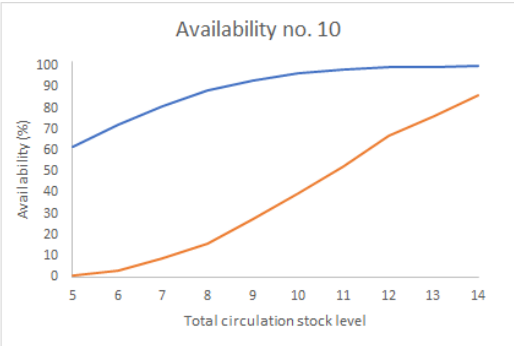


Figure E.99: Availability vs total circulation stock level no. 10

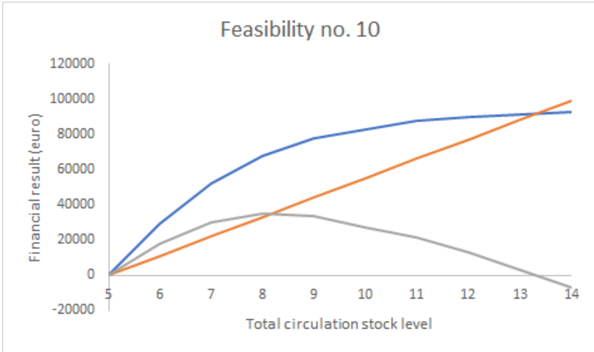


Figure E.100: Marginal value of additional stock item vs total circulation stock level no. 10

F

Research paper

Evaluating performance improvement strategies in a closed-loop supply chain

A case study at KLM E&M Component Services

D.G.C Munsters, G. van Schie, M.W. Ludema, M.B. Duinkerken, L.A. Tavasszy

***Abstract*— KLM Engineering & Maintenance Component Services manages a spare part pool. They are responsible for ensuring spare part availability for their contracted customers. For rotable spare parts, which are interchangeable and repairable, the supply chain is closed-loop. As the demand for spare parts is sporadic, with large zero demand periods, a loan service is introduced for non-contracted customers in order to increase the spare part utilisation rate and gain additional revenue. This research evaluates potential strategic options to increase the contribution of the loan desk to the performance of KLM Component Services. It is important that the effect on the availability service for contracted customers is limited. Gaining control over the availability decision regarding non-contracted customers was considered as top priority. It was found that the risk-based availability decision could result in a revenue increase of 24% of the loan service, yet enables management to control the effect on the availability service regarding contracted customers.**

I. INTRODUCTION

KLM Engineering & Maintenance Component Services (CS) is responsible for ensuring spare part availability for its contracted customers. According to contracts with customers, KLM CS must fulfil 100% of the spare part requests. In 2018, a revenue of €910 million was gained from maintenance contracts. The supply chain of rotable spare parts is a so-called closed-loop supply chain. Rotable spare parts are repairable components that are interchangeable. When a contracted customer requests a spare part, a serviceable (SE) component is shipped to the customer. The customer returns the unserviceable (US) component to KLM Component Services. Then, the US spare part is shipped to the repair location, either in-house or outsourced, where the rotable spare is repaired and retrieves its SE status. Hereafter, the spare part is shipped to the logistics center (LC), where the spare part is restored. The demand for spare parts has a sporadic nature and consists of large zero demand periods. In order to increase the spare part utilisation rate and to gain additional revenue, a loan service is introduced. The loan desk enables external customers (without contracts) to borrow a spare part against a predetermined fee. In 2018, a revenue of €1,5 million was gained by the providence of this additional service. However, the providence of this additional service should not negatively affect spare part availability regarding contracted customers. Especially, the back-order costs due to the providence of this service should be limited. As KLM CS must meet the supply obligations laid down in contracts with customers, spare parts are back-ordered (borrow, exchange-in or purchase) in case of unavailability. The researched closed-loop supply chain system consisting of two demand types served from a single inventory storage location, and is diaplayed in Figure 1.

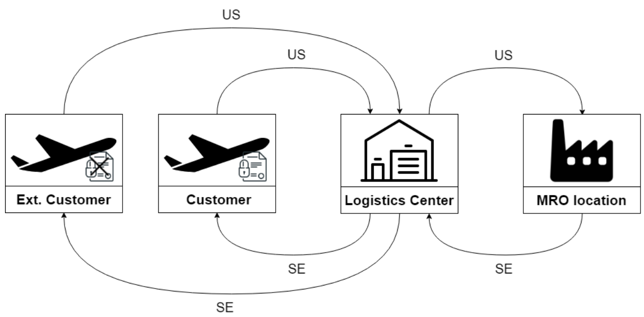


Fig. 1. Closed-Loop Supply Chain of rotable aircraft spare parts including external customers

According to employees, there is an imbalance between both processes. In other words, KLM's loan desk negatively effects spare part availability regarding contracted customers. Accordingly, the objective of this research is to evaluate potential performance improvement strategies for the loan desk. In order to achieve this, the following research question was formulated:

What strategic improvement option(s) should be employed in order to increase the contribution of KLM's loan desk to the performance of KLM Component Services?

II. CURRENT STATE SITUATION

A. System description and context

The researched system consists of a single inventory source of rotable aircraft spare parts from which contracted and external demands are served. With respect to contracted customers, KLM Component Services must fulfil 100% of the requests, with the right spare part, to the right customer at the right time according to

Service Level Agreements (SLAs). In case of unavailability, the requested spare part is back-ordered, borrow-in or purchase, in order to meet the supply obligation. As external customers are non-contracted, their requests are solely accepted in case the requested spare part is determined to be available. When the requested spare part is available, the fee for the loan service is negotiated with the external customer. In 13.5% of the quoted external requests, the customer ordered the spare part.

Rotable spare parts are interchangeable. When a serviceable (SE) spare part is supplied to the customer, an unserviceable (US) return spare part is shipped to the logistics center of KLM Component Services. Here, the US spare part is send to the repair location where spare part MRO takes place. At KLM Component Services, this can either be in-house at a repair shop or outsourced at a vendor. After the repair, the SE spare part is shipped to the logistics center where it is restored at the Magazijn Logistiek Centrum (MLC) storage location. The spare part is now available for a new request.

The causal relations and interactions of the system are determined. It is important to understand the complexity of systems in order to develop better operating policies and strategies, and guide effective change (Sterman, 2001). The causal relations of the system are presented in Figure 2. Here, the dotted part represents the causal relations related to the loan desk.

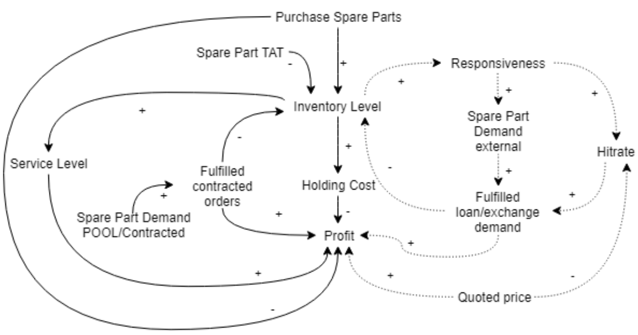


Fig. 2. Causal map of a the total closed-loop supply chain system

In the figure, some important interactions can be denoted where well considered trade-offs should be made. As both demands are satisfied from the same inventory source, fulfilling external demand could result in spare part unavailability and decrease Service Level (SL) regarding contracted customers. This makes the availability decision regarding external customer of high importance, as contracted unavailability could result in back-order expenses. Inventory and turn around time are the most important variables of the system. A trade-off between holding inventory and service level is made. KLM strives to keep the total circulation stock as low as possible, yet meeting the agreed service levels. When turn around time is lowered, the on-shelf inventory level increases which positively effects service level. So, effective inventory management and lowering turn around time are of high importance to meet SLAs and increase profitability of the availability service. Some factors were detected that influence the number of orders at the loan desk. Increasing responsiveness in terms of reaction speed and availability could result in an increased order acceptance rate. In addition, the quoted price to the customer effects the customer' hitrate. A trade-off should be made between the quoted price and hitrate.

Currently, the decisions-making policy at the loan desk regarding availability and pricing, are mainly based on feeling and experience. There are no standard procedures nor decision rules.

B. Exploring the loan market characteristics

The loan market is a demand driven market. At the loan desk, 230 requests are handled on a weekly basis. As only rotables with a known part number (PN) can be offered to external customers, not all requests are useful. On average 26% of the requests are useful. When investigating the request frequency per PN, it turns out that some spares are more frequently requested than others. In 2018, 39 different external customers used the loan service of KLM. Large differences in number of orders and the amount of money spend were noticed. It seems that frequently returning customers spend less compared to customers that occasionally use the service. On average external customers spend €6.163,10 per order. External customers can either borrow or exchange a spare part. When borrowing a spare part, the spare part with the same part number and serial number should be returned. In case of an exchange, the customer returns a spare part with the same part number and a different serial number. Here, spare parts are interchanged. At KLM's loan desk, the distribution between both order types is 50-50. On average, the time between supply of the spare part and receiving a spare part back from the customer takes 8 days longer in case of a loan order compared to an exchange order.

C. System performance

At the loan desk, one Key Performance Indicator (KPI) is tracked, which is revenue. Management set a target of €200.000 per month, which is met in only 17.5% of the months. At the loan desk, employees log the characteristics of each request. From this data, it could be concluded that 79% of the useful requests from external customers could not be quoted to customers due to critical or zero on-shelf inventory levels. Based on customer and order characteristics, stock issues result in €175.000 lost potential monthly revenue.

The main KPI of KLM Component Services with respect to the availability service regarding contracted customers is service level. In 2017 and 2018, the average SL equalled 82%. According to service level agreements (SLAs), this should be 94.7%. So, the performance of KLM Component Services is rather poor. This low SL results in large back-order expenses as 14% of the requests were fulfilled via a back-orders. For the B737, this resulted in more than €500.000 back-order expenses per month.

III. DEFINE POTENTIAL IMPROVEMENT STRATEGIES

The first step in Business Performance Management (BPM) should be to develop strategic goals by specifying objectives and KPIs (Lummus, 1998). A five step method is proposed (adapted from (Lummus, 1998)):

1) Develop Supply Chain Strategic Roles
2) Identify/Prioritise Improvement Opportunities
3) Define Goals
4) Determine Performance Measures
5) Monitor Progress & Make Adjustments

A. Goal and vision

KLM strives to be a High Performance Organisation (HPO). The definition of a HPO contains the following elements: good financial results, customer satisfaction, employee satisfaction, productivity and innovation, aligned performance measurement and strong leadership (De Waal, 2007). KLM Component Services is also part of this program. Therefore, several business improvement programs were initiated and the Balanced Score Card (BSCOR) was introduced to track performance, which is presented in Figure 3.

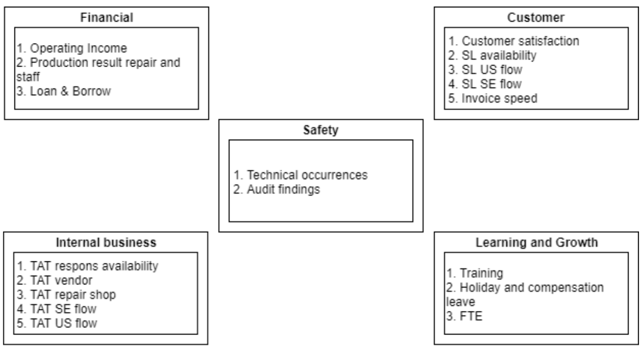


Fig. 3. Balanced Scorecard of KLM Component Services

The main goal of KLM CS is to provide spare part availability for its contracted customers and achieve high customer satisfaction. It is especially important that the right spare part with the right specifications is send to right customer and delivered at the right time. In addition, KLM is a profit seeking organisation and strives to increase its profitability, while meeting the contracted customer SLAs. In any case, the operation should be safe. In order to achieve this, KLM CS focuses on lowering spare part turn around time (TAT) and inventory management improvement strategies. This study focused on the latter. Here, KLM tries to maintain the lowest possible inventory level to meet the SLAs. In the BSCOR of CS, the contribution of the loan desk to the KPIs of KLM CS can be found in the financial box. The loan desk is introduced as a Strategic Business Unit (SBU). The main goal is to contribute to the financial performance of KLM CS, while not negatively affecting the spare part availability regarding contracted customers. Especially, the back-order costs due to the providence of the loan service should be limited.

B. Potential improvement strategies

A strategy is a set of hypotheses about cause and effect (Kaplan, 2001). In Figure 2, the causal relations of the closed-loop supply chain system are presented. Here, areas that effect performance can be detected. When looking at the causal diagram, one may notice that the spare part TAT, directly influences the on-shelf inventory level. In case the TAT decreases, spare parts are restored faster, which results in a higher average on-shelf inventory level. However, decreasing spare part TAT is not within the scope of this research. Therefore, this performance improvement area is not further discussed throughout this paper. The following improvement areas were identified:

- *Total circulation stock level* - increasing the total circulation stock to improve the loan desk's responsiveness in terms of availability of spare parts regarding external customers.
- *Availability decision* - develop a rule/fact based decision methodology for KLM's loan desk that is able to make a trade-off between the opportunity of gaining additional revenue and the risk of back-ordering expenses due to component unavailability for contracted customers by loaning or exchanging the requested spare parts.
- *Pricing method* - develop a pricing method that enables to translate the potential risk of component unavailability regarding contracted customers into a price that is worth accepting the risk of additional back-order expenses. In other words, a pricing method that takes into account the risk of a shortage regarding contracted customers, while striving to increase the revenue gained from KLM's loan desk.

After detecting improvement areas, the balanced scorecard framework is used to organise strategic objectives in four different perspectives: financial, customer, internal business and learning & growth. After mapping the strategy, the research was re-scoped. The rest of this paper focuses on internal business improvement options. Gaining control over the *availability decision* was considered as top priority, as wrong decision could have a large financial impact. Furthermore, based on the finding that 14% of the requests from contracted customers are fulfilled by the borrow department (back-ordered), in combination with 79% of external requests being unavailable due to zero or critical stock levels, the strategic option of *increasing the total circulation stock* was also considered as top priority.

C. Performance metrics and Constraints

Performance metrics were developed in order to be able to evaluate the strategic improvement options. The first performance metric is the *Availability Rate* (AR). The AR represents the percentage of the total external demand that was found to be available for an order. The AR is calculated according to formula 1.

$$AR = \frac{\sum Q}{\sum R_{external}} \cdot 100\% \quad (1)$$

Here, Q represents the number of requests for spare part that were available for loan or exchange, and thus quoted to the external customer. $R_{external}$ indicates the total number of requests received by the loan desk from external customers.

The second performance metric is the *Fill-Rate* (FR). The FR is the percentage of requests from contracted customers that could directly be supplied from stock. The FR is calculated according to formula 2.

$$FR = \frac{\sum H}{\sum R_{contracted}} \cdot 100\% \quad (2)$$

Here, H represents the number hits, or the number of requests for spare part that were directly supplied from stock. In other words, request that were not placed on hold or back-ordered. $R_{contracted}$ indicates the total number of requests from contracted customers.

The third performance indicator is the *Total Result* (TR) generated by the loan desk (or profit). This performance metric presents the financial contribution of the loan desk. TR equals the *Total Income* (TI) subtracted by the *Total Cost* (TC). Here, TI is the total income from external orders. TC equal the total back-order costs due to the providence of the loan service in order to meet supply obligations regarding contracted customers. TR is calculated according to formula 3.

$$TR = TI - TC \quad (3)$$

For the evaluation of the second improvement option, increasing the total circulation stock, some some additional performance evaluation measures are introduced. The *Marginal value of an additional stock item* (F) is introduced to be able to evaluate the feasibility of increasing the circulation stock level. By subtracting the total benefits of increasing the circulation stock level with the additional costs of increasing the circulation stock level, the marginal value of an additional stock item is calculated. Here, the benefits consist of: decrease in total back-order cost (ΔTBC) and additional income (ΔTI) generated by the loan desk. The costs consist of: purchasing cost (PC) and holding cost (HC). For this research, the marginal value of an additional stock item is calculated over a 5 year time period. If the marginal value is positive, increasing the circulation stock level is feasible. Formula 4 shows how the feasibility is calculated.

$$F = \Delta TI + \Delta TBC - PC - HC \quad (4)$$

In addition to the performance measures, one performance constraint is introduced, the *Cost-Benefit Ratio* (CBR). This is the ratio between the total income generated by the loan desk and the back-order costs due to the providence of the loan service. The configurations of the business improvement strategies are constraint to a maximum value of the CBR. Here, the value of the CBR differs per spare part type, which is explained in following chapters. The CBR is calculated according to formula 5.

$$CBR = \frac{\sum TI}{\sum TC} \quad (5)$$

By introducing this constraint, the effect of the loan desk on the spare part availability service becomes controllable. As spare parts have different characteristics, different cut-off values were determined.

IV. SPECIFY MOST PROMISING IMPROVEMENT STRATEGIES

A. Spare part characteristics

Before specifying strategic improvement options, characteristics of spare parts were analysed. This is of high importance as strategies should be able to cope with different types of spare parts.
First, spare parts were classified according to their demand characteristics. Based on their Average Demand Interval (ADI) and their Coefficient of Variation (CV), spare parts were categorised, as presented by (Kipli, 2004). The nature of aircraft spare parts can be divided into four categories:

- *Smooth Demand* - No great variation in the inter-demand intervals and quantities.
- *Intermittent Demand* - No extreme variation in quantity but many zero demand periods.
- *Erratic Demand* - No grate variation in the inter-demand intervals but many variation in demand sizes.

- *Lumpy Demand* - Random demand with many zero demand periods and many variation in demand sizes.

It turned out that for both contracted and external demand, the majority of the spares can be classified as intermittent.
In addition, spare parts are classified according to their critically, indicated by the Essentiality Code (ESS). Spare parts can be divided into three categories: ESS1 (NO GO), ESS2 (GO IF) and ESS3 (GO). If an ESS1 component fails, the affected aircraft cannot take off (NO-GO). In case of an ESS2 component failure, the aircraft can take off under certain conditions (GO-IF). Only in case of an ESS3 component failure, the component exchange can be delayed and the aircraft may take off (GO).
As stated earlier, spare parts are repaired either at a repair shop (in-house) or at a vendor (outsourced). When investigating the repair times, large differences were found between in-house and outsourced repairs. The repair time characteristics are presented in Table I.

TABLE I
REPAIR TIME CHARACTERISTICS FOR IN-HOUSE AND EXTERNAL VENDOR REPAIRS

Repair type	N	Mean repair (days)	Std. deviation (days)
In-house repair shop	20738	17.16	17.45
External vendor	18579	34.87	25.51

Lastly, the cost structure of providing an availability service was investigated. The costs of providing an availability service consist of mainly three elements: inventory holding, ordering and back-order costs (Carter, 1978). The annual holding costs are 17% of the spare part's market value. The costs of back-ordering were determined based on historical data and equal on average 38% of the spare part value per back-order.

B. Availability decision

For the availability decision regarding external customer requests, two alternatives were specified. The first alternative is a *risk-based availability decision.* Here, risk refers to the risk shortage regarding a contracted customer when loaning the spare part to an external customer. The second alternative is a *minimum on-shelf inventory level based availability decision.* Here, a cut-off value for the minimum on-shelf inventory level determines whether a spare part is available for an external customer or not.

1) Risk-based availability decision: According to literature, the Poisson distribution is a good approximation for the removal pattern of aircraft spare parts (Dekker, 2013). Based on a Poisson distribution, the probability of a shortage during the spare part turn around time is calculated according to Formula 6.

$$p(I_{shelf} - 1 < k) = \sum_{k=I_{on-shelf}-1}^{\infty} \frac{D_{TAT}^{k} \cdot e^{-D_{TAT}}}{k!} \quad (6)$$

In this formula, $p(k > I_{shelf} - 1)$ represents the risk of a shortage, where the probability is calculated whether the number of removals regarding contracted customers k is bigger than the on-shelf inventory level when offering the spare part $(I_{shelf} - 1)$. And D_{TAT} represents the expected number of removals during the TAT of the spare part, which is calculated as presented in Formula 7.

$$D_{TAT} = \frac{D_{year} \cdot TAT}{365} \quad (7)$$

In this equation, D_{year} indicates the average yearly demand which is based on historical data. And TAT, presents the estimated total turn around time of the spare part for either in-house or outsourced repairs. Which is the time window between the supply date to the customer until re-storage date. Based on historical data, the estimated total TAT equals 27 days for repair shops and 47 days for vendors. In case the calculated risk of a shortage exceeds the maximum acceptable risk cut-off value the spare part is not available and therefore not quoted to the external customers.

2) Minimum on-shelf inventory level based availability decision: This alternative is less complicated compared to the risk-based availability decision. For this alternative, the on-shelf inventory level at the moment an external customer places a request determines whether the spare part is available or not. In case the minimum on-shelf inventory exceeds the on-shelf inventory level at the moment a request is placed, the spare part is available. Here, the cut-off value for the minimum on-shelf inventory level differs per spare part type.

C. Total circulation stock level

At KLM's loan desk, approximately 2.000 different spare parts were requested during the first 44 weeks of 2018. For almost 80% of the requests, stock issues were reported. Therefore, the option to increase the circulation stock level was investigated. This option is evaluated by determining the feasibility of increasing the circulation stock. One way to manage large number of Stock Keeping Units (SKUs) is to aggregate them into groups, and determine the inventory policy per group (Millstein, 2014). It is often found that a small percentage of the SKUs contributes to the majority of the sales and revenue of a company, which led to the 80-20 rule (Pareto, 1971). The top 20% of the items are classified as A, the next 30% as B and the bottom 50% the C classification. At

KLM, no inventory classification is determined based on solely external demand. Based on the demand size per spare part, the external customer hitrate and the average income per order, the demand value is estimated for each spare part requested at the loan desk. In Table II, the demand value for each class is presented. A Pareto distribution was found.

TABLE II

Characteristics of the ABC classes regarding KLM's loan desk (based on the first 44 weeks of 2018)

Class	SKUs count	Estimate revenue contribution (euro)
A	296	€ 3.614.139,04
B	444	€ 544.585,78
C	740	€ 155.248,89
Total	1480	€ 4.313.973,71

For this research, the feasibility of increasing the circulation stock is investigated for 10 case spare parts. The selected spare parts are all class A and differ in characteristics, such as: demand, criticality and repair location.

V. Modelling Improvement Strategies

To evaluate the presented strategic options, a Discrete Event Simulation (DES) has been set up.

A. Conceptual model

A conceptual model is defined as follows: *"a non-software specific description of the computer simulation (that will be, is or has been developed), describing objectives, inputs, outputs, content, assumptions and simplifications of the model"* (Robinson, 2008). The *objective* of the simulation model is to evaluate the presented performance improvement strategies.

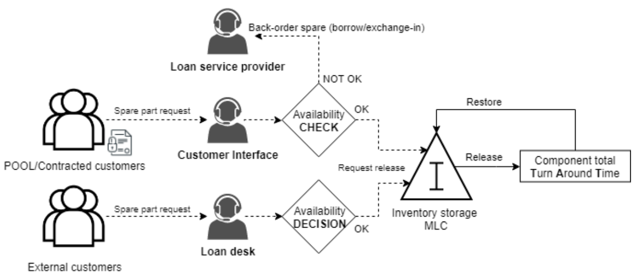


Fig. 4. Simplified system flowchart

In Figure 4, the first strategy can be detected in the decision box in the lower line. The second strategy, increasing the total circulation stock, can be detected in the right part of the figure in the triangular box.

Some *assumptions* are made. First, the demand is modelled as Poisson. Second, the external customer hitrate is fixed to 13.5%. Third, the income generated from a loan order equals 2% of the spare part value per day and for exchange orders 3% per day. Fourth, annual holding costs are set to 17% of the spare part value. Fifth, the cost of back-ordering equals 38% of the spare part value. As demand is modelled via a Poisson distribution, the typical characteristics of each demand class are lost. Therefore, the cost-benefit ratio is multiplied by a penalty factor for each demand class. For erratic and intermittent demand 1.25 and for lumpy demand 1.5. Furthermore, in collaboration with experts of KLM, a maximum CBR value for each criticality class was determined, which are presented in Table III. The cut-off values differ as the impact of a shortage depends on the criticality of a spare part. Especially a NO GO item shortage can result in aircraft downtime, which is extremely costly.

TABLE III

Maximum cost benefit ratio per ESS class

Essentiality	Maximum value of the CBR
GO (ESS 3)	0.5
GO-IF (ESS 2)	0.25
NO-GO (ESS 1)	0.10

As stated earlier, the *input* consists of 10 case spare parts. The simulation model is *simplified* by developing a single component simulation model where no queues are modelled. The most important characteristics of the case study spare parts are presented in Table IV. Furthermore, turn around times of spare parts are modelled by a distribution function, which are spare part specific and were fitted based on historical data.

TABLE IV

Case spare part characteristics

No.	ESS	Yearly demand contracted	Yearly demand external	Repair location	Value
1	1	46.4	5.2	VEN	€ 12.835,88
2	3	24	5.0	RS	€ 69.997,92
3	2	196.8	4.3	VEN	€ 5.702,56
4	1	15.2	9.0	RS	€ 106.418,28
5	2	1.6	6.3	VEN	€ 12.697,62
6	1	32	6.0	RS	€ 452.618,64
7	2	19.2	10.0	RS	€ 78.512,95
8	1	51.2	1.3	VEN	€ 31.220,00
9	1	32	8.5	RS	€ 5.971,05
10	1	24	6.0	VEN	€ 5.971,05

The model *outputs* are used as input for the calculation of the KPIs.

The conceptual simulation model is implemented in the Simio simulation software version 9.158.15009.

B. Verification & validation

Simulation models are increasingly being used to support decision-making. Therefore, the correctness of the model is of high importance. Verification is about understanding whether the model is built correct according to the specifications. Validation is concerned with determining whether the model is an accurate representation of the system.

C. Verification

The simulation model was built in steps. After adding a process, the results were inspected and checked whether this was expected or not. Furthermore, balance check were performed in order to inspect whether all created entities were destroyed. Lastly, the behaviour of the model was inspected by adding labels and counters at every model object. By changing the input variables, the behaviour of the model was inspected and verified. Besides verification checks, two verification runs were performed. First, an extreme condition test, where the value of the maximum risk of a shortage was set to 0 and 1. When set to 0, all requests were available, and when set to 1, zero requests were available. Besides the extreme condition test, the number of components in the system was plotted. The number in system never exceeded the total circulation stock. Hereby, the model was verified.

D. Validation

First, *structural validation* was performed. Experts within KLM were asked whether the behaviour of the model is reasonable, this technique is called face validation. The experts validated the structure of the model and its behaviour.
After validating the model structure, *data validation* was performed. When comparing the model output to historical data, large differences in terms of fill-rates were detected. By consulting data experts within KLM, the conclusion was drawn that the inventory data set was highly polluted. In order to obtain realistic results, *model calibration* was performed. Here, the circulation stock levels were calibrated based on the spare part specific fill-rates obtained from historical.
Lastly, *performance validation* was performed based on the determined circulation stock levels. When inspecting the average yearly back-orders, no large differences were found. Hereby, the model was validated.

VI. Experiment & Results

A. Experimental plan

For the experiment, a warm-up period of 4 weeks was used in order to remove the atypical system conditions. This was determined by graphically inspecting the number of spare parts in the system. The run length was set to 260 weeks with 250 replications. By doing so, the half width of the 95% confidence interval of the KPIs was below 5% of the average.
For the risk based availability decision, the configuration variable: maximum risk of a shortage, was varied from 0 to 1. For each case spare part, the best configuration was chosen based on the KPIs in combination with the CBR performance constraint. For the minimum on-shelf inventory level based availability decision, the configuration variable: minimum on-shelf inventory level, was incremented from 0 up to the total circulation stock level. Again, based on the performance metrics and CBR performance constraint, the best configuration was determined for each case spare part. Hereafter, different scenarios were simulated in order to test the robustness of the strategies. Hereafter, a generic availability decision method was determined based on the model results.
For the total circulation stock level strategy, the generic availability decision was used. The configuration variable: total circulation stock level, was incremented by one for in each configuration. The feasibility of increasing the total circulation stock level was determined based on a 5 year period.

B. Availability decision

As stated earlier, for each case spare part, the best configuration of the strategy was determined based on the KPIs and the performance constraint. For example, the financial results for each value of the configuration parameter of the risk based strategy of spare part no 1 are presented in Figure 5 and the resulting CBR in Figure 6.

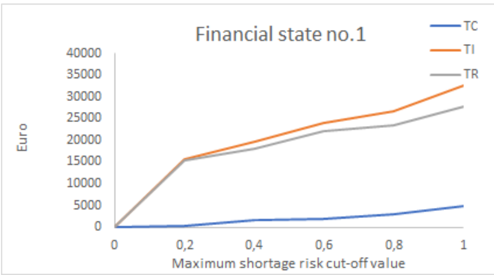


Fig. 5. Financial KPIs versus maximum risk of a shortage

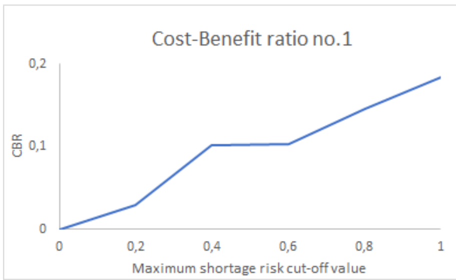


Fig. 6. Cost benefit ratio versus maximum risk of a shortage

This case spare part is classified as ESS1, so the CBR is constrained to 0.10, which is met for the range 0-0.6. In this range, the result (or profit) is at its maximum at 0.6, and is therefore the best strategy configuration for this spare part. The results for all case spare parts of the risk-based availability decision are presented in Figure 7, and the results of the minimum on-shelf inventory level based availability in Figure 8. Note, the best configuration for each spare part is presented.

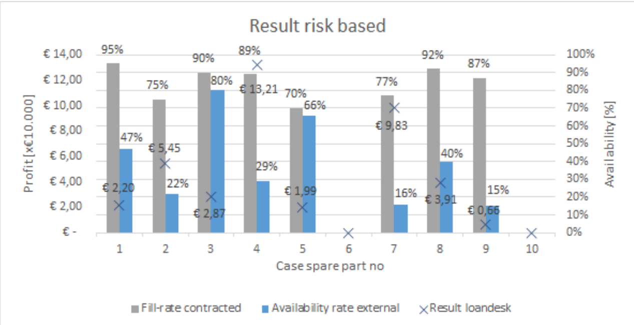


Fig. 7. Model results risk-based availability decision in best strategy configuration per case spare part

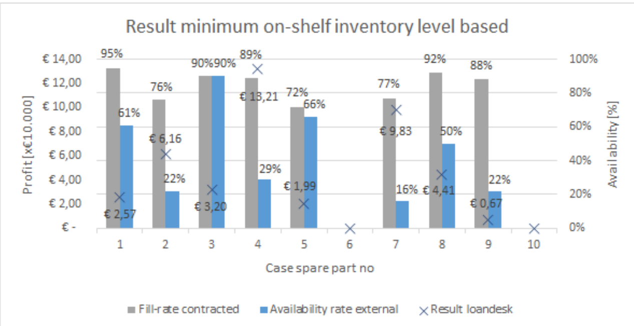


Fig. 8. Model results minimum on-shelf inventory level based decision in best strategy configuration per case spare part

The results do not show large differences. However, the results of the scenario analysis in order to test the robustness do. The results of the scenario analysis are presented for both strategy alternatives in Table V and VI.

TABLE V

ROBUSTNESS OF THE RISK-BASED DECISION

Input	Δ Input	Δ FR contracted	Δ AR external	Δ Result loan desk
Contracted Demand	+10%	-4%	-11%	-12%
Contracted Demand	-10%	+4%	+15%	+4%
External Demand	+10%	0%	-1%	0%
External Demand	-10%	0%	+0%	-5%
Repair Time	+10%	-2%	-7%	-11%
Repair Time	-10%	+2%	+10%	+1%

TABLE VI

ROBUSTNESS OF MINIMUM ON-SHELF LEVEL BASED DECISION

Input	Δ Input	Δ FR contracted	Δ AR external	Δ Result loan desk
Contracted Demand	+10%	-6%	-13%	-19%
Contracted Demand	-10%	+4%	+15%	+4%
External Demand	+10%	-1%	0%	+0%
External Demand	-10%	0%	-1%	-8%
Repair Time	+10%	-4%	-5%	-15%
Repair Time	-10%	+2%	+10%	+0%

As can be concluded from the tables, the risk-based availability decision is more robust. Especially an increase in contracted demand causes problems in the minimum on-shelf availability decision. Therefore, the generic availability decision should be risk-based. In order to determine the maximum risk of a shortage for each essentially class, all spare parts were treated as ESS1, ESS2 or ESS3. Based on the CBR performance constraint and resulting KPIs, the cut-off values were determined and presented in Table VII.

TABLE VII

GENERIC DECISION RULE: MAXIMUM RISK OF A SHORTAGE PER CRITICALITY CLASS

Essentiality level	Maximum risk of a shortage
GO	0.8
GO-IF	0.6
NO-GO	0.2

Table VIII, presents the estimated results when applying this availability decision rule.

TABLE VIII

RESULT GENERIC AVAILABILITY DECISION RULE

Essentiality level	Share of external requests [%]	Availability rate [%]	Δ total back-order cost [€]
GO	7.7%	9%	1%
GO-IF	59.7%	33%	2%
NO-GO	32.6%	43%	3%

Based on the share of external requests, the availability rates, the average income per external order and historical demand data, the estimated increase in revenue generated by the loan desk equals *€375.000 per year*. Furthermore, the availability rate increases with *24%*. More importantly, this availability decision method allows to control the effect of the loan service on the availability service regarding contracted customers.

C. Circulation stock level

For each spare part, the feasibility was plotted against the total circulation stock level, starting at the current circulation stock level. For case no 2, the marginal value of additional stock items is presented in Figure 9.

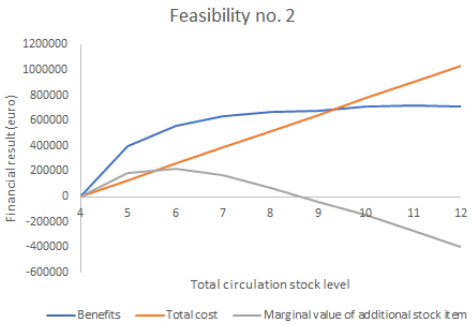


Fig. 9. Marginal value of additional stock item versus total circulation stock level case no. 2

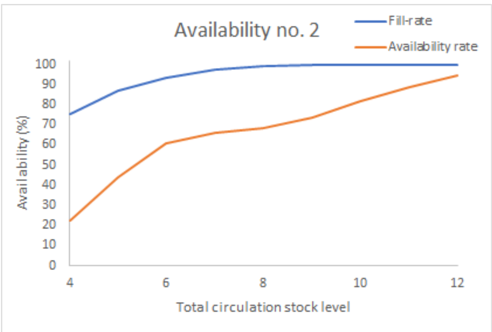


Fig. 10. Availability versus total circulation stock level case no. 2

In the figure can be seen that the total cost linearly increase. The benefits of increasing the total circulation stock also show an increasing pattern. However, the increase of the benefits stagnates as the total circulation stock increases. At a certain point, the fill-rate approaches 100% and no back-order costs are needed. When this point is reached, the benefits still increase until the availability rate regarding external customers equals 100%. Hereafter, no additional benefits are gained. The effect on the availability regarding both contracted and external customers is presented in Figure 10. In Tables IX and X, the results for all spare parts are presented.

TABLE IX
RESULTS AVAILABILITY OF INCREASING CIRCULATION STOCK

No.	Additional circulation stock	Δ FR contracted	Δ AR external
1	0	-	-
2	4	23.9	46.1
3	3	7.0	1.4
4	1	7.5	28.2
5	0	-	-
6	5	21.5	63.4
7	3	21.7	53.7
8	0	-	-
9	2	8.6	17.6
10	8	3.0	75.5

TABLE X
FEASIBILITY OF INCREASING CIRCULATION STOCK

No.	Additional circulation stock	Δ TI loan	Δ Total back-order cost	Δ HC	Δ PC	Δ F
1	0	€ -	€ -	€ -	€ -	€ -
2	4	€ 58.000	- € 531.000	€ 238.000	€ 280.000	€ 71.500
3	3	€ -	- € 33.000	€ 14.500	€ 17.000	€ 1.500
4	1	€ 120.500	- € 147.000	€ 90.500	€ 106.500	€ 70.500
5	0	€ -	€ -	€ -	€ -	€ -
6	5	€ 802.500	- € 3.420.500	€ 1.923.500	€ 2.263.000	€ 36.500
7	3	€ 128.000	- € 437.000	€ 200.000	€ 235.500	€ 129.000
8	0	€ -	€ -	€ -	€ -	€ -
9	2	€ 8.000	- € 20.000	€ 10.000	€ 12.000	€ 6.000
10	8	€ 10.500	- € 81.000	€ 40.500	€ 48.000	€ 3.000

VII. DISCUSSION

Due to unreliable inventory data, it was necessary to perform a model configuration step in order determine the circulation stock levels that resulted in realistic service levels and number of back-orders. However, in collaboration with experts of KLM it was found that this was the best option to be able to evaluate the strategic improvement options. Due to the lack of inventory data, no concrete recommendation regarding increasing circulation stock level could be provided. However, based on back-order data and simulation results, the recommendation to reconsider the current inventory management policy could be made. Data unavailability also caused issues when defining the problem, as the number of back-orders due to the providence of the loan desk is currently not known.

Additionally, for determining the configuration of the availability decision, 10 case spare parts were used. It is recommended to add more case spare parts to further configurate the maximum risk of a shortage cut-off values.

Demand is modelled as a distribution with an inter arrival rate. Therefore, demand characteristics such as fluctuations were not present. In order to deal with this, the cost benefit ratio was multiplied with a penalty factor for each demand class. It is recommended to implement the generic decision rule for the 10 case spare parts and to validate the results before implementing on a larger scale.

The turn around time of spare parts is modelled by fitting distributions and setting server capacities to infinity. Therefore, the effect of demand fluctuations on the turn around times are not present in the model.

In the model, it is assumed that in case of contracted customer spare part unavailability a back-order is placed after 5 days. In reality, the priority differs per request, which results in different request holding times. However, when comparing the back-order results from the model, no large differences were detected when comparing to historical data.

This research presented an innovative way of using the cost-benefit ratio in order to gain control over the flow and impact of an additional loan service on spare part availability regarding contracted customers. In this

research, the CBR was used as a performance constraint instead of a performance measure, which has never been done in previous research. By constraining the ratio between the benefits from this service and the costs caused by the service, the spare part flow initiated at the loan desk becomes manageable and makes the balance within such system consolable.
Furthermore, this research provided a solution for the availability decision regarding external customers. The risk-based availability has high potential, and should be further elaborated. Soon KLM will arrive at a digital era were many data will be collected and stored. The risk of a shortage can be estimated with high precision with the availability of additional data. This research proved the usability of a risk-based availability decision and showed its potential.

VIII. CONCLUSIONS

The objective of this research was to evaluate strategic options to increase the contribution of KLM's loan desk to the performance of KLM Component Services. When analysing the current state, it was found that the procedures regarding pricing and availability decision at the loan desk are rather vague. In addition, it was found that the availability regarding external customers is low due to stock issues. Gaining control over the availability decision was considered as top priority. Furthermore, the strategic option to increase the total circulation stock was considered as an important option. It was found that by introducing a generic risk-based availability decision, the availability regarding external customers increases with 24%, which results in an estimate increase in revenue of €375.000 per year. The presented method enables to manage the level of risk that can be taken at the loan desk. In addition, it was found that for 7 of the 10 case spare part, increasing the total circulation stock is feasible within 5 years. Therefore, the current inventory management policy should be reconsidered.

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