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Improving inventory management and material replenishment at KLM Engine Services

In cooperation with KLM Engineering & Maintenance

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Improving inventory management and material replenishment at KLM Engine Services

A Thesis that finalizes a MSc program in Engineering and Policy Analysis

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Abstract

The financial crisis that has started in 2008 has forced private organizations to increase their focus on improving efficiencies in order to reduce costs. One company that has been seriously effected by the crisis is KLM (Royal Dutch Airlines). Many projects have been started to save costs in the different divisions of KLM. This research focuses on cost reduction in the logistical system of the Engine Shop of the KLM. This logistical system is complex of nature and involves very high material costs. The research emphasises on inventory cost reductions. A comprehensive system analysis has been performed that gives insights in the logistical processes of the Engine shop. A data analysis has been executed to evaluate the logistical performance of the engine shop and helped to derive to the root of problems. This report suggests five alternatives that can jointly result in a significant reduction in capital employed in the engine shop's inventories. The alternatives give suggestions for improvements that require almost no investments nor structural changes, which facilitates acceptation and eases implementation. The research can give insights, also for third parties, in how cost savings can be obtained in the field of inventory control in a high tech MRO (Maintenance, Repair and Overhaul) shop.

Keywords: Inventory control, material replenishment, aviation spare parts, MRO

List of Abbreviations

KLM	Koninklijke Luchtvaart Maatschappij (Royal Dutch Airlines)
EM	Engineering and Maintenance (A division of KLM)
ES	Engine shop
JIT	Just in Time (Logistical concept)
BPR	Business Process Reengineering
SC	Supply Chain
SCM	Supply Chain Management
CPFR	Collaborative Planning Forecasting and Replenishment
VMI	Vendor Managed Inventory
MRO	Maintenance, Repair and Overhaul
MM	Material Management
CC	Completeness Check
PO	Purchase Order
RDD	Requested Delivery Date
PV	Picked up at Vendor
ERP	Enterprise Resource Planning

Management summary

This report describes a research that has been executed at the Engine Shop of KLM Engineering and Maintenance. The end goal of the research was to reduce costs in the field of inventory control and material replenishment at the engine shop. In order to achieve this goal, first an understanding of the current, complex, situation was necessary. The processes involving material management have been comprehensively analyzed and mapped out. Different data analyses have been performed to measure the performance of the defined processes. From these analyses indications were found concerning an underperformance at the engine shop on the field of material management. The data analyses also facilitated the search to the root of problem situations. During the different analyses there was a high actor involvement, which concerns KLM personnel from different fields and levels. The high actor involvement during the research phase facilitates a higher change of acceptation during implementation.

This report suggests 5 alternatives for the engine shop to improve its inventory control and material replenishment, which can lead to significant cost reductions in inventories (see chapter 5). Besides a reduction in inventory could certain alternatives lead to a decrease in workload of personnel. In addition are certain alternatives expected to result in a more ordered way of working which gives management the possibilities to have a better estimation of workload and therewith better opportunities for capacity planning. Below, a small business case is introduced, which discusses the implementation of the these suggestions. This includes a discussion on the gains for the KLM, the risks that might come along, the requirements in terms of investment and resources and the organizational change that might be required together with a discussion on actor acceptation.

Business case

This business case is not an extensive description of the required steps for a successful implementation, but it gives an elaboration on the costs savings that can be expected, on the risks that are involved and a discussion on the different requirements that are necessary together with the acceptation of related actors.

Expected Cost Reduction
A first note should be given: not all the alternatives are easily quantifiable in terms of expected cost savings, more details are shown in chapter 5.

Cost savings can be expected in the following fields

Field	Quantified saving	Related alternative
Aprep inventory	approximately 10 million euro's	1. JIT delivery to aprep
Warehouse inventory	Estimated range 5 – 15 million euro's	1. Correct project planning in SAP 2. Redefine contractual lead times with vendors 3. Redefine consumption posting in SAP 4. JIT delivery for 'direct procurements'
Workload saved (man hours)	Not quantifiable with current info at hand	1. Application of direct procurement 2. JIT delivery to Aprep

The figure bellow shows that in the previous financial year the warehouse stock had a size around 70 million euro's in terms of employed capital. The second largest inventory is located at aprep with an capital employed of 12 million euro in new parts, on average. The norm stock at the engine shop is 23 million euro. The rest of the employed capital in the warehouse can mostly be considered as surplus. Many of those surplus parts can not be used by the KLM anymore. This research gives suggestions to improve the inventory control and replenishment that can reduce the norm stock by millions.

All new parts that are present in the aprep department can be seen as excessive or waste if they are not part of any process. Measurements have shown that the processes can be completed in a view days before the assembly process starts. The suggestion is to not have new parts present at aprep prior to the start of these processes, which leads to the estimated cost saving of 10 million euro's.

The current stock can be considered as excessive. If stock is not coherent to the consumption rate, parts are in stock for a too long period. This also increases the risk that a part can not be used anymore due to the continuous increasing technological demands in the aviation industry (Service Bulletins). In other words, reducing the inventory to a level that is coherent to the consumption level will facilitate avoiding surplus situations in the future. This research does not give suggestions for dealing with the current surplus stock.

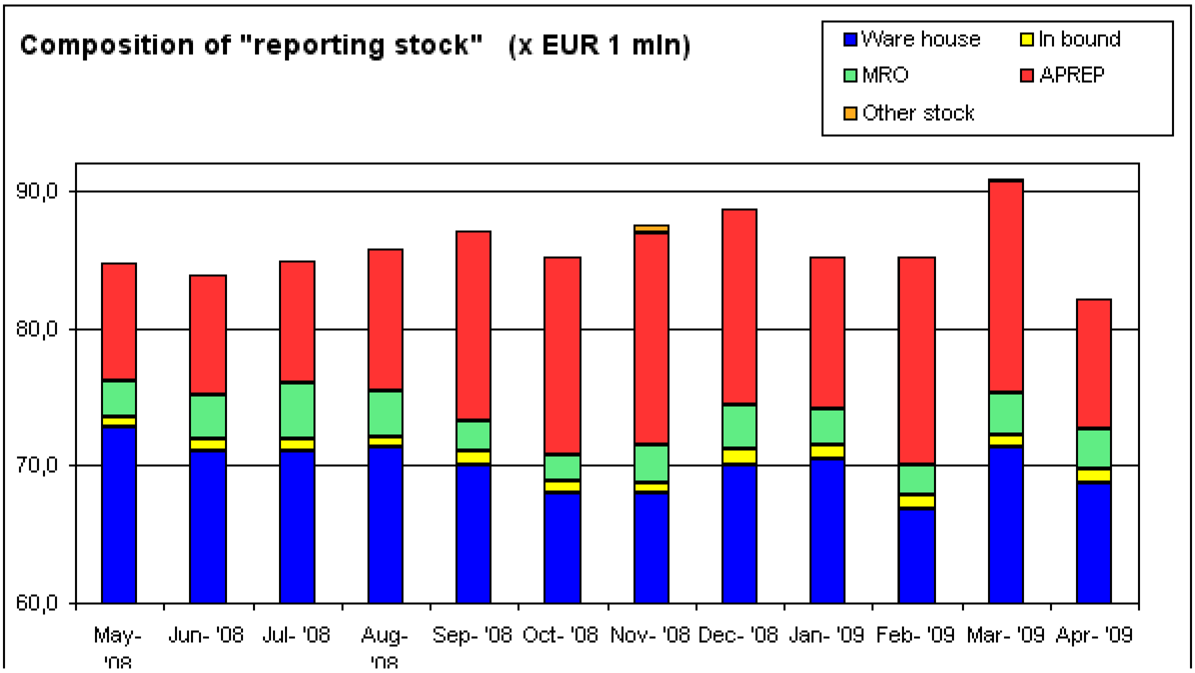

Fig. I *Annual overview of the engine shop's inventories in terms of employed capital*

Another notification should be made which will increase the awareness on the significance of the outcomes of this research. The engine shop is often used for pilots that will, when proven to be successful, also be implemented in the other units of KLM EM. The material management is currently accomplished with the support of SAP in the engine shop. The management of Engineering and Maintenance have indicated that this system (SAP) is also going to be applied in the other units of KLM. The suggestions for improvements in the engine shop should also be taken into account when implementing SAP at the other units in order to avoid excessive stock situations in those units in the future.

Risks related to the alternatives
When the module, ‘material management’ from the SAP system (MySAP), was activated within the Engine Shop, the management has approved certain forecasting profiles that have a specific risk factor related to it. SAP uses intelligent models that calculate stock levels based on historical demands and their variations. None of the suggested alternatives lead to more risk then was accepted by the management prior to this research. When stock levels are reduced, logically some additional risk can be expected in comparison with the current situation. However the alternatives suggest a reduction in stock that can be considered as excessive and do not increase the current risk profiles.

Requirements
All the suggested alternatives do not require any capital investment. The relatively very little costs that can be expected, are the costs related to man hours for the implementation. In the implementation the discussion, understanding and cooperation is needed from different KLM personnel such as MRO mangers, SAP specialists, material planners and inventory and aprep personnel.

Some alternatives might require a change in SAP. For these changes, SAP specialists are required. Other alternatives require small organizational changes in which the acceptation of personnel is necessary. In order to reach acceptation, involvement is considered as an important process. This involvement comes with a costs, but the costs are of no significance compared to the expected savings.

Implementation
The alternatives, supportive by the different data analyses, indicate there is high potential for high cost savings. It is in favour of the KLM to get the alternatives implemented as soon as possible. The carrying costs that are involved with the expected inventory reduction are calculated to be around 200.000 euro each month (18% annual carrying costs on the total capital employed).

Some of the alternatives require further investigation. The investigation includes data analysis on vendor performance, a further analysis on the performance of the aprep and warehouse departments and an analysis on the possibilities of adaptations in SAP. In addition a supervision for implementation is necessary. Managers and personnel need to be informed about the alternatives and need to acknowledge the advantages of the alternatives in order to make the implementation a success.

Overall conclusion of the business case

The implementation of the suggested alternatives are expected to result in a millions euro cost saving at the KLM Engine Shop. The alternatives require hardly any investment and the risks for stock out have not been set higher then was accepted by management beforehand. However, additional analysis and supervision is necessary to make the implementation a success.

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Gerard Nijhoving

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1 Introduction

The increasing high competition in this world today leads to many reforms in especially private organizations. In order to survive, provided services are being improved where at the same time there is a continuous search for cost reduction and efficiency growth. This competition between firms has recently lead to a focus on the supply chain a lot (D.J. van der Zee, 2005). Due to liberalization and more transparent markets and the introduction of advanced information technology, collaboration among industrial partners is becoming more convenient. This collaboration facilitates more agile logistics for all the firms in the supply chain. It removes a big deal of the uncertainty costs which are mostly translated into back up inventory stocks.

One company that has been focusing on improving its logistical processes is the Engine Shop of KLM Maintenance and Engineering. KLM (Royal Netherlands Airways) is the largest airline in the Netherlands. The KLM has its own maintenance department located at Amsterdam airport for both airplanes as their engines. Below a small introduction into KLM in general, KLM Engineering and Maintenance and the engine shop is given

Royal Dutch airlines
KLM operates worldwide scheduled passenger and cargo services to more than 90 destinations. KLM is the oldest airline in the world still operating under its original name, originating from 7 October 1919. Officially the KLM is not an independent entity anymore as of 2008 due to the merge with Air France in 2003. Customers of KLM may not have noticed the merge intensively, as the services, logo and other factors that make KLM unique, remained. However internally, organizational and operational changes have found place due to the merge. The merging of both airlines gives them a better market position then working independently. Air France – KLM as a merge is the largest airline company in the world in terms of total operating revenues and passenger-kilometres.

Fig. 1 *Airplane tails with logo of the merging airlines Air France - KLM*

KLM Engineering and Maintenance (E&M)
With approximately 5,000 employees, KLM Engineering & Maintenance is the third Business of KLM Royal Dutch Airlines, next to Passenger Transport and Cargo, and one of the largest MRO companies affiliated to an airliner in the world. At Amsterdam Airport Schiphol KLM E&M use 10 wide body and 11 narrow body positions and various modern warehouses, shops and test facilities.
KLM Engineering & Maintenance offers a broad portfolio of tailored products and services such as various Total Aircraft Care and supporting services like engineering, line maintenance, technical training and other tailor-made services. Apart from its location at Schiphol, E&M has operations at 50 airports worldwide. KLM E&M has permanent maintenance contracts with over 20 airlines, the largest of which is KLM.

For a long time KLM E&M has worked on the maintenance of one of General Electric's most successful engines, the CF6 series. Through its collaboration with GE Engine Services E&M is participating in the Six Sigma program, in which GE already has more than five years experience.
[source: http://www.klm.com/engineeringmaintenance/site/en/]

Engine Services (ES)
In 1925 KLM had founded an engine shop that took care of KLM engine repair. Over the years the engine shop has grown into a commercial subdivision of KLM Engineering and maintenance with customers from all around the globe. The engine shop is located at a strategic location at the airport of Amsterdam offering an 'engine of airplane' time that is as short as possible. Currently the engine shop is one of the worlds leading repair station for the General Electric engine CF6. The three main types that are currently overhauled in the Engine shop are presented in the figure below.
[source: http://www.geae.com/engines/commercial/]

CF6-50

CFM 56

CF6-80C2

The Maintenance, Repair and Overhaul (MRO) of the engines in the KLM Engine shop are strongly schedule driven. The entire process is divided in 4 phases that each have their norm times that need to guarantee a certain customer service level. The management of the engine shops is stimulating improvements concerning cost reduction and throughput times. This research focuses on the logistical system of engine parts, which is one of the most important systems in the engine shop. An engine is build up of around 10.000 parts and during the MRO the engine is almost entirely disassembled. This results in complex logistics that are the main contributors for the defined norm times. In addition, inventory costs form a significant part of the total costs of Engine services. The reduction of inventory costs is the main focus of this research, which will be discussed in the next chapter.

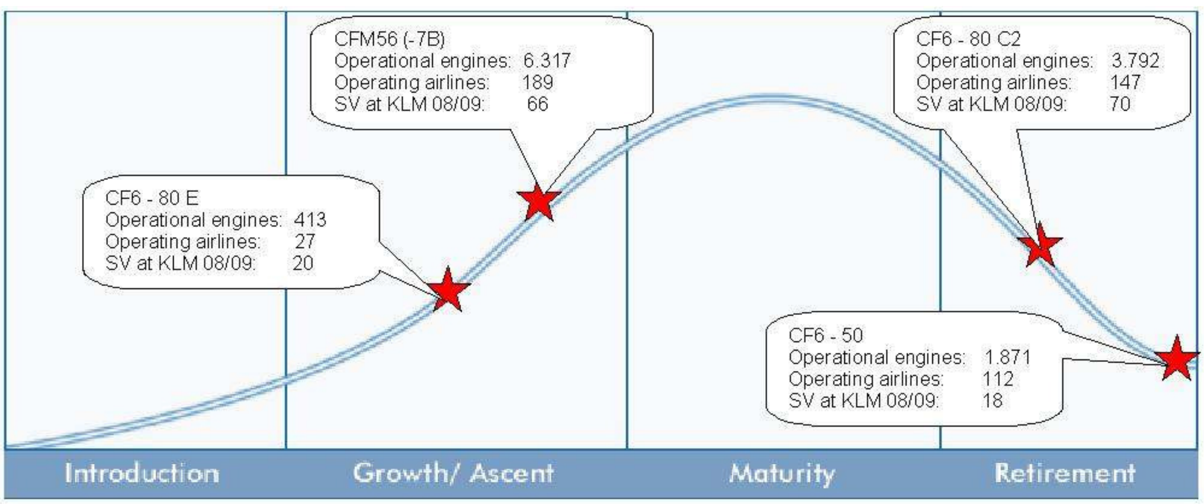


Fig. 2 *The main overhauled Engine types located on the product life cycle*

The engine shop, even though it is a subdivision of KLM Engineering and Maintenance, can be considered as a commercial company on its own, trying to maximize profits. Of all the engines that are overhauled annually in the engine shop, about 40 percent is belonging to Air France KLM. This means that for 60 percent of the work the engine shop is depending on projects from other airlines for which the engine shop has to compete with other shops around the globe. The main factors that determines market position is overhaul lead time, quality, price and shop location. In addition there is quite a high customer loyalty in this field, as the overhaul of engines is a complex process in which there is continuous communication between the shop, vendors and clients about, for example, the work scope and problems that can arise in the process.

Currently the KLM Engine Shop overhauls four types of aircraft engines. The four engines are shown on the product life cycle curve together with some related figures in Fig. 2. In the real world every engine type has its own and unique lyfe cycle, which will probably have different shape then the standard curve in this figure. Not enough information was present to give a more realistic picture of the life cycle, however this figure does give a good indication of the market situation.
The biggest engines for the engine shops in terms annual projects, are the 80C2 and the CFM56 engine with 70 and 66 shop visits (SV) in 2008/09, respectively. It is important to see their potential market together with the location on the life cycle in order to make policies or predictions on future demands. This research does not focus on any specific engine. The suggested alternatives apply for any material of any engine. These alternatives are elaborated in chapter 5.

The application of ICT systems in KLM ES

Within KLM different ICT systems are used in order to assure effective communication and to get a control on complex processes, like the logistical processes at the Engine shop. One system that is used in different parts of the organization is SAP. SAP is a software produced by a German company. The abbreviation stands for *Systeme, Anwendungen und Produkte,* in the German language. SAP delivers different kind of packages that are focussing on a specific business. For the bigger clients, like KLM, these general packages are customized to meet the conditions of the organization. Within the industry specific package, the client can choose specific modules that it wants to use. Within the Engine Shop a customized package is used specially for the MRO business in the Aerospace and Defence industry. Within this research the focus lies on the modules *Material Management* and *Business Warehouse* which are used at the engine shop within the ERP (Enterprise Resource Planning) software called mySAP.

The research topic

As was mentioned, this research is conducted in the engine shop of KLM, where the management has indicated to be willing to reduce lead times and decrease capital employed in their inventory. This research should facilitated the management in making a plan that can accomplish a part of their goals. Making a structured and well analyzed plan is important for the success of the supply chain. A poor plan can have a major impact on the business processes leading to e.g. excessive inventories, severe backlogs or the bullwhip effect. Therefore the research started with a comprehensive analysis of the problems at the engine shop to make a clear problem formulation and pose clear research questions for whom the answers can help achieving the goals of the engine shop. The main focus herein is related to inventory control and material replenishment. For the engine shop the logistical processes are very complex of nature. The engine overhaul concerns many different, expensive parts for whom the repair or replenishment has strong time pressure. In addition are there many actors involved for which a high cooperation is required to make the engine overhaul a success. Giving more insights in the complex processes is very important not only for the understanding but it is the fundament for improvement and innovation.

Besides being of an advisory purpose for the management of the engine shop, this report gives insights in how a very complex logistical system can be analyzed and how alternatives can be generated and evaluated. There are several factors that make this system complex, one is the high data intensity that is generated during engine disassembly, second is the strong schedule driven project environment, third is the high variety of logistical streams that materials can follow and fourth is the necessity of cooperation between actors and it related communication. In such a complex system even the problem formulation itself is time taking and difficult.

In this thesis report, first a research framework is presented (chapter 2). This research framework first explains the general goals of the engine shop and its related problems. The chapter gives a boundary to the research and the system within the engine shop that will be analyzed. Research questions are stated that should function as a guidance in the research. This chapter also explains the methodology that has been applied in this research. The third chapter explains the processes within the system and shows a conceptualisation of it. The fourth chapter discusses the performances of the processes described in chapter three, by means of data analysis. The fifth explains the different alternatives that have been derived from the system and data analysis, and therewith it gives suggestions for improvements in the engine shop's inventory control. Chapter six gives a summarizing conclusion of the research, and it discusses if the posed research questions have been answered. Chapter seven concerns a small reflection on the research process and on the personal experience that are gained.

2 Research framework

This chapter presents the framework for this research. The start and formulation of this research is the result of a problem perception by the management of the KLM engine shop. First this problem perception will be formulated more clearly and a set of research questions that should guide this project is presented. A first description of the system and its boundaries are given in the 3rd section. The methodology that is applied for this research is presented and motivated.

When formulating a problem it is mostly described from the point of view of an actor, referred to as the problem owner. In some cases other actors will perceive the problem to be the same and of equal importance, but in other cases actors there can be a conflict concerning the problem formulation. This is important to keep in mind. For the engine shop the goals specified at a higher abstraction level are accepted by all actors, however at a lower abstraction level, actors can have conflicting goals, which will be elaborated in a multi actor analysis later in this research. It is important to keep in mind the overall goals of the problem owner when formulating and tackling its problem. In some cases solving a problem can contribute to accomplish a certain goal but can conflict with another goal. When performing research it is important to have a concrete focus and therefore define boundaries. But it can be good to keep in mind the overall picture. The research focus is visualized in the abstract goal hierarchy below.

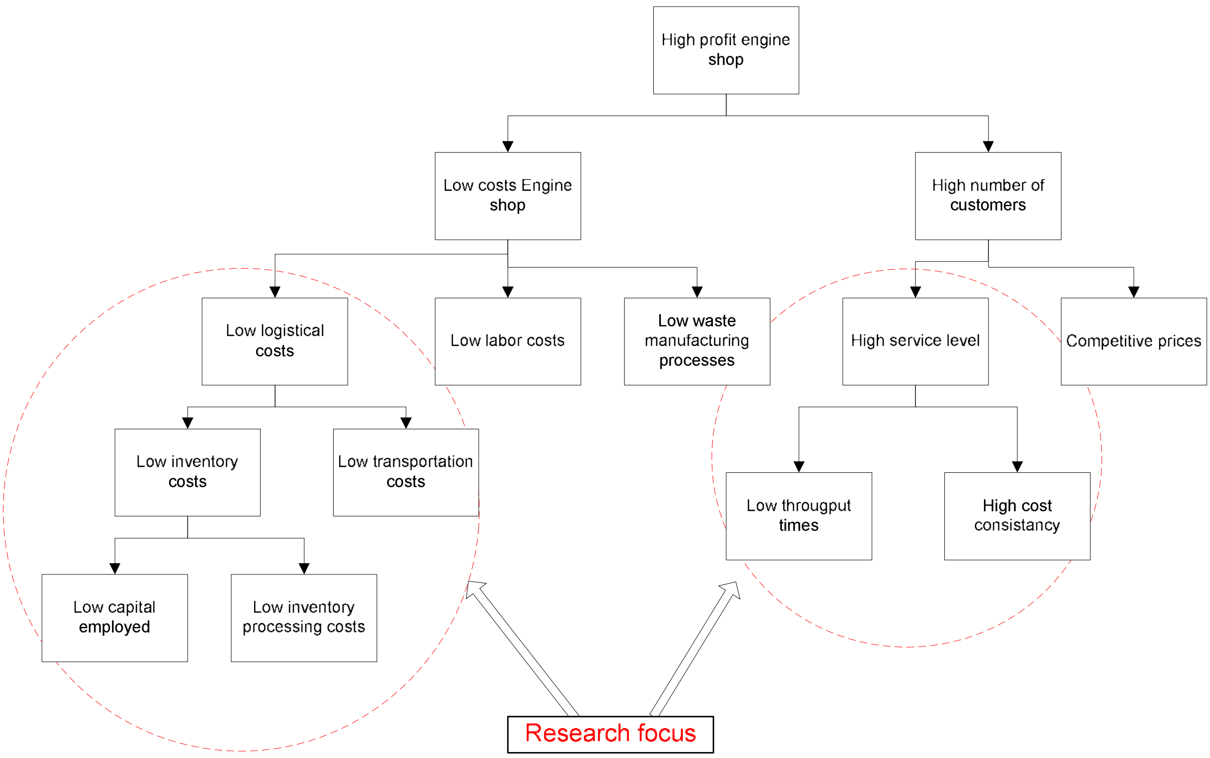


Fig. 3 *Goal hierarchy with research focus*

The overall goal of the engine shop is profit. All other goals should be facilitating this main goal, which is the basis for any private company, as Goldratt emphasizes in his book *The Goal* (2007). In the next sections will be clear that this research focuses on reducing capital employed under the condition that inventory processing costs are constant and under the constraint that throughput times are not increased. So on a higher abstraction level can be said that the research focus is on lowering logistical costs without reducing service level, that is what Fig. 3 indicates. More details follow in the next sections.

2.1 problem formulation

"Successful problem solving requires finding the right solution to the right problem. We fail more often because we solve the wrong problem than because we get the wrong solution to the right problem."
Russell L. Ackoff, 1974

The quote by R.L. Ackoff indicates the necessity of the right problem formulation. A clear and founded problem formulation is a vital start of any project. However in process improvement projects like the one at hand, a sharp description of the actual problem situation is difficult to deliver. The controllers of the system (e.g. managers and quality engineers), notice themselves to be in an inefficient situation but do not know the source of it. The start of these projects is not based on a clearly visual and solid problem but on suspicion of system controllers concerning process performance. For this project, the management of the KLM Engine Shop as defined the following problem situation.

The Maintenance, Repair and Overhaul (MRO) process brings along a significant and complex material flow. In the engine MRO business the logistic supply chain becomes more and more important. In order to reduce capital employed there is a shift towards Just In Time (JIT) and consignment stock solutions. With these mentioned concepts the supply chain of Engine Services will change together with the control of this supply chain. For analyzing the plausibility of this new logistical approaches, KLM defined the following research objectives:

- Describe the current situation of demanding material throughout the Engine Shop.
- Describe how material request are processed through the SAP system and how the physical material flow is organized throughout the supply chain.
- Develop alternatives and new ways of requesting materials taking into account the supply chain as a whole.
- Make an advice about the stock levels and the effect of different control concepts on the stock levels of Engine Services.
- Develop the concept of agile logistics in the domain of material demand.

Problem formulation by KLM

From the situation described above can be concluded that the management at the engine shop sees opportunities for working more JIT in order to reduce capital employed. However this statement is more based on expectations resulting from experience than on quantified evidence. Because of this lacking evidence the search for problems and bottlenecks has been part of the research itself.

The fact that the management did not elaborate their wishes with quantified evidence is due to the exceptional and complex situation in which this project is located. The complexity in this case is a result of a very data rich environment at the parts level. At the engine disassembly an enormous material flow of individual parts with individual attributes, such as status and route, is created. The logistical process can differ significantly per part. On a higher abstraction level, there is a strict schedule driven demand for the engine MRO. Finding the right link between this data rich environment at the low level and the schedule driven demand from the high level is a difficult task. In order to complete this task, KLM uses advanced ICT systems for the control of their logistical processes. These algorithms used in the ICT system (SAP) are complex of nature and often affects factors related to the responsibility and interests of multiple actors.

Considering the problem situation described above, the following problem has been formulated:

Currently the replenishment processes and inventory management are inefficient. There is a need for more agile logistics and lower stock levels, however the alternatives should not lead to trade off's such as a reduce in customer service (e.g. lost sales due to out of stock). In addition is the cooperation and trust of other actors are necessary for success which means that their evaluation of the alternatives also count.

2.2 research questions

A thesis in general, is helpfully framed as a question that defines the issue under consideration, instead of only stating a topic (Neufville, 1998). A question gives more direction for research as it requires an answer. However, it should be emphasized that the question can be refuted because else it would be a truism of no real interest. In addition is it important to make sure the question is interesting for a specific audience. The answering of the thesis questions posted in this research are especially interesting for the management of the KLM engine shop and related personnel. For people from outside of this organization the research gives insights in how alternatives for inventory management and material replenishment can be found in a complex logistical system. The readers interest should basically be activated when reading the problem statement that is formulated below.

In order to finalize this research an answer must be given to the following problem statement.

"Which alternatives for replenishment and material management algorithms can jointly lead to the highest inventory cost saving for the KLM engine shop taking the multi actor setting into account?"

This research questions basically seeks to find alternatives that can jointly lead to the highest inventory cost saving, which is implementable (which e.g. requires the acceptance of actors). Oden et al. (1975) separate inventory costs in three categories, namely:

- *Holding or carrying costs*; costs relate to physically holding items in storage. They include interest, insurance, taxes, depreciation, obsolescence, deterioration, spoilage, pilferage, breakage and warehouse costs (heat, light, rent and security). The 'holding costs factor' within KLM is estimated to be 18% of the inventory capital employed.
- *Ordering costs*; costs associated with ordering and receiving materials for inventory. This is usually a fixed costs which includes creating orders, inspecting incoming goods and the moving of goods. The KLM has set a fixed ordering cost of 50 euro per order.
- *Shortage costs*; cost that result from stock out situations, examples are: loss of sale, loss of customer goodwill, lateness charges etc. Shortage costs for the KLM Engine shops are extreme.

In this research, the goal is to reduce the holding costs by reducing the amount of capital employed in the inventory. This means that the focus is not on reducing the holding costs factor (e.g. by assuring less breakage ore arranging better loans). In addition the condition is set that order costs are constant and that shortage costs are a research constraint. In other words, The definition of inventory costs from Oden et al. (1975) is used for this research, but with a focus on reduction of employed capital, which will be explicitly mentioned throughout the research. More elaboration on this issue can be found in the next paragraph (discussion about performance indicators).

Supportive to the main research question, four sub questions are formulated. These four sub questions should guide the research in a chronological way, which is elaborated in the section concerning 'methodology'. When all the sub questions have been answered, enough information should be present to answer the main research question

Research sub questions:

1. *What are the logistical processes at the KLM Engine shop*?
At first a more comprehensive analysis of the logistical processes is necessary to understand the system in which the formulated problem is located. When understanding the processes the source of problems can be traced.

2. *What is the performance of these processes*?
It is necessary to know the performance of the defined processes in order to know if problem perceptions are true and if they are significant. When this question is answered, significant knowledge of the system and its problems/bottlenecks are known which can be used to generate alternatives for improvements.

3. *Which alternatives can lead to costs savings in the logistical system*?
This questions strives to generate alternatives that can lead to cost savings within the logistical system. The answers of the previous questions need to be present prior to the start of answering this question.

4. *Which (combination of) alternative(s) lead(s) to the highest costs saving for KLM including all consequences*?
This question requires a more comprehensive analysis of the consequences of the alternatives. Cost savings can be the result of (unfavourable) trade-offs in other parts of the system, this needs to be described. When the overall behaviour of the alternatives are known, they can be evaluated and weighted. The interrelations between the alternatives also need to be worked out. Some alternatives can support each other, leading to even more benefits. Other alternatives might not be able to be implemented together.

2.3 System diagram and boundaries

In order to give an abstract overview of the logistical system at the engine shop that is going to be studied, a system diagram is presented (Fig. 4). Within the system boundaries the different departments are present which are considered as sub systems, as every department has a set of processes in which it is active or for which it is responsible. The classification of the different processes into subsystems in accordance with the departments (actors) was therefore practical. The inter-relationships between these departments/subsystems are indicated with an arrow. A single arrow means that information and physical flows are dominated in one direction. A double arrow indicates a more mutual relationship. The arrows do not indicate any organisational hierarchy. Later in this report a more comprehensive description of the actors and their relations is given (section 3.1). In addition is a description of their internal process variables, with a more detailed focus on the sub system material management, given in section 3.2 and 3.3. Apart from these internal variables and factors that will be described in more detail, it is also important to consider which factors are external, which will help to formulated a boundary of the system and therewith make the research focus more clear. The system diagram is proven to be a good tool to visualize the demarcation of the problem situation.

The objective of such a system diagram is to (Enserink, 2008):

- define the system and borders and to identify what falls within the system and what outside it
- define the structure and relations within the system
- define the output of the system as ‘outcomes of interest’ (criteria)
- Definition of relevant contextual factors (external factors)

The most relevant external factors derive mainly from two actors, namely vendors and customers. These two actors in turn, are affected by many factors that are truly external, such as raw material prices for vendors or an economic crisis for the customers (airlines). These truly external factors are also affecting this system, but in a filtered way through these actors. The external factors described in the diagram can have some influence by forces from within the system, that is why they are considered not to be truly external. If this influence from inside of the system is significant, a double arrow is shown in Fig. 4. One example is the lead time from vendors. KLM can not control the variables, they are in the end the decision from vendors. However KLM can in some cases influence this factor, e.g. by paying more so the vendor can create a finished goods inventory. However, the KLM does have some factors that are under its direct control, that can influence system and related criteria for obtaining defined goals.

In this system the Management Team (MT) of engine services can be seen as the problem owner and has a few control variables to influence the system, of which the main ones are stock levels determination, choosing material sources for new parts or repairs and it can use different information communication technologies to improve its system. By adjusting its control variables the management can influence the criteria that it considers to be important performance indicators. However these relationships are in most cases far from linear and unknown. This research should facilitate in making this grey field more transparent.

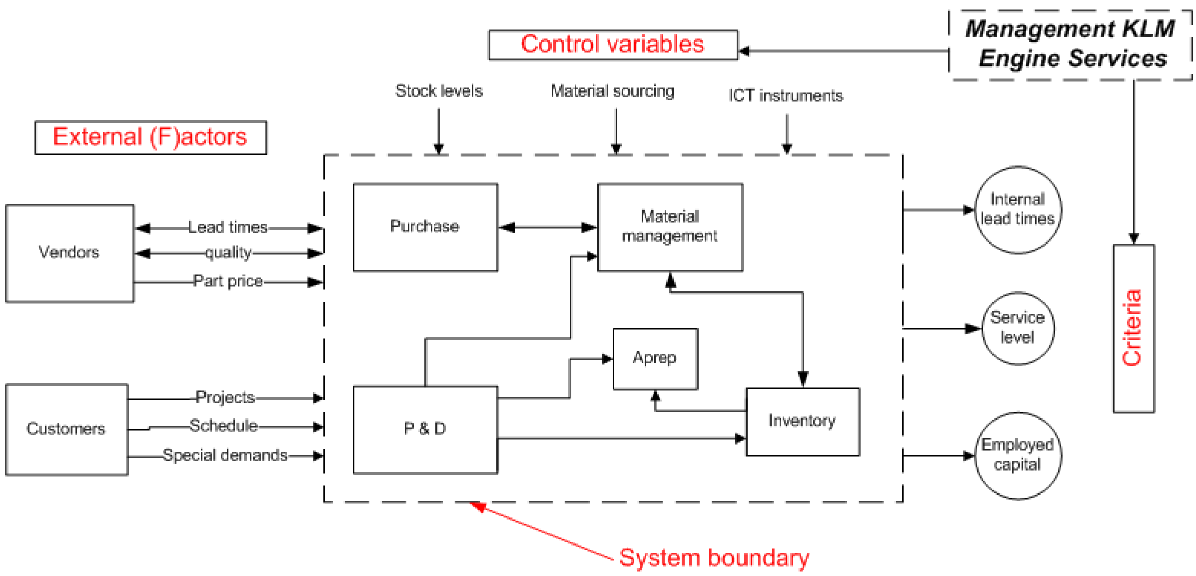


Fig. 4 *System diagram*

The system diagram shows a system boundary (dotted line). All variables and factors that have direct influence on the inventory levels can be seen as inside of the system. Variables that are in control of actors that are not part of KLM Engine services are considered as external. When analyzing and modelling the system it is important to keep a focus on the main objective, as is defined in the beginning of the research. As the focus should lie on inventory costs savings, throughput times and resource utilization is considered as not interesting if they have no significant, direct or indirect, influence on inventory cost savings. Resource utilization is often considered as a key performance indicator in many modelling and simulation studies, but is less relevant in this research.

It is important that there is a coherence between the goals of the management team of engine services, the goals of this research, the research questions that have been posted and the system boundaries that are set. When looking at the problem formulation and the research questions, they are seeking for improvements that can help achieving the goals in Fig. 3. In order to have a measurement for controlling if the goals have been achieved and if questions have been answered, a set of key performance indicators can be formulated, which are quantifiable variables. As can be concluded from the previous sections in this chapter, the overall focus of this research is on cost reduction. The key performance indicators should therefore be cost related. The major cost factors for the engine shop are as followed:

1. *Materials Costs*; The material costs are external, as the demand is determined by the customers and the prices by the market (vendors). Therefore it is not a key performance indicator in this research.
2. *Cost related to TAT (turn around time);* Each day an engine is 'off wing' is very costly. For the Engine shop a higher TAT is not directly more costly, but customers will pay less. Still, TAT is seen as costs as the costs of 'off wing' time are directly translated to the engine shop. KLM is executing several 'Lean Six Sigma' projects to lower the TAT in order to reduce costs. TAT is not in the scope of this research and in addition others are already researching the possibilities for improvement. Therefore it is not a key performance indicator in this research.
3. *Inventory costs*; The annual inventory costs are 18% of the Capital Employed in the Stock. These include inventory holding costs, loan interests, insurance etc. As was mentioned, material costs are very high. This means that stocks also involve high costs. Reducing this stock is the main focus of this research.
4. *Costs related to stock outs*; A stock out situation can lead to the increase of TAT. Often, alternatives related to inventory management are effecting the change of stock out. This relation is an important limitation for this research and therefore this factor is considered as a key performance indicator. This factor can be measured in two ways. By the intensity of the delay duration, which is the number of days that the project is delayed. An other measurement is the intensity of occurrence, which basically is the rate of delay occurrence due to stock out.

Considering the described focus in this research and the explanation of the major cost factors at the engine shop, a few measurements can be derived that could be used to evaluate alternatives. These measurements include the capital employed in the inventory (in euro's), the number of delays that are cased by stock out situations and thirdly the measurement of the intensity of a delay due to stock out situations (in days of project delay).

2.4 methodology

This section describes the methodology that is applied in this research. A methodology should always be selected based on the problem situation and adapted towards it. This research is performed with a system thinking approach. Shannon (1975) gave the following definition of a system:

“ *A group or set of objects united by some form or regular interaction or interdependence to perform a specified function”*

This definition of a system will be used throughout the research. The system can be considered as the perception of the real world by the analyst within the boundaries defined by this analyst. System thinking is applied in a wide range of research fields, varying from social science and economics to hard engineering areas (P. Checkland, 2000). In this research the system is part of a physical organization (KLM). As was mentioned in the previous paragraphs, the focus of this research is to improve certain parts of the organization. In other words, the defined system needs to be engineered in order to maximize the specified goals of the organization. P. Checkland (2000) wrote about Systems Engineering:

“In systems engineering (and also similar approaches based on the same fundamental ideas, such as RAND Corporation systems analysis and classic OR) the word `system' is used simply as a label for something taken to exist in the world outside ourselves. The taken-as-given assumption is that the world can be taken to be a set of interacting systems, some of which do not work very well and can be engineered to work better”

This philosophy of ‘Engineering’ the organization’s system(s) is applied in this research. In order to successfully accomplish this system engineering, a methodology is applied that corresponds with the literature but is adapted to the specific situation, which is described below.

Sage and Armstrong state that ‘regardless of the way in which the systems engineering life-cycle process is characterized, and regardless of the type of product or system or service that is designed, all characterization of the phases of systems engineering life cycles will necessarily involve’ a *formulation of the problem*, an *analysis of the alternatives* and an *interpretation and selection* of the analyzed alternatives.

The problem formulation phase includes a *problem definition* step, a *value system design* which involves selection of the set of objectives or goals that guides the search for alternatives and a system synthesis which involves searching for, or hypothesizing, a set of alternative courses of action or options.

The Analysis of alternatives is completed by 1) a *system analysis and modeling* in which the specific impacts or consequences of the alternatives that were specified as relevant to the issue are determined, and 2) a *refinement of the alternatives* in which the system variables are adjusted in order to best meet system objectives (J. E. Armstrong Jr., 2000).

The interpretation and selection phase includes the decision making steps which involves the evaluation of impacts or consequences of the alternatives and making a selection based on the formulated objectives. In addition it includes the planning for action which involves the communication of results of effort to this point and the generation of a plan for the next phase which would be deployment or implementation of the selected alternative(s). This phase is not discussed in detail because it will also not be part of the research at the KLM engine shop (J. E. Armstrong Jr., 2000).

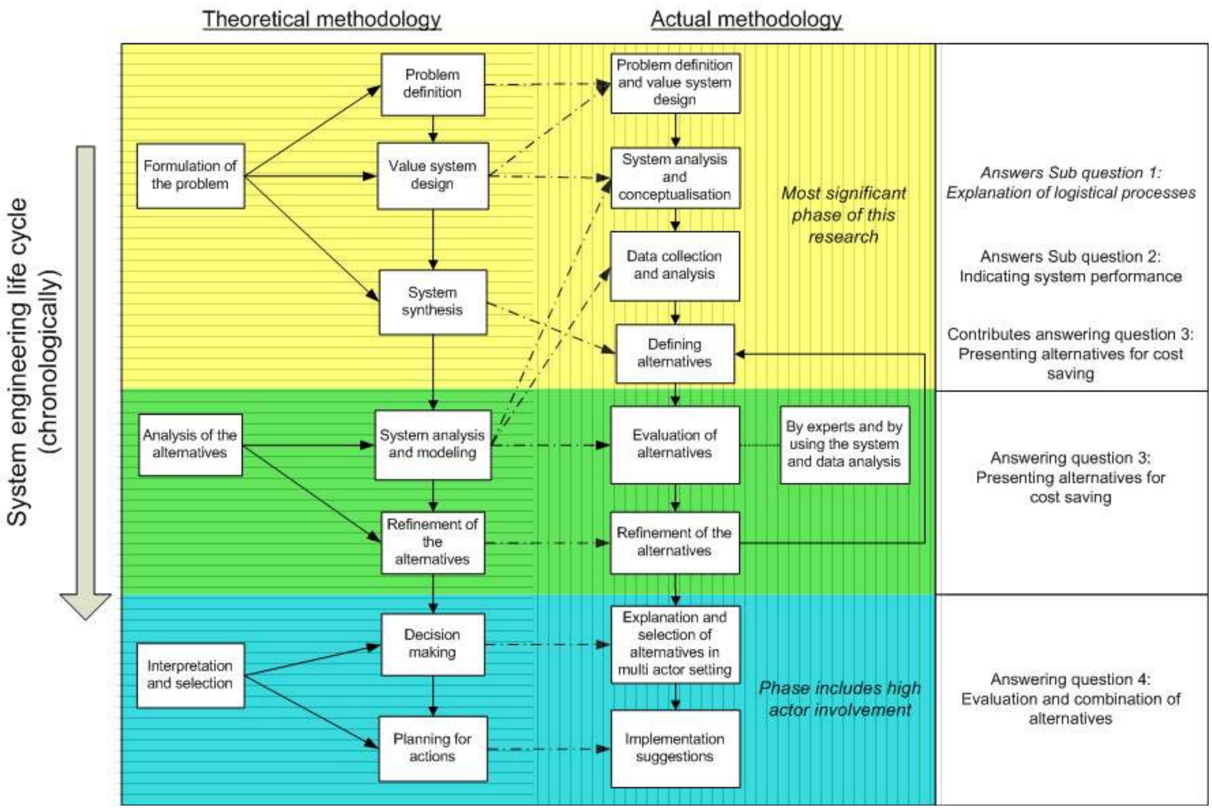


Fig. 5 *Steps in a system engineering study theoretically and how it is applied in this research*

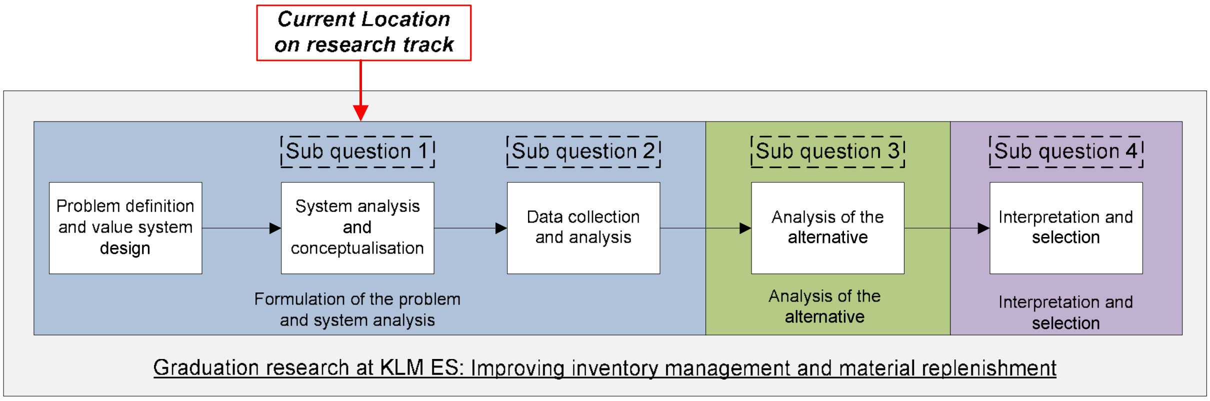
The methodology for executing a system engineering research according to Armstrong et al. is visualized in the picture above as 'theoretical methodology'. In this research this theoretical methodology is used as a framework, but the actual application is slightly different as is also visualized in Fig. 5. At first a problem definition is given and the objectives and goals of the research are defined (value system design), which is documented in the chapter you are currently reading. The next step is defined as 'system analysis and conceptualization'. In this phase a better understanding of the system is achieved by looking at the business processes and their documentations (if present) and by performing interviews and discussions with actors. From this gathered information, conceptual models are designed which are evaluated by the different actors again. This phase will facilitate answering research sub question one (as is shown in Fig. 5).

The next phase concerns a data analysis of these defined processes, which will explain their performance and therewith answering research sub question 2. Analyzing relevant data can, in some cases, also facilitate searching for the root of problems. This phase is the most time taking one, however it is very essential. The reason for executing a data analysis at the more early phases of the life cycle has to do with the highly time oriented and data rich problem situation. The problem owner has defined that the current replenishment process is inefficient, but this problem perception is more based on experience then on system analysis. So in order to confirm the formulated problems and objectives, a thorough system analysis was required.
The availability of sufficient and relevant data is key for the success of any modeling research. If there is no data present of the processes in the real system, a model can not be created. If there is a certain data list available for a process, an appropriate statistical method should be used for generating modeling input in order to get a valid model. It is important to discuss the possibilities for data collection with the problem-owner/system-controller.

Statistical data of these process are often not clearly present at KLM. Some processes have been measured in the past for testing, but at different moments then other processes for example, which makes the use of these statistics less appropriate for generating a trustful model.
One advantage for the data collection is the use of the ERP software MySAP within KLM engine services. SAP registers all of the inputs by the different users within engine services (varying from internal material reservations to vendor orders or repaired product transfer). From this massive data collection, statistics can be gathered. However finding a way through this massive data collection takes a lot of time, and the software is not very user friendly when it comes to statistical output generation. However, at least there is sufficient data and possibilities for analysis that can lead to conclusions about the performances of the Engine shop, that can facilitate the generation and evaluation of alternatives. Herewith the first, but most significant, part of the research is finished (the 'formulation of the problem').

The evaluation of the alternatives mostly occurs by referring to the data analysis and by discussions with the different actors. The people who work an a daily bases can foresee most of the practical implications when implementing alternatives. An other way of alternative evaluation, that has proven to be successful in similar industries, is simulation. This tool is considered less appropriate for this research, a motivation and small discussion about this tool is given in the appendixes IV and V.
The last step of the research concerns a selection of the alternatives and a suggestion for implementation. During the research many information is gathered and many idea's for alternatives have been suggested by the annalist as well as by the different actors at KLM. For the alternatives a boundary is set depending on their relevance and the significance towards the research goals. This has lead to a selected number of alternatives which have been worked out in more detail and for which a suggestion for implementation is given.
The methodological steps that are described above are in coherence with the lay out of the report and strives to answer the research sub questions in a chronological manner. After finalizing al the steps, all research questions, including the main research question, can be answered. The discussion on the answering of research questions is shown in chapter 6.

3 System explanation and conceptualization



In this chapter a more detailed description of the system is given. It will give the reader a better understanding of how the logistical processes are organized within the engine shop. Throughout the chapter conceptual models are used to support system explanation. This system explanation and conceptualization should facilitate in answering the first research question, as is indicated in the research track above.

This chapter starts with a multi-actor analysis. This paragraph introduces the key actors of the earlier defined system and it explains which processes the actors are responsible for. The role of the actors will be more clear after also reading the second chapter in which the processes they perform are explained. As in the description of the processes often a reference to the actors is made, the multi actor analysis is presented prior to the description of processes. However the information should be interpreted parallel rather then sequential.
The third paragraph is more of a continuation of the second chapter but then specifically for the process that are placed under the direct responsibility of the central actor in this research, which is the department of material management.

3.1 Multi actor analysis

Any organization faces the challenge to let its departments and people cooperate and utilize these actors in the most efficient way that will maximize the results satisfying specific goals. The fact that this is still a challenge today, for all these companies, has to do with the complexity of multi actor settings. Every actor, within or outside of an organisation has its own interests and means to reach them. Companies usually generate these interest among their departments themselves. They give actors tasks and responsibilities, and often these actors will be rewarded or punished accordingly. For the KLM Engine Shop, this situation is no different. In this chapter the key actors will be identified together with their interests and means. One way of accomplishing the understanding of the actor's interests and behaviour is to analyze how its performance is measured and how it is rewarded or punished accordingly. The assumption in this analysis is made that the actors will behave rationally and therefore in accordance with their way of being evaluated by management. This makes the actor analysis more simplified then is usually the case in most scientific actor analysis. However, it does give a good impression of the behaviour of actors, which has been acknowledged by different KLM personnel. Enserink et al (2008) recommend a step wise actor analysis with the following procedure:

1. "Formulation of a problem as a point of departure.
2. Inventory of the actors involved.
3. Exhibiting the formal chart: the formal tasks, authorities, and relations of actors and the current legislation.
4. Determining the interests, objectives and problem perceptions of actors.
5. Mapping out the interdependencies between actors by making inventory of resources and the subjective involvement of actors with the problem.
6. Determining the consequences of these findings with regard to the problem formulation."

The analysis in this section is not performed in accordance with this procedure. This procedure is found to be too excessive, as the primary goal of this actor analysis is to give insights in the system and its behaviour. It does not have the purpose of analyzing and solving problems that are possibly present between actors. Nevertheless, certain recommendations from the literature have been applied. First of all does this chapter function as a inventory of the actors involved. Secondly the interests and objectives of actors are mapped out when possible. Like mentioned earlier, this is mainly based on the assumption that actors behave rationally.

Summarizing, the main function of this section is to give the reader an understanding of which actors play a role in this system and how this role is fulfilled. In the next section the specific processes that actors perform are worked out in more detail, which also makes interrelations more clear.

CRO
The CRO (centrale regie) department is responsible for the project schedule. It is the central communicator concerning timing which, for example, involves the repair department for repair duration and the department material management for expected delivery dates for new part. The CRO department and its staff will be evaluated according to the number and intensity (length) of project delays.

Warehouse
The warehouse or inventory department is responsible for the material inbound, material storage and material outbound process. The key performance indicators for this department are processing time (e.g. time of reservation fulfilment), inaccurate stock level (number of measured stock level differences between SAP and actual, per month) and damage (euro's per month).

- The KPI Inaccurate stock level is always measured by zero stock checks. When according to the Warehouse Management System (SAP WM) the stock level reaches zero as a result of fulfilling the specific reservation, a notification is shown to the warehouse staff. A staff member will check if the inventory slot is actually empty and will report this condition.

- The KPI processing time is measured as the difference between reservation creation and the moment of warehouse outbound. However, the performance for so called 'runners' are separated from other reservation. Runners are reservations that have top priority, usually because it is generated in stage 3 (assembly process). Regardless of the priority, the goal for the warehouse is to handle the reservations within 24 hours and the management team of engine services will evaluate accordingly. However the situations in which a reservation can not be fulfilled by the available stock (misgrijpen in Dutch) is also included in the performance measurement.

The warehouse department in the engine shop has the target to fulfil all the reservations within 24 hours. This is being monitored, and they have proven to be successful under the condition that there is a stock level.

Material Management
The department of material management consists of a team of material planners and stock analysts. The material planners generate purchase orders, normally generated after receiving a purchase requisition from the SAP system. The stock analysts control the re-order points. They function as a supervision over the SAP system regarding material management. They check if the forecasting models and suggested ROP from SAP are acceptable and will act accordingly. The department of material management has the complex task of managing the inventory by finding an optimal economic situation, in which the ROP's are reduced to a level at which customer service is not affected by e.g. project delays or quality loss. The evaluation of this department and its personnel is depending on the success of accomplishing this complex task.

Clients
An approximate 60% of all engine shop visits is financed by an external party (non KLM or Air France). Therefore, any project owner is called a client. Clients are aware of the competition of the KLM engine shop and can perform rational decision making based on the typical indicators quality, costs and lead time. There is however a strong factor 'brand loyalty' involved in this industry. The factor quality is not a very strong trade off factor in the Aerospace industry as there are very high standards. Competing engine shops can not compete under a certain quality level, as their products would not be airworthy anymore. However clients always try to get these three key factors utilized as much as possible, which puts pressure on the Engine Shops' performance.

Vendors
Rationally, vendors are willing to utilize their production output. In terms of microeconomics: find their optimum price quantity relation on the demand curve. In addition, vendors would prefer delivering parts with low life cycles, so they can sell more on the long run. Finally, vendors would prefer as least delivery lead time constraints as possible. However, the real world is to complex to act in such a rational manner. The market is strongly regulated in terms of product quality. Also the engine shops will evaluate the products according to product life cycle.
The relationship that KLM has with its vendors is very strong. In this industry, there are few competitors due to the very technical advanced and capital rich nature of the components. On the other hand are there also few clients for the vendors. This assures a mutual interest in good relationships. ICT systems are installed that should facilitated tight and effective communication between the engine shop and its vendors.

Actor identification according to stage philosophy and related drifting responsibility
As will be elaborated more in the paragraph 3.2.1 *Stage philosophy*, the engine shop is designed in different phases. The phases indicate the chronological steps of a shop visit, but it also functions as a classification of departments. Every stage as its own manager who is responsible for all the activities in that stage, and who reports to the management team. The stages are subdivided in operational departments. Stage 2, who's main responsibility is to make sure that all parts are available on time (before start stage 3), consists of the departments material management, warehouse and aprep. The main idea is that the departments operate within their stage and as the operation of all stages are executed in a chronological way, a chain should be created in which al actors are working towards the same end goals.
However in practice the chain is not very smooth. Due to incomplete information transfer certain departments can not function as the might have could, which can result in project delays. For example, stage 2 is responsible for providing all the material, but if the demand is not clearly communicated from stage 0 and 1, they can still fail to complete their tasks, even though stage 2 had sufficient time. Another fact that indicates the chain is not very smooth are the logistical streams from the inventory. As mentioned, the inventory is located under stage 2, however they also supply a significant amount of parts to stage 1 and especially stage 3. In addition are parts from the inventory regularly send to other units within KLM Engineering and Maintenance.

3.2 Description of general processes

This chapter describes the processes within the engine shop from a helicopter view. Most employee of KLM ES will know these general processes but for an outsider it is important to know them before going in more depth towards solving the formulated problems. All the process linked together that form the logistical system, are to complex to understand by mental models only. Conceptualizing the system is therefore an essential step in this research.

Conceptualizing the system and its processes can give a better understanding which is important for further analysis. A second advantage of conceptual modelling is that it can be considered as a communication means. Third parties that are not familiar with the system generally understand conceptual models better then a big report in which all the processes and factors are written down. This communicative means is the main purpose of this paragraph. Also, when there are discussions within KLM ES concerning e.g. process improvement, these models can be used to facilitate efficient communication.
For conceptualizing the processes in a system, different ways of modelling can be applied depending on its behaviour. Engine parts, that can be considered as entities, flow through different streams in the system. When analyzing these entities and their flows, the actors involved, process sequences, process durations and schedules are interesting information considering the problem formulation. The utilization of resources, which is often a key performance indicator in discrete event simulation studies, is less relevant, as was explained in the paragraph 'system diagram and boundaries'. Modelling techniques that have been used in this research are object oriented descriptions, causal relation diagrams, task actor diagrams, physical flow diagrams and information flow diagrams. Their added value is discussed where applied.

Object oriented description
Below a object oriented description is shown. With this description a definition framework is built; a 'vocabulary' that can be used to describe the system (Verbraeck, 2005). The conceptual models that are used later in this chapter can contain ambiguous formulations for which an explanation can be found in the object oriented description. The descriptions show object classes. An object class describes the general characteristics applying to all individual instances that belong to the object. The tables show the attributes that are belonging to instances of the specific class. Also a description of the object is given, to make this conceptual model more appropriate for using it as a vocabulary. Thirdly a moment of creation is given or a moment of action when it concerns an active object. The schedule driven projects determine a big part of the systems behaviour. The moment of action of an object is therefore very relevant. In Appendix VII, a UML (Unified Modelling Language) diagram is presented, that gives an insight in the relations between the classes. It should be noted that UML is a language or a notation that can be used in conjunction with any methodology (it is not a methodology itself) (S.R. Schach, 2004). It should be seen as a supportive tool for the designer in communication.

Passive object

Object class: reservation

Attributes:	*Explanation object class*	*Moment of creation*
Creation date reservation Part number Serial number* Quantity Requirements date	Internal order for a certain part, (informational) directed to the inventory	Normally created after inspections. Sometimes during assembly when part quality is insufficient or during repair.

(*) Serial numbers are used for expensive part to differentiate individual parts within a part number

Object class: Purchase requisition (order proposition)

Attributes:	*Explanation object class*	*Moment of creation*
Quantity Material number Requested delivery date	Requisition generated by SAP	1 After ROP is exceeded. 2 When need in reservation could not be fulfilled by the inventory

Object class: Purchase order

Attributes:	*Explanation object class*	*Moment of creation*
Creation date Quantity Material number Requested delivery date Order number	External order for vendor created by material planner	After the material planner processed the purchase requisition

Object class: internal repair order

Attributes:	*Explanation object class*	*Moment of creation*
Creation date Material number Repair order number Description of Error Code repair station Requirements date	Internal order for the repair department	After parts and disposition

Object class: External repair order

Attributes:	*Explanation object class*	*Moment of creation*
Creation date Material number Order number Requested delivery date	An order that is placed at a vendor for repairing a rejected part	After parts and disposition

Active Objects

Object class: Part and disposition

Attributes:	*Explanation object class*	*Moment of action*
Number of inspectors	Inspects disassembled parts and defines route	Stage 1

Operations:
Inspect part
Create reservations
Create external repair order
Create internal repair order

Object class: Material management

Attributes:	*Explanation object class*	*Moment of creation*
Number of material planners	Determines stock levels, creates purchase orders and external repairs. It also measures vendor performance	Stage 2

Operations:
Create purchase order

Task- actor diagram; The model can visualize which actor is responsible for a specific process. In the logistical systems there are different actors involved that often have several tasks. The big number of interrelations often result in the failure of a cognitive understanding when using only mental models and perceptions. In appendix IX a task-actor diagram for the defined system is given. The diagram shows a flow that explains the chronological sequence of processes. The flow should not be interpreted as an entity flow as in some cases an arrow can represent a physical product flow and in an other case an information flow.

In Fig. 6 the MRO planning for an engine shop is visualized with the location of theoretical order creation location. The process of order creation is zoomed in by showing an actor-task-data diagram. This is a very essential moment in which different actors have to cooperate to ensure a successful and agile replenishment, which is the reason for the zoom. The moment of order creation and the length of and between its processes are very important for the performance of material management. If the processes will be time taking the replenishment window will be decreased. In addition, accurate information flow between these actors is key to the performance. The introduction of ICT systems such as SAP is facilitating the speed and consistency of information.

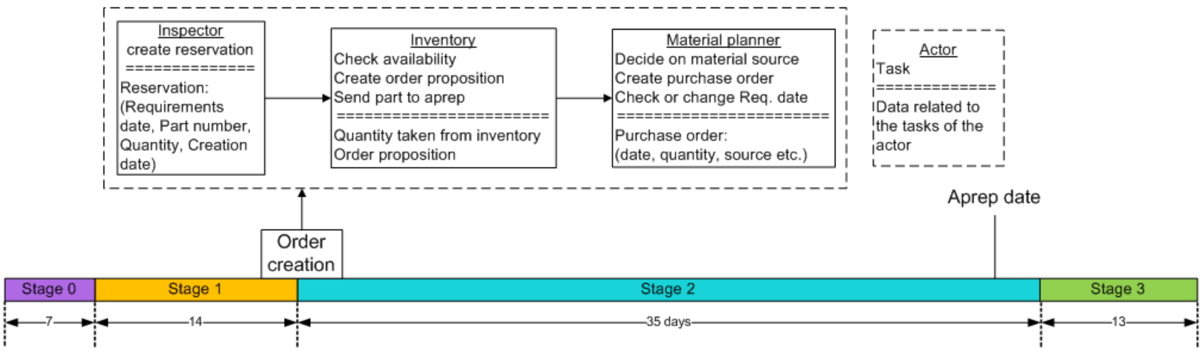
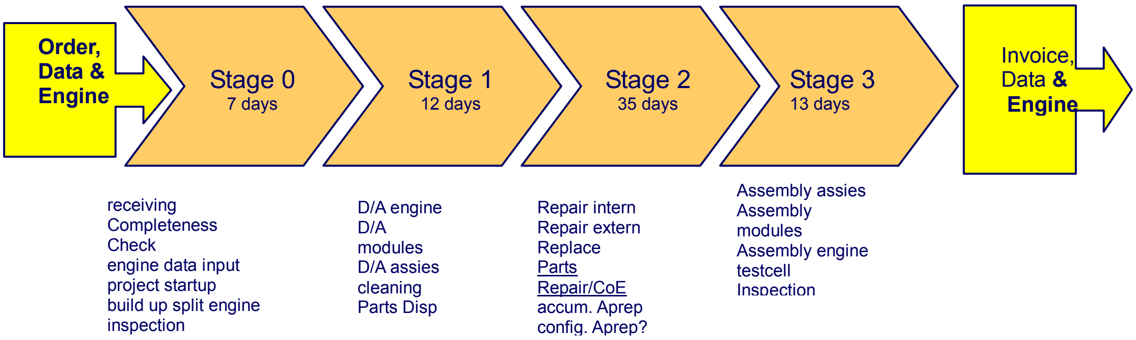


Fig. 6 *Overhaul planning with a zoom on order creation*

3.2.1 Stage philosophy

The management of the Engine shop has organised the operational processes into different stages. Every stage includes specific processes that, all together, need to be finished within a specific time frame. Al phases connected will lead to an accumulated lead time for the MRO of approximately 68 days per engine. This is the estimation that KLM E&M offers to its clients, any significant delays can be seen as customer service loss. The engine and all of its related data enter stage one in which a project planning will be made. The project planning includes specific customer wishes and is based on a estimated work scope which is derived from engine data input and first inspections. In stage 1 the disassembly starts based on the planning made in stage 0. The engine is first disassembled into modules, the modules then into so called assies and the assies finally into parts. The way this is completed may differ per project. Stage 1 also includes the inspection of the different parts. At the end of stage 1, which is after approximately 12 days, the order date arrives after which stage 2 starts. The order date is a milestone in the planning that is defined as the date at which the material requirements for the MRO should be identified. Stage 2 is, with an estimated duration of 35 days, the most time taking part of the entire engine MRO. In this stage all the materials are processed before they are later assembled again in stage 3. This processing could be in the form of cleaning and/or repair or replacement which will be explained in paragraph 3.2.3 in more detail. At the end of stage 2, a check will performed to make sure that al required parts for the assembly are present. The end of stage 2, after the check, is called the parts date as all parts need to be present by then. Stage 3 involves the total assembly of the engine and related inspection to finally declare the engine to be serviceable again.



3.2.2 Engine disassembly and assembly

During engine disassembly some parts are disassembled earlier than others. The disassembly personnel are instructed to send critical parts to the parts and disposition department as soon as possible. Critical parts are parts that have a repair or replenish lead time that (almost) equal the length of stage 2. These critical parts have a priority over other parts.
The way engines are disassembled and assembled in the engine shop are almost equal when mirrored. Therefore we will only describe the assembly more detailed in a conceptual way which is visualized in Appendix VIII. At day one of the assembly, individual parts are assembled into so called assies. Under normal conditions, all the assemblies of assies start at day 1. Different assies are assembled together into modules (for a detailed conceptualization of this process see Appendix VIII). Some module assemblies start at day 2 of stage 3, others at day 5. The exact sequence of assembly, the required conditions and the required resources are all described in detail by either the engine manufacturer (e.g. GE) or KLM E&M and are documented in WPI's (work process instructions), that are accessible to al technical staff. The final step involves the assembly of modules into a finished engine. From a material management perspective the moment at which the parts are actually needed for assembly is interesting. If certain expensive parts are assembled in the end phase of stage 3, then they are a more interesting candidate for JIT replenishment, because they have the possibility of having a longer stage 2 which makes replenishment less critical and in addition investments can be delayed. Unfortunately this is not the case for the majority of parts. A small discussion on this issue is given in the intro of chapter 5.

3.2.3 Logistical material flows

This paragraphs elaborates the material flows that are present in the logistical system of the engine shop. First a conceptual description is given of the general material flow which concerns al disassembled parts, which is visualized in Fig. 7. After the general description, more detailed logistical processes and flows are explained.

At first the engine arrives at the shop together with all relevant data. The engine will be disassembled (level of assembly differs). Ship smart parts (parts that can only be repaired externally) are send to the vendors, others to P&D for inspection. An evaluation of the part will be made, some are approved and are therefore ready to be assembled again. Others need to be repaired or replaced. At the engine shop an inventory is located. Certain parts are in stock according to forecasts drawn from historical data using SAP software (inventory forecasting will be discussed later in this report). If there is nothing in stock, a purchase order needs to be placed. When the part is available it will be moved to the department *aprep* (assembly preparation). If the inventory drops below the ROP (re-order point), it will be filled up to the planned level again. At aprep all the parts necessary for the assembly of a specific engine are collected and when all present they are brought to the assembly area.

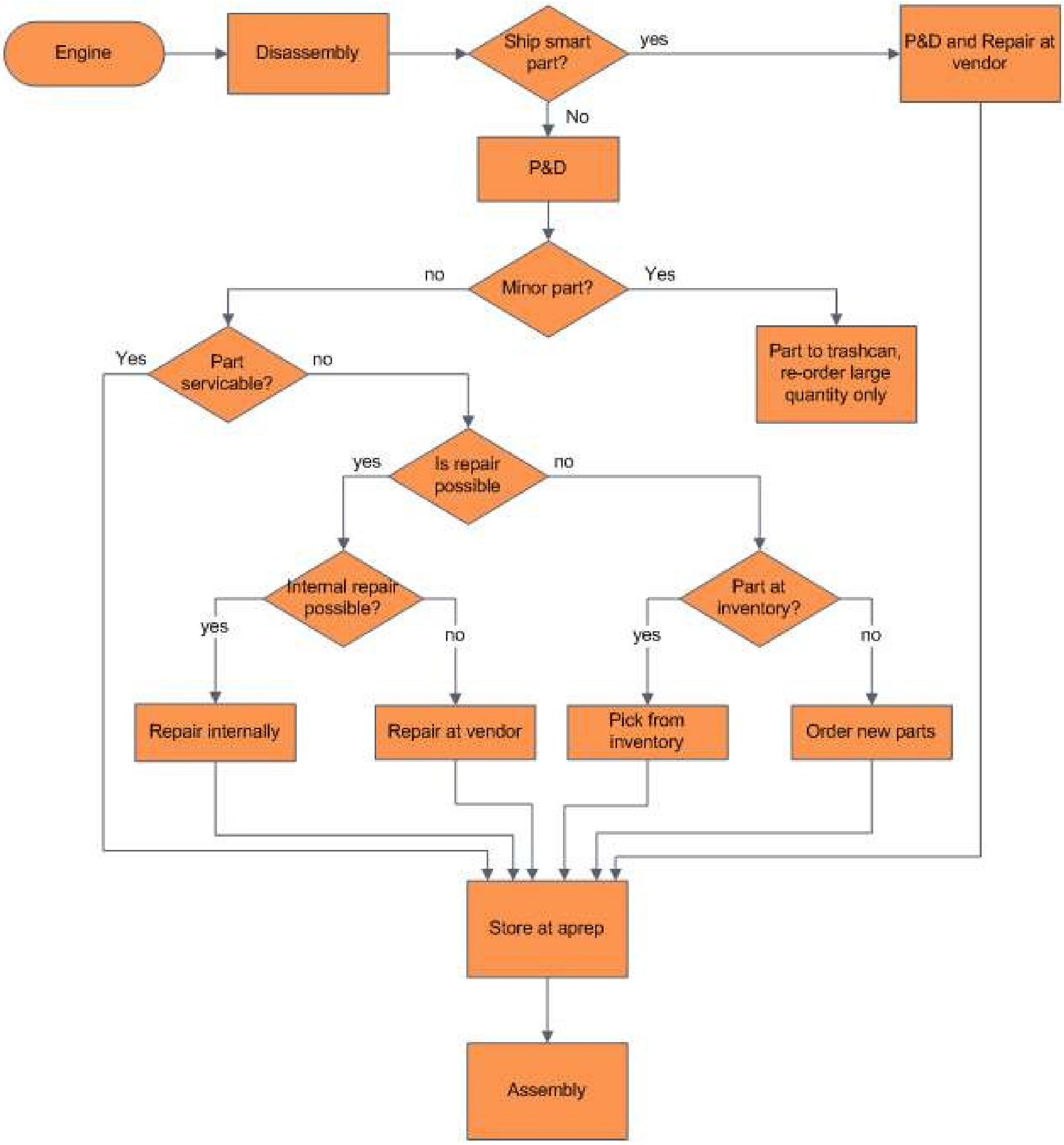


Fig. 7 *general material flow during engine overhaul*

Parts and disposition (P&D)

The department parts and disposition at the engine shop is responsible for determining the main route that individual parts will follow after disassembly. Parts, theoretically, arrive at P&D in the same sequence and with the same time interval as the disassembly was performed, with the exception of priority parts. Priority parts are logistically critical parts with long lead times that are transported to P&D as soon as possible and skip the queue. An other way of priority setting is the 'ship smart' procedure that is implemented after a six sigma analysis on the external repair process by KLM black belts. The ship smart procedure focuses on shipping the critical external repair parts to the vendor as soon as possible (right after disassembly). The next paragraphs will describe the logistical material flows of the different routes in more detail

External repair

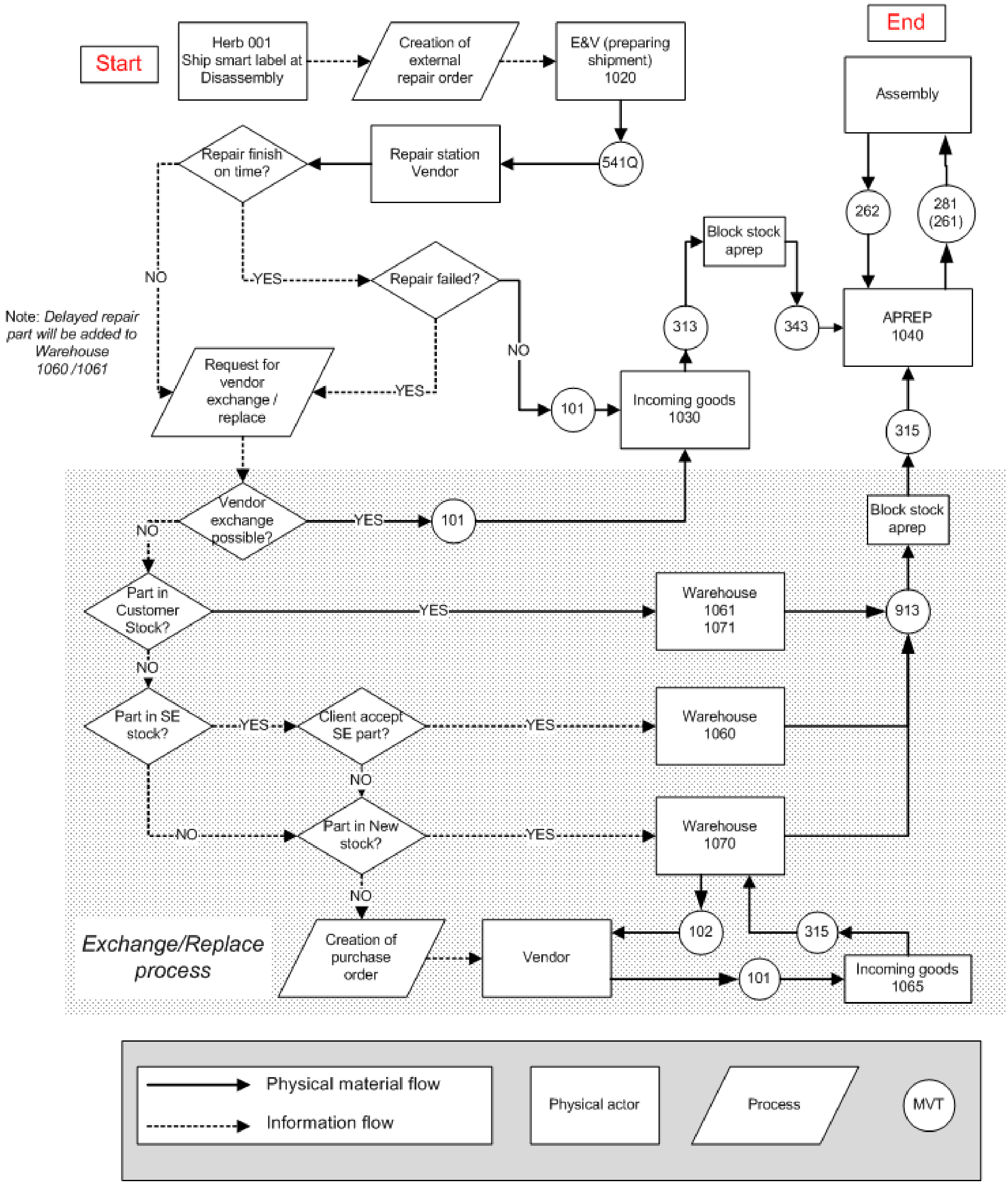


Fig. 8 *Physical flow diagram of external repair Herb 1*

External repairs are theoretically the result of a ship smart. The ship smart procedure is applied for all parts that can not be repaired internally. In Fig. 8 the flow diagram of this external repair route is visualized. Note that it only concerns Herb 1 parts (see 3.3.2.1), as these are the more expensive parts that are often repaired. The diagram also includes the exchange and replace process, which can also occur in other routes such as the internal repair. The diagram includes movement types (MVT) as is also shown in the legend. For any transaction, SAP generates a movement type. This makes the system more transparent and it facilitates the analysis of material flows. The visualization of how MVT's are used can be very useful in the discussion for the determination of MVT that are relevant for consumption determination. This discussion is explained later in this report. These MVT types

discussions might also be interesting for non KLM readers that are also working with SAP as the use of MVT's is a general SAP application.
The diagram shows there are different storage points. There is a small one at incoming goods. The biggest storage points are 1070 for new parts, 1060 for repaired parts and 1061 and 1071 are customer parts stored at the KLM engine shop. In addition, there is the storage point 1040 aprep (assembly preparation).

Internal repair
The internal repair flow is not very complicated as can be seen from Fig. 9. If a repair can not be finished on time, or if it fails, there will be an exchange process. When the repair was successfully completed it will straightly go to the aprep department. The internal repair processes are not very interesting for this research as their lead times (TAT) are not critical for stage 2 and the processes do not influence the stock levels (theoretically).

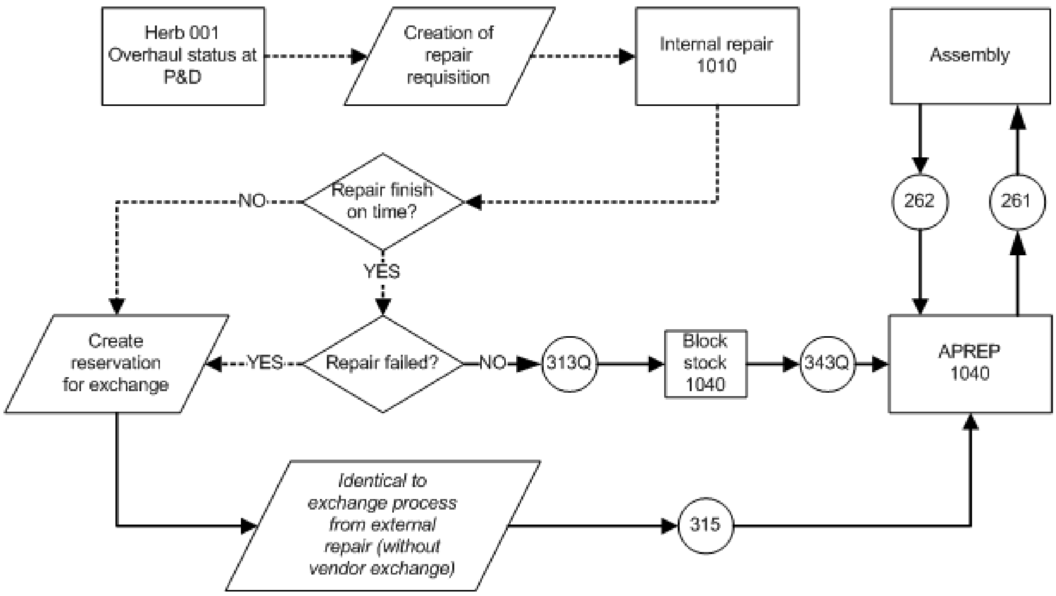


Fig. 9 *Physical flow diagram of internal repair*

Rejected parts
Parts can be rejected due to a failed internal repair or as an outcome of inspection at P&D (parts and disposition). If there is no replacement in the inventory a purchase order will be created (see Fig. 10). Most parts are ordered by 'warehouse procurement' which follows the 315 route after incoming goods, a few are ordered by 'direct procurement' which has a 313Q transaction (going straight to aprep). The differences and the pro's and con's will be discussed later in this report.

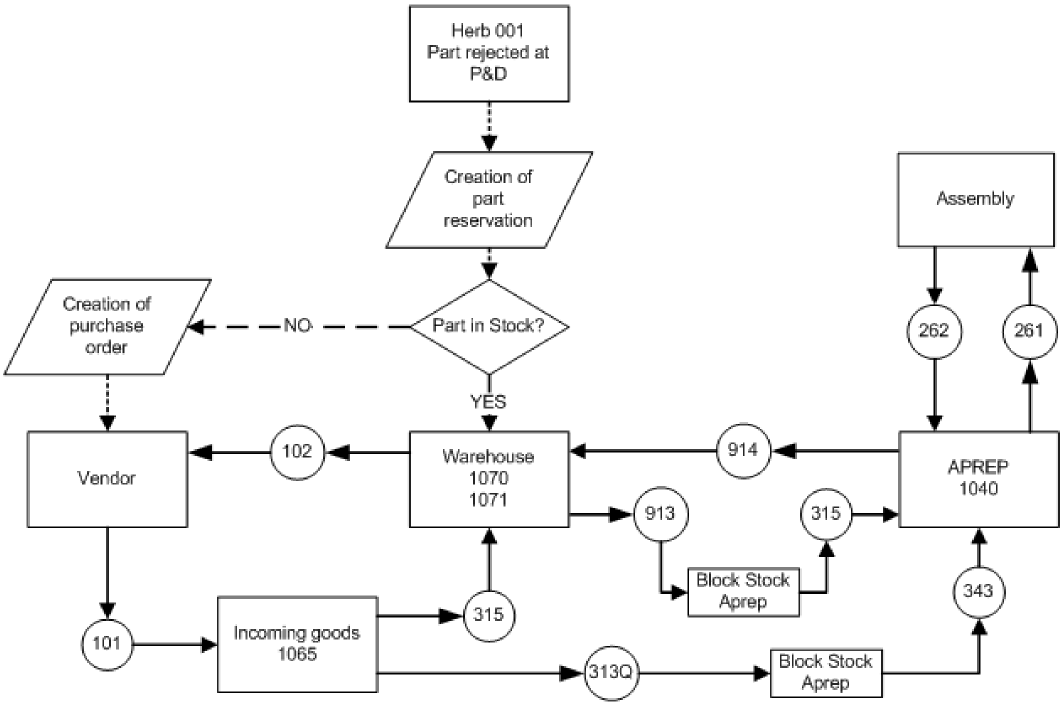


Fig. 10 *Physical flow diagram Rejected herb 1 parts*

Incoming goods and warehouse management

At the warehouse of the engine shop a department incoming goods is located. This department is responsible for checking the material bill, performing a visual inspection and deciding the route. The flow of material is visualized in Fig. 11. The sketch shows that there are 3 main flows of incoming goods. On going straight to aprep, which are the project dedicated parts. The non dedicated parts are send to the inventory of which new parts and repair parts are separated. The biggest category of employed capital in the inventory is that of parts that are hardly consumed which can be repaired parts or non leading parts. The composition of the total employed capital in the inventory will be explained later in this report (section 4.1).

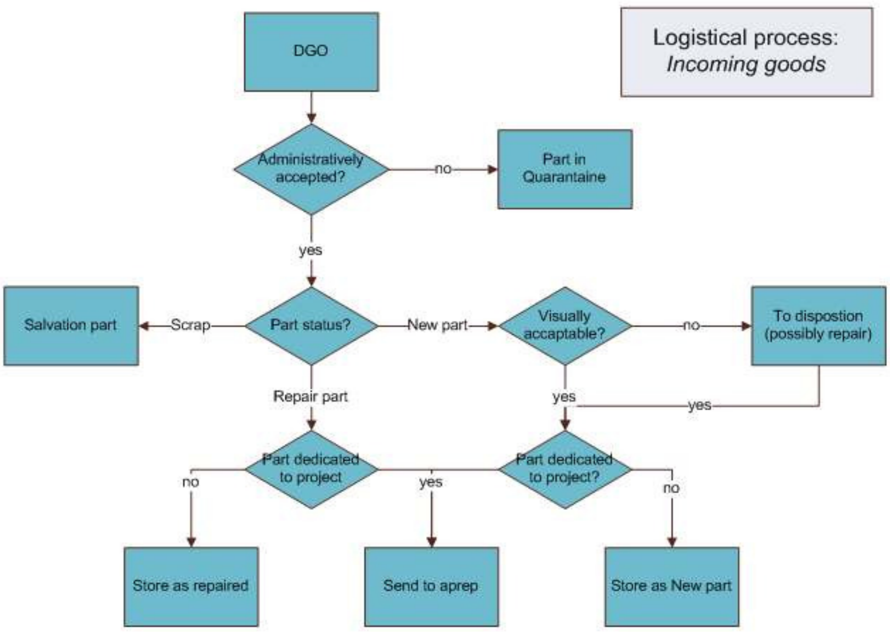


Fig. 11 *Flow diagram of incoming goods*

3.2.4 Logistical information flows

This paragraph gives insights in what kind of information flows between the different actors. Most of the information is transferred through the SAP system. Fast and clear informational interaction is key in this logistical system. If an order is send to a vendor too late because of communicational problems, the vendor may not have enough time to fulfil the demand. In addition it is important to make the informational flow transparent in order to make correct decisions for certain improvements. For example, an improvement can include the necessity to have certain communication to occur earlier or faster. It is then important to know which actor(s) to steer.
The information sender inserts data in the system, like for example a request for material. The receiver will check the insert data, like in this example the inventory can see there is a request for material. The blue blocks represent the actors and the green blocks the type of information.

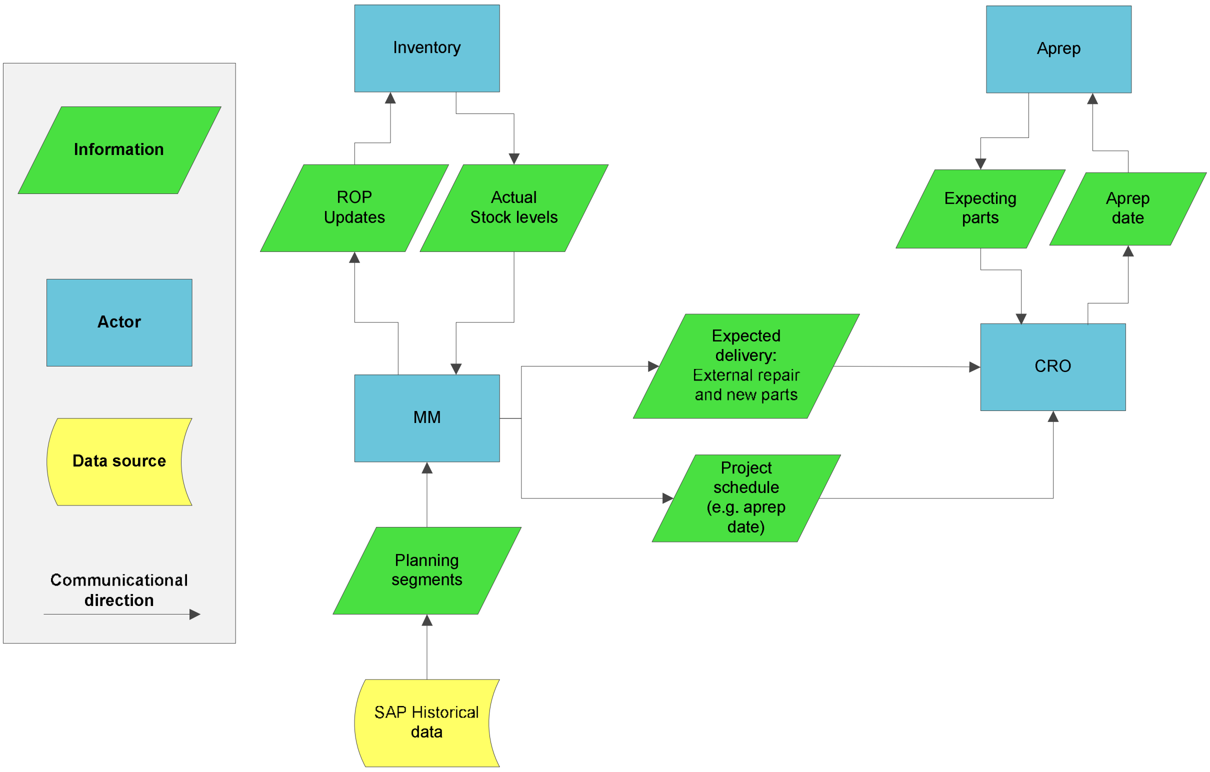


Fig. 12 *Information flow between the central actors*

In
Fig. **12** the information flow between the key actors for the inventory control are shown. The department Material Management (MM) will receive a suggestion for assigning a certain planning segment to a part type based on historical consumptions. Material management is responsible for setting the ROP and updating them. This will have an influence on the inventory. The inventory will keep MM informed on the actual stock levels. The CRO department (Centrale Regie Officier) is responsible for the project schedule. The CRO will need information about repair duration, delivery expectations etc., in order to generate a schedule which will be communicated to the relevant actors in return.

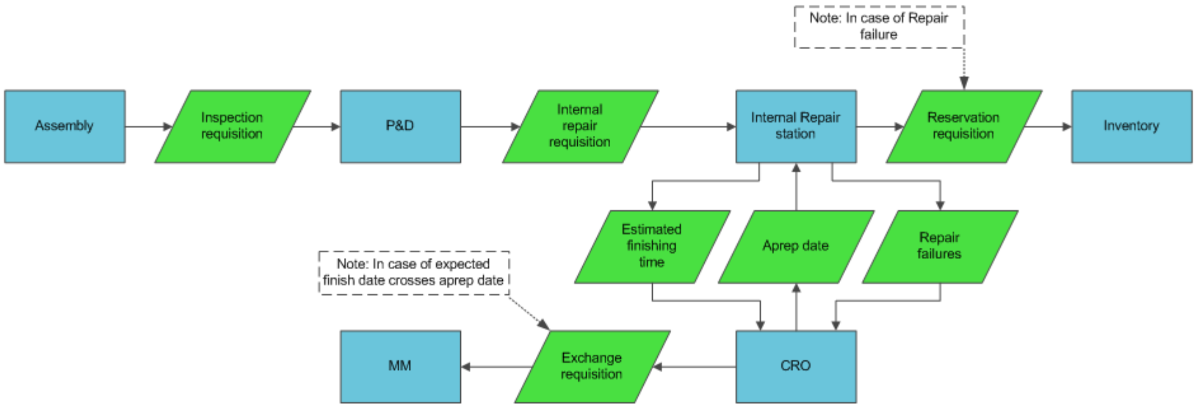


Fig. 13 *Informational flow internal repair*

An internal repair is started after an internal repair requisition (or order) is send to the repair stations together with the physical part. During the repair process the repair station is mostly sharing information with the CRO deportment. The CRO is responsible for reporting the aprep date (date before repair needs to be finished). In order to make the project schedule and updating it, the CRO needs the estimated finishing time for a repair, and needs to know a repair failure as soon as possible. When a repair fails, the department MM is informed and needs to create a purchase order at a vendor.

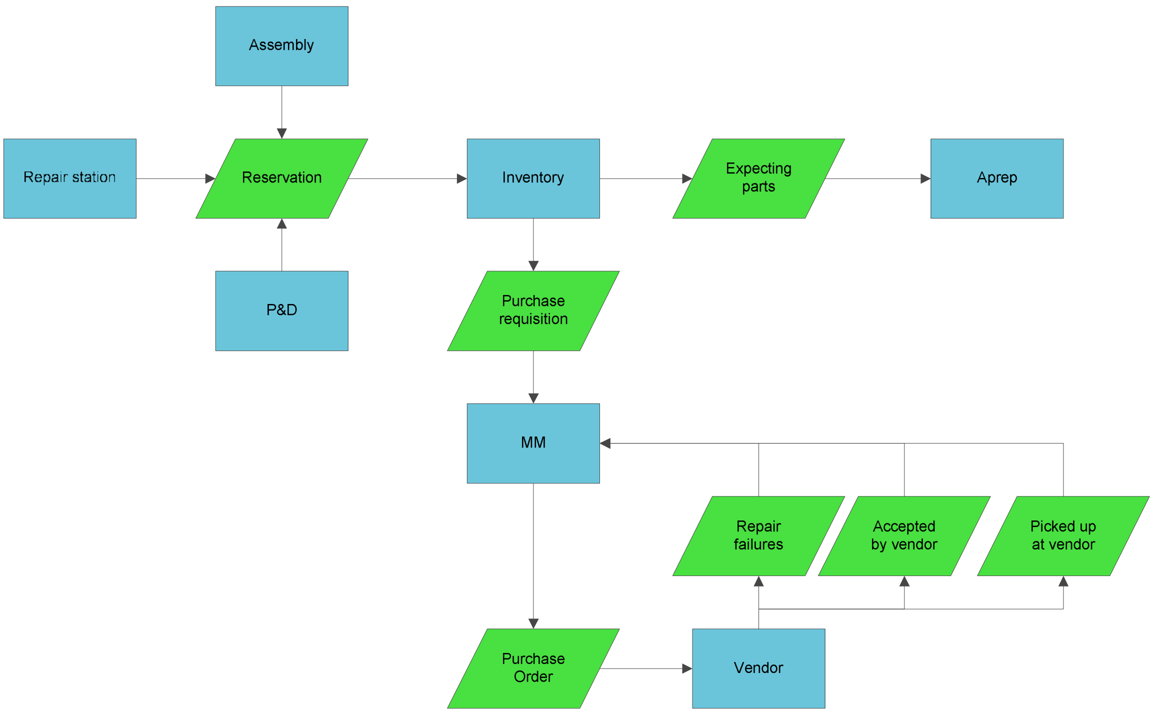


Fig. 14 *Informational flow order process*

The inventory can receive a reservation (material request) from three different actors, namely the assembly line, the repair station (failed repair or equipment) and P&D after a reject. The Vendor receives a purchase order (see object oriented description) from Material Management (MM). The Vendor keeps MM informed about the status by showing when the order is accepted and when they have send the part.
The informational flow of an external repair is quite comparable with the order process, but more simplified. Usually the assembly department generates an external repair order (through the department Expedition and Sending) to the vendor. The vendor keeps the MM department informed concerning repair status, moment of vendor acceptance and return shipment (picket up at vendor).

3.3 Description processes material management

As was mentioned in the actor analysis, the department of material management is responsible for the inventory planning and control. Oden et. al. (1975) stated two main objectives of inventory planning and control:

1. "*Maximize the level of customer service* by having the right goods, in sufficient quantities, in the right place at the right time.
2. *Minimize the cost* of providing the desired level of customer service, including inventory holding costs, setup costs, ordering costs and shortage costs."

In its daily processes, material management tries to achieve these two objectives as well as possible. This research can be seen as a comprehensive analysis on how to obtain those goals more effectively.

The processes of material management are very complex of nature. There is a high uncertainty about the demand of material specifications. Assuring that the right materials can be assembled on time is a continuous struggle. The department material management uses SAP software to generated a forecast of part consumption for the next period, primarily based on historical data. Based on this forecast and on part property, such as cost and delivery time, the safety stock and reorder point are determined. These parameters are depending on the planning segments that are assigned to a part based on the those mentioned criteria. Some parts are treaded in an exceptional way due to unique behaviour, which is explained later in this paragraph. Firstly, a causal relation diagram is presented and discussed in order to explain the dynamic behaviour of the subsystem 'material management'.

Causal relation diagram

A causal relation diagram shows the direct causal link between two variables, which can be either positive or negative. A positive relation means that if A increases or decreases, B will do the same respectively. A negative relation works visa versa. The benefit of a causal relation diagram is that the indirect influence of one variable on another can be found by looking at the nodes in between. This gives a better understanding of the system behaviour.

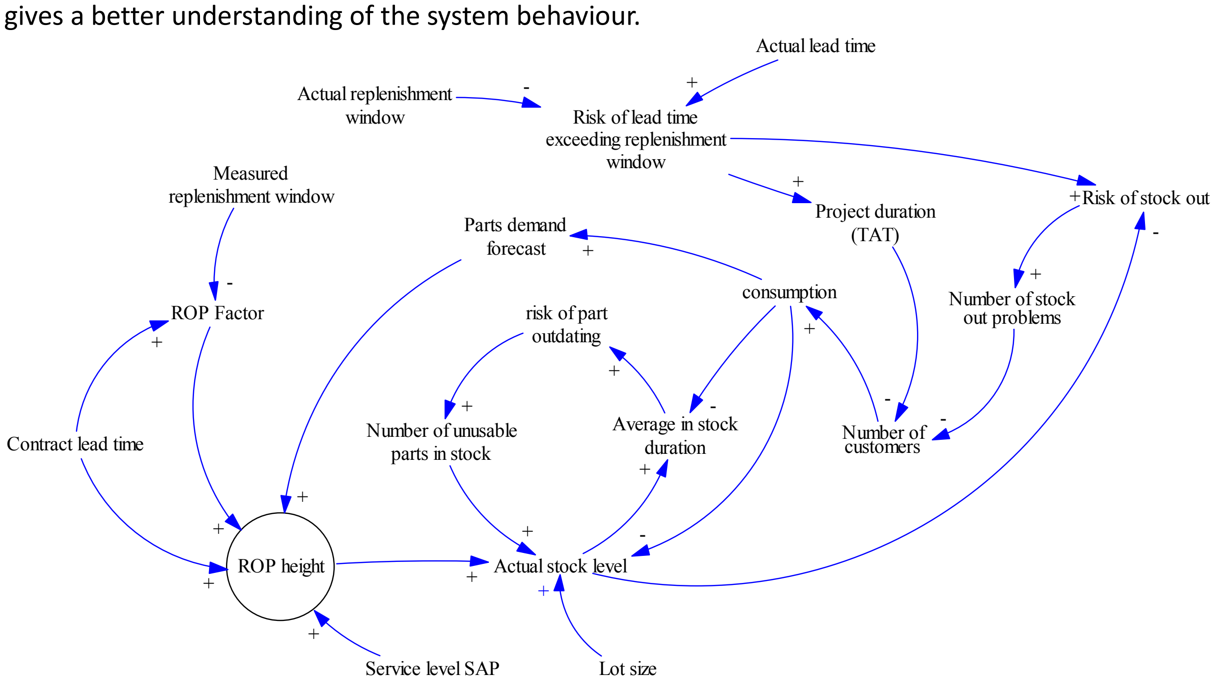


Fig. 15 *Causal relation diagram*

This causal relation diagram is focussing on the logistical system abstractly, in which ROP height is considered as the central variable or in other words as the most important key performance indicator (KPI). The actual stock level could have been considered as the key performance indicator, but it is

mostly depending on the ROP height (norm level). The reason why the actual stock level has not the focussed will be more clear in section 4.1 *Monetary inventory composition*.
The diagram shows the system as it is currently functioning. The way the system is functioning is mostly depending on the way ICT systems are used, in this case SAP. In SAP the ROP level is first of al depending on the ‘ROP factor’ (see 3.3.2.2 about the replenishment window). The ROP factor will result in a yes or no decision for stock, this factor is of very high importance for defining the ROP but it does not mean that ROP will increase when the factor increases. The definition of this factor and other variables are shown in Appendix I. When the ROP factor generates a ‘yes’, the height of the ROP is mostly depending on the forecasted demand of the specific part, which in return is fully based on historical consumption patterns.
The central performance indicators in the system that is being researched at KLM ES, are Stock levels (or ROP height which is the norm level) and problems due to out of stock situations (delays). The diagram shows which factors influence these mentioned performance indicators directly and indirectly. In Appendix I a description is given of the factors mentioned in the diagram. With this description the diagram should be understandable. The next paragraphs will explain the process of material management in more detailed. Often a reference to this relation diagram is made to show the influence of the specific variable on the rest of the system. Therefore the diagram can be seen as a framework for explaining the processes of material management in this paragraph.

3.3.1 Planning segments

Within KLM, all parts that are involved in the engine overhaul are labelled with a specific planning segment. The planning segment labelled to the material is depending on the different material classifications: ABC, Herb, consumption behaviour and inside or outside window, in this research they are called ‘*planning segments determining variables*’. The planning segment is registered in SAP and describes how material replenishment should be handled. It tells material planners which forecast model SAP is using, what the ROP and safety stocks are, which service level is demanded and which type of lot sizing is applied. These mentioned variables are, in this research, called ‘*planning segments depending variables’.* How these depending variables are set is indicated by the colour of the planning segment in the figure below. The representation of every colour is shown (in Dutch) in Appendix II. A green colour, for example, indicates that there is a MRP (material requirements planning) activated in stead of a ROP planning. This means that SAP is suggesting not to have any stock for the specific part. The decision for having a ROP planning or not is mainly depending on the lead time of the material being within or outside the replenishment window, which is a *determining variable* that will be discussed in the next paragraph.

		A				B				C			
		1	2	3	4	1	2	3	4	1	2	3	4
Within window	Smooth	1	2	3	4	5	6	7	8	9	10	11	12
	Intermittant	13	14	15	16	17	18	19	20	21	22	23	24
	Erratic	25	26	27	28	29	30	31	32	33	34	35	36
	Lumpy	37	38	39	40	41	42	43	44	45	46	47	48
	None									49	50	51	52
Outside window	Smooth	53	54	55	56	57	58	59	60	61	62	63	64
	Intermittant	65	66	67	68	69	70	71	72	73	74	75	76
	Erratic	77	78	79	80	81	82	83	84	85	86	87	88
	Lumpy	89	90	91	92	93	94	95	96	97	98	99	100
	None	[illegible]	[illegible]	ON03	ON04	[illegible]	ON06	ON07	ON08	ON09	ON10	ON11	[illegible]

Fig. 16 *Planning segments applied at KLM ES* (I. Sohl, 2007)

By applying these planning segments, the KLM engine shop tries to have a minimum stock level under the constraints of the different logistical properties. In the conclusion of this chapter a small discussion on the usefulness of the planning segments is given.

Exceptional segments

In the engine shop the replenishment of some part is handled in an exceptional manner duo to their unique situation. These parts are not automatically determined and updated by SAP but are inserted manually. In most cases these exceptional segments are assigned to expensive parts with irregular consumption behaviour. The replenishment parameters are determined by different commissions depending on the kind of U-profile. These commissions mostly determine the parameters based on the long term schedule (if known) and experience. Theoretically, parts are frequently evaluated to see if they still belong to a certain segment. Currently, all the parts that are referred to as a exceptional (U-profile) are representing about 11,7 million euro out of the 23 million norm stock, according to data analysis performed on SAP outputs.

3.3.2 Planning segments determining variables

In this paragraph, the variables that determine to which planning segment a specific part belongs, are explained.

3.3.2.1 Material (entity) classification

All the materials at the engine shop are classified as a specific HERB type, a consumption pattern and they get a A, B, or C status. This paragraphs explains how these classifications takes place and why.

The materials at the Engine shop are classified in different ways. First a so called HERB classification is made which separates minor parts, consumption parts and repair parts. Minor parts are small, cheap and non structural parts that are always replaced during maintenance and their ordering occurs in large quantities. Consumption parts are usually not structural and are only disposed when rejected. Finally the repair parts are the more expensive and mostly structural parts that are, if possible, repaired after a rejection by the inspection. These are called Herb 1 and have the focus in this research.

A second classification is according to the well-known logistical ABC classification. Parts group A is responsible for 80% of the total revenue, group B for 15 % and group C for 5% of the total revenue. In most industries Group A contains about 20% of the total products, group B about 30% and C 50%. However after analyzing the total material consumption of the KLM engine shop over one year, a very uncommon and extreme ABC relation was found (see Fig. 17)

This extreme outcome (1% of the products is responsible for 82% of the total revenue) can be explained by the exceptional industry. Parts classified as A are mostly very expensive parts that are used regularly (like engine blades). Group C on the other hand concerns many small and cheap parts of which many are not regularly used. Many classified as C were not even consumed during the last year.

# Products	% Products	% Revenue
429	1.0	81.7
1443	3.3	15.3
42504	95.8	3.0
44376	100	100

Fig. 17 *ABC analysis KLM Engine Services*

The third classification is according to the consumption pattern, we separate the following:

Smooth: Constant demand during entire year

Intermittent: Constant demand at a few (random) periods over the year

Erratic: Non-constant demand during entire year

Lumpy: Non-constant demand at a few (random) periods over the year

The parts are classified as such by collecting two variables, the variability coefficient and the average demand interval. The first gives insights in the variety of demand between periods and the latter in the occurrence of consumption periods. Below the equations of the mentioned variables are given.

$$VC = \left(\frac{\text{standard deviation demand}}{\text{Average demand}} \right)^2 \qquad ADI = \frac{\text{number of periods without demand}}{\text{number of periods with demand} + 1}$$

The variety coefficient has a leverage point of 0.49 (above the demand deviation is higher) and the Average Demand Interval has a leverage point of 1.32 (above the number of periods without demand is higher). These coefficient will determine the classification. The demand patterns are important information for the forecast models and therewith the inventory control. Fig. 18 shows the different patterns.

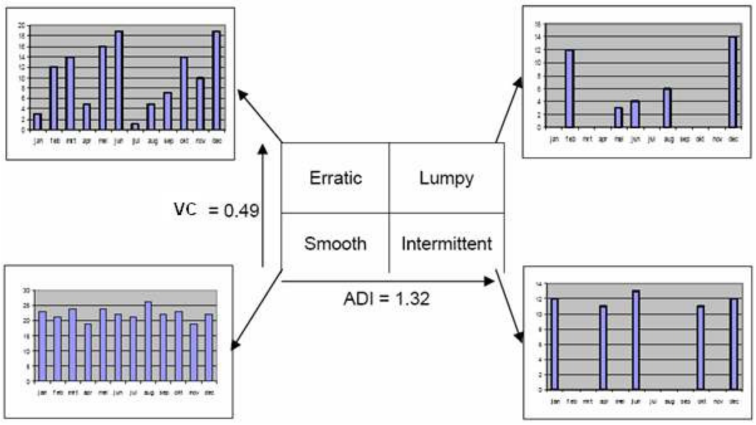


Fig. 18 *Demand pattern classification* (I. Sohl, 2007)

3.3.2.2 Determination of the replenishment window

The replenishment window is defined as the difference between the requirements date and the reservation creation date. The requirements date is the date at which the material is required to be present at the aprep department, which is right before the C-check. The date of reservation creation for rejected parts should theoretically be before stage 2. However in some cases, the reservation creation date is located late in stage 2. This delay has multiple explanations. The first explanation concerns the significant demand that is created during repairs. During the repair stage, sub parts are often required or if the repair fails it will result in the creation of a new part reservation. Secondly the Parts and Disposition process (inspection), which should theoretically be finished within stage 1, can have a delay due to, for example, an unexpected amount of parts or excessive inspection durations.
Theoretically the replenishment window of rejected parts should have an approximated length equalling the length of stage 2. The figure below shows a visualization of the described replenishment window determination.

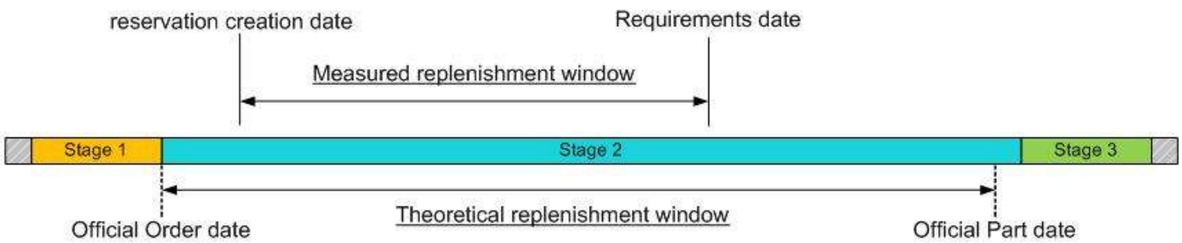


Fig. 19 *Visualization of theoretical and measured replenishment window on stage planning*

After performing an analysis on the determination of the requirements date in the SAP programming it was concluded that the requirements date is automatically defined in a created reservation by SAP as 54 days (the length of stage 0, 1 and 2) after the project creation date. This project creation date is the date that is registered in SAP when a project is accepted in the Engine shop. However the actual work for the project often starts later due to different reasons. In addition, the static stage planning is quite ambitious and the average actual stage duration also has a significant variation from the norm durations (according to process controllers). More details are given in section 4.3, in which a data analysis on this matter is performed.

If the replenishment window is measured inaccurately it could have serious consequences for the inventory control. Especially a too small measured replenishment window can lead to inaccurate inventory decision making in SAP that will result in excessive stock levels. This statement is based on the fact that within SAP a material is placed into a specific planning segment. As was described in paragraph 3.3.1, the planning segment of a material is strongly depending on the lead time being longer or shorter than the measured replenishment window. If the delivery time is shorter then the measured replenishment window (in window), then there is no ROP planning, which means no stock. The replenishment window per reservation is measured and saved for 15 months. The tool that is used for inventory control at the Material Management department, decides on having stock depending on the contractual lead time fitting in to 80% of the measured replenishment windows (over 15 months).

3.3.3 Planning segments dependent variables

In this paragraph, the variables that are dependent on the type of planning segment a specific part type is belonging to, is explained.

3.3.3.1 Forecast models

Forecasting demand is one of the most important issues of inventory management. Stock levels are always strongly depending on the expected (forecasted) demand. However, the demand on the short term is very difficult to forecast in the aircraft repair and overhaul industry. In many production environments, demands are more precise as customer orders often give full insights in the need of (raw) materials. For the Engine overhaul process, the actual demand per order is only known after disassembly. Therefore the forecasts at KLM Engine Services are fully depending on historical consumptions.

As was mentioned in the introduction, spare parts in this industry are very expensive, however their unavailability can lead to excessive down time costs. Finding the optimal stock level is a continuous challenge, this includes considering parts holding costs and costs involved with the risk of stock out situations.

In the aircraft repair and overhaul industry, demand patterns are usually showing intermittent behaviour. Many forecasting models are inappropriate for this type of behaviour. High demands occur randomly, which sometimes results in great time intervals. The forecasting models are expecting low demand after a longer period. If suddenly a significant demand is needed, the inventory levels might not be sufficient (Ghobbar and Friend, 2003). For the engine shop, the four different patterns are equally common, in terms of total number of parts (not monetary), as can be seen in Fig. 20.

Ghobbar and Friend have conducted a research in which they evaluated forecasting methods for intermittent parts demand in the field of aviation. Based on a literature and a case study at KLM-UK they concluded that “weighted moving averages is much superior to exponential smoothing and could provide tangible benefits to airline operators and maintenance service organisations forecasting intermittent demands”. For evaluating the accuracy of the different forecast methods they calculated the Mean Absolute Percentage Error (MAPE, because of its “advantageous performance with intermittent demand”) for the different experimental factors and their interrelations in an analysis of variance (ANOVA). They concluded that ADI has more influence on MAPE (errors) when having a quarterly SPL (Seasonal period length) then a monthly or weekly (Ghobbar and Friend, 2003).

An additional conclusion was that Hard Time (HT, depending on flying hours) have a better forecasting accuracy compared to condition monitoring (CM, reject depending on condition). The advantage of Hard Time parts is that they could theoretically be traced throughout their life, and that the end of their life could be expected at a certain moment which increases demand predictability. However, at the KLM engine shop, the HT parts (or Lyfe Cycle Parts) are only forming a small part of the total demand that is created in a engine's overhaul, as is shown in Fig. 23 (REJ 3 status). It would be unpractical to adapt business processes ant ICT systems for these few parts.

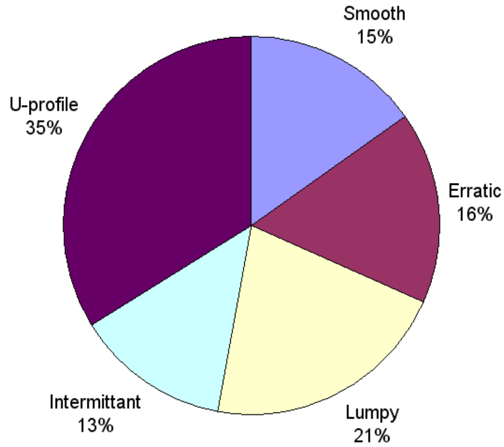


Fig. 20 *Classification of all materials used in ES according to demand pattern*

Internal research (KLM) has shown that changing the mathematical model in SAP for material forecasting could not attribute to any cost savings. However, points for improvement can still be found in the data collection or model input (M. Hoekstra and W. Couzy, 2002). This advice is taken into account and in addition did first conceptualization and data analysis conclude that redefining certain parameters can lead to inventory cost savings, which will be explained throughout this report.

3.3.3.2 Re-Order Point (ROP)

As was mentioned earlier in this chapter, within the engine shop certain materials are replenished based on a ROP planning and others on MRP models. An order point system, in this cased computer based, monitors the depletion of the stock-on-hand of each inventory item, issuing a replenishment whenever the supply drops below a predetermined quantity (ROP). By contrast, a material requirements planning (MRP) system plans to have on hand only the components required to support the 'final assembly schedule'. MRP systems are, on the contrary of ROP systems, often *pro-active* (Oden, 1975). This means that replenishments occur based on calculated expectations of stock out. Within the engine shop, the MRP models that are used are more of a *reactive* nature. This means that instead of relying on predictive calculations the system relies on extremely fast replenishment response by vendors, which is comparable to *Kanban* systems (Oden, 1975).

According to Oden et. al. a reorder point is always a sum of the quantity expected to be used during lead time, plus an extra safety stock in order to reduce the probability of a stock out during lead time. There are four factors which determine the reorder point quantity:

1. Rate of demand (In KLM: based on historical consumption collected from SAP)
2. Length of lead time (In KLM: contractually determined by vendors)
3. Extend of Demand and lead time variability (collected by SAP)
4. Degree of stock out risk acceptable by management.

The way reorder points are used within KLM engine services is in coherence with the literature. How the safety stock of this ROP is determined is described below.

The behaviour of the safety stock (SS) height can be explained by analyzing the way it is formulated in SAP. The formulation of the safety stock and the description of its related factors are described in Appendix I, as mentioned earlier. Three variables are key in the determination of the height:
(*note*: it is recommended to have the variable explanation list, that is shown in Appendix I, at hand when reading the next descriptions)

- *Delivery time*; The delivery time is a variable that influences the safety stock height, depending on its relation with the Norm time. The bigger the difference between delivery time (contractual lead time + 7 days) and the norm time, the bigger the influence on SS but less and less as it has goal seeking behaviour due to a square root. This square root function is added because it is wanted to have the inventory increased if a part is needing more time then there is time available. But if the lead time is very high, it does not mean that high stocks are needed. A second notifications is related to the fact that if delivery time is smaller than the norm time the ROP will go down linear. The added value of this delivery time factor on the safety stock is that the demand variation is covered in the period of reordering. If the consumption for a part is high on average, a long delivery time can contribute to a project delay as after the ROP was triggered the replenished material did not arrive within the timeframe of total stock consumption.
- *Mean absolute deviation*; This variable is generated to cover expecting variations in consumption (based on historical value's), which is the main function of a safety stock in a Just In Time Replenishment system. It calculates the average of the difference between monthly consumption and the basic value over a period of 12 months. The basic value is calculated as the average consumption over the same 12 periods or weighted over the last 4 months. This weighted moving average model is applied for materials with smooth behaviour (as it will respond faster to small changes) and with lumpy behaviour (as the occasional extreme value's will be filtered out faster). For parts with intermittent and erratic consumption behaviour, the moving average model is used for the calculation of the basic value.
- *Safety factor*; The variation in the past might not be representative for the future. A safety factor is added just in case the variation might be higher then expected. The determination of this factor is depending on part property (mostly price) which is indicated in the planning segment. The department of material management is responsible for allocating these safety factors to the planning segments.

3.3.3.3 Lot sizing

Lot sizing is a very important variable in terms of influence on inventory levels (see Fig. 15). Vendors often offer quantity discount for the large lot sizes, which together with order costs influences lot sizing decision making. However, if the lot sizes are not consistent with the demand patterns, then in-stock durations and therewith the overall stock levels, will go up. Theoretically, there is always a mathematical optimum for every purchase to be found, called economic order quantity (EOQ), as is shown in Fig. 21. The discounts of bigger lot size should overcome the additional costs of storage in the expected consumption time, in order to be preferable. For the engine shop this EOQ calculation is mostly interesting for the cheaper herb 3 parts, as for expensive parts the order costs are ignorable compared to the inventory holding costs. However in practice a mathematical calculation of the economic optimum is often difficult, because not al pro's and cons are quantifiable. In addition political games between different parties mostly affect lot sizing decision in practise. Even though these political purchases also occur at KLM, most of the lot sizes in purchases are determined by SAP. In SAP there are different options for lot sizing, which we will be summarized below.

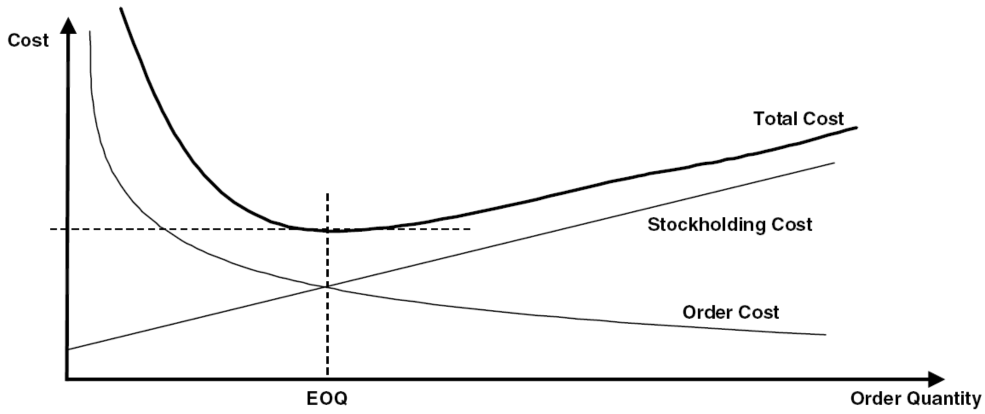


Fig. 21 *Economic Order Quantity (equilibrium) determination* (J.T. Dickersbach, 2007)

In SAP there are three categories of lot sizing, namely

- Static lot sizing, lot sizes depend on e.g. what has been consumed (lot for lot), always a predetermined lot size (fixed lot size) etc.
- Periodically lot sizing; lot sizes depends on the consumption in a specific period (e.g. daily, weekly, monthly)
- Economical lot sizes; lot sizes depend on the outcome of a selected economic algorithm. Examples are: Part period balancing, Least unit cost, Dynamic lot size, Groff reorder.

The general factors that are influencing the economic algorithms are: Demand pattern, length of planning horizon and the ratio between set up costs and material price.

There has been an internal research at KLM, to evaluate which type of lot sizing would most satisfactory for the engine shops situation. Below two important quotes on lot sizing, that were shown in the internal reported, are stated.

“There does not appear to be one “best” lot-sizing algorithm that could be selected for a given manufacturing/maintenance environment, for a class of items, and in most cases even for a single specific item. For purposes of material requirements planning, the lot-for-lot approach should be used wherever feasible, and in cases of significant setup cost (typical in the fabrication of component parts) any EOQ technique should provide satisfactory results”

“All the discrete lot-sizing algorithms are based on the implicit assumption of certainty of demand. This is the true Achilles’ heel of lot sizing, because, in most cases the pattern of future demand is never certain.”

The conclusion of the KLM research was that all ROP driven parts can be reordered according to the lot for lot procedure in SAP. For the non ROP driven parts, the reordering occurs according to the MRP (material requirements planning) which is currently set as ‘Least unit cost’ lot sizing. The Least unit costs procedure operates like this:
Non fulfilled demands are added up, taking their requirements dates into account, until a minimum costs per part is found. The costs consists of ordering costs which are 50 euro per order and inventory holding costs which is shown below:

$$\text{Inventory costs} = \frac{\text{Demand x price x } 0.18\,(18\%\text{ inventory costs) x days in stock}}{365}$$

In the real system, the difference between requirements dates of reservations, of parts without a ROP, are usually too high to define an economic order quantity, as parts need to be delivered on time. <u>Therefore in practice most parts will still be ordered in a lot for lot manner</u>.

3.3.3.4 Purchase ordering process

The material planners from the department Material Management are responsible for generating purchase orders (PO's) at vendors. The planner receives a purchase requisition which is the result of a not fulfilled reservation at the inventory or a crossing of the ROP from a specific material (see the conceptual models in paragraph 3.2.4 Logistical information flows). In Fig. 14 the information flow between the actors that will lead to purchase orders of components, is shown.
As shown in the object oriented description, a purchase order contains several attributes, such as part number, quantity, creation date etc. This paragraph will focus more on the attribute 'requested delivery date'. This variable is very important for this research, because it will tell how Just In Time a part is replenished and if the part will be on time or not. Vendors will steer according to the requested delivery date accurately, as will be explained in the sections 4.4 and 4.5.
Currently, by default the material planners will handle a purchase order as a warehouse procurement. This means the part is ordered for the KLM, and will also be stored for a short while until the (internal) reservation is fulfilled after which the part will be send to aprep and financially linked to the customer. This way of procuring is not always very efficient, as will be explained in paragraph 5.1.

The requested delivery date is linked to a purchase requisition as the creation date of the requisition plus the contractual lead time. For parts that are replenished due to ROP crossing the requested delivery is not very crucial. But for parts that are actually linked to a project it is very important. If the requested delivery date is beyond the aprep date, the part will arrive too late. If the date will be set before the aprep date, the part will arrive to early which goes against JIT principles.

Like was explained in the previous paragraph, the parts that are outside window are having a ROP planning, but the part that are within window have a MRP planning. When the MRP planning is activated, SAP will check if the requested delivery date in a purchase requisition is not crossing the requirements date in a reservation. If this is actually the case, the material planner will receive a notification to adjust the requested delivery date to a more early date. The planner will in most cases equal the requested delivery date to the requirements date. The previous paragraph explained that the requirements date is often set to early, due to some defects. This means that the replenishment under the MRP planning will not function as Just In Time as it is designed to be. However a requirements date that is set later than the actual aprep date can lead to purchase orders that will be received too late. This will however not occur in practice, as the requirements date is often earlier but never later than the actual project schedule.

3.3.4 Parts exchange process

With part exchange is referred to the exchange for one part for the other. The exchange of parts can occur in different situations, mostly based on a decision from the material management department. In this paragraph the exchange situations are discussed. The simplified exchange decision tree is visualized in 3.2.3 *Logistical material flows*.

Exchange after internal repair: When a part is repaired internally, it can occur that the repair fails. A reservation will be started that exchanges the specific part with a new part from the inventory. When no new part is available, a 2nd option could be to exchange with an other repaired part that is in inventory. This will be communicated with the client, who usually don't want to exchange repair parts with other airlines. The KLM engine shop applies a 'return own engine' policy, which means that repaired parts are from the clients own engine and other parts are new leading parts from a vendor. The 3rd option for exchange is to order a new part. This is option is not preferred as due to the lead time of parts a delay in project planning could occur.

Exchange during external repair: External repairs sometimes fail, or the external party notices that the repair will be taking more time then expected which can lead to a delay in the engine project planning. This will usually result in an exchange, of which the options are the same as in the internal repair

The process of parts exchange is very complex. A decision can often not be made by a standardized decision tree or other tool, but needs to be the result of an analysis of the unique situation. Some key variables that influence the decision making are:

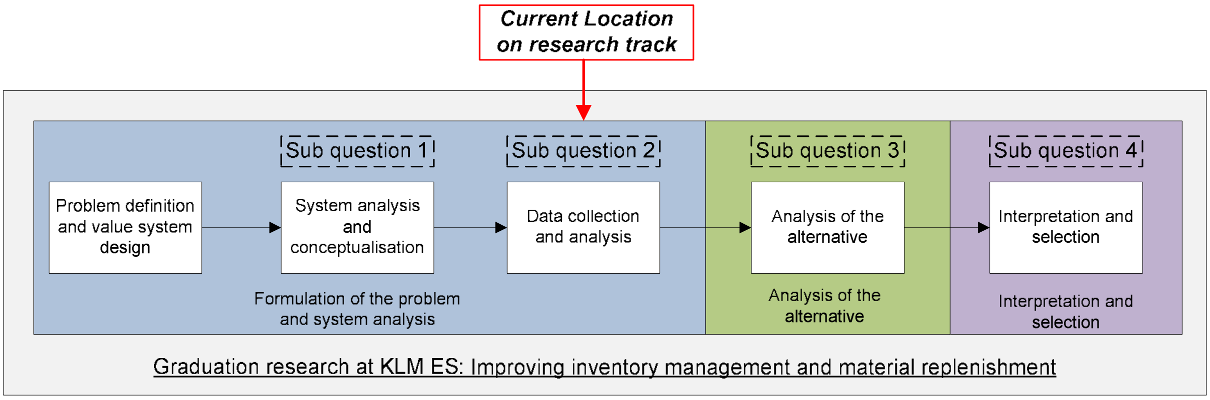
- *The moment of exchange decision making on the project schedule*; if the exchange moment is late in stage 2, fast has a higher priority then e.g. thorough price comparisons. In other words the options that provide fast solutions are having a preference over others.
- *Client demands*; clients can refuse or prefer certain exchange suggestions
- *Stock level*; Having a stock of new parts is a major advantage when an exchange situation occurs. It prevents project delays and the option is almost always accepted by the customer. The disadvantage of using new parts from the stock for an exchange, is the storage of the delayed repair part. As was mentioned earlier, clients do not like to have repaired parts from other airlines assembled in their engine. Therefore, repaired parts in stock usually result in being surplus inventory.

3.4 Conclusion system description and conceptualisation

First of all, this chapter gave more insights in the logistical processes at the KLM engine shop, which answers research sub question 1 (see paragraph 2.2). The conceptual models can help discussions later in this research, but can also be used for future research and discussions within KLM. A comprehensive analysis of the logistical processes has not been completed, documented and presented at the Engine shops' management, prior to this research.

It can be concluded from the material management algorithms applied, that KLM tries to minimize stock levels when possible, which is reflected into the use of ICT systems. It uses planning segments to activate inventory control models and replenishment models according to the logistical properties of the specific materials. It is an intelligent tool that tries to work as economically as possible in terms of having inventory, and when there is a ROP planning, in terms of the stock level height, lot sizing and safety factor. Theoretically, these algorithms that are applied, should result in a lean engine shop in terms of its logistical processes and related costs. However, the assumption that mentioned variables and parameters in these algorithms are properly applied, needs further investigation. The system controllers have indicated to be in an inefficient situation (see chapter 2). The reason that this still has not been completed even with these intelligent (ICT) algorithms at hand, needs to be investigated by measuring the performance of the logistical processes and have a more comprehensive analysis to the root of (potential) problems.

4 Data collection and analysis



The collection and analysis of data is key to any modelling or simulation study, but in this research especially. Therefore, an entire chapter is dedicated to this part of the research track. The chapter should give more insight in the performance of the processes that have been introduced in the previous chapter. This should lead to the answering of research sub question 2 as is indicated in the research track above

As was mentioned earlier during the system analysis, the logistical system at the engine shop is rich in detailed data. Even though this is obviously a much better situation than one in a data poor environment, it also brings along some points of attention. One should always question himself if the data gathered from a system is representing reality. For example the date related to the lead time of a repair process in the engine shop. In SAP this is measured as the difference between the start of the repair process until the start of the next process. In reality their might be a time frame present in which the repair is already completed but the part is waiting for the next process to start. Drawing conclusions from such data is risky and should therefore always be dealt with carefully. The saying "garbage in garbage out" also applies for modelling and simulation studies (A. Verbraeck, 2005).

As mentioned earlier, SAP is used for facilitating the information flow in the supply chain of the engine shop. In SAP, different essential steps are registered, together with their time of occurrence, after being entered in the software. Examples of these steps are Disposition outcome, Reservation creation, order creation and part Picked up at Vendor (PV). By analyzing these data we can make an evaluation of the current way of handling material. The data gathered from the system is present in massive numbers. The analysis is completed in either Microsoft Excel or Microsoft Acces and different statistical conclusions are drawn by using these mentioned software, SPSS or ARENA's input analyzer. The next paragraphs show these data analysis and give a conclusion about some system facts.

In this chapter the performances of different processes are measured. The sections are dedicated to the analysis of a specific process or issue. There is no clear flow presented in this chapter. But the order of the topics is in coherence with the previous and next chapter, as much as possible. For a few paragraph's a fixed sequence was necessary, for example first a description about lead times and then the analysis of vendor performance.

4.1 Monetary inventory composition

As was mentioned earlier, the material management involves 75 % of the total costs for an engine overhaul. Therefore it is carefully monitored by control engineers who report to the higher management. This paragraph uses data from the control engineers to draw conclusions. This date will help in understanding the significance of the problem. When improving processes it is always necessary to quantify the performance in order to understand what is going on. In this specific case, showing what the inventory levels for the different stocks in the engine shop are, gives an insight in were possible bottlenecks are and where there is a possibility for improvement.

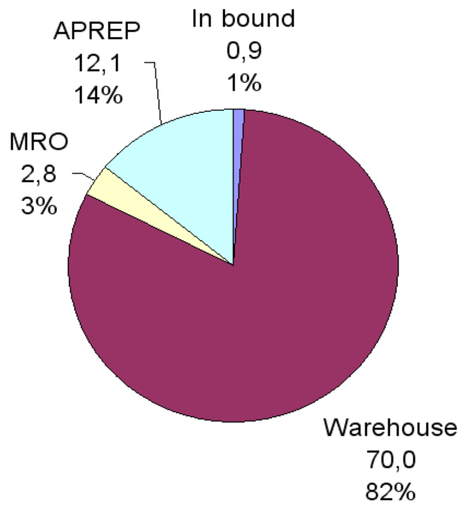


Fig. 22 *Composition inventory capital employed [million euro]*

The warehouse in the engine shop is representing the most significant part of the total inventory capital employed, namely 82% (see Fig. 22). With 14 %, APREP is a significant second contributor to the total capital employed. For the determination of the ROP in the warehouse, the stock levels in APREP are not included. The ROP in SAP are set to have a JIT replenishment system in accordance with a defined service level (see paragraph 3.3.3.2). Thus, the aprep inventory that is used is additional stock that is working against the JIT philosophy. When reservations would be adapted to deliver JIT to the aprep inventory, a significant amount of money is expected to be saved, which is elaborated in section 5.5.

One note concerning the amount of capital employed in the warehouse should be given. The norm stock, which is an accumulation of all the ROP's registered in SAP, is representing 23 million euro of capital employed on the warehouse. This means 2/3 of the capital employed in the warehouse of the Engine shop is filled with parts for which no stock is wanted. Most of these parts concern parts that have extreme low consumption, or parts that are not airworthy anymore due to the requirement of higher technological standards. Most of these parts need to be salvaged or sold on the market (often with big losses in terms of sunk costs). In this research, this surplus inventory is considered to be out of the scope. However, one notification should be made: by reducing norm stock levels, which is basically the focus of this research, the risk for having parts that expire reduces, as the in stock duration will drop (assuming accurate forecasts). In other words, this research could contribute in reducing the rate at which surplus stock is filled. The avoidance of surplus in the future, can be an interesting scientific research. Getting rid of the current surplus is more appropriate for salesman to solve.

Purchasing and consumption

Stock levels are also depending on how parts are procured, as was explained in 3.3.3.1. Besides lot sizes, the type of procurement can have several cost (dis)advantages over the other. In the engine shop two types of procurement are separated, namely direct procurement and warehouse procurement. Of all the Purchased Orders that are placed, about 20% concerns direct procurement (20 million euro annually), which means that the part is dedicated to a project and will not go to the warehouse. In terms of capital employed, most purchases orders, namely 80%, result in a warehouse delivery instead of aprep (125,8 million euro annually). A significant part of these warehouse deliveries are not due to ROP crossings. Theoretically, a part only needs to be procured for the warehouse if a stock is planned for this specific part. The chosen procurement type can have effect on cost efficiencies, which will be elaborated in section 5.1.

4.2 Parts and disposition

This paragraph give insights in the size of the three main logistical streams (rejected, overhauled and unserviceable) that were presented in paragraph 3.3.2. Rejected parts need to be replaced by other (new) parts. As this logistical stream involves the replenishment process and inventory control, it is the one that has the focus in this research. The repairs (unserviceable) and serviceable parts (overhauled) are the biggest streams in terms of the number of parts per project that follow the root.

As was mentioned in paragraph 3.2.3, all parts classified as Herb 1 are brought to parts and disposition (P&D) for inspection. In SAP the parts and their result of P&D is recorded. From analyzing the SAP output data, the percentages of parts with a status of Reject (REJ), unserviceable (US) and overhauled (OH) are calculated, which is visualized in Fig. 23. There can be several reasons for assigning a reject status, which is explained by the number (e.g. REJ 7)

As can be seen from the diagram, 60% of the Herb 1 parts needs repair during the engine MRO. Of the parts that are being repaired, still a significant amount will result in a reject status, which means a new part is required.

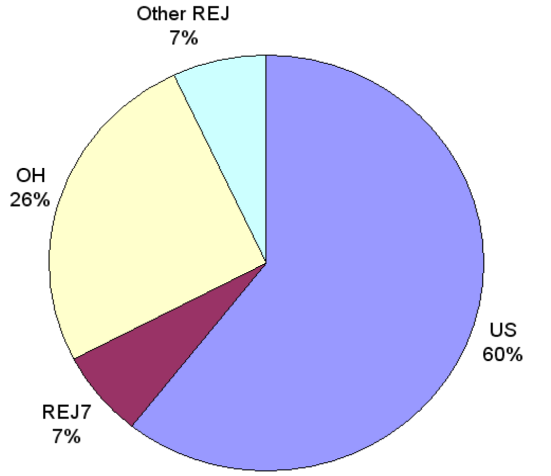


Fig. 23 *Status outcome after P& D of Herb 1 parts*

4.3 Comparing static planning SAP with actual project planning

As was concluded from the causal relation diagram and discussions on planning segments in chapter 3, the replenishment window is a key variable determining the decision on having stock. In paragraph 3.3.2.2 the way of measuring the replenishment window is discussed, and the implications that can arise with it. In this paragraph these implications are quantified. Therewith, one part of the performance of the current way of inventory control is analyzed.

From data analysis on the current stock a remarkable fact has come above. From the norm stock level that is set at the Engine shop, around 50% of all the part numbers has a lead time that is shorter then the theoretical replenishment window. This replenishment window is set at 24 days, which is the length of stage 2 (35 days) minus 4 days for Aprep check and minus 7 days for transportation and incoming goods. These parts that have a smaller lead time then the replenishment window are responsible for an employed capital of 9.5 million euro's. These parts are candidates for being replenished in a JIT manner.

The resulting hypothesis is that the requirements date is not corresponding to the actual project planning, as was mentioned in chapter 3.3.2.2 *Determination of the replenishment window*. The direction of this difference is negative. Which means that the requirements date is set in SAP to early which leads to the measurement of a replenishment window that is lower than the actual replenishment window, which in return has a significant impact on stock level decision making. This hypothesis has been proved by comparing SAP data with the actual project planning, which is documented by the CRO department. The details below given an indication of the error.

Project8C/0079273 (80C2 Engine)

In SAP	Aprep date: 14-02-2009	In CRO planning	PD: 17-04-2009
	Req date: 04-02-2009		

Project 7B/0078912 (CFM56-7 engine)

In SAP	Aprep date: 08-04-2009	In CRO planning	PD: 11-04-2009
	Req date: 24-01-2009		Start stage 0: 18-02-2009
	Basic start: 18-02-2009		

Project 8E/0078911 (80E Engine)

In SAP	Aprep date: 03-04-2009	In CRO Planning	PD: 06-04-2009
	Req. date: 27-01-2009		Start stage 0: 14-02-2009
	Basic start: 19-02-2009		

We can conclude from these data that the actual planning is also documented in SAP as the Aprep date in SAP mostly corresponds with the actual PD (always 3 days earlier). In addition is the basic start date in SAP corresponding with the start of stage 0 in the CRO planning. However, the requirements date is not linked to these schedule changes that are entered in SAP. This has to do with the way the requirements date is formulated in SAP.

After a thorough analysis in cooperation with SAP consultants, the formulation of the requirements date is found together with some examples that can confirm the earlier stated hypothesis. After examining the programming in SAP it can be concluded that the Requirements date is equalling the earliest finish date aprep in SAP. When the earliest finish date aprep is not specified by a SAP user from the KLM, it is set automatically at a date that is equalling the project starting date in SAP plus the norm times (as was explained in paragraph 3.3.2.2 Determination of the replenishment window). At the KLM engine shop, the registration of an engine project in SAP is completed far before the start of the actual work. This results in a too early defined aprep date. When a reservation is created, the requirements date will be calculated depending on the Earlies Finish Date (EFD) aprep. However, if the EFD aprep is set in the past, meaning before the creation date of the reservation, the requirements date will be equalling the creation date.
In Fig. 24 a list of reservations is shown chronologically, together with their related requirements date. At 13.06 that day, the CRO has updated SAP according to the actual project schedule. From that moment the requirement date is realistic again, which means that the vendor has 33 days to replenish the requested material, instead of 0 days. This has a significant impact on the determination of ROP heights in SAP.

Reserv.	Creation	Time	Req. date	source
8448788	24-02-09	13:02:25	24-02-09	1070
8448790	24-02-09	13:03:04	24-02-09	1070
8448794	24-02-09	13:03:48	24-02-09	1070
8448799	24-02-09	13:04:29	24-02-09	1070
8448802	**24-02-09**	**13:05:28**	**24-02-09**	**1070**
8449343	**24-2-2009**	**13:06:11**	**29-3-2009**	**1070**
8449346	24-02-09	16:18:31	29-03-09	1070
8449369	24-02-09	16:24:22	29-03-09	1070
8449370	24-02-09	16:31:21	29-03-09	1070
8449375	24-02-09	16:33:58	29-03-09	1070
8449377	24-02-09	16:46:20	29-03-09	1070

At this moment the CRO has insert the earliest finished date aprep that is linked to the project schedule

Fig. 24 *Reservations with requirements date*

4.4 Lead time

In the previous chapter was indicated that lead times have a crucial role in inventory control and material replenishment. Contractual lead times are used for making stock decisions and for the replenishment in warehouse procurement (see next paragraph and 5.1 for additional discussions). The actual lead time has a (indirect) causal relation with project duration (delays), which makes it interesting to gather statistics on this variable. Also the relationship between the lead time that is requested and what was actually performed is analyzed. The analysis performed in this paragraph is a significant measurement for the supply chain performance (between engine shop and vendors).
First a small explanation of the different lead times, as they are defined and applied in this research, is given.

Contractual lead time is the lead time that is defined as the standard lead time of a part after a purchase order, unless the user defines it differently. In most cases these standard lead times are defined in a contract with the Vendors. This lead time defined in the contract is a maximum lead time, crossing these contractual lead times on a regular basis can lead to financial penalties.

Requested Lead time is the time between the creation of the purchase order and the requested delivery date (RDD). In some cases the RDD entered in SAP is before the creation date of the purchase order, in that case the part is needed as soon as possible. This might be a result of an exchange situation. An example would be that the internal repair of a part eventually failed, thus a new part is ordered as a replacement.

Actual lead time is defined as the number of days between the creation of the purchase order and the moment the part is Picked up at the Vendor (PV).

When an order is created in SAP, the software automatically generates a requested delivery date as the creation date plus the contractual lead time. The material planner can however, change this requested delivery date manually if the situation requires so. From the data analysis can be concluded that in 47% of the generated orders the requested lead time equalled the contractual lead time. Of the generated orders 45% were having a requested lead time that is shorter than the contractual lead time and 8% longer.

Another aspect that is interesting to know is how often the requested lead time is actually met. Fig. 25 visualizes the purchase orders of half a year with their requested and actual lead times (filtered below 50 days as any lead time above 50 days is very exceptional). If the logistical system was perfect, the requested lead time would equal the actual lead time which is visualized by the red line ('in time diagonal'). All orders above the line arrived later then wished , which could lead to delays later in the system and orders under the line arrived too early which can results in a temporary inventory that can be considered as excess capital employed. As can be seen, most orders are scattered around both sides of the line meaning that improvement can still be searched for. The fact that a significant amount of the parts arrive later than requested, is in 63 % of the cases not due to vendor underperformance. This means that in most of the cases in which an order is later then requested, the requested lead time was most probably defined to ambitious and unrealistic. However this ambitious setting of requested lead times can be explained by the very big grey part that underlies the contractual lead time. As mentioned earlier is the contractual lead time the maximum time a vendor gets for fulfilling the order. There is no information on a minimum lead time in which the vendor can fulfil an order and about the conditions. If the vendor has the part in stock, the order can often be fulfilled in a few days. In other cases the part needs to be processed in someway (produced/assembled etc), which will result in a longer minimum lead time. This will be analyzed further in the next section.

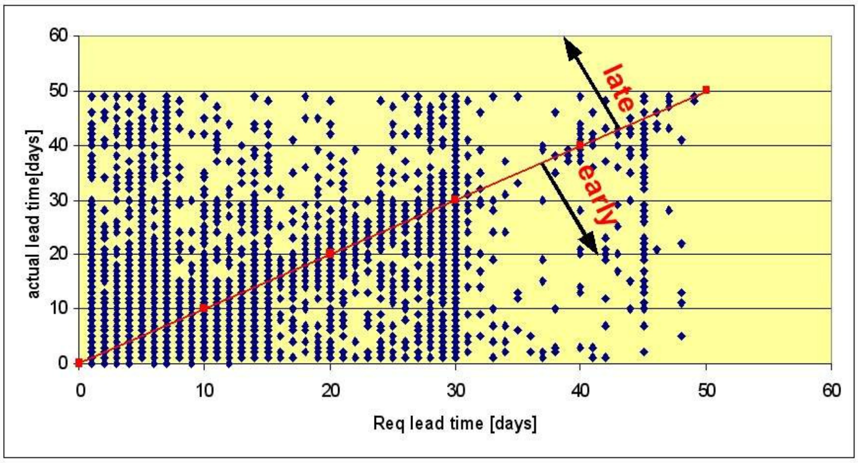


Fig. 25 *Requested lead time VS actual lead time*

When considering the graph above, the material replenishment at the engine shop looks very troublesome, even when requested lead times are often set ambitiously (as was mentioned earlier). However, the graph shows thousands of orders that are measured over a long period of time. Therefore it is useful to display the situation 3 dimensionally, which is shown in Fig. 26. This figure shows that most of the measurements are mostly spread very near the '*in time diagonal*' in steep normal distributions. This 3d graph indicates that the performance of the replenishment system is actually very well, whereas the 2d graph looked troublesome.
It can be noted from the diagram that there is a set of normal distributions located on the 'ReqLeadTime' rows. This has to do with the fact that most purchase orders are completed as a warehouse procurement, in which the requested lead time is equalling the contractual lead time by default (see paragraph 3.3.3.3 and section 5.1). Furthermore, most of the materials have a contractual lead time located in a specific 'lead time group' as is elaborated in section 5.7.

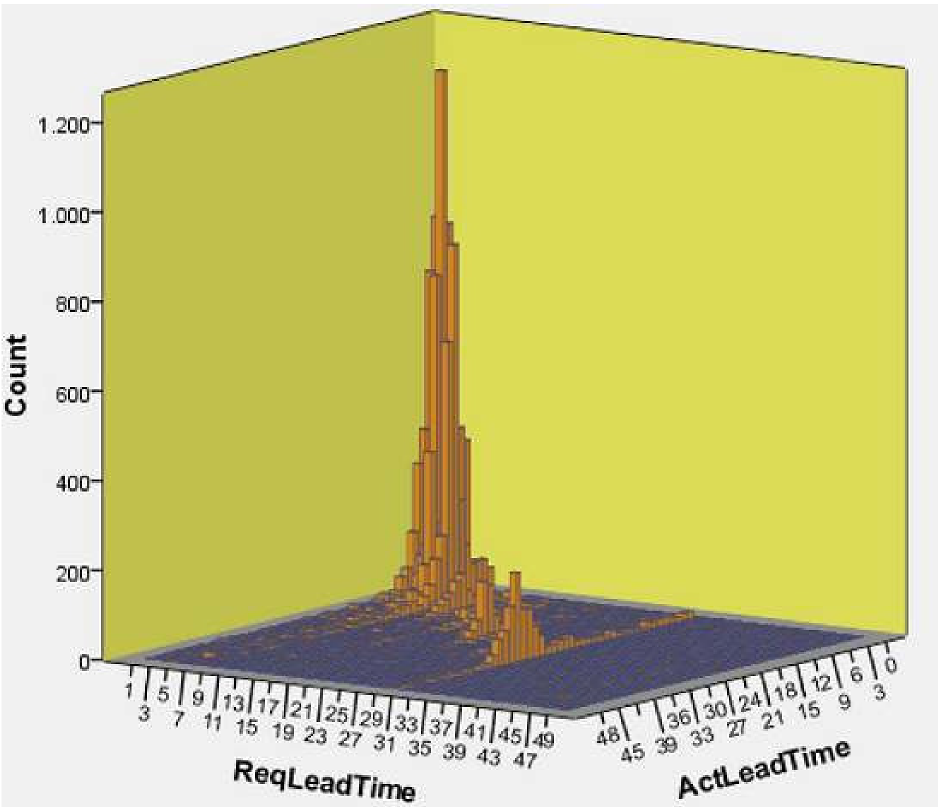


Fig. 26 *3D visualization of the performance the material replenishment at ES*

4.5 Vendor performance on order processing

This paragraph discusses the vendor performance under different conditions. The previous section indicated that there is uncertainty concerning the actual capabilities of vendors. This section tries to measure performance to give an indication of the capabilities of vendors.

As mentioned before, 47% of the orders has a requested lead time that equals the contractual time. The initial hypothesis was that in most cases vendors will send the ordered part as soon as possible, however from the analysis can be concluded that the vendors steer fully based on the requested delivery time which is visualized by the graph below. This conclusion has been drawn from a filtered data set, which included the 47% of the cases in which the requested lead time equal the contractual lead time. This filtering is performed as from these data the most reliable conclusion can be drawn concerning vendor performance. If the requested lead time is only one day while they contractual lead time is 30 days, it will be difficult for the vendor to deliver the order as requested.
Fig. 27 indicates that the vendors steers according to the wishes of the KLM engine shop. The graph shows the counts of individual delta lead times (actual minus contractual lead time).

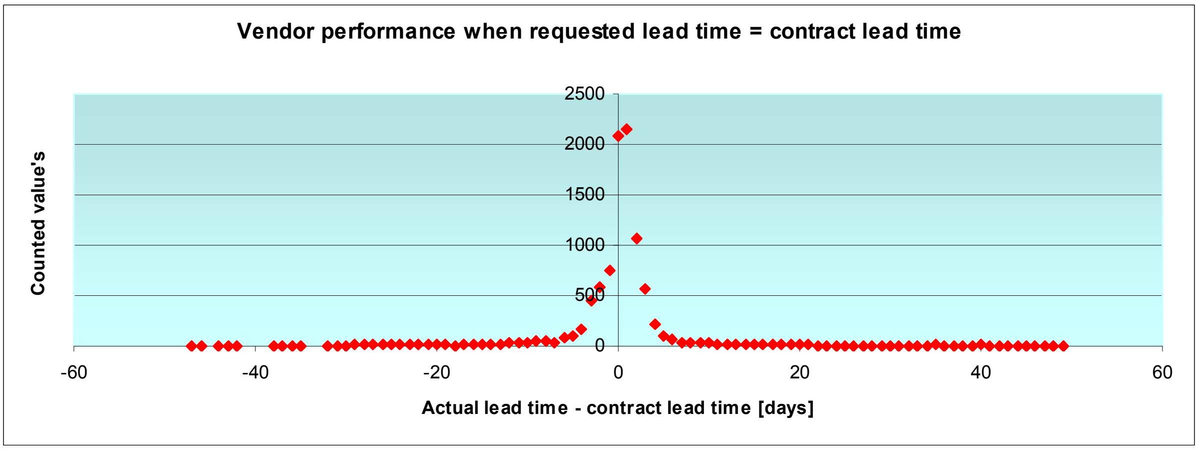


Fig. 27 *Vendor delivery performance when requested lead time equals the contractual*

Note: In the graph above, 89% of the delta lead times are located within 3 days around zero, which means that the vendors almost always deliver as requested when the requested lead time equals the contractual lead time

In Fig. 28 the vendor performance is visualized under the condition of contract ignorance, which means that the material planner at KLM requested a lead time that is significantly shorter (<10 days) then the contractual lead time. It is interesting to see how the vendor will perform in such cases. Will they stick to the contractual lead times or will they try to obey customer wishes, and if so can they fulfil them often or not. To get an indication of the vendor performance under this condition the same graph as before is shown, but now filtered to the cases in which the requested lead time was at least 10 days shorter then the contractual lead time.
The graph again shows a steep normal distribution, with its peek on 0. This means that the vendor always steers according to the requested lead time, and is often successful in doing so (under the filtered conditions). As the normal distribution is very steep, it does not require a statistical test to proof this conclusion.

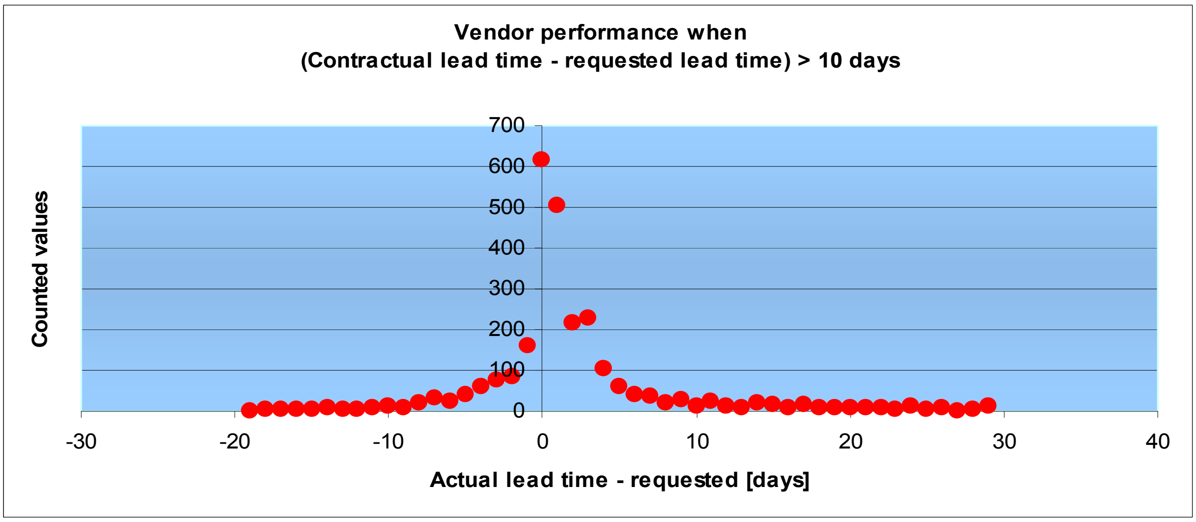


Fig. 28 *Vendor delivery performance under contract ignorance*

4.6 Repair

As explained in the previous chapter, repairs can be completed internally or externally. The external parts are the most critical for the engine planning in terms of Turn Around Time (TAT). The analysis of these repair duration can give insights in why delays occur.

4.6.1 Internal repair duration

In SAP every single repair process is documented. One specific part can flow through up to almost 20 different repair steps to complete its total repair. Raw data has been collected from SAP and the average total repair length per material number has been determined as 25 days. The related variation was found to be very high, as the type of repairs are very different case. A clustering of material, just like for other variables, is recommended when making a model in future research. The outcomes of internal repair duration are not used in this research, as its performance is not critical for project duration, but it can be in future research.

4.6.2 External repair duration

The external repair duration is the most interesting performance indicator concerning the stage 2 lead time (TAT) in the engine shop, as the external repair has the longest duration compared with all other material flows (e.g. new parts or internal repair). In other words the length of stage 2 is currently depending on the external repairs, which makes it a bottleneck (Goldratt, 2007). Within KLM ES the search for lead time reduction is a continuous process as it will reduce their own costs and in addition it gives them a stronger position in the competitive market.
The external repair duration also has an indirect influence on the possibilities for JIT replenishment and therefore on stock levels (see the causal relation diagram in Fig. 15). If external repair durations would be reduced, the length of stage 2 would be reduced and along the replenishment window for ordering new parts. Smaller replenishment windows lead to stock increase as vendors have less time to fulfil demands which could lead to an increase of uncertainties related to project delays.

The figure below shows vendor performance for external repairs over two annual periods.
Long refers to delays that are caused by the contractual lead time being longer than the defined replenishment window of 24 days. The term late (in red) means that the vendor delivered a repair part late even though its contractual lead time is within 24 days. Both long and late means a delay for engine services (unless an exchange takes place, see paragraph 3.3.4). However, separating these two classes is very important as there are different alternatives for solving these two unwanted situations.
As can be seen below, in both years most of the orders were fulfilled on time. These periods were measured before the ship smart policy was introduced. The ship smart policy has lead to a significant improvement of the vendor repair performance. Most of the external repair parts currently arrive on time. This conclusion is quoted from an interview performed with a Six Sigma Black Belt from KLM. This black belt has also provided the pie chart below. Data analysis on the current performance, which means after the introduction of ship smart, has not been provided yet.
In this research, the reduction of TAT (Turn Around Time) did not have a focus. In addition, Black belt professionals are performing research on this matter already. However, like stated above, it should be taken into account that TAT reduction has an influence on inventory control (due to smaller replenishment windows, see section 3.3).

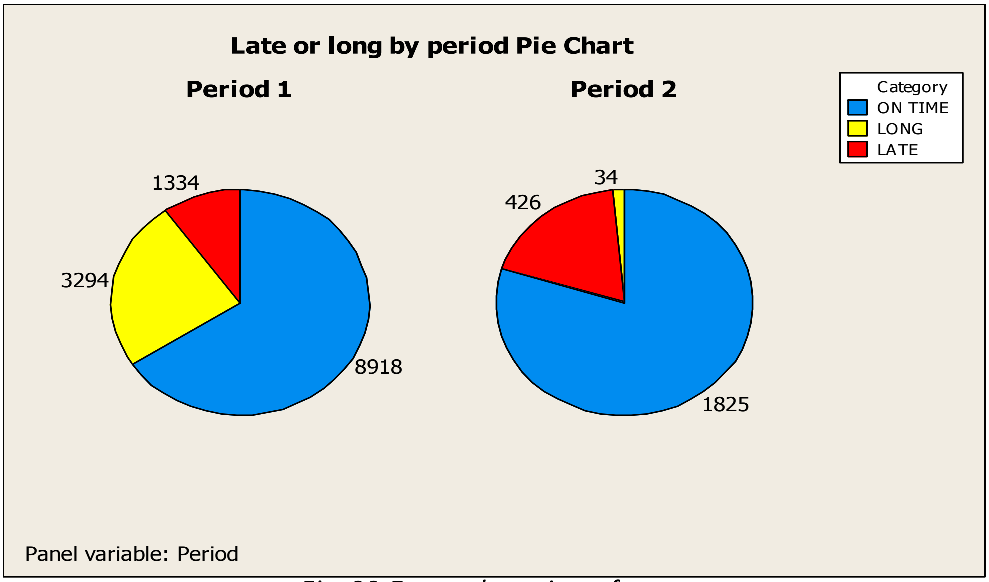


Fig. 29 *External repair performance*

4.7 Lead time grouping

The material flow that is generated during the MRO of an engine is so extensive that simulating al individual parts as entities in a simulation model would be close to impossible. More effective would be the grouping of different part types according to commonalities regarding its attributes. Examples could be a grouping according to vendor lead time for new parts, duration of repairs or on part price. Analyzing the behaviour of a cluster of material instead of individual parts has two advantages. First it is less time taking and second it gives an idea of all the materials in that group, a single part might not be a good representative for other parts.

The clustering of materials according to lead times is searched for. For the materials with the logistical A classifications the contractual lead times are analyzed. The result is shown in Fig. 30. Four lead time groups are created. The groups have the following representation of the total parts list:

Group 9 represents 6% of all materials
Group 13 represents 59,8% of all materials
Group 25 represents 11,2% of all materials
Group 37 represents 23% of all materials

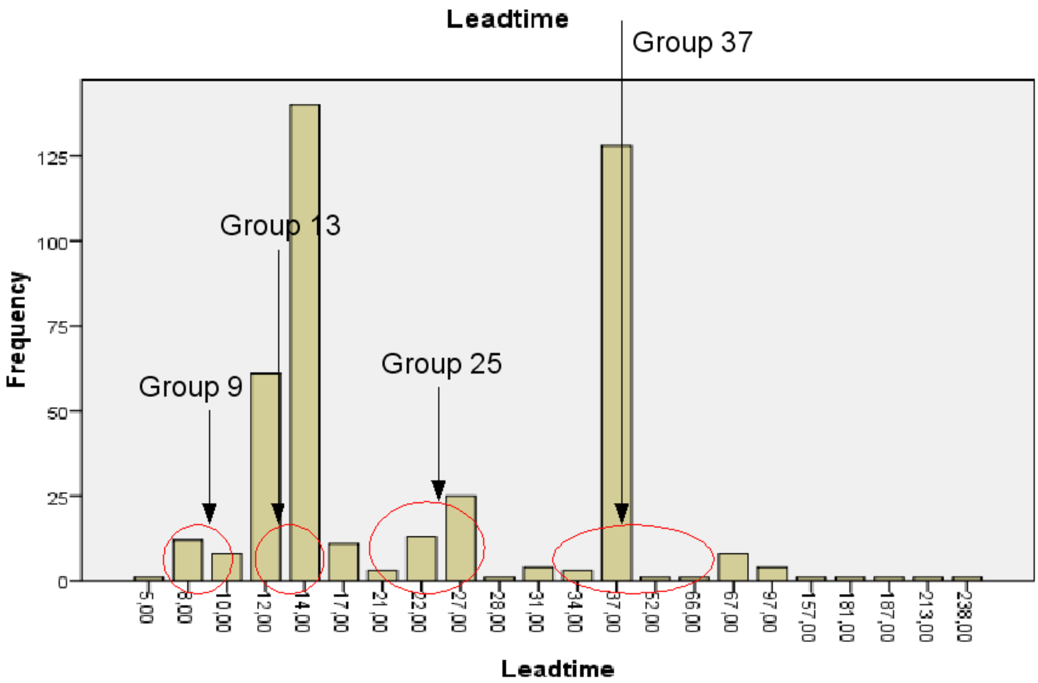


Fig. 30 *Frequency of material numbers per lead time and related material grouping*

Mapping out the lead times from vendors gives insights in the possibilities for JIT replenishments. Group '9' and '13' are theoretical candidates for a JIT replenishment (within replenishment window of 24 days) which means deactivating ROP planning. In addition can grouping of material by lead time facilitate making a more compact and understandable simulation model. In this research there is not a simulation model generated that used the lead time grouping, but it can be supportive for future research. Nevertheless can this classification according to lead time facilitate the understanding of the significance of problems and potential cost savings. For example, the impact of implementing the alternative described in section 5.3 is more clear when using the results of this analysis.
Another note can be posted when considering these lead time groups. In section 4.5 was concluded that vendors can perform better then contractually defined. Fig. 30 could facilitate that statement as it is very questionable if al those thousands of unique parts that are used in the engine MRO have very similar actual lead times (which should be a reflection of production times).

4.8 Consumption measurements

As was mentioned in the system analysis and conceptualisation chapter, stock levels are highly depending on historical consumption (demand). This historical consumption is, as was also mentioned, registered by the SAP system. It is important to not make assumptions about the functioning of ICT systems that fulfil essential tasks in a company's business processes. Capital employed in the inventory is a significant part of the total costs of the engine shop. Therefore any parameter that has a high influence on the determination of the inventory height should be well analyzed. One way to check if consumption is measured correctly is by comparing the different logistical streams financially. Changes in capital employed should be the result of an imbalanced financial in and out flow. Visa versa, a constant inventory in terms of capital employed will require a balanced financial in and outflow.

The inventory at the engine shop has seen no radical changes in terms of capital employment in the passed 18 months. However in April and may 2009 the official financial report of the engine shop showed a procurement of 80 million euro's and also a consumption of around 80 million euro's. The consumption is gathered from SAP and is calculated in terms of money. The value's in SAP should be of a comparable level as in the financial report. The calculation from the SAP data showed a annual consumption of 150 million euro. This significant difference was the trigger to start a more comprehensive research of the definition of 'consumption posting' in SAP. In SAP certain movement types (transactions) are registered as consumption. Depending on their direction there are registered as a positive or negative consumption, influencing the total annual consumption. The use of these movement types is explained in paragraph 3.2.3 *Logistical material flows*.

It is found that certain movement types are registered as consumption in SAP, even though, from a logical perspective, they should not be registered as such. A more detailed investigation is suggested in section 5.4

The measured consumption in SAP has a linear causal relation with the ROP of a part. This means that if the consumption measured in SAP has significant differences with the financial reports, some problems have been occurred. As was mentioned earlier, the reports of April and may showed a balanced in and output of around 80 million. However, in the months June, July and august of 2009 the financial reports showed an in and output of around 130 million euro. Afterwards is found that the financial reports in may and April were based on wrong calculations. This means that the 130 million is an indication of the actual flow. This is still a significant difference with the 150 million that is still indicated by SAP but less then was assumed before. In other words there is room for improvement. This situation proves once more that data (source) validation is very important for research conclusions.

4.9 Conclusion data analysis

From this chapter several conclusions, that have significant impact on the formulated key performance indicators and/or research question(s), can be drawn, which is listed below.

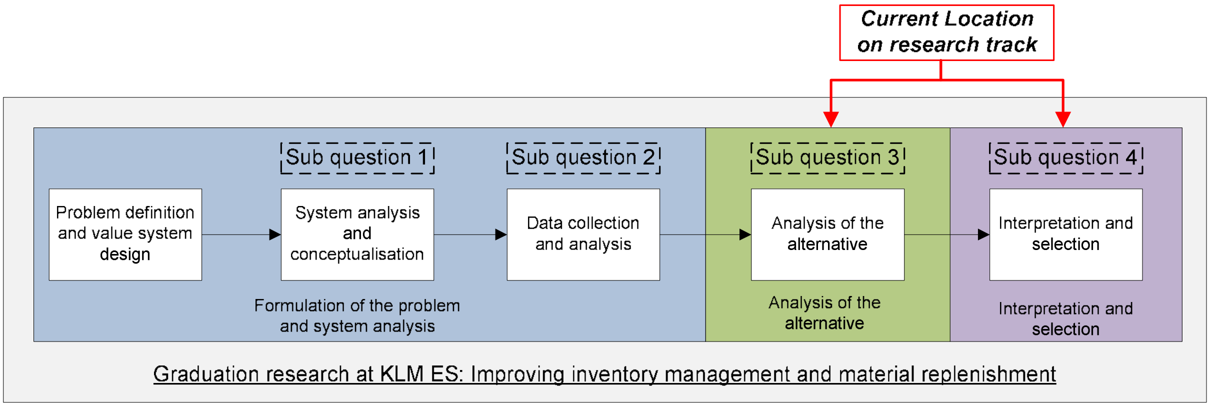
1. A first conclusions concerns the requirements date. It is found that this date is often showing a wrong date (too early) on the reservations. We know from the conceptualisation that too early requirements dates will result in a lower measured replenishment window, which can lead to an activation of ROP planning. The data analysis has shown that the requirements date is at first the project activation date in SAP plus the norm time, until the CRO department updates the aprep date in SAP. It is estimated that millions of euro's of excessive stocks are the result from this static planning in SAP.

2. Vendors steer according to the requested delivery date that is set in purchase orders, regardless of the situation. If a purchase moment is placed at the vendor at moment X. But the requested delivery date is 4 weeks after date X, the vendor will still make sure that the part will be there exactly 4 weeks later, no sooner nor later. The hypothesis that vendors delivery on a 'as soon as possible' basis, can be rejected.

3. Vendors can often deliver faster then the contractual lead time. The SAP system uses contractual lead times for the activation of ROP planning by checking if the lead time fits in the average measured replenishment window. However the contractual lead times are a given from the vendors, no evaluation of the lead time as been completed. The analysis showed that most vendors could still deliver accurately, even when setting a requested delivery date 10 days before the contractual lead time would allow.

4. The monetary parts consumption in SAP is significantly lower then conclusions in the financial reports, which is 150 to 130 million euro's respectively. This difference is due to an incorrect use of movement types for the registration of consumption in SAP.

5 Creation, explanation and evaluation of alternatives



This chapter describes the alternatives that have been derived from this research. During system analysis different suggestions have been raised by KLM personnel and by the analyst. However not every alternative has been worked out as a boundary is set for the alternative generation. For the selection of alternatives for further analysis the flowing limitation is applied:
Alternatives get a priority over others if the overall requirements are more favourable then others in terms of *research time needed, expected resources and investments needed* (Euro's) and *the gains* (cost saving) in euro's.
The annalist has to make a selection of alternatives, for further investigation, based on an estimation of these criteria. Some alternatives that did not meet the criteria, as well as the elaborated alternatives in this report, are:

Vendor Managed inventory; Vendor managed inventory could potentially lead to cost savings for KLM. First of all because the current inventory is located at Schiphol Airport, which is a very expensive location. Secondly, because in theory, Supply chain communications are improved as the vendor has full insights in the inventory control and related (historical) demands (Achabal et al, 2000). However this alternative was not chosen, as the other alternatives that are elaborated in this research should be able to reduce stock levels significantly. A full shift from the current inventory to VMI would be impossible as there are always unexpected needs in the engine shop (e.g. when a repair fails at the end of stage 2). A careful selection of materials then has to be made. In addition would this shift bring significant organization change and significant related costs, which the other alternatives did not have.

JIT delivery to assembly; this alternative would imply that parts are delivered right before they need to be assembled. The condition, under which this alternative would be interesting, is that there is a significant amount of expensive parts that are assembled in a later phase of stage 3. This would lead to a smaller WIP (work in progress) stock. However this condition is not met. In appendix VII a conceptual model of the assembly steps are shown. Almost all (expensive) parts are necessary at the first days of stage 3. That means there is almost no added value of the alternative. The major disadvantage of the alternative is that there would be no possibility for a C-check anymore in Stage 2, which means there is less certainty on the completeness of engine components at the start of the assembly.

The alternatives that are suggested in this report are effecting the system on different abstraction levels. Some alternatives suggest a change in (SAP) algorithms (like 5.1 and 5.4), other suggest informing and educating personnel on algorithms (5.3) and other alternatives requires structural changes in the business processes of the engine shop bringing along organizational changes (5.5). For every alternative the creation process is mentioned together with an explanation of the alternative, a description of expectations on system behaviour (when significant) and an evaluation of the alternative. This evaluation of alternatives is mostly accomplished by means of discussion with key actors.

First should be noted that during the entire process of analyzing the system and generating alternatives, actors from different levels are interviewed, which facilitated a practical formulation of the alternatives. After the generation and rational evaluation of the alternatives, the alternatives are presented in several meetings after which discussion took place. These discussions function as a important evaluation step. The managers in KLM have a lot of practical experience and can foresee practical implications that are sometimes difficult to realise from theory. The suggestions that arose from the discussion are included in the description of alternatives, and their expected impact on system behaviour.
In particular the *JIT delivery to aprep* policy brought discussions as it brings along organizational changes. There was a doubt if the inventory would have efficient capacity in busy situations, which was the reason to make a small simulation model (see 5.5.4). Also the conditions for success, e.g. correct estimation of days necessary for all the processing before aprep date, need to be carefully formulated and analyzed.
The other alternatives are mostly related to small adaptations in SAP parameters or in definition of algorithms. The operations of actors will not, or hardly, be affected by the implementations of these policies.

5.1 Direct procurement

5.1.1 Generation of the alternative
As was reported in paragraph 3.3.3.4, the process of purchase ordering was analyzed. Initially the goal of this analysis was to see how material planners generated the requested delivery date in a purchase order, as this date will tell how JIT the purchasing process is. But from interviews with material planners was found that this date is always the creation date of a reservation plus the contractual lead time. They elaborated that this is in accordance with the warehouse procurement procedure. However parts that have no stock don't need to be procured for the warehouse, which means other procedures can be used, that can lead to cost savings, which will be explained in this paragraph.

5.1.2 Explanation of the alternative
Currently within the Engine shop, the material planner will define manually in a purchase order if the order is a direct procurement or a warehouse procurement. Direct procurement means that the order is dedicated to a project. This type of procurement has advantages for two flows, namely financially and physically. In the financial flow, the order is linked immediately to the project, whereas a warehouse procurement is handled as a normal stock product and will be linked to the project later, which means another administrative step. The physical flow is also shorter, as the ordered part will go directly from incoming goods to aprep and skip the warehouse (aprep route in Fig. 11). If a part is actually dedicated to a project but is defined as a 'warehouse' procurement, it will undergo unnecessary physical steps in the warehouse. In addition do the additional steps of warehouse procurement create risks of damage or risks of delaying the project (which involves very high costs), as the extra steps take time.

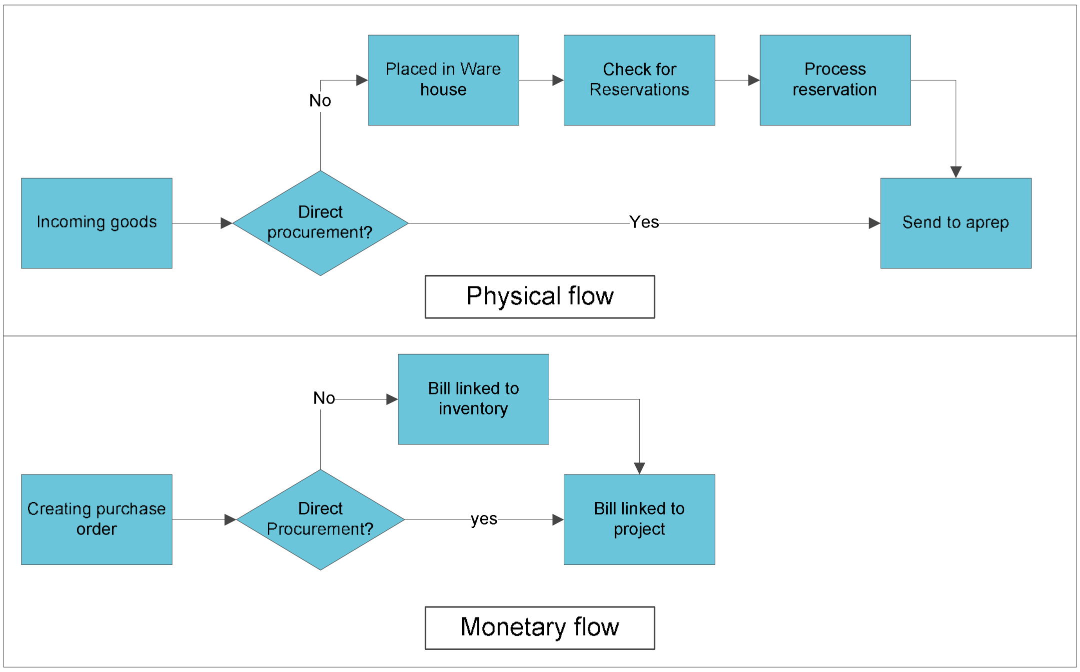


Fig. 31 *Direct VS Warehouse procurement*

Concluding from interviews with several personnel from the department of material management, it is found that in most cases a direct procurement is not given to a purchase order of a part that is actually dedicated to a project. In other words, the material planners will in most cases manually set dedicated parts as a normal purchase which is a 'warehouse procurement', which has disadvantages, as was just mentioned. The reason they do not use direct procurement is because the current 'direct procurement' option in the SAP software generates a related bill for the part that is 70 % of the standard price. The current direct procurement option is only meant for serviceable parts, which are parts that are second hand parts that are still (or again) qualified to be installed in the engine. The customers can not be charged with the same price as a new parts.

An alternative way of working would be to make a modification in SAP, which will automatically generate a direct procurement when the purchase order concerns a part that has a ROP equalling 0 (MRP planning). If there is no ROP it means that the part that will be ordered would be dedicated to the project anyway, but under a 'warehouse procurement' it would include unnecessary additional steps. This modification is a 'new' direct procurement options, which should concern new parts only.
If a modification in SAP is costly, material planners can be instructed to always handle a purchase as a direct procurement if it concerns a part that has an ROP equalling 0.

5.1.3 Evaluation of the alternative

Apart from the SAP programming, this alternative does not bring any implications. No change in organization or reengineering of business process is required to implement this alternative.
In addition is the change that will be generated in the system easy explainable, as is shown above with the facilitation of Fig. 31. For the evaluation, interviews are performed with material planners, inventory staff, and MRO managers from the engine shop. All related parties acknowledge the advantage of direct procurement in the described scenario's (no ROP planning). No complications are expected.
For an evaluation of the alternative in terms of cost saving, a quantification of costs could be calculated by the number of days it takes before a part is allocated to a project (days in inventory). Secondly by the man hours that can be saved in the inventory, which is estimated as 10 minutes per part. Thirdly by the risks of damage. Currently there is not enough data available to make this quantification of cost savings.

5.1.4 Application of requirements date planning for direct procurement

If the direct procurement alternative is implemented, it is important to consider the requested delivery date that is linked to the order. In terms of cost reduction, it is preferred to work in a JIT manner. In addition should parts not be requested too late.

Currently, a requested delivery date is linked to the purchase order (PO) that equals to the moment of PO creation plus the contractual lead time (warehouse procurement). Taking the contractual lead time as the requested lead time is acceptable for warehouse procurement as it should not have the necessity to be delivered at a fixed date because it would logically concern a crossing of the ROP. For the application of Direct Procurement, however, it is strongly recommended to make sure that the requirements date, which is linked to the reservation and purchase requisition, is used for formulating the requested delivery date (RDD) in a purchase order. Currently, the requirements date is unreliable, however the alternative in section 5.3 *Dynamic planning in SAP*, suggests a solution for the incorrect requirements date problem.

It is important to have a requested delivery date linked to the PO that is in coherence with the aprep date in the actual project planning. The data analysis showed that vendors steer according to this date, and are very accurate in doing so, even when requesting significantly lower lead times then are contractually defined. For some situations the contractual lead time is too long for the specific project planning (see section 4.5). This means that if no measures are taken a project delay can occur. Currently, the material management department avoids these situation by giving all the material planners a 'Critical Parts List' (CPL), which informs the planners about purchase orders for which the RDD needs to be manually modified in order to avoid delays. This can be considered as unnecessary fire fighting or 'waste' in lean philosophy. The suggestion for using the requirements date in direct procurements is expected to remove this waste.

The second benefit, like indicated earlier, is that using a representative requirements date enhances JIT delivery, compared to a situation in which a small contractual lead time is applied after which the part has to wait for weeks before assembled.

5.2 Redefine contractual lead times with vendors

5.2.1 Generation of the alternative

As was concluded from the data analysis on vendor performance in section 4.5, contractual lead times often give a wrong indication of the delivery capabilities from vendors. In most cases the contractual lead times are set too high. The vendors have an interest in setting high contractual lead times, because they can get penalties when they are under performing. As a customer, it is important to put some pressure on the vendors to demand a lead time that is acceptable, as inventory control is depending on it (see section 3.3). This means that it is still manageable for the vendor to deliver without significant risk for underperformance. The problem for KLM in this gaming dilemma, lies with the in-transparency of the vendors capabilities. The KLM can compare with competitors from the vendor, however for many parts the vendor has a monopoly position. However, from the data analysis we can conclude that often they can deliver faster, but to give exact value's is very difficult.

5.2.2 Explanation of the alternative

Basically, this alternative means re-evaluating contractual lead times and try to adapt them when possible. Vendors need to cooperate and need to be persuade about the necessity. The problem for KLM in this gaming dilemma, lies with the in-transparency of the vendors capabilities. The KLM can compare with competitors from the vendor, however for many parts the vendor has a monopoly position. However, from the data analysis we can conclude that often they can deliver faster, but to give exact value's is very difficult.

The redefining of contractual lead times with vendors can have big advantages, the positive effects are twofold. Firstly, the determination of planning segments for individual parts is depending on the contractual lead time. A smaller contractual lead time for a part results in a higher chance for the part to be replenished within the replenishment window. This can result in the decision (in SAP) to not have any stock (see section 3.3). Secondly, an accurate lead time facilitates making more accurate decisions regarding the ordering process. If the material planner notices that the vendor's contractual lead time is significantly bigger than the specific replenishment window, he can decide to source differently, even though the vendor might be able to fulfil the demand in time. This can also be an argument in the negations with the vendor, as they might also miss orders in the current situation.

5.2.4 Evaluation of the alternative

The alternative requires a more extensive investigation in the performance of vendors for the specific parts. The risk for failed deliveries (late) should be discussed with vendors when decreasing the lead times. As there are no insights at this moment on this kind of information, an objective and unambiguous evaluation seems impossible.

In addition is the cost saving, that can be expected when implementing this alternative, very difficult to quantify as it is necessary to evaluate every individual part or part group from different vendors. In addition is the adaptation of contractual lead times strongly depending on a political game of which the outcomes can not be predicted beforehand.

5.3 Dynamic planning in SAP

5.3.1 Generation of the alternative

In the system explanation and conceptualisation phase was concluded that a too shortly measured replenishment window has big impacts on stock levels (see paragraph 3.3.2.2). In addition, during data analysis was found that the replenishment is often measured wrong due to wrong requirements dates (see section 4.3). It was found that the requirements date can be more accurate by defining the correct aprep date in SAP.

The analysis of the determination of the replenishment window was extensive. The start of this extensive analysis was motivated by the observation that a significant amount of capital employed in the inventory was represented by expensive parts with small lead times. Theoretically the replenishment window should be no less then 24 days (see section 3.3.2.2). Within this window all materials defined as group 9 (lead time around 9 days) and group 13 in Section 4. 7, should fit, which means having no stock. The observation performed during first analysis in this research indicated millions of euro's in the current stock are represented by parts from those two groups.

5.3.2 Explanation of the alternative

The analysis that has been completed to come to conclusions about the (under)performance of inventory control was very extensive. The alternative that derived from this analysis is a less complicated but logical result:

The CRO department is suggested to update SAP dates prior to order date, in order to assure a realistic requirements date and therewith a realistic replenishment window resulting in more economic stock levels.

5.3.3 Elaboration on expected system behaviour

The consequences of implementing this alternative will be slowly visible. It will take the length of the replenishment measuring period (15 months) before the ROP planning is definitely deactivated (set to zero). Even when the ROP is deactivated, there might still be parts in stock from the moment there was a ROP. In other words, slowly over time the actual stock level will reduce. Certain parts could be evaluated by stock analysts to see if they could already be set at zero. The costs savings will be obtained faster but has two disadvantages:

- First of all, this is a difficult decision, which requires a lot of background information that SAP has been gathering for over a long time period. In addition is the list of materials enormous.
- Secondly, a sudden drop in norm stock would result in significantly lower orders to vendors until the actual stock has been consumed. Vendors are adapted to a certain demand pattern. In other words, an abrupt decrease in norm stocks can lead to an unbalanced supply chain, which is unfavourable for al the SC members.

5.3.4 Evaluation of the alternative

The alternative is presented to MRO managers of the KLM engine shop and to the personell of the CRO department. They have acknowledge the important of updating the actual planning in SAP in a more early stage of the project. After the presentation, the management was informed about the consequences for the inventory control. The alternative does not bring along any disadvantage, apart from a small additional task for one of the CRO staff. The acknowledgement of the key actors was the main evaluation of this alternative. An evaluation of expected costs could be made, but is difficult:

Currently an approximately 9,5 million euro's of the capital employed in the engine shop stock is represented by parts with a contractual lead time shorter than 24 days. Theoretically these parts do not need to have a ROP. In practice some of these parts can be regularly ordered late in stage 2 which would still result in a ROP planning. Therefore, the actual expected cost saving is less optimistic, but providing a concrete figure for inventory cost saving is very difficult.
In addition a note should be placed regarding the cost saving. Of the 9,5 million euro's of employed capital in the stock, with a lead time shorter then 24 days, 5 million euro concerns parts with a U-profile. As explained in paragraph 3.3.1 *Planning segments*, U-profiles are exceptional profiles in which the ROP level is not updated by SAP, but manually. This means that the suggested alternative will have no influence on parts with a U-profile. A suggestion is given to the department material management of the engine shop, to re-evaluate the parts with low lead times, to see if they really need a U-profile. Usually a U-profile is given to expensive parts for whom SAP systematically recommends ROP's that are (too) high according to the inventory annalists. The inventory annalists therefore, manually set the ROP levels lower. However, if a situation occurs that SAP would normally suggest an even lower level or even zero stock, the U profile is not updated, which is unwanted.

5.4 Redefine flows that influence inventory parts consumption

5.4.1 Generation of the alternative
As was concluded from the system analysis and conceptualisation phase together with the data analysis, the consumption registration in SAP is not very accurate due to wrongly defined movement types (see section 4.8). The SAP system measures approximately 1⁄6 of the actual consumption too much in terms of money, which will affect inventory levels as is elaborated in section 3.3 (See also Fig. 15)

5.4.2 Explanation of the alternative
In order to avoid unnecessary stock levels there are two policies suggested:

- SAP experts, give the exact formulation of consumption posting, which includes the effect of any movement type on the consumption together with its direction (negative or positive). When the formulation of consumption is made transparent, a discussion should be completed with the managers that are responsible for the material management and logistics at the engine shop. A careful selection of movement types should be made, and the changes need to be reprogrammed in SAP.
- The department of material management will create their own query in SAP business warehouse, which is selective in the movement types it chooses, in accordance with the wishes of the department. The results of the query can be analyzed and function as an input for the SAP forecaster in order to assure more accurate stock levels. This option is more easy in terms of implementation, as reprogramming SAP is a difficult task and also politically sensitive within KLM.

5.4.4 Evaluation of the alternative
During the data analysis, SAP specialists have analyzed the programming of consumption posting in SAP. The specialists have confirmed that certain movement types are wrongly defined. In addition, the tool that the department of material management uses for its forecasts, uses these consumption data from SAP as an input in its mathematical models. This has been doubled checked by stock analysts within KLM. It is acknowledged by the inventory analysts, that the use of correct movement types can lead to a more accurate and appropriate inventory control. This will most probably involve a decrease in stock level (which is favourable in terms of costs), as the current consumption measurement is defined to high (see section 4.8).

The impact of consumption posting in SAP on ROP height is linear. In other words, the higher the consumption, the higher the ROP level. However it is still difficult to quantify the expected cost savings as the decision to have stock is depending on contractual lead times and the measured replenishment windows. One part number can be consumed very often, but still have a ROP equalling zero. The 20 million euro difference between the measured consumption and the financial report might be represented by parts that do not have ROP.

5.5 Just in time delivery to aprep

5.5.1 Generation of the alternative

As is shown in Fig. 22, the capital employed in the aprep inventory is extensive and according to this research, excessive, which will be explained in the next paragraph. In Fig. 14 is shown how reservations are generated by different actors and that they will result in a delivery from inventory to the aprep department. These reservations are handled as soon as possible, even though no process or activity requires this material anytime soon. This is why the aprep inventory is considered as excessive.

5.5.2 Explanation of the alternative

Currently, material reservations for inventory parts are fulfilled as soon as possible. Theoretically, if a part is in stock it will be replaced from the inventory to aprep right after order date (OD). This means the parts will be in aprep for approximately one month (length stage 2). This will put more load on the aprep inventory but also a new part is ordered one month early. With this aprep inventory an extra buffer is created which is ignored by the ROP setting for the warehouse. This means that there is one part to many in stock for one month, referring to the replenishment settings in SAP.
Having a JIT delivery to aprep might bring more risk of stock out then the current way of working, however the risk is already calculated in the ROP setting in SAP. In other words, the current way of working goes against the procedures that are set by the KLM by using the SAP replenishment system. The benefit of delivering JIT is that the costs for a part to be in stock for one month can be saved. In other words, the overall capital employed in the aprep inventory can be reduced.

For the implementation of a just in time delivery to aprep the SAP system is a perfect supportive tool. As was mentioned in section 5.3, the updating of real life project dates in SAP is very important. Assuming that this will be acknowledged and obeyed in the future, the requirements date that is linked to a reservation can be used for assuring the just in time delivery to aprep.
The implementation of a just in time delivery to aprep requires a different way of working for the aprep department than is contemporary performed. A just in time delivery would mean that all the reservation are handled at once at aprep. This would result in discrete heavy workloads for the department, whereas currently the inflow is almost randomly distributed over the replenishment time. The aprep department will need a few days of handling time before the C-check. In addition, the aprep department is requested to already perform first material assembly and measurements, in order to make sure the assembly department can have a lean work flow. The time necessary for these tasks and handling need to be quantified (visualized in Fig. 32 as X). When an exact time frame is known in which the tasks and handling can be completed, the determination of the requirements date can be based on back scheduling from the CC date (aprep date). Currently the requirements date is set as 6 days before the earliest finish date aprep. If this is sufficient time for the handling and other tasks, it needs no modification.

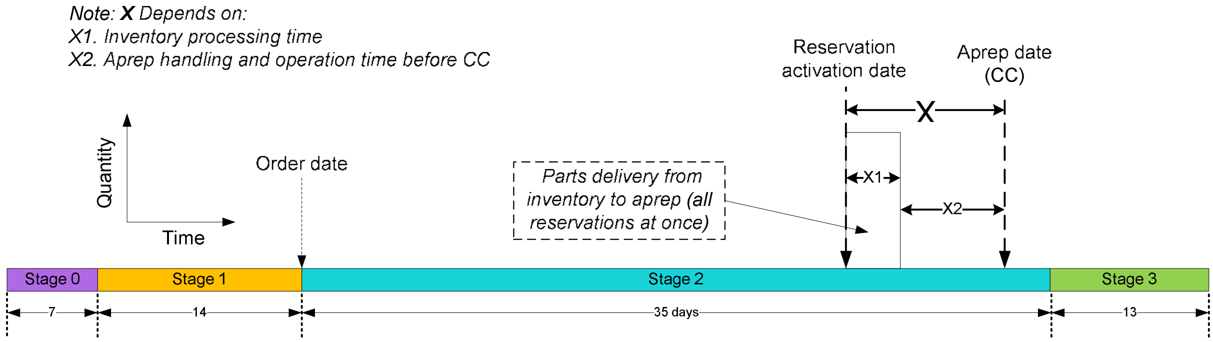


Fig. 32 *JIT Delivery to Aprep on project schedule*

5.5.3 Elaboration on expected behaviour

For the aprep department, the implementation of this alternative will effect the inflow of new parts into the aprep inventory. This inflow will be of a discrete nature (see Fig. 34), which is a contradiction of the current inflow of goods, which is almost continuous. This discrete inflow is more transparent as the workload for a specific day is already known for weeks (since order date). This makes capacity planning (e.g. personnel) more effective, which is an additional advantage of this alternative.

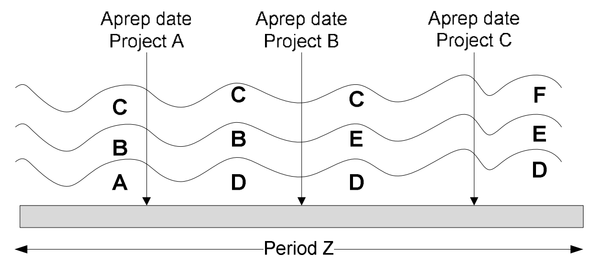


Fig. 33 *Material flow aprep current situation*

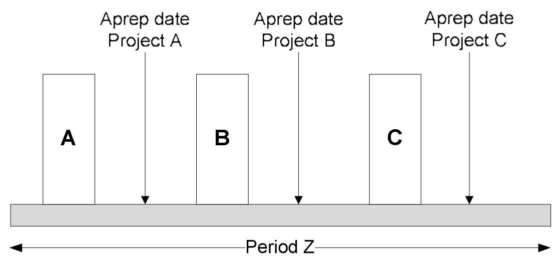


Fig. 34 *Material flow aprep suggested JIT*

Besides aprep, the warehouse department also needs to change its way of working when implementing the JIT to aprep policy. As for one project al stock materials will be released at one specific moment. The inventory needs a certain amount of man hours for a specific material delivery quantity. The inventory estimated that with their current occupation (3 inventory reservation handling staff in two shifts) they can handle 500 reservations per day, which about the average size of a project. This also needs to be taken into account for the calculation of moment X.

The activities that the aprep department needs to perform before its C-check is related to a specific group of materials. These materials can get a priority status concerning reservation handling. The parts with priority form a fraction of the entire list of reservations for one project. The non priority (or non 'aprep critical') parts can be handled within the entire period X, whereas the priority parts need to be fulfilled within X1. In Fig. 36 the handling of reservations over time is shown, in which prioritizing aprep critical parts (for the projects B and C) is visualized. Even though X2 can function as a buffer for the fulfilment of reservations by the inventory, there is still a threat of project delays due to the drum beat of the engine shop, which is explained below.

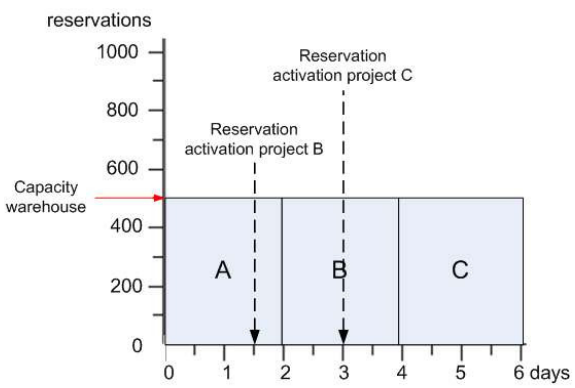


Fig. 35 *Increasing delay due to 'drum beat'*

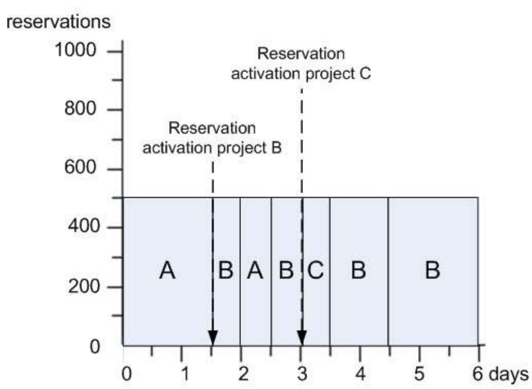


Fig. 36 *Prioritising 'Aprep critical' parts*

The physical work in the engine shops is performed in work shifts. There are two work shifts per day, seven days a week. In the assembly process there are several slots available. The engine shops works with a drum beat of 3 shifts between projects. In other words every 3 shifts there will be a slot available again for the a new project. Annually, the engine shop performs around 160 engine overhauls. The engine shop however has a maximum capacity of 243 slots (projects) per year. This would mean that every 3 shifts there will actually be a slot re-occupied. However, in practice this target is unrealistic as there are many uncertainties in the overhaul process that can delay the project and cause a slot not to be available on time. So currently there are (243 -160) 83 slots empty per year. This equals 249 shifts of buffer annually that can act as a back up for uncertainties.
As mentioned earlier, the inventory needs on average 2 shifts to fulfil one project. If there would be a long series of big projects (more then 1.000 reservations), separated with a drum beat of 3 shifts and without any break, it could eventually lead to a delay in the project. As there will be a delay of 1 shift per project for the inventory, which will accumulate over multiple projects, the timeframe X2 might not be sufficient to cover it. This results in a reserved slot that is still waiting for materials to arrive from aprep.

'Drum beat' of the engine shop

Fortunately there are buffers and in addition projects differ in size. The advantage of the JIT delivery to aprep is that the inventory department can predict their workload very accurately, already from order date (see Fig. 32). The inventory can therefore schedule in advance the projects that they are going to handle according to buffer moments and project sizes.
The capability of the inventory to manage this scheduling needs to be investigated more close. In addition the risk of project delays in different scenarios needs to be made transparent. Simulation modelling can be an appropriate tool for finding bottlenecks in this specific system, which therefore is a recommended method for further research.

Note: It is important to separate non stage 2 reservations and reservations dedicated to the repair process from reservations dedicated to aprep (stage 2). The reservations for the repair process need to be excluded from this policy and need to be fulfilled as soon as possible, in order to avoid project delays. This means that the inventory needs to have more capacity then the capacity necessary to cover the 'normal' project reservations. As material demands often randomly occur during stage 3.

5.5.4 Evaluation of the alternative

A small simulation model is generated to check if the JIT to aprep alternative can form a threat for the project planning. After analysing the reservations of several different projects of the three most overhauled engine types, the conclusions was that on average around 500 reservations (source inventory, not aprep 1040) are created per project. A minimum project size of 90 reservations and a maximum of 619 reservation per project was found. In the model this is reflected by a creation of reservations as TRIA(4,5,8). This means that for every project (arrival) there are minimally 4, most probably 5 and maximum 8 reservations created (for modelling ease the reservation numbers are divided by 100). This demand pattern is significantly higher than was concluded from the data analysis, which is chosen to perform a worst case analysis. The time between arrival was set as 1,5 day (3 shifts), while in reality there is often is buffer between projects as was mentioned earlier. The inventory capacity is, for the same worst case reason, set at minimally 350, normally 500 and maximally 550 reservations per day.

The time that aprep needs for handling and processing the material is collected from an internal research on the performance of the aprep department (Mantje, 2005). The figures for aprep's performance, in terms of activity durations, prior to the C-check are:

Engine	Average X2 duration	Norm time (capacity = 5 man)
CF6-50	115 Man hours	23 hour
CF6-80C2	110 Man hours	22 hour
CF6-80C2E	110 Man hours	22 hour
CFM-56	105 Man hours	21 hour

Fig. 37 *Measured performance aprep* (Mantje, 2005)

The figures show that for all engines, with the current average capacity of 5 man, that the average X2 duration is within the engine shops' drum beat of 3 shifts (24 hours).

As the inventory level is not a KPI for this model, the inventory level is set in such away that there is always sufficient material available for the reservations to be fulfilled.
The simulation model is small and its outcomes are logically to explain and is approved by KLM staff. The model run for 1 year with 5 replications. The model run continuously, which indicates there were no stock outs. Fig. 38 shows model outputs for the relevant queue's. The average amount entities in aprep were 7.9. This represents 790 parts at aprep on average. This means approximately 1.5 projects, in new parts, are continuously present in aprep processes before C-check. This is easy to explain as the aprep period X2 is set at 1.5 days and the time interval between projects as 1,5 days. The fact that the model shows 1.5 projects in stock in stead of 1 is because of the material that is flowing in to aprep during period X1 (Fig. 32).
The utilization of inventory staff for the handling of project reservations was 0.76 according to the model. No significant queuing was noticed at the inventory reservation handling. The average number in queue was 170 reservations.

Queue Detail Summary

Time

	Waiting Time
Aprep.Queue	55.07
Inventory reservation handling.Queue	11.63
Stock.Queue	10.82

Other

	Number Waiting
Aprep.Queue	7.91
Inventory reservation handling.Queue	1.67
Stock.Queue	16.55

Fig. 38 *Queue details output arena model*

7.5.5 Conclusion JIT to Aprep alternative

Delivering just in time to aprep by activating all reservations for one project at once, X days before C-check, can result in a significant costs saving without increasing the contemporary accepted risks. The ROP for the inventory should already cover the risks resulting from demand variation. Therefore, Aprep would only be an additional stock buffer. Aprep needs a certain processing time, referred to as X2, which still needs to be measured. The length of this time frame will determine the aprep stock level height.

From a small simulation study was concluded that the inventory currently has sufficient capacity to operate under the JIT to aprep alternative. The simulation inputs were al set under hard and stochastic conditions, which still lead to stable outcomes. In the real world, not only the conditions are less harsh, there is also the possibility to adopt control variables, e.g. inventory staff, depending on the situation. The new policy makes the work load for the inventory very transparent and therefore eases scheduling. Considering this fact, together with the simulation study outcome, the conclusion can be drawn that the inventory should be able to work effectively (maybe even more efficiently) under the just in time alternative.

The cost saving that can be expected by implementing this alternative is depending on the time frame that is necessary for aprep handling and processing (X2). In the simulation model a time frame (X2) of 3 shifts was chosen, which resulted in a continuous presence of new parts from approximately 1.5 projects. Every project contains of 800.000 euro worth of new parts on average. In other words, according to the mode,l the stock level in aprep, before the C-check, would be around 1,2 million euro in terms of capital employed. An additional 800.000 euro should be added for the expected capital employed in Aprep in total, as there is also continuously one project in the process ‘c-check’. Currently, on average, the amount of capital employed in the aprep inventory is 12 million euro (see Fig. 22**)**. This means that an estimated 10 million euro cost saving is expected when this alternative is implemented. This also involves an additional estimated annual costs saving of 1.8 million euro (18% inventory costs).

6 Conclusion, discussion and future research

A comprehensive system analysis of the logistical processes at the KLM engine shop has been completed. The focus of the research was on inventory costs savings without increasing risk of stock out. The system analysis included data analysis and a conceptualisation of processes. During the research many interviews with staff from different departments and from different levels in the organization are performed, which mostly lead to the indications of problems related to SAP parameters and algorithms. While analyzing the problems, and while gaining more knowledge of the system at hand, the usability of simulation modelling seemed of decreasing added value for the understanding of the system and to the generation of alternatives . Also implications were expected for model validation due to the big differences between parts and high variance in the stochastic processes. The root of the perceived problems have been found and have been proven by data. This report also gives suggestions for alternatives that can solve these problems. Some alternatives suggest a change in (SAP) algorithms (like 5.1 and 5.4), other suggest informing personnel on algorithms (5.3) and other alternatives require structural changes in the business processes of the engine shop bringing along organizational changes (5.5). All the alternatives that are suggested in this research concern a different issue. This means they can be implemented together. Some of the alternatives facilitate each other (like improving the requirements date accuracy in 5.3, facilitates JIT suggestions in 5.1 and 5.5), but they do not disfavour one another. In addition should be noted that the complexity of an alternative does not give an indication on the significance of economical added value. This means that some alternatives suggest a small change which can result in very high costs savings. All alternatives together are expected to save millions of euro’s, mostly on inventory costs. In the next section will be discussed if this has also satisfied the research goals and if it answers the research questions that have been posed at the start of this research.

6.1 Discussion; have the research questions been answered?

Even though the research went through a different path then originally planned and the problem formulation as had some adaptations, the questions are answered sufficiently, which will be discussed in this section. First is discussed if the goals from KLM are obtained. Secondly, the answering of sub research questions is discussed and finally the main research question.

Initially, KLM formulated a research proposal with the following objectives:

1. Describe the current situation of demanding material throughout the Engine Shop.
2. Describe how material request are processed through the SAP system and how the physical material flow is organized throughout the supply chain.
3. Develop alternatives and new ways of requesting materials taking into account the supply chain as a whole.
4. Make an advice about the stock levels and the effect of different control concepts on the stock levels of Engine Services.
5. Develop the concept of agile logistics in the domain of material demand.

The first two points are reported in chapter 3 *System explanation and conceptualization*. Not only does it form the foundation for the research, but it is also useful information for KLM for future research or discussions. The points 3, 4 and 5 are all reported in chapter 5 (alternatives). The concept of more agile logistics was not possible on the scale as initially thought, which was a JIT replenishment and also JIT delivery to the assembly process. One alternative suggest the JIT delivery from the inventory to aprep, which satisfies the goal of point 5, but possibly in a different way then was initially expected

Discussion on research objectives from KLM

6.1.1 Answering research sub questions

In section 2.2, a set of research sub questions was posed. These sub questions served as a guidance for the research. In this paragraph the answering of these questions is discussed.

1. *What are the logistical processes at the KLM Engine Shop*?

In Chapter 3 all relevant logistical processes are described. This chapter shows the different actors that are involved with the logistical processes. The second section shows a description of the general logistical processes. In this section different conceptual models of the material flows and related information flows in the engine shop are shown. This gives a good insight in what is logistically going on in the engine shop and which actors are involved. The third section concerns a more detailed descriptive system analysis of the processes related to the department of material management. Together with supportive conceptual models such as a causal relation diagram, a good understanding of inventory control is obtained.

2. *What is the performance of these processes*?

In chapter 4 the performance of the processes that were described in chapter 3 are shown by means of data analysis. These performance measurements indicate if certain problem perceptions are significant or not. In addition it has shown were there is room for improvement. In the concluding section 4.8, the processes for whom a significant (under)performance is found, are shown. These include an underperformance in consumption measurement, replenishment window measurement (effecting decision making on stock levels) and vendor lead times.

3. *Which alternatives can lead to costs savings in the logistical system*?

In chapter 5, several alternatives are presented that can lead to cost savings. Of the alternatives, five were selected for a more extensive analysis. These five have been selected based on estimations of expected cost savings and resource requirements. In the next paragraphs a summary is given of each of these selected alternatives for cost savings.

4. *Which (combination of) alternative(s) lead to the highest costs saving for KLM including all consequences*?

In chapter 5, several alternatives have been worked out in detail. These alternatives can be implemented simultaneously. The alternatives that have been presented are not involving major organizational changes, but mostly changes in material management algorithms. This means that the system is seen as a given and that the alternatives are suggestions for improvement in the processes. Often when fundamental changes are made, there are several alternatives for one issue, in other words multiple options for a way of working. The alternatives that were suggested in this research were not substitutable with others. This basically means that the current way of working is considered to be inefficient, and the alternatives are the only (logical) way to do it right.
As was mentioned earlier, some alternatives facilitate each other. In section 5.3, a suggestion for the improvement of accuracy of the requirements date is given in order to have a better measurement of the replenishment window. When this requirements date is accurate, it can be used in the generation of 'direct procurements' (see section 5.1) which ensures more just in time and accurate deliveries. The requirements date could also be used for the activation of internal reservations as was discussed in section 5.5.

6.1.2 Answering the main research question

Based on the problem formulation, a main research question was stated in section 2.2. The question tries to seek for inventory cost savings by suggesting alternative ways for the material replenishment and by adapting material management algorithms (in section 2.2 the definition of inventory costs is given). One clear emphasis in the research question is that the acceptance of actors is a key condition for the success of implementing alternatives for the purpose of (inventory) cost savings. The question was posed as follows:

"Which alternatives for replenishment and material management algorithms can jointly lead to the highest inventory cost saving for the KLM engine shop taking the multi actor setting into account?"

Basically, chapter 5 gives a detailed answer to this questions. In this chapter several alternatives are given that are expected to result in inventory costs savings. Here we will give a short elaboration on these alternatives.

1. *Direct procurement*; this alternative suggests a change in the algorithm of the ordering process. The idea is to always dedicated a purchase order, and the related part, to the specific project, instead of having a warehouse procurement. The direct procurement is suggested to be delivered in a JIT manner to the aprep department. This means the parts, that have no ROP, are not added in the stock for a few days, which will help reduce the current inventory level. In addition are less physical steps necessary, which can be seen as a cost reduction in terms of capacity efficiency or less risk for damage. An additional advantage is that the bill of the purchased part can be immediately linked to the project of the customer. This makes the (financial) processes more transparent. For example, the current warehouse is in terms of financial registration separated into plain inventory parts and customer parts. This classification will be more easy to complete.

2. *Redefine contractual lead times*; This alternative suggests to redefine the contractual lead time with vendors. From data analysis in chapter 4 was concluded that vendors can perform significantly better then is currently contractually defined. The contractual lead times are used for decision making on stock levels, which means, high contractual lead times will result in (high) stocks, which is unfavorable. A more comprehensive analysis on vendor performance is suggested. However, there will always be in-transparency about the actual capabilities of the vendors. The new defined contractual lead times will probably be the result of a political game for which the outcome is unpredictable. Therefore an estimation of expected cost savings is impossible, but the possibilities are significant. It is up to the management of the Engine Shop to deal with this important factor in the logistical system.

3. *Dynamic planning in SAP*; This alternative suggests to update SAP in accordance with the actual project planning in a more early phase of the engine overhaul. SAP uses this project planning (schedule) for the determination of a requirements date for the materials that need to be replaced. It is important that this requirements date is accurately defined, as it determines the length of the replenishment window of materials, which is a major factor in stock level decision making. Analysis has shown that 9,5 million euro's in the norm stock is represented by parts for which theoretically the contractually lead time is short enough to fit in the replenishment window, which means no stock is necessary. In practice not all the replenishment windows will be as short as the theoretically window, however it is expected that still a significant cost savings (millions of euro's) derive from this alternative.

4. *Redefine consumption measurements in SAP*; This alternative suggests to make a reevaluation of which movement types (transactions) should be considered as a consumption measurement. The forecast models that are used for the determination of stock level heights use historical consumptions, which is measured in SAP. It is found that there is a significant difference between what is measured as consumption by SAP and with the actual bill of materials for the engine MRO. It is difficult to give figures about the expected cost savings, but it is clear that currently, inappropriate stock levels are applied due to a wrong measurement of consumption posting. Future research can give a concrete suggestion on which movement types to use, after which an expectation on cost savings might become easier.

5. *JIT delivery to Aprep*; This alternative suggest to activate internal reservations a view days before the aprep date (c-check) as is visualized in Fig. 32. By this way of working a Just In Time delivery to aprep is accomplished. Currently there is an excessive stock present at the aprep department. New parts are flowing throughout stage 2 into this stock, even though no process requires their presence yet. The idea is to have all the required materials available in aprep, right before the aprep processes need to start. This will result in a stock that does not need to exceed the total amount of new parts for around 2 or 3 projects. This means that around 2 million euro in the aprep department, in terms of capital employed, can be expected to represent the new stock level. This is a 10 million euro cost saving compared to the current situation (and a related 1.8 million euro annual inventory cost savings)

During the system analysis and generation of these alternatives, many actors have been interviewed and involved. This gave actors a better understanding of the end conclusions which influences the acceptance. The final alternatives have been discussed with they relevant actors and has been presented to the management. Some points of discussion have come above which has been used to make a refinement of the alternatives which can bee seen as a feedback loop to the generation of the alternatives (see Fig. 5). After the refinement, all key actors have acknowledged the alternatives as good suggestions for cost savings and in additions are no serious complications expected.

It can be concluded from this summarizing section that the main research question has been answered, as several alternatives are suggested that can jointly lead to significant inventory cost savings, without the necessity of radical change or high investments. In addition do the key actors within KLM not expect any serious complications, in fact they all think that the alternatives are a better way of working.

6.2 Recommendations for future research

Some of the alternatives described above suggest (or need) more analysis before implementation, in order to assure the most inventory cost savings. Alternative number 4 suggests an analysis on the movement types that need to be selected for consumption measurements in SAP. For alternative 2, it is recommended to have a more comprehensive analysis on the performance of vendors. This analysis can be used in the discussion with vendors on decreasing the contractual lead times. In addition a additional calculation is suggested on the equilibrium of decreasing lead times vs ordering costs by vendors(e.g. for having more finished goods stock). This means the optimum lead time in which the sum of the KLM inventory costs and costs for ordering is the lowest (the costs of ordering is expected to go up when a significant decrease in contractual lead time is demanded).

7 Reflection on research process and personal experience

This chapter gives a small reflections on the research and its process together with the student's personal experience that has been gained in the process.

7.1 Research progression by struggling through

As was quoted in the problem formulation chapter by Russell L. Ackoff, finding the right solution for the right problem is often a difficult task. This is also experienced in this pragmatic research at the KLM engine shop. While analysing the logistical system, different problems have been found or have been indicated by other KLM staff. A certain problem is perceived (e.g. the requirements date that is often incorrect in SAP), but the root or source of the problem is unknown. Also a cognitive view of the consequences of the problem is lacking. Every person within the company has a specific task to fulfil. They notify a problem because it has a consequence for the process in which they work or are responsible for. They find a non root solution or way to work around the problem, however the problem might still do damage in other parts of the system that are less transparent.
During this research the different problem perceptions have been asked from different staff when analyzing the system. After one actor high lighted a problem, the root is searched. The root problem is presented to other related actors to see what impact it has on their processes. When a problem seemed significant, the root needs to be proved. It is important for the analyst to make sure that (s)he really arrived at the root of a problem and that (s)he can motivate it in a scientific way (e.g. by data).When the root problem is formulated and proven, the (cognitive) consequences need to be explained and quantified when possible (e.g. costs). In this research the search for problems and there roots was extensive.

The focus of this research has also changed over time. At first the idea was to have a scientific discussion on the application of discrete event simulation for the purpose of facilitating decision making concerning Just In Time replenishments. The more information of the system was obtained, the less relevant a different just in time procedure seemed and the added value of simulation was also doubted, which is described in more detail in appendix V. The first system analyses have indicated that there is potential for cost savings, but it was clear that simulation would not facilitate in elaborating the possibilities for cost savings. In this research process, the annalist has explicitly chosen for a more comprehensive analysis to obtain the highest cost savings for the KLM and therewith not focussing on the theoretical discussion on the use of discrete event simulation in this specific field. This required a reorganisation of the research approach and has resulted in a more pragmatic research.

7.2 Threat of ICT systems that steer material management

The ICT system that is used for material management within the engine shop is SAP. This software is a very big and intelligent system that is used by organizations around the world. SAP has different packages depending on (e.g.) the industry. When implementing a system that will control al of the logistical processes in a company, like KLM, adaptations of the software are necessary. However not everybody can be involved in the design of the ICT system. The people that make decisions on the design of the ICT system might lack the cognitive view and understanding of consequences for specific processes. On the other hand, the people that do see consequences, don't know where its origin lies as the big ICT system is not transparent for normal users. Other consequences might not be noticed by anyone (like the problem with not using the right movement types for consumption measurement that is used for stock level determination).

It is important to keep in mind that the ICT systems works as a machine that does not stop because of these errors. In traditional logistical systems, in which information communication is mostly accomplished verbally, these errors might be noticed or would not have occurred at all. Of course, for these big companies with very complex logistical systems, the introduction of ICT systems is a enormous improvement. However, even though al materials arrive and products still get produced and sold with profit, there might still be a lot of costs saved by checking the parameters and algorithms that are controlling the material management in ICT systems.

7.3 Policy analysts should always be excluded from hierarchies

As Mintzburg, an authority in the science of organisational behaviour, also indicated in his book 'structure in fives' , the technostructure should be separated from the hierarchical structure in the main operations. Policy analysts are located in this technostructure. The policy analyst should perform objective analysis and report the results to the strategic apex. If an analyst is placed in the hierarchical structure in the middle line or operating core, the situation might arise that the analyst finds inefficiencies in processes for whom his or her manager is responsible. This can seriously effect cooperation in the research. When the hierarchical power is strong, the analyst might be forced to research different, less sensitive topics, which can be less favourable for the overall performance of the organisation.

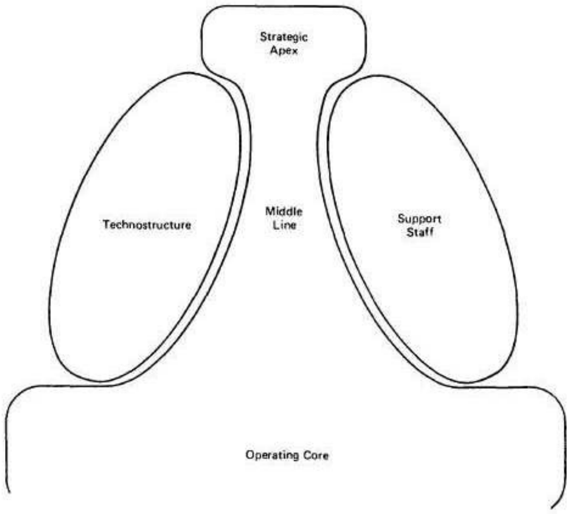


Fig. 39 *The five organizational parts*
(H. Mintzberg, 1992)

In this research the analyst has also experienced the sensitivity of analysis on performances in a hierarchical structure. Nevertheless, the KLM (middle) managers have responded professionally towards the suggestions for improvement. However, this can not be assumed to be the reaction in every organization, which is an important note in this reflection.

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Appendix I

Variable explanation for (causal) relation diagram (see App. VI)

Variable	Description	Determined
ROP height	Re-order point	Expected consumption (basic value) within the delivery time + Safety Stock
ROP Factor	Only if the factor is positive there will be a stock level	Contractual lead time – measured replenishment window
Safety stock		R * $\sqrt{W}$ * MAD
Factor R	Factor depending on Service level Service level [%] shows the number of fulfilled reservations by stock	An exponential function with service level. (Min 0 and max 4)
Factor W	Makes sure there is a causal relation between re order point and the delivery time	Delivery time / norm time stage 2 (30 days)
Delivery time		Lead time + 7 days (transport and processing)
MAD (mean absolute deviation)	If the consumption is very dynamic, this factor increases. It is the average of the absolute deviation between historical consumption and Basic value	$\frac{\sum (C(i) - bv)_n}{n}$ C(i) = consumption in individual (i) period N= number of periods
Basic value (bv)	Average consumption over 12 periods (monts) or weighted average consumption over 4 months (for smooth and lumpy material)	(weighted average: First (last) period 40% Second 30%, third 20% and fourth 10%)
Measured replenishment window	The time registered in SAP that a part has to be processed (e.g. purchased)	Requirements date - Creation date reservation
Actual replenishment window	The actual time a part has to be replenished.	Difference between moment of demand creation and aprep date
Contract lead time	Lead time agreed with vendor	

Service Level SAP	A factor in SAP that indicates the tolerance for delivery delays	
Contractual time external repair	Lead time agreed with vendor for external repairs	Discussed with vendor
Norm time stage 2	Theoretical length stage 2	Length of process, currently external repair is most critical
Norm times stages	Theoretical length of stages	Length of its processes
Requirements date SAP	The date generated by SAP that tells when part should be at aprep	Earliest finished aprep date in SAP – 6 days
Reservation creation date	Date a reservation is created in SAP	
Parts price	The purchase price of a part	By vendor (market)
Parts consumption forecast	Forecast of part consumption based on historical data from SAP	
Stock out problems	Indicates the rate of stock out that cases project delay and its severity	When ROP = 0 Then: Actual lead time outside of replenishment window

Appendix II Description of planning segments (Dutch)

Type		Strategie	Omschrijving
MRP planning	1	MRP type ZD (MRP planning) Forecast model 0 (No forecast) ROP 0, Safety stock 0 Lot sizing WI (Least unit cost)	Geen voorraad hanteren. De MRP doet wel een bestelvoorstel op basis van least unit cost wanneer er een behoefte ontstaat.
	2	MRP type ZD (MRP planning) Forecast model W (Weighted moving average) Service level 95% Lot sizing WI (Least unit cost)	Safety stock wordt bepaald door SAP. Het servicelevel van 80% resulteert samen met het weighted moving average model in een beperkte safety stock dat scherper reageerd op veranderingen in verbruik. De MRP doet een bestelvoorstel op basis van least unit cost wanneer de voorraad onder de safety stock komt.
	3	MRP type ZD (MRP planning) Forecast model G (Moving average) Service level 95% Lot sizing WI (Least unit cost)	Safety stock wordt bepaald door SAP. Het servicelevel van 80% resulteert samen met het moving average model in een beperkte safety stock dat langzaam reageerd op veranderingen in verbruik. De MRP doet een bestelvoorstel op basis van least unit cost wanneer de voorraad onder de safety stock komt.
ROP planning met handmatig ROP	4	MRP type ZM (ROP planning) Forecast model 0 (No forecast) ROP = maximale verbruik Safety stock = gemiddelde verbruik Lot sizing EX (Lot for lot) met EOQ	Handmatig ROP op basis van maximum verbruik binnen geselecteerde periode. Safety stock op basis van gemiddeld verbruik binnen geselecteerde periode. MRP doet een bestelvoorstel (EOQ) wanneer de voorraad onder het ROP komt.
	5	Manier van plannen bepalen op basis van overlegstructuur.	Planningstrategie en daarmee ROP/safety stock wordt bepaald door comitè van MM, IL, CG, PMT en MT. Afhankelijk van diverse zaken als levertijd, verbruik, technische achtergrond, prijs, etc.
ROP planning met automatisch ROP	6	MRP type ZM (ROP planning) Forecast model W (Weighted moving average) Service level 80% Lot sizing EX (Lot for lot) met EOQ	ROP (en safety stock) wordt bepaald door SAP. Het servicelevel van 80% resulteert samen met het weighted moving average model in een beperkt ROP dat scherper reageerd op veranderingen in verbruik. MRP doet een bestelvoorstel (EOQ) wanneer de voorraad onder het ROP komt.
	7	MRP type ZM (ROP planning) Forecast model G (Moving average) Service level 80% Lot sizing EX (Lot for lot) met EOQ	ROP (en safety stock) wordt bepaald door SAP. Het servicelevel van 80% resulteert samen met het moving average model in een beperkt ROP dat langzaam reageerd op veranderingen in verbruik. MRP doet een bestelvoorstel (EOQ) wanneer de voorraad onder het ROP komt.
	8	MRP type ZM (ROP planning) Forecast model W (Weighted moving average) Service level 85% Lot sizing EX (Lot for lot) met EOQ	ROP (en safety stock) wordt bepaald door SAP. Het servicelevel van 85% resulteert samen met het weighted moving average model in een gemiddeld ROP dat scherper reageerd op veranderingen in verbruik. MRP doet een bestelvoorstel (EOQ) wanneer de voorraad onder het ROP komt.
	9	MRP type ZM (ROP planning) Forecast model G (Moving average) Service level 85% Lot sizing EX (Lot for lot) met EOQ	ROP (en safety stock) wordt bepaald door SAP. Het servicelevel van 85% resulteert samen met het moving average model in een gemiddeld ROP dat langzaam reageerd op veranderingen in verbruik. MRP doet een bestelvoorstel (EOQ) wanneer de voorraad onder het ROP komt.
	10	MRP type ZM (ROP planning) Forecast model W (Weighted moving average) Service level 90% Lot sizing EX (Lot for lot) met EOQ	ROP (en safety stock) wordt bepaald door SAP. Het servicelevel van 90% resulteert samen met het weighted moving average model in een gemiddeld tot hoog ROP dat scherper reageerd op veranderingen in verbruik. MRP doet een bestelvoorstel (EOQ) wanneer de voorraad onder het ROP komt.
	11	MRP type ZM (ROP planning) Forecast model G (Moving average) Service level 90% Lot sizing EX (Lot for lot) met EOQ	ROP (en safety stock) wordt bepaald door SAP. Het servicelevel van 90% resulteert samen met het moving average model in een gemiddeld tot hoog ROP dat langzaam reageerd op veranderingen in verbruik. MRP doet een bestelvoorstel (EOQ) wanneer de voorraad onder het ROP komt.
	12	MRP type ZM (ROP planning) Forecast model W (Weighted moving average) Service level 95% Lot sizing EX (Lot for lot) met EOQ	ROP (en safety stock) wordt bepaald door SAP. Het servicelevel van 95% resulteert samen met het weighted moving average model in een hoog ROP dat scherper reageerd op veranderingen in verbruik. MRP doet een bestelvoorstel (EOQ) wanneer de voorraad onder het ROP komt.
	13	MRP type ZM (ROP planning) Forecast model G (Moving average) Service level 95% Lot sizing EX (Lot for lot) met EOQ	ROP (en safety stock) wordt bepaald door SAP. Het servicelevel van 95% resulteert samen met het moving average model in een hoog ROP dat langzaam reageerd op veranderingen in verbruik. MRP doet een bestelvoorstel (EOQ) wanneer de voorraad onder het ROP komt.

Appendix III

Current methodology for process improvements in KLM E&M

Within KLM Engineering & Management the philosophies of Lean and Six Sigma are applied for process optimization. KLM has trained a selected group of managers to become six sigma black belts that are full time focussing on solving 'defects' in the Engine shop. Several interviews with these black belt personnel has been performed, and the outcome is used for describing the process improvement methodology in KLM. In addition most of the staff will get training in the lean philosophy in order to generate alternative ways of working from different levels and fields within the company. Before specifying the situation at KLM, the generic aspects of lean and six sigma are presented.

Pande and Holpp Define six sigma in there book 'What is six Sigma' as:

1. A statistical *measure* of the performance of a process or a product
2. A *goal* that reaches near perfection for performance improvement
3. A *system of management* to achieve lasting business leadership and world-class performance

The term six sigma originates from the company Motorola in the United States and its name is derived from the statistical field in which it is used to define the variation of a statistical result. The variation in processes (e.g. lead time or costs) can also be considered as a measure of performance.
In any business there will be some defect in service delivered due to different reasons. Six sigma acknowledges that 0 defects are impossible but sets goals for having a continuous reduce in defects per million opportunities, in order to get a higher customer satisfaction and lower costs (Pande et al. 2002). When six sigma is applied for process improvement, most often the methodological sequence of DMAIC is used. With these steps it tries to answer the following fundamental questions:
(source: Lean Sigma Institute)

Define	Phase	*What is important?*
Measure	Performance	*How are we doing?*
Analyze	Opportunity	*What is wrong?*
Improve	Performance	*What needs to be done?*
Control	Performance	*How do we guarantee performance*

Lean thinking is developed over the past 50 years by Toyota in Japan. Lean philosophy focuses on removing waste, which is defined as non value added, from the systems processes. In lean practice the focus lies on the bare bone essentials. When problems are identified, a root analysis will start. Tackling the problem at the root will reduce 'fire fighting' behaviour. The focus of Lean is on Process flow. Tools used for the practice of Lean are oriented to visualization.

Lean and six sigma, although often differentiated, can go together hand in hand and complement each other. A new approach has therefore been derived under the name of lean six sigma. The unification of both methods leads to a structural approach for process waste reductions with higher speed (lean) and a more quantitative approach that will give a better understanding of the process and lead to quality improvement in the processes (Six Sigma). The theoretical advantage of combining lean with six sigma is visualized in the graph below by the lean sigma institute.

[http://www.sixsigmainstitute.com/images/lean%20six%20sigma%20yield%20matrix.png]

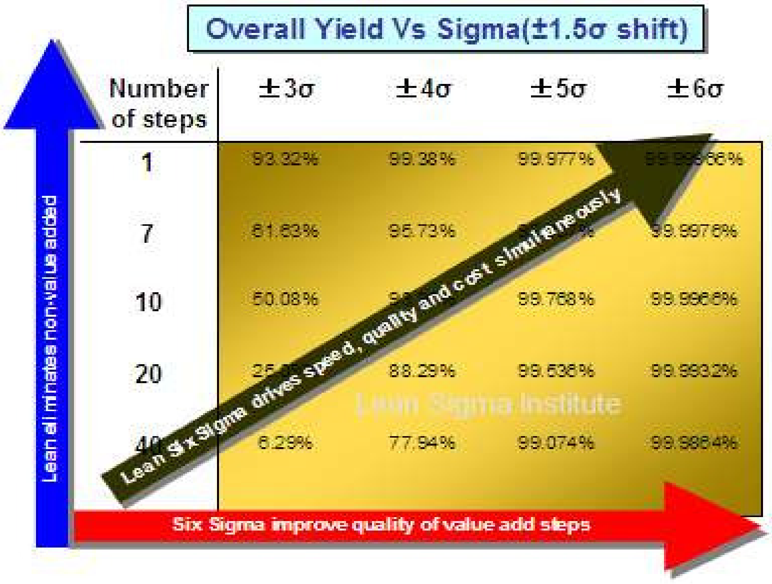


Fig. 1 Theoretical results of Lean Six Sigma

Within KLM Engine services the lean approach is mostly applied for stages 0 and 1 whereas six sigma is the usual approach for analyzing and optimizing stage 2. Stage 2 is very data rich and requires a more quantitative approach. Lean is mostly used for solving problems that are indicated by the actors in the engine shop (usually via the management). The problem solving within the engine shop by means of Lean is accomplished in a structural way with a multi actor perspective. The problem perception of the different actors is formulated and often actors are brought to getter to generate solutions in brainstorm sessions. The application of lean in ES can be considered as a facilitator in problem solving as the lean experts do not search for problems nor solutions themselves. One black belt quoted: 'the people that perform the work know 95% of the system and its defects, the manager knows 5 % and the lean facilitator only 1%'.
The application of Six sigma has a less integrated and less active approach for problem solving with respect to the multi actor setting and actor involvement. The approach involves more data analysis and rational decision making based on results of the system analysis. However, the application of six sigma within ES in practise differs from the theoretical intensions. In most cases, the management indicates a problem situation and in addition gives a limited amount of solutions. The black belts in result often function more as a evaluation tool for alternatives instead of alternative generators. The solutions that are presented by the management are mostly procedural and hardly incorporate structural change.

The methodology of system engineering and the way it is applied in this research differs from the current methodology applied in KLM ES. In this research an analysis of the specified system is made. Within the boundaries, problem area's and bottlenecks are searched for. This is very different from a situation in which the problem is already a given (even though it might not be the only cause for the effect that we want to eliminated or reduce). Looking to the system as a whole and exploring the relationships between different factors within the defined boundaries, is what separates the methodology in this research from the one generally applied at ES, and has a higher chance of leading to more structural and more radical alternatives as there is no fixed route.

Appendix IV

Additional review on relevant literature

A small literature review is given in this appendix to discuss the status quo on research findings related to this topic. In this section some recent studies on simulation in general and specifically for SCM are discussed to see what the status quo is for this field of research. This is shown in the appendix as initially the focus in this research was to discuss the role of simulation for the evaluation of logistical systems. In addition some commonly used strategies for improving replenishments by collaboration between SC partners are compared, because changes in actor collaborations are inevitable if a significant change in replenishment is wanted.

Just in time replenishment
Niall Waters-Fuller has published a clear literature review concerning the topic of just in time purchasing and supply. Gathered from different literature he stated the following activities as major JIT purchasing practices:

- "small purchase lot sizes, delivered in exact quantities compared to traditional large batch delivery within 5 per cent volume either way;
- few suppliers, ideally one per component or family of parts rather than multi-sourcing; supplier selection and evaluation based on quality and delivery performance as well as price, rather than solely a price decision;
- quality inspection is performed at the supplier's facility unlike traditional incoming inspection practices;
- design specifications are looser and more freedom is given to the supplier in meeting the specifications;
- no annual rebidding compared to traditional frequent retendering;
- paperwork reduces and becomes more informal.
- Improved data exchange" (Niall Waters-Fuller, 1995)

Summarizing these purchasing practises lead to a definition of JIT purchasing that has a high correlation with those defined in different literature:
"Just in time purchasing requires small but frequent deliveries of total quality parts from single sourced, local suppliers, with whom there is a close relationship rounded on mutual dependency and frequent communication." (Niall Waters-Fuller, 1995)
Large batch deliveries will result in higher stock levels which is against JIT philosophy. Therefore, lot sizes need to be small. In order to still fulfil the demand, the frequency of deliveries will go up. The cost disadvantages of smaller lot sizes and more frequented deliveries should be compensated by inventory cost savings. In order to let a replenishment process, with small frequent deliveries, flow smoothly, communication and relations with suppliers need to be excellent.
For the KLM Engine shop the philosophy for replenishment is already shifted towards JIT. The relationships and communication with one major supplier (General Electric) can be seen as an example for other companies. The demand in the engine shop is communicated by using ICT systems in relatively fast and accurate manner. The fact that most parts are sourced from this main supplier is another example that facilitates JIT replenishment according to the literature.

Collaborative Planning, forecasting and replenishment (CPFR) vs Vendor Managed inventory (VMI)
A Vendor managed inventory approach leads to the shift of control on the retailers inventory from the retailer to the vendor (see definition below). This approach is initiated by certain manufactures to improve both retail customer service levels and inventory turnover. In a traditional supply chain, in which the retailer works alone and place orders at vendors, not the same productivity increase can be

achieved as compared to VMI because "the vendor is the one able to provide a more responsive replenishment system based on more demand information" (Achabal et al, 2000).
CPFR can be seen as a broader agreement between multiple members in the SC to improve sales forecasts through information sharing. However, a CPFR approach is usually less accurate as the VMI as the forecasting is collaborative and for VMI the vendor(s) can respond quickly (Achabal et al, 2000).
The relevance of these mentioned concept with the graduation thesis lies with the fact that KLM E&M already applies a certain form of CPFR with its SC partners. However, VMI might be a very realistic alternative for supply chain cost saving, that can be evaluated by a simulation model, for example.

Status quo on Simulation
Patel et al of General Motors did research on discrete event simulation in the automotive industry. By using ARENA for simulating their discrete events in the Final process of automotive manufacturing they have succeeded in finding bottlenecks in the system and making the process more effective and efficient. They emphasize however, on ,,the importance of asking the right questions in the beginning of a simulation project and keeping the focus on analytical aspects of the project" (V. Patel, 2002). In this research we keep this advise into account. Firstly by this proposal in which the purpose of the research and the research questions are carefully formulated. When the research is started modeling questions will be worked out in cooperation with KLM.

De Vreede et al give a good overview of what the current opportunities and future challenges are for using discrete-event simulation for business process modeling. They report, relying on other literature, that the use of simulation as a modeling tool for BPR is less then 10% . Many companies are not familiar with simulation as a modeling tool for BPR and usually use static conceptual models. Another might be related to the main disadvantages of simulation which are high costs and a time taking research process. The authors give the following conditions that need to be met for using simulation (citied):

- the business process is of stochastic nature – events that trigger activities occur stochastically
- there are complex interdependences between activities and resources in the process which lead to dynamic changes in the process
- the business process consists of complex flows of activities , which can best be understood by visually depicting its dynamics
- alternatives to change the business process are risky and costly, so the effects of change have to be measured accurately as possible (G. de Vreede, 2005)

The authors report three key challenges and opportunities for further research and development on the use of simulation for business process modeling. The first key challenge concerns the importance of collaboration management during the simulation modeling process. Often the business processes that are simulated involve many stakeholders who need to be involved when modeling. In addition the simulation needs a big time slot for the specific managers or executives who, for example, need to understand the simulation.
A second key challenge is reducing model building time. The real world is dynamic and uncertain and these factors are rather increasing then declining. Policy making needs to be more and more fast in certain industries (especially in times of crisis), which make a long simulation research an inappropriate tool for supportive decision making.
A third key challenges concerns a creation of more awareness about benefits and pitfalls regarding simulation modeling (G. de Vreede, 2005).

Van der Zee et al suggest a modeling framework for supply chain simulation. The modeling framework classifies the model's structure into agents (members of the SC), jobs and flows (physical and informational). The framework is meant as "an explicit guide for the analyst in building higher quality simulation models with respect to transparency and completeness". The main motivation for design of this framework lies with a commonly reported disadvantage: Intransparency. A simulation model is mostly build by one specialized analyst who presents outcomes at the end of the study, of which the correctness is often doubted by SC partners. Consequently, most analysts are involving SC partners more by paying company visits during the modeling process and incorporating their information and reporting model logic occasionally during the modeling project. An interactive simulation model, involving the major SC partners, would be ideal for gaining trust but is not practical (Van der Zee, 2005).

Possibilities for simulation modeling in the Engine shop's logistical system

As came out of the literature research on the status quo of simulation modeling, it has been proven to be a successful tool for policy evaluation at an early stage, under certain conditions. Other motivations for the choice of simulation lies at the hart of the system at the engine shop. The system is very complex and dynamic, over time different scenarios could occur. In addition are changes in the system and their consequences in the system very expensive which makes testing with the real system impossible. In this paragraph first the main types of simulation modeling in SCM will be discussed. After that we discuss if the conditions for our chosen simulation method is met, in other words an elaboration on methodology choice.

Spreadsheet simulation is a more accessible (computer) simulation method, which makes it credible for managers (J.P.C Kleijnen, 2005). There are different types of spreadsheet simulation focusing on SCM but are criticized for being to simple and unrealistic. Some spreadsheet simulation methods do apply randomness but do not deal with dynamics over time.

System dynamics is a (computer) simulation method used for modeling complex systems over time. In a system dynamic study, causal relations and causal loops are identified and modeled into a computer software in terms of stocks and flows. Forester (1961) developed industrial dynamics, which he later extended and called system dynamics. He examined dynamic behavior between actual and target inventories, which in 1997 became known as the bullwhip effect (J.P.C. Kleijnen, 2005).

Business games are getting more popular as there is interest in getting expectations on human behavior in certain business situations from both the academic as the professional world. To simulate technological and economical process are relatively easy compared to the complex human behaviors. Except from the fact that the unpredictable factor 'human behavior' is added in this simulation, it has the advantage that different (key)players are involved in the simulation which gives a more likely acceptance towards the outcome of the simulation.

Discrete event simulation is a very promising tool for simulating supply chains. The main advantage of this type of simulation over the other mentioned concepts is that it can simulate individual events and that it can include randomness and therefore uncertainty. Analyzing discrete events that occur stochastically in a dynamic system over time is central in discrete event simulation. For supply chain alternative evaluation it has been proven to be very successful, as it encounters the most important characteristics the were just mentioned. In the chapter 'status quo' some examples of the application of DES are given.

In order to get an orientation for a choice between the mentioned methodologies a list can be made to mention the systems behavior at the KLM engine shop.

Possible behavior	System behavior (at KLM)	Elaboration
Static vs Dynamic	Dynamic	Different events occur over time which is key to the system
Continuous vs Discrete	Discrete	The material flow, customer orders and other processes are not a continuous flow but discrete events
Determenistic vs Stochastic	Stochastic	There is a behavioral pattern but individual events still have randomness in there occurring.

The concerned system at KLM can be classified as dynamic, discrete and stochastic. This because discrete events such as customer orders or inventory replenishment occur at certain moments that contain randomness. If the mentioned behaviors of the system at the engine shop at KLM are added up, discrete event simulation is concluded to be the most appropriate simulation tool for evaluating this system.

Appendix V

Revising research framework

When performing research, preliminary problem perceptions can be, and often are, changed during the process. Different problems require different solutions and often a different method for reaching solid solutions. For this specific research this was also the case. Due to the lack of system knowledge, it is difficult for the analyst to formulate research questions that will help solving the true problems.
In this chapter the change of research framework will be discussed. First, the new problem definition together with an explanation for this choice. Secondly the methodology that is applied to come to alternatives, which is slightly different then initially planned.

Problem formulation and research questions
The problem statement that was formulated in the beginning of this report, and also shown below, is used as a guide line in this research.

"Which Just In Time replenishment alternative for the engine job shop will lead to the highest cost saving and which alternative is ranked the highest in the trade-off list of the key actors?"

However the first goal in the statement is found to be incorrect after analyzing the system. The problem statement poses that the current way of working is not JIT jet and that there are different ways of JIT. It is difficult to compare different Just in Time alternatives as Just In Time is a philosophy. In this philosophy one tries to reduces inventory to zero when possible. In the literature review the philosophy of JIT is explained more broadly. But it is difficult to say which JIT alternative is leading to the highest cost saving. It is better to say that the alternative that saves the most inventory cost under the given constraints (e.g. no increase in stock outs), is most Just In Time.
During the analysis of the system it is found that the ICT system SAP which is applied at KLM is already designed to work according the JIT philosophy. IT uses intelligent mathematical models to predict future consumption based on historical consumption, as was discussed in this report. The outcome of the forecasting models, together with other material behaviour (e.g. contractual vendor lead time, measured replenishment window etc.) leads to the smallest stock level with a certain safety factor. From the literature review the following summary was quoted about Just In Time replenishment:

"Just in time purchasing requires small but frequent deliveries of total quality parts from single sourced, local suppliers, with whom there is a close relationship rounded on mutual dependency and frequent communication." (Niall Waters-Fuller, 1995)

When considering the replenishment environment of the KLM engine shop, it has a close match with the formulation of JIT purchasing. The engine shops often purchases expensive parts that come in small lot sizes on a regular bases. These parts usually come from one source (e.g. General Electric) with whom there is a very strong relations ship. Moreover there are advanced ICT systems set up between the Engine shop and the main vendors (sources) which results in an almost continuous information transfer. In addition the way the forecast models and planning segments are designed in such a way within SAP that it is always trying to find the optimal balance between risk of stock out and minimizing stock level, which is in accordance with JIT philosophy.

This conclusion has lead to a shift in the research. The focus was no longer on finding different replenishment ways that are JIT but on the way the important variables for the stock levels are influenced. Therefore the problem formulation is adapted, as is shown below.

"Which alternatives for replenishment and material management algorithms can jointly lead to the highest inventory cost saving for the KLM engine shop taking the multi actor setting into account?"

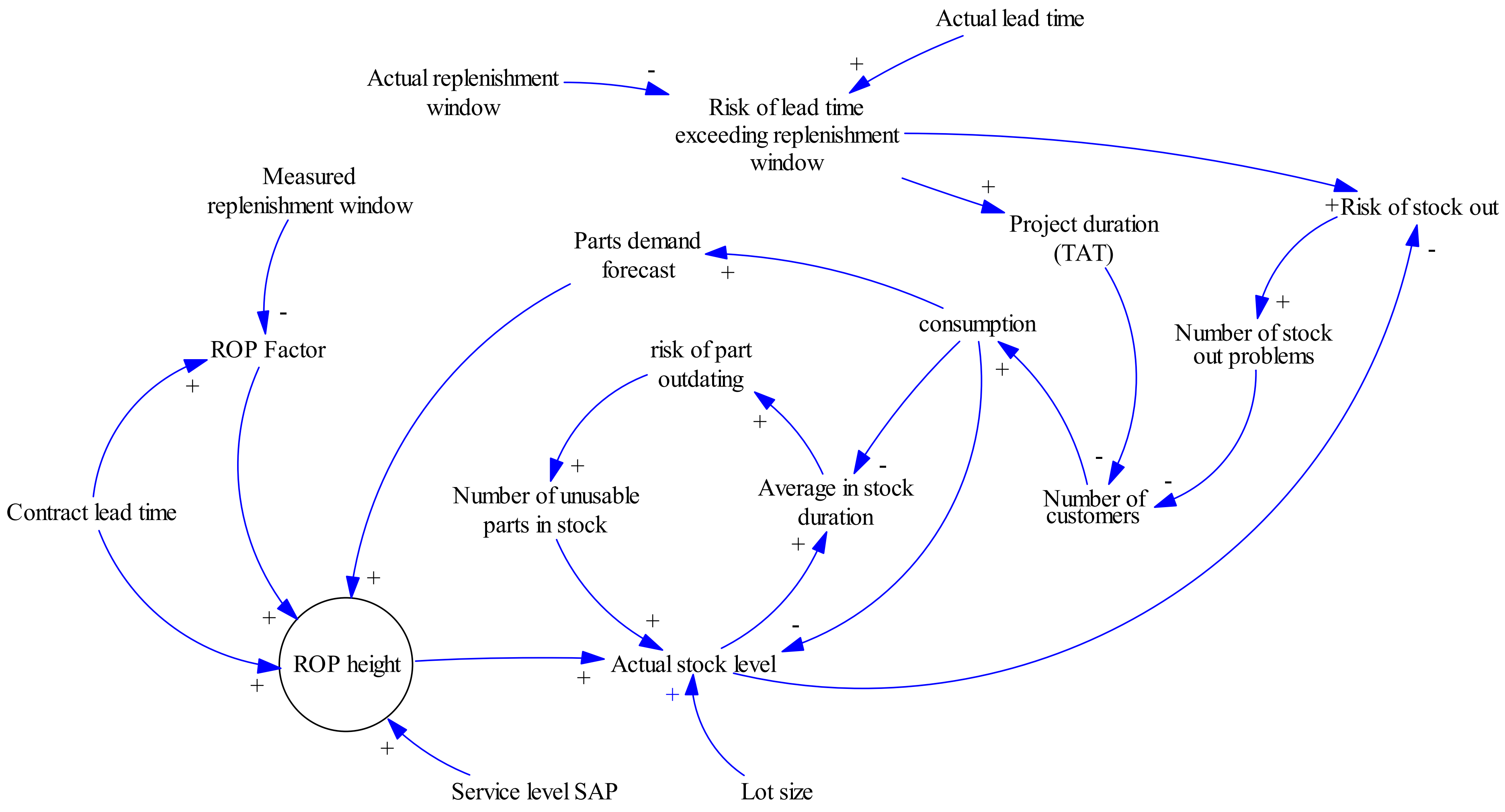
The new problem formulation directs the remaining part of the research (e.g. generation of alternatives) to improve replenishment in general and find more intelligent and logical algorithms within the SAP system than can lead to inventory cost savings. This formulation is the result of the findings from system conceptualization and data analysis in which significant problems have been found with algorithms in SAP or the understanding and knowledge of those algorithms among KLM personnel (e.g. the problem derived from not updating project planning in SAP).

6.2 Applied methodology

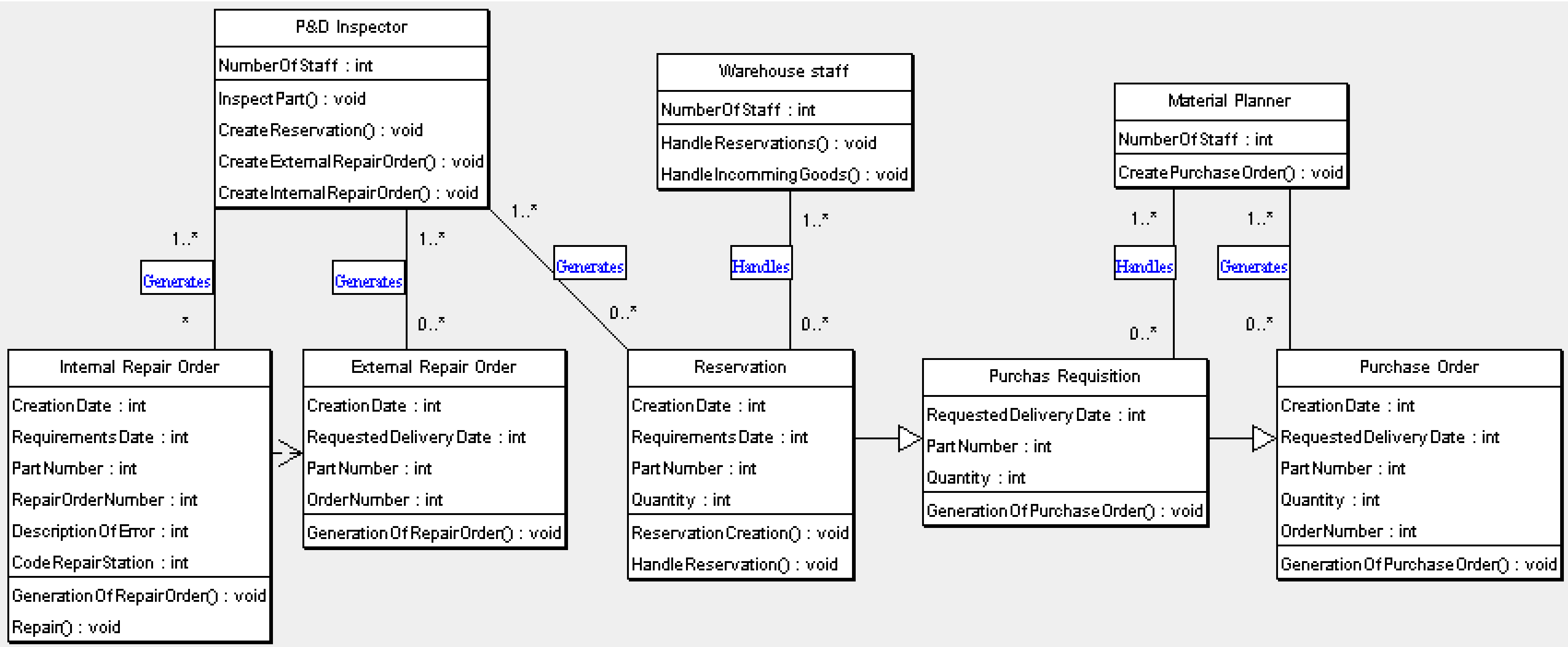
The methodology that was shown earlier in the report is used as a guideline in this research. It was very well estimated that the system analysis phase, which include conceptualization and data analysis, was the most time taking phase in this research. The alternatives were generated mostly based on this system analysis and mental logic but also trough discussion with different KLM personnel from different fields and levels.

Initially the goal of this research was to use simulation modelling to get more understanding of the system and its behaviour and to evaluate the alternatives, that would lead to costs saving, by using the validated model. However simulation modelling is a 'means' and should never be an 'end', it is a tool that needs to help answering question relevant to the research. After performing the system analysis based on conceptual models, mental models and data analysis, an answer could be given to the research questions stated at the beginning of the research. The alternatives that followed should be understandable, also by third parties, with the support of the conceptual models. A simulation model would not have significant added value. In addition would a simulation model of this specific logistical system never be a quantitative representation of reality. There are thousands of different materials with a great variance in most of their processes, which would reduce model validity significantly.

Appendix VI Causal Relation Diagram

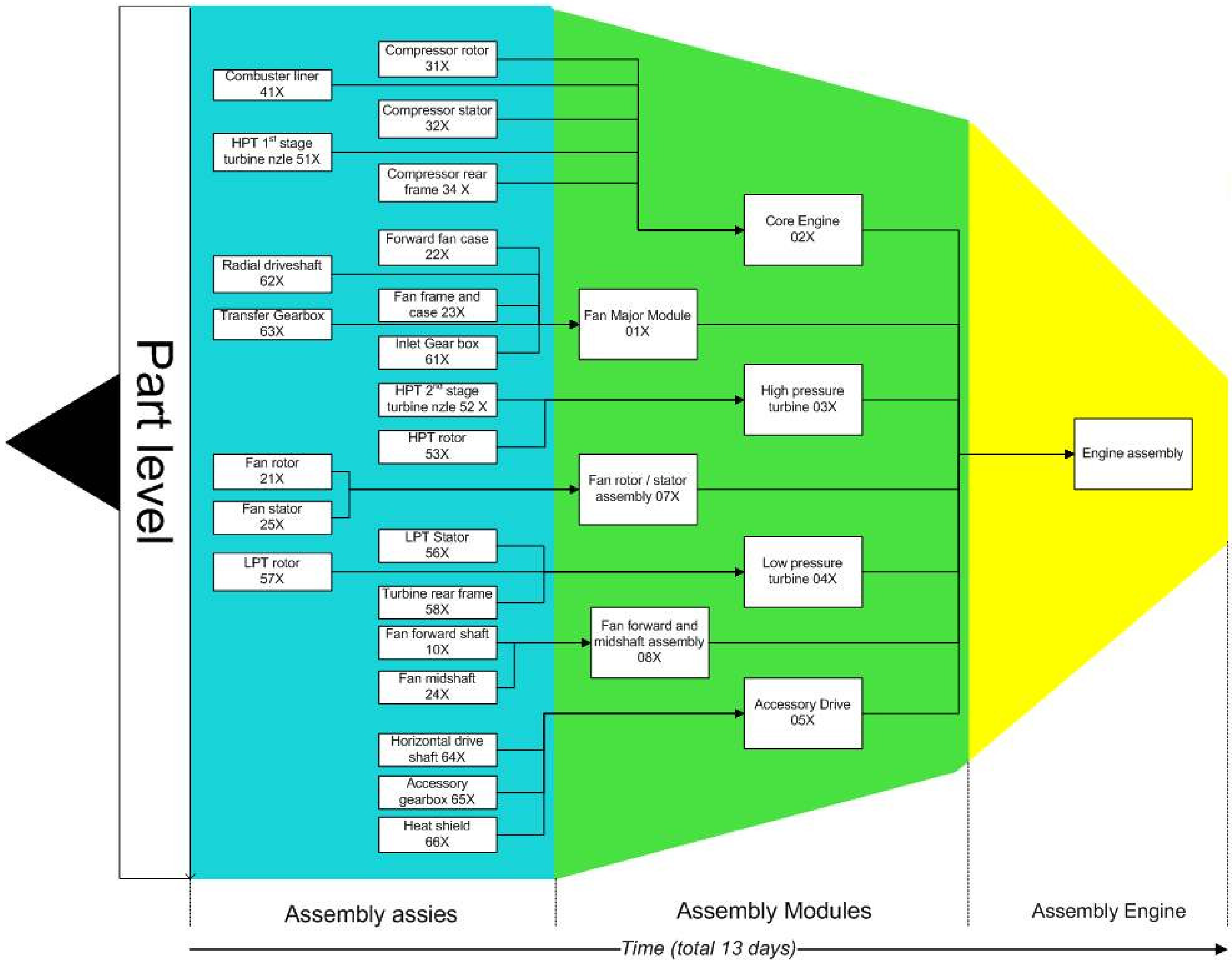


Appendix VII Object Oriented Description

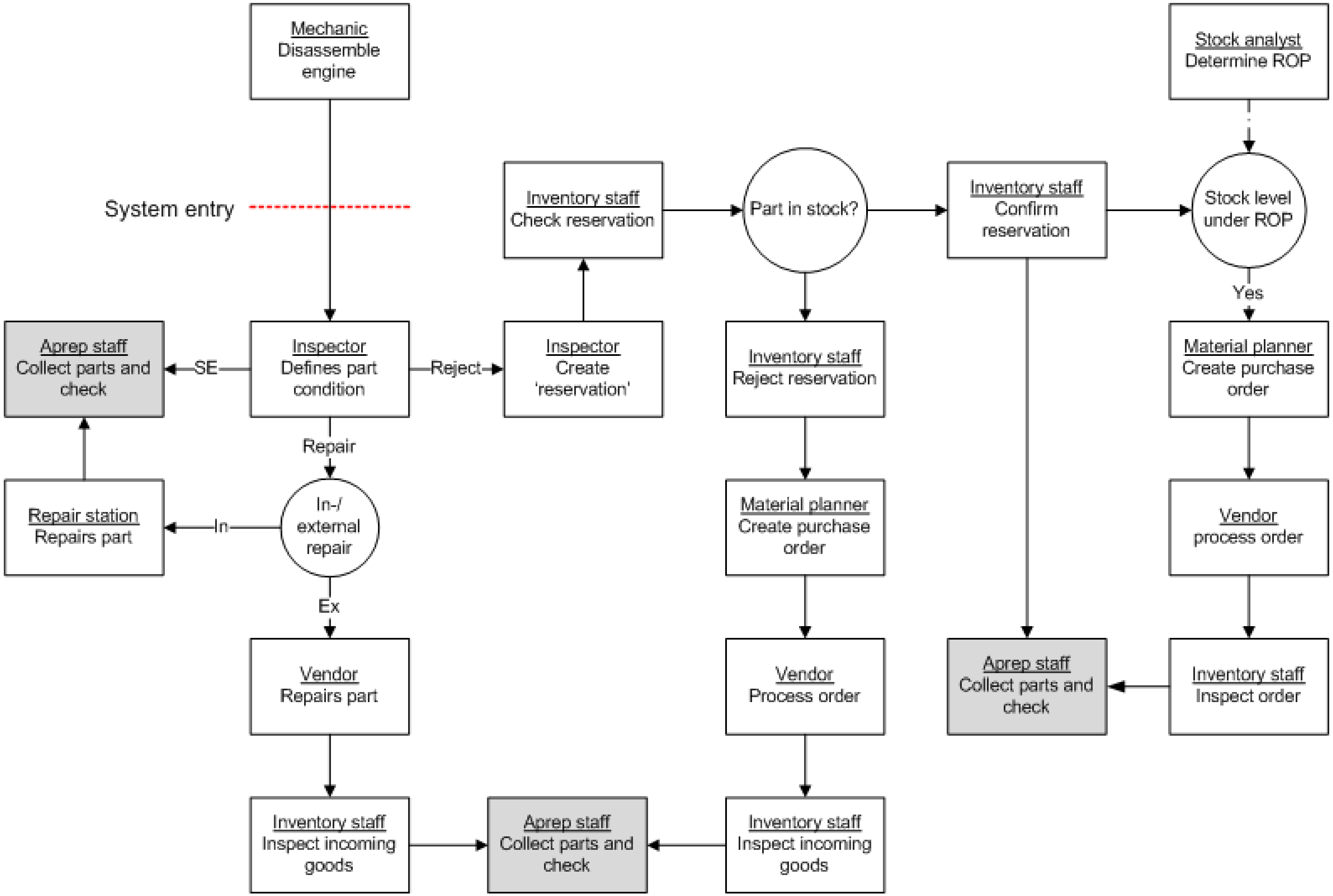


In the object oriented class relation diagram above, the relevant classes in the logistical system are shown together with their relations. The name of the class is stated on top of a class diagram, in the middle the attributes are shown, the lowest lines state the processes in which this class participates. In the diagram above, the top three classes are active classes, the lower ones are passive. The active classes have a relation with the passive ones, mostly by means of a process. For example, one inspector can 'Generate' many internal repair orders. The diagram also indicates there is a dependence between reservation, purchase requisition and purchase order. The dependence arrow indicates the transformation of the class. This means that the reservation will become a purchase requisition and eventually, by interference of a material planner, becomes a purchase order.

Appendix VIII Sketch of engine assembly process (visualized in an engine)



Appendix IX Task actor diagram of logistical system KLM ES



Appendix X Screen dump of simulation model JIT to APREP