Improving the maintenance process at Component Services, KLM Engineering and Maintenance

A framework to identify and eliminate performance bottlenecks

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Preface

This report which concerns my graduation project conducted in Lean Six Sigma Office, KLM Engineering and Maintenance aims to be my final step in completing my Master of Science degree in Management of Technology at Delft University of Technology in the faculty of Technology, Policy and Management.

The conducted research concerns the development of a framework for the identification and elimination of performance bottlenecks, within Component Services KLM Engineering and Maintenance. The proposed framework is the outcome of an action research that has been conducted at Component Services, KLM Engineering and Maintenance and resulted in the identification of the main bottleneck that halts the performance within Avionics & Accessories Repair Shop. Additionally, an intervention plan that can eliminate the identified constraint has been provided.

Nevertheless, the completion of this graduation project could not have been realised without the support of several people who I would like to thank from the bottom of my heart.

From KLM E&M, I would like to thank my supervisors Guus Philips van Buren and Alex Gortenmulder who offered me this great opportunity to work in KLM. The experience I gained throughout this research project is of paramount importance. Their guidance and support facilitated in the realization of this project. Additionally, I would like to thank all the people from KLM who shared their knowledge and experience with me and provided me with all the necessary data.

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Summary

Abstract

Within this report, a framework for the identification of performance bottlenecks within Component Services, KLM Engineering & Maintenance is developed. The proposed framework is developed through a combination of the essential process management cycle and process analysis, intertwined with the Theory of Constraints, based on the OPDCA (observe, plan, do, check, act) cycle of ongoing improvement. A series of steps are defined by the presented framework, including understand current condition, understand source of information gap, develop intervention plan, check results and fix the identified problem through implementing the intervention plan. The implementation of the presented framework in Avionics & Accessories (A&A) repair shop and moreover, the performance analysis of the repair turnaround time metric revealed a performance constraint. Therefore, a set of solutions for the elimination of it has been developed and proposed. The intervention plan which includes setting a fix monthly number of actuator repairs, a priority rule for actuator repairs and implementing payment and incentive models for the production increase has been suggested. Recommendations that can facilitate in the implementation of the intervention plan together with some additional suggestions regarding the inventory management through the redefinition of the relation between the warehouse/pool and the repair shop have been provided.

Situation

Component services is a division within KLM Engineering & Maintenance that provides Maintenance, Repair and Overhaul (MRO) solutions to aircraft components, ranging from wheels and brakes to lights and actuators. The Component Services system of processes includes two distinct processes; to organize component availability and to provide component MRO. The former one concerns the maintenance of the stock level that needs to be available for the customers, whilst the latter includes all the proper repair activities. The process is initiated when Component Services receive an order or request from a customer. The next step includes checking the availability for the requested component in the warehouse (purchase or rent in case of no availability), issuing this component to the customer, replacing the used with the requested one and then shipping the used and unserviceable back to the warehouse. Subsequently, the unserviceable component is delivered to the Repair Shop where MRO activities are performed and afterwards it is shipped and stored in warehouse (pool), maintaining thus the stock level. The maintenance process performance is currently monitored through the use of turnaround time (TAT) performance metrics (Key Performance Indicators – KPIs). However, the performance of the repair shops and more particularly the performance of Avionics & Accessories (A&A) Repair Shop is considerably low, indicating thus performance inefficiencies that have to be identified and eliminated.
**Problem**

The research objective is to design a framework that can identify the main performance bottlenecks at Component Services and more particularly in A&A repair shop when applied. This framework provides a decomposition of process steps in order to identify the relations with the ingredients of a process (manpower, machine, method and material) that halt the performance. Therefore, the root causes of poor performance can be identified and subsequently eliminated.

The research question that will facilitate in developing a framework appropriate for the identification and elimination of performance bottlenecks within Component Services is as follows:

*“How can the performance of an MRO process be improved, in terms of turnaround time”*

Additional sub-questions that facilitate in structuring the research in question and eventually develop the framework that is the objective of this presented research have also been identified.

**RQ1:** What can we learn from literature, regarding the process performance improvement and bottlenecks’ identification?

**RQ2:** What is the current process performed at Component Services KLM Engineering & Maintenance?

**RQ3:** How is responsibility distributed within this process?

**RQ4:** What is the added value that this process delivers to the final customer?

**RQ5:** How is process performance currently monitored at Component Services KLM Engineering & Maintenance and more specifically, what are the KPIs that check the maintenance performance?

**RQ6:** Which are the critical parts within the maintenance process that affect the process performance?

**RQ7:** What are the suggested solutions that can eliminate the identified bottlenecks within the maintenance process at Component Services KLM Engineering & Maintenance?

**RQ8:** How can the suggested solutions be implemented at Component Services Engineering & Maintenance?
**Approach**

In order to tackle with the above mentioned problem, a research framework has been developed. Extensive background research has been conducted in order to identify approaches, methodologies and tools that can facilitate the conduct of the research. Therefore, a framework comprised by the essential process management cycle, process analysis and Theory of Constraints has been developed. The benefits that accrue from the presented framework include providing a roadmap, or in other words a series of steps for the identification of bottlenecks that burden the process performance and the development and implementation of an intervention plan that can eliminate the identified constraints.

**Observe**

The first step of the proposed framework includes all the required actions in order to understand the current state at Component Services. This step is really important, since it provides a stepping stone for the identification of the main performance constraint. A thorough understanding of the current situation facilitates in identifying the process’ critical parts that may conceal bottlenecks.

Therefore, this first step includes a process analysis in order to define the current state of Component Services, in terms of the current process performed, the responsibility distribution per process step, the value that this process delivers to the end customer and the identification of additional sub-processes that are included in the basic process. Moreover, for the complete understanding of the current state, this process step includes a study of the current performance metrics that are included in Component Services Connected Business Balanced Scorecard. Furthermore, a placement of those identified metrics within the process has been performed in order to make clear what is the nature of those KPIs, in terms of what they really measure.

In more details, the Component Services system of processes includes two distinct processes; to organize component availability and to provide component MRO. The former entitles the maintenance of the stock level that has to be available for the customers, in case of repairs, as defined in the contract with the customer. The latter one includes all the necessary actions for the repair of the unserviceable components. Additional sub-processes that are already included in the main process have been identified and subsequently designed. Those include pool availability (maintenance of the stock level in the warehouse), Closed Loop (request for the repair of the same component removed from the customer) and Time and Material (initial evaluation of the repair that determines whether pool availability or closed loop will be performed).

In order to understand the nature of the process performed at Component Services, identifying the responsibility roles in terms of supplier-customer relationships per process step has been necessitated. With the use of the Supplier-Input-Process-Output-Customer (SIPOC) tool, an analysis per process step has been performed revealing the supplier and customer roles together with the input and output per process step. This analysis provides a clearer overview of the nature and the flow of the process.
Exploring a process in depth, aside from analyzing and understanding the process itself, necessitates the identification of the value that this process delivers to the final customer. Therefore, a series of semi-structured interviews have been conducted which revealed that the main goal of the Component Services is “to provide component’s availability” to the customer. In other words, the goal of the process for KLM is to be able to serve its customers, by repairing or delivering (depending on the kind of contract) the right component, with the right specifications at the right time.

Understanding the current condition, aside from exploring the nature of the process, additionally includes monitoring the efficiency of the process in question. Therefore, the current performance measurement system should be analyzed. At Component Services KLM Engineering & Maintenance, the process performance is measured with the use of turnaround time metrics listed in a Connected Business Balanced Scorecard (CBBSC). In more details, the Component Services CBBSC is comprised by 4 categories of performance metrics, including “making the numbers” (elements that contribute to the financial success of the company), “Organizational development” (with metrics such as training that depict the ability to change and improve), “Customer delight” (customer satisfaction or Service Level Availability) and “Operational Excellence” (TAT metrics that show if the MRO process performs efficiently). The Key Performance Indicators have subsequently been located within the identified sub-processes in order to provide a more complete view of their nature; what they really measure.

Plan

The second step of the proposed framework is of paramount importance, since it entails the identification of the constraint that halts the performance. This step uses the turnaround time repair KPIs included in Component Services Balanced Scorecard as a stepping stone for a data analysis of all the registered orders in Avionics & Accessories (A&A) repair shop from March 2014 until June 2015. The performance of the orders, which have been retrieved from the company’s SAP system, has been analyzed and revealed the cell, the workstation within the cell and finally, the component handled by this workstation that have the lowest performance; the analysis path is as such: A&A Repair Shop→Cell 7→Workstation ES. ELECTRO MECH→Actuators.

Having identified the component with the poorest performance led to the calculation of the waiting time before repair (buffer time), touch time (the actual time spent for the repair service) and waiting time (time spent waiting and not performing repair) for a sample of late orders. This analysis, revealed one symptom of the bottleneck; there has been high waiting time before repair, a finding that has also been confirmed by the high levels of unserviceable components’ inventory that has been observed in the cell. Therefore, the performance constraint has been identified as poor order management.
Do
The third step of the presented framework entails the development of the intervention plan that can lead to the elimination of the identified bottleneck. Therefore, this step includes a series of suggested solutions that can improve the performance in the repair shop. For the development of the intervention plan, a background research has been performed in order to define which approach is more suitable for the elimination of performance constraints within the repair shop. Additionally, a background research also facilitated in identifying and therefore proposing relevant models that can enhance the mechanics’ productivity in the repair shop.

The intervention plan that has been developed and thus proposed includes setting a Drum Buffer Rope (DBR) of 12.5 actuators’ repairs on a weekly basis, together with a priority rule for actuators against the rest of the components repaired in the workstation. Moreover, based on scientific research, payment and incentive models that can increase the productivity in the shop, including pay for performance and profit sharing plans have also been suggested. The former one necessitates the implementation of objective performance evaluation systems that can measure each mechanics’ performance through setting respective KPIs. Thereinafter, a respective reward system based on their performance can also be applied. On the other hand, profit sharing models (worker’s compensation is tied to the total organizational performance) will offer an incentive to mechanics to increase their performance.

Check
The fourth step regards the evaluation of the results upon the implementation of the intervention plan. However, since the proposed solutions that have been developed in the previous step have not been implemented in A&A repair shop, the simulation tool has been used in order to evaluate the efficiency of the suggested intervention. Hence, simulation revealed that implementing the Drum Buffer Rope and priority rules can indeed eliminate the identified constraint since the inventory would have been decreased almost 50% by the end of June 2015, provided that the DBR had been set and used as 50 from March 2014. Additionally, the impact of the proposed DBR on the other types of components has been measured, confirming thus the prevention of the development of other performance bottlenecks within the workstation.

Act
The final step of the proposed framework includes the actual fixation of the identified constraint. Therefore, additional suggestions that can facilitate in the implementation of the proposed intervention plan have been provided. First of all, the implementation of the DBR as 50 actuator repairs per month necessitates the redefinition of the relation between the warehouse/pool and the repair shops. As a result, it is very important that the repair process becomes a “pull” process instead of “push” which currently is. Moreover, time, effort, universal approval and careful design and implementation from the KLM stakeholders involved are required for the implementation of the payment and incentive models that can enhance the productivity of the mechanics. Additionally, proper metrics that measure the mechanics’ performance and productivity should also be developed and objectively checked for the needs of the models.
Beyond the proposed solution, the inventory management and the repairs ordering at Component Services is proposed to be reexamined, since a more dynamic approach between the supply and demand of serviceable components is needed. As a result, defining two new indicators is proposed; a) a marginal spare support inventory level for critical parts driven by minimizing the total backlog cost expected among the requests or by the number of the predefined, expected aircraft’s checks of every customer and b) their respective actual pool inventory levels. In case the marginal inventory level is higher than the actual, priority should be given in the repairs of the critical parts (eg. actuators) through setting a proper DBR. On the other hand, in case the actual level is higher than the marginal level, the FIFO rule in repairs can be applied. Defining and monitoring such indicators necessitates the establishment of proper buffers, where the unserviceable critical parts (eg. actuators) that do not yet need repair can be located.

**Conclusions and Recommendation**

In the end of the presented report, the main conclusions driven from the conducted research, together with a list of additional recommendations have been provided. The findings of the presented research confirm that the main performance constraint at Component Services, A&A Repair Shop is the poor order management. Therefore, by setting a priority Drum Buffer Rope of 50 actuators on a monthly, or 12.5 per week, the high inventory levels of unserviceable actuators can be dramatically decreased. Additionally, a reexamination of the relation between the warehouse/pool and the Repair Shop is suggested, in order to establish a more dynamic approach of the inventory management at Component Services.

Moreover, research recommendations have been provided categorized in framework, Component Services, A&A Repair Shop and actuators. Regarding the framework, since the performance constraint identification has been the outcome of a data analysis performed for turnaround time KPIs, quality or cost metrics should additionally be tested. Moreover, testing the applicability of the developed framework in repair processes and repair conditions other than those in question is also suggested. Regarding Component Services, further research is recommended in order to explore the impact of the proposed intervention plan on the pool availability and cost decrease. Moreover, additional research is proposed for the reexamination of the inventory management and critical components’ order priority at Component Services, as provided in the previous section. Additionally, the implementation of it in Base Maintenance Support Shops (BMSS) Repair Shop of Component Services is also recommended. For A&A Repair Shop, repeating the framework for the identification of additional bottlenecks is suggested together with exploring the impact of the intervention plan on the inventory level of other unserviceable components, with the use of real time data rather than the norms of the repair process. Last but not least, measuring the real touch time of actuators’ repairs is proposed in order to set a more realistic DBR for actuators repairs.
Contribution

The contribution of this research is threefold: scientific, managerial and societal. First of all, this research provides a framework, a series of steps and sub-steps for the identification and the elimination of performance bottlenecks. This proposed framework has a scientific character since it comprises the OPDCA (Observe, Plan, Do, Check, Act) cycle of ongoing improvement, the essential process management cycle, process analysis and Theory of Constraints for the identification and elimination of performance bottlenecks.

Moreover, the presented framework has a scientific contribution, since it can be applied both in other repair processes (other than actuators) that resemble the conditions of A&A repair shop and more generally, in various push, flow shop manufacturing and production processes that handle their orders under specific conditions. Those conditions include the simultaneous performance of different, hence standardized, flow shop processes, under the FIFO (First arrived, first handled) scheduling rule, with shared capacity (the same workers are capable of handling different orders and not exclusively one specific type of them).

Additionally, this research is related to a managerial aspect of Component Services KLM Engineering & Maintenance, since it provides the identification of a specific performance bottleneck within A&A Repair Shop and also develops an intervention plan for the elimination of it. Furthermore, the proposed framework can be additionally used for the BMSS repair shop as well as for other repair shops in KLM E&M that resemble the repair conditions of A&A repair shop. Finally, the societal relevance of the research concerns the value that is delivered to the final customer. During the presented research, the added value of Component Services has been identified as “to be able to serve its customers, by repairing or delivering (depending on the type of contract) the right component, with the right specifications at the right time”. Hence, the improvement of the maintenance process at Component Services that can accrue from the identification and elimination of the identified performance constraints can contribute towards achieving this goal.
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1. Introduction

1.1 Introducing KLM Profile

KLM (Koninklijke Luchtvaart Maatschappij) or else Royal Dutch Airlines is the heart of the KLM Group, also including KLM cityhopper and transavia.com. KLM consists of three core businesses; passengers’ transportation (Passenger Business), cargo transportation (KLM Cargo), and last but not least aircraft maintenance, performed in KLM Engineering & Maintenance (E&M) facilities.

KLM E&M provides maintenance, repair and overhaul (MRO) solutions to the customer. In more details, aircraft, engine and component MRO, together with the included logistical processes in most of the cases (as defined by the customer contract) are performed in KLM E&M. Figure 1 displays the main MRO\(^1\) services provided by KLM.

\[\text{Figure 1: MRO services and their respective processes}\]

\(^1\)According to Cambridge Online Dictionary maintain is to “keep something in good condition”, repair is “the act of fixing something that is broken or damaged” and overhaul means “to repair or improve something so that every part of it works as it should”. The difference between repair and overhaul is that the latter one includes disassembly, clean, inspection, repair, reassembly and test according to the standards.
The Aircraft MRO includes all the necessary services for the maintenance of the airframe (radomes, wings etc.), whilst the Engine MRO includes all the required services for the maintenance of the aircraft’s engines. At Component Services, particles of the aircraft are maintained.

![Diagram of relations within Component Services]

**Figure 2: Relations within Component Services**

As figure 2 displays, when the customer sends a new order, or in other words a request for a new component, Component Services picks a serviceable (fully functioning) component from the CS (warehouse located in logistics Center) and sends it to the customer. In case there is no availability, Component Services purchase or rent a component from an external vendor and subsequently ship it to the customer. Thereinafter, exchange is performed at the customer and the unserviceable part (part that needs MRO) is sent to the CS. Subsequently, this unserviceable component is sent to the MRO shop, which performs all the needed repair services that will make it serviceable again and sends it back to the CS (warehouse). Hence, the stock level of serviceable, available components in the warehouse is maintained. In some cases, the customer can request the repair of its own component. In this case, there is no exchange since the unserviceable part is removed from the customer, sent to CS, which subsequently sends it to the repair shop. After the repair of the component, it is sent back to CS and then to the customer; this case is called closed loop.

The maintenance of the components is performed in two distinct shops; BMSS (Base Maintenance Support Shops) that offers airframe and some components’ MRO services, such as carrier assies, wheels and brakes, engine parts and aircraft panels and A&A (Avionics and Accessories) that exclusively offers maintenance services to parts including fuel and pumps, hydraulics, electro mechanical services, bottles and computers repair.

Every unserviceable part shipped from the warehouse (CS) to the Repair Shop is initially delivered to the expedition point (figure 3).
Thereinafter, the Customer Interface Repair Officer (CIRO) picks it up and performs an incoming test (figure 4), including unpacking, checking the serial number in the system, printing the job card (the series of steps performed during the repair) and the component’s label and put them all together in a plastic bag.

Subsequently, this bag is delivered to the Cell’s shelves. At this point, the cell’s mechanics pick the unserviceable component from the shelf, perform the proper repair processes together with the accompanied paperwork (the repair process will be further analysed in chapter 5.1) and upon completion of the repair process and the final test, they deliver the now serviceable component back to the cell’s shelves. Figure 5 displays the testbench used for the final test of actuator, upon repair completion.
Thereinafter, the CIRO picks the serviceable component and performs an outcoming test, including checking the component together with the accompanied papers (signatures and serial number), printing the tracking sticker, make a proper packaging of the component and finally, delivering it back to the expedition point. From the expedition point, internal logistical processes are performed for the delivery of the serviceable component back to the warehouse (CS). Figure 6 displays the process performed in the Repair Shops.

The presented research has been conducted at Component Services and more specifically in A&A repair shop. A&A consists of 8 different cells and each of them further includes 1-3 workstations. Additionally, every workstation repairs a plethora of components based on the FIFO rule (First In First Out), which indicates that the first component delivered to the workstation, will be the first to be repaired. Nevertheless, the FIFO rule is not applied on late orders, since repair priority is always offered to the delayed orders. Moreover, the repair of the components is performed with shared capacity, which means that every mechanic repairs several types of components and not one type exclusively. For instance, in cell 7 and workstation ES ELECTRO MECH, the capacity is shared among several types of components, generally categorized into sensors, relays, lights, fan, ballasts and actuators.

In A&A Repair Shop, the performance of the repair process is checked with the use of turnaround time Key Performance Indicators (KPIs) which are included in the Connected Business balanced Scorecard of KLM E&M. Those KPIs measure the real time needed for the completion of the repair process. However, these indicators currently display a rather poor maintenance performance; the
turnaround time needed for the completion of the maintenance, repair or overhaul process exceeds the predefined target, adding thus considerable delay. Therefore, deep inspection of the MRO process is necessitated, in order to identify the root causes, the constraints or possible bottlenecks that halt the performance. Subsequently, interventions that will eliminate the identified root causes of poor performance should be provided. During the presented research, a framework has been designed, consisted of a series of steps for the identification of the root causes that halt the performance within A&A Repair Shop. Additionally, proper suggestions that will facilitate in the elimination of those root causes are also provided by the presented framework.

1.2 Problem description

Technology, market internationalization, increasing competitiveness and changes in the supply and demand have a turbulent effect on economic markets. Therefore, different sectors of industries, including manufacturing and MRO are deeply influenced by the above mentioned factors. Additionally, changes in the economic markets have an unquestionable influence on customers’ needs creating thus great variation in orders, labor and capacity decisions which influence on a great extent the MRO industry. Moreover, the aviation MRO industry has to deal with the coordination of unscheduled, high priority removals and maintenance, different removal strategies, applied to the needs of each customer and the growth of aircraft Original Equipment Manufacturers (OEMs) becoming though major MRO leaders, thus threatening the independent MROs. From the customer perspective, MRO industries have to deal with keeping cost low but quality high, guarantee turnaround times, as specified in the contract and provide a fully Serviceable aircraft when it is required (Al-kaabi et al. 2007; Cobb 1995; Reményi et al. 2014).

In Aviation MRO Industry, all the necessary actions are performed in order to retain or restore an aircraft to that condition that is specified as operable, and airworthy; flying as long as possible in the skies. However, structure and components do deteriorate because of its flying hours and travels, leading thus to a condition that renders the aircraft un-airworthy. This is the point where maintenance process is performed in order to bring the aircraft back to a flyable condition, render it again airworthy (Sahay 2012).
Introduction

![Figure 7: Added value to the end customer through maintenance processes (own illustration)](image)

**Maintenance performance**

In KLM E&M, there are three distinct systems of processes aircraft, components and engines services. These MRO processes are very complex and work together in a parallel way in order to build up a maintenance system that delivers serviceable parts, engines and aircrafts to the customer, rendering thus every aircraft airworthy again. However, inefficiencies in the main maintenance processes, in terms of manpower, material, machine and method, add considerable delay in the completion of the repair orders, lowering thus the overall performance of the system. Moreover, a delay in the order delivery can additionally lead to cost increase, since the pool (warehouse of Component Services) may be forced to purchase or rent new parts/components in order to compensate customers. Therefore, the control of each process step and the relation of those steps with the 4 Ms (manpower, machine, method and material), together with the implementation of interventions in order to improve the process performance are required. Reducing maintenance turnaround times and thus lowering inventory cost through improving the utilization of the capacity, together with offering high quality and customer service improvements are of high importance (Cobb, 1995) for MRO Industry and more specifically for KLM E&M.

**TAT Repair Shop**

At Component Services KLM E&M and more specifically in A&A repair shop, the maintenance performance is currently monitored through a turnaround time (TAT) Key Performance Indicator. In other words, the repair TAT indicator represents the total time needed to complete the MRO task; it starts at the point of time that the unserviceable component is delivered and placed on the cell’s shelves (waiting for the mechanics to pick it) and ends when the now serviceable part is placed by the mechanics on the cell’s shelves (waiting to be picked up and then delivered to the customer). In KLM E&M, each customer contract predefines a TAT of the order’s delivery. This TAT includes the TAT of the logistical processes and the TAT of the repair process. For component repairs performed in A&A repair shop, the repair TAT is set as 14 days.
Stakeholders analysis

Within Component Services, roles have been set in order to efficiently monitor the process performed. The process owner is accountable for monitoring the whole performance of the Component Services and make proper decisions in order to increase performance efficiency. Process owners are the only authorized to change the design of the process and the targets of the performance metrics. Additionally, process managers are also assigned to each process for the efficient control of the process execution and performance. Since Component Services include two distinct processes: provide component availability and provide MRO, two are the process managers, each one assigned to each process. In the case of Component Services, the process owner is the Vice President of Component Services, while the process manager of the MRO process is the Production Unit Manager.

Within A&A repair shop, there are two production lines, Hydro mechanics and Avionics, each of them further including 4 cells. A production line manager has been assigned to each production line, in order to monitor the performance and the productivity of each cell together with financial aspects, including FTEs and budget of the production line. For the efficient operation of the cells, including repair planning and work shifts schedules on a weekly basis, cell managers have been assigned. The cell managers have daily meetings with the mechanics in order to develop the repair planning of the day.

Figure 8 displays a stakeholders’ analysis within Component Services KLM E&M and A&A Repair Shop, including all the above mentioned, identified roles.

![Stakeholders map at Component Services, A&A repair shop](image)
In A&A repair shop, the maintenance performance scores considerably low, indicating thus the possible existence of performance constraints that may be related with the 4 Ms (manpower, machine, method and material). Therefore, an appropriate research that will lead to the identification of the root causes that halt the performance and the subsequent elimination of those is necessitated. By reviewing the whole maintenance system and identifying inefficiencies, interventions that can increase the efficiency, effectiveness and reliability can be applied (Johnson et al. 2000). Hence, decisions regarding the design, the resources, the capacity, the output or throughput will contribute in performance improvement.

The presented research provides a performance analysis in A&A Repair Shop that leads to the identification of the root cause that halts the overall performance of the Repair Shop and additionally provides a list of suggestions that can facilitate the elimination of it. Since proper authority is required for the implementation of the suggested intervention plan, the presented research is therefore addressed to higher management level, the process owner of Component Services and the process manager of the MRO process who monitor the process performance and intervene, when needed, in order to improve the performance with proper decision making.

1.3 Research Objective and questions

The research objective is to design a framework that can identify the critical parts of the repair process that halt the maintenance performance at Component Services. This framework provides a decomposition of process steps in order to identify the relations with the ingredients of a process (manpower, machine, method and material) that burden the performance. Therefore, the root causes of poor performance can be identified and subsequently eliminated (figure 9).

![Figure 9: Decomposition of process steps in MRO (own illustration)](image-url)
The research question that will facilitate in developing a framework appropriate for the identification and elimination of performance constraints within Component Services is as follows:

“How can the performance of an MRO process be improved, in terms of turnaround time”

For the purpose of the objective of the research question, a combination of different methodologies takes place in order to develop the presented framework for the identification and elimination of performance constraints within the Component Services, KLM Engineering & Maintenance. An analysis of the current state of Component Services has been initially performed, in order to get a clear insight of the process, the KPIs that are currently used for the performance measurement and the responsibility distribution per process step. Subsequently, the constraint that halts the performance in one of the two repair shops has been identified and thereafter, suggestions that can eliminate the identified constraint are provided.

Additional sub-questions that facilitated in structuring the research in question and eventually develop the framework that is the objective of this presented research have also been identified. The methods and tools that have been used for each of the below mentioned questions, together with the chapter related with them will now be provided.

1. What can we learn from literature, regarding the process performance improvement and bottlenecks’ identification?

A background research has been conducted in order to understand methods, approaches and tools that can be used for the identification of performance bottlenecks and constraints. Keywords that were used during this research include process improvement, process management and performance constraints identification. During this research several theories and approaches were found leading thus to the combination of the essential process management cycle and Theory of Constraints as the roadmap for the constraints’ identification and performance improvement. The above mentioned background research can be found in chapter 2, together with the description of the presented framework and the pillars on which it is based.

2. What is the current process performed at Component Services KLM Engineering & Maintenance?

3. How is responsibility distributed within this process?

4. What is the added value that this process delivers to the final customer?

For the purpose of the above mentioned sub questions, the current state of Component Services has been defined. In more details, the process steps that are currently followed at Component Services have been explained, additional sub-processes that are included in the current process have also been identified and mapped and finally, the added value delivered to the final customer and the responsibility roles per process step have also been defined. Hence, a broad overview of the current situation at Component Services has been given in order to facilitate the next steps of the research.
Defining the current state at Component Services has been realized with the use of a series of tools. First of all, the Component Services process has been retrieved from the local BPM ARIS system of KLM and the additional sub-processes that were identified have been subsequently designed with the use of the Google Drawings tool. Furthermore, the responsibility roles per process step at Component Services have been provided with the use of the SIPOC (Supplier-Input-Process-Output-Customer) tool that revealed the supplier-customer relationships per process step. Finally, a series of semi-structured interviews revealed the added value delivered to the final customer. The analysis of the current state of Component Services is given in chapter 3.

5. How is process performance currently monitored at Component Services KLM Engineering & Maintenance and more specifically, what are the KPIs that check the maintenance performance?

For the needs of this sub-question, an overview of the current performance measurement system at Component Services, KLM E&M has been provided, with the use of the Connected Business Balanced Scorecard for Component Services. Therefore, the turnaround time KPIs that measure both the process and the maintenance performance have been explored and located within the current processes, in order to offer a clear view of their nature; what they really measure. Providing a clear overview of the performance measurement system, currently used at Component Services in terms of turnaround KPIs, can facilitate in identifying process constraints that halt the performance. The overview of the performance measurement system of Component Services, KLM E&M is provided in chapter 3.

6. Which are the critical parts within the maintenance process that affect the process performance?

In order to identify the main constraint within the maintenance process that halts the performance, a data analysis has been performed. Moreover, the performance of the turnaround time (TAT) Repair Shop KPI has been analyzed for the Avionics & Accessories Repair Shop (A&A) of Component Services for rotatable orders (components that can be multiply repaired and used again) of the period March 2014 - June 2015. This data analysis revealed the cell, workstation and finally the component with the lowest performance. Additionally, the buffer time, touch time and waiting time within repair has been calculated for the component with the lowest performance. This analysis, combined with a number of observations conducted in A&A revealed some symptoms of the bottleneck and eventually the constraint of the process performance.

For the identification of the process’ critical part, statistical tools including frequency tests, performance graphs and simulation have been used. Additionally, the lean technique GO GEMBA (make real time observations) has been used, in order to make close observations and evaluate the current situation and symptoms of the performance constraint. Chapter 4 provides the overview of the data analysis performed.
7. **What are the suggested solutions that can eliminate the identified bottlenecks within the maintenance process at Component Services KLM Engineering & Maintenance?**

For the needs of constraint’s elimination, an intervention plan has been developed and proposed. First of all, the constraint’s capacity has been calculated and therefore, a Drum Buffer Rope, or in other words, a predefined number of repairs that should be performed on a weekly basis has been proposed. Additionally, priority rules and models that can increase the productivity in the shop have also been suggested. In order to prevent the development of additional performance bottlenecks, the impact of the proposed intervention plan on the other types of components repaired within the workstation has also been calculated. Finally, the efficiency of the proposed intervention plan has been tested with the use of simulation. An overview of the developed intervention plan is given in chapter 5 and its efficiency has been tested in chapter 6.

8. **How can the suggested solutions be implemented at Component Services Engineering & Maintenance?**

The implementation of the proposed solutions necessitates a number of additional suggestions that accrue from the intervention plan. These suggestions include all the necessary actions that need to be taken in order to maintain the elimination of the identified constraint. More information about the implementation of the suggested solutions at Component Services is provided in chapter 7.

1.4 **Research Methodology**

The research methodology that will be followed is based on the research question and sub-questions and will guide the whole research execution, the data gathering and analysis and finally the design of the final framework to be delivered.

The starting point of the research in question is an identified problem within the Component Services KLM E&M, therefore the research methodology will be action research. According to O’Brien (1998), action research is the methodology used in real situations since its main focus is to solve real problems. This approach necessitates the active participation of the researcher, in order to identify, analyze and solve a problem. Action research is a practical and problem-solving approach, since the conducted research is directed towards the deep exploration, analysis and finally improvement of a real world problem, over a time period (Yen et al., 2002).

According to Baskerville (1997), the action research approach is based on the contention that a process is best studied through changes’ implementation and then results’ observation. Therefore, the research method is approached by an interventionist’s perspective and the researcher both participates and observes. Moreover, the action research is specified through a series of steps; an action research cycle, as displayed in figure 10.
The action research cycle starts with diagnosing and then action planning, action taking, evaluating and specifying learning are performed. In more details, diagnosing regards the identification of the organizational problem that needs to be solved; action taking includes the implementation of intervention plans, the results of which are subsequently evaluated. The final step of the process entitles the ongoing process of improvement (Baskerville, 1997).

For the needs of the research, appropriate data will be gathered with the use of triangulation. Triangulation entails the study of a phenomenon by applying a combination of different methodologies (Cunningham, 1997). In the context of the research in question, three different data sources will be of use; a background research in literature in order to explore process performance improvement and constraints’ identification methods and approaches and how those can be applied in an organizational context. The second data source, which is the Connected Business Balanced Scorecard (CBBSC) of Component Services, KLM Engineering and Maintenance, constitutes the most representative tool of real time performance measurement, through a list of predefined Key Performance Indicators, including KPIs that measure the performance of the repair process that takes place in the repair shops of KLM. The CBBSC is the most important tool for the identification of the performance constraints, since analyzing the scores of the relevant turnaround time KPIs will reveal the shop-cell-workstation and component that halts the performance. Additional to the CBBSC, interviews with the KLM people who are responsible for the control of the processes and their performance, together with shop floor observations in the Repair Shop that will facilitate in identifying weaknesses and factors that influence the performance will be of use as data sources. The research methodology that will be followed is displayed in figure 11. In this figure, the relations between the research design and research questions and methods used are displayed. Additionally, the reader can observe the reflection of the research methodology, which is action research, on the research design and also the reflection of the OPDCA cycle of ongoing improvement on the research questions. The OPDCA cycle is the basis of the research framework and will be described in the second chapter.
1.5 Research deliverables

As it has been mentioned earlier, the objective of this research is to design a framework that can identify the main performance constraints at Component Services when applied. This framework, which will be further described in chapter 2, provides a series of steps including identification of the current state of Component Services, understanding the source of information gap (identify the performance constraint), development, evaluation and finally implementation of an intervention plan (set of proposed solutions to eliminate constraint). For each of the proposed steps, additional sub-steps have also been developed and proposed for the efficient implementation of the framework.

Additionally, since the above mentioned framework has been the outcome of an action research in KLM E&M, there is a set of deliverables that are addressed there. In more details, the identification of the poor management of actuators’ orders/repairs in Cell 7 and Workstation ES ELECTRO MECH, as the main constraint within A&A repair shop is one of the research deliverables addressed to KLM E&M. Moreover, the set of the proposed solutions, including setting a fix number of actuators that should be repaired on a weekly basis, together with a priority rule for actuators’ order and the implementation of models that can increase mechanics’ productivity constitute another research deliverable addressed to KLM E&M. The identification of the performance constraint and the proposed solutions are described in chapters 4 and 5 respectively. Finally, additional suggestions have been provided to KLM E&M regarding the efficient implementation of the developed intervention plan, together with a dynamic inventory management recommendation through the reexamination of the relation between the pool and the Repair Shops. These additional suggestions can be found in chapter 7.
1.6 Contribution
The contribution of this research is threefold: scientific, managerial and societal.

First of all, this research presents a framework for the identification and the elimination of performance constraints. This framework provides a series of steps including the exploration of the process' current state, understanding the source of information gap, development, evaluation and implementation of the intervention plan. Additional sub-steps that facilitate the completion of each step have also been proposed. This proposed framework has a scientific character since it comprises the OPDCA (Observe, Plan, Do, Check, Act) cycle of ongoing improvement, the essential process management cycle as denoted by Hammer (2010), process analysis and Theory of Constraints for the identification and elimination of performance constraints.

The scientific contribution of the presented framework is additionally enhanced by the fact that the applicability of the proposed series of steps exceeds the limits of the actuator repair processes. In more details, as depicted by Mogendorff (2015), the repair of combustors (component within the aircraft’s engine) in KLM E&M follows a predefined, standardized repair route: incoming check, disassembly, inspection & work scope, repair, assembly and final check. Moreover, the mechanics that perform the combustor repairs in KLM Engine Services, work with other components as well, without using any priority rule on the order handling. Under these conditions, the presented framework can be implemented in order to identify the performance constraints and eliminate them through applying the proposed set of solutions; through setting a drum buffer rope and priority rules for combustors, together with the models that can increase the mechanics' productivity. Additionally, the inventory management proposed solutions for the redefinition of the relation between the Engine Services and the warehouse/pool, rendering thus the repair process as “pull” rather than “push” can also be applied.

Nevertheless, the implementation of the proposed framework is not only limited in repair processes, but rather on various push, flow shop manufacturing and production processes that handle their orders under specific conditions. Those conditions include the simultaneous performance of different, hence standardized, flow shop processes eg. the repair/manufacturing/production of different types of components/products, each of them following its own, standardized repair route, under the FIFO (First arrived, first handled) scheduling rule, with shared capacity (the same workers are capable of handling different orders and not exclusively one specific type of them).

Secondly, this research is related to a managerial aspect of Component Services KLM Engineering & Maintenance, since it provides both a performance analysis that leads to the identification of a performance constraint within A&A Repair Shop and also an intervention plan that can be applied and eliminate the identified constraint. Furthermore, the proposed framework can be additionally used for the BMSS repair shop as well as for other repair shops in KLM E&M that resemble the repair conditions of A&A repair shop.
Finally, the societal relevance of the research concerns the value that is delivered to the final customer. During the presented research, the added value that Component Services delivers to the end customer has been defined as “to be able to serve its customers, by repairing or delivering (depending on the type of contract) the right component, with the right specifications at the right time”. Hence, the improvement of the maintenance process at Component Services that can accrue from the identification and elimination of the identified performance constraints can contribute towards achieving this goal.

1.7 Research Outline

The research report is structured based on the steps of the proposed framework. In chapter 2, there has been an extensive background research on process management and process analysis approaches, performance measurement frameworks and systems and theories for bottlenecks’ identification that facilitated in structuring the proposed framework. In the end of chapter 2, the proposed framework is presented and described. In chapter 3, a brief description of Component Services and the definition of the current state is given. This chapter includes an analysis of the current process performed at Component Services, the supplier-customer relationships per process step, the identification and design of additional sub-processes and an analysis of the performance metrics that are currently used at Component Services and in maintenance process.

In chapter 4, the constraint that halts the performance of the A&A repair shop is identified through a quantitative analysis of the repair performance together with a series of observations in the shop that revealed the symptoms of this constraint. In chapter 5 an intervention plan for the elimination of the identified constraint that comprises setting a Drum Buffer Rope (fix number of component repairs on a weekly basis), priority rules for repairs and models that can increase productivity in the repair shop is proposed. In this chapter, the impact of the proposed solutions on the other types of components has been explored. In chapter 6, the impact of the intervention plan on the constraint has been evaluated with the use of the simulation tool and in chapter 7 further recommendations that can facilitate in the implementation of the intervention plan are also provided. Additionally, inventory management recommendations through the redefinition of the relation between the Repair Shop and the Warehouse/Pool (dynamic approach) are provided. Final conclusions, research limitation and recommendations are given in the final chapter.
2. Background Research

In this chapter, a background research on literature will be presented. This literature played a key role in structuring the presented methodology. First of all, the process management PDCA cycle of ongoing improvement (or Deming) cycle of Observe, Plan, Do, Check and Act functioned as the basic pillar of the developed framework. On this pillar, the essential process management cycle, the process analysis steps, and the Theory of Constraints for the identification of performance bottlenecks have been combined for the development of the presented framework. In this chapter, the main theories and approaches that have been reviewed will be presented. Furthermore, a description of the developed framework will also be provided, together with a review of its general usability and implementation restrictions.

2.1 Maintenance

Maintenance comprises all the required technical and the respective administrative actions in order to retain or restore an item to a previous, desired operational state. It is a function that includes important assets’ investments and contributes in achieving organizational goals (Muchiri et al., 2011; Parida, 2006). According to (Kumar et al., 2013) maintenance includes the engineering decision together with the respective necessary actions to optimize the capability (ability to perform within a range of performance levels) of an equipment. The maintenance costs in asset-intensive industries constitute a considerable amount of the operational costs and are calculated as 1500 billion euros per year for Europe. On the other hand, the loss of the revenue resulted from non functionality is also important and can reach 0.5 million per day for a 747 out-of-action Boeing plane (Parida et al. 2009). The maintenance process may include corrective and preventive maintenance (Sahay, 2012).

2.1.1 Aircraft industries maintenance

Maintenance facilities are provided by Engineering and Maintenance departments or divisions of the airlines companies, even though currently it is common that those facilities are outsourced to small, independent MRO companies. Basically, for the first case, the MRO customers could be categorized as its own fleet, LCCs (Low-Cost Carrier) and small carriers, leasing companies, airlines taking location advantage, airlines looking for cost reduction on special services (Sahay, 2012). The airlines’ MRO business model basically combines logistics with the technical capability, while supply chain, together with outsourcing activities are vertically integrated. Since the main goal of an MRO airline industry is to provide fully functioned aircrafts when needed, in optimum quality and in the minimum possible cost (Al-kaabi et al. 2007) MRO process performance should be high. Therefore, ongoing management and improvement of the standard maintenance processes should be performed and interventions that will improve the overall performance should be
applied when and where needed. In this direction, Business Process Management has been introduced and applied by various industries, including manufacturing and airlines MRO.

2.2 Process
In this subchapter, the definition of the process will be provided. Additionally, the contribution of process management in the improvement of customer satisfaction will be explored.

2.2.1 Process definition

Process is the conversion of inputs (actions, methods, material, operations) into outputs (products, services, information) that are transferred to the final customer. For the successful production of an output, appropriate inputs’ definition, monitor and control should take place (Oakland, 2007). A process can be seen both internally as a sequence of activities or sub processes and externally as a black box. The latter case is a representative perspective of how top management or external parties see the process whilst the former one represents employees and managers inside the business (Willaert et al., 2006).

As Willaert et al. denoted (2006), in the external, top-down approach, appropriate questions for exploring the process include: “Which processes are creating value?, Which processes should we improve?, Who are the stakeholders of this process?, What is the goal of each process, Who could take responsibility and/or ownership over which process?”. On the other hand, in the bottom-up approach, appropriate questions are “How can we improve this specific process?, Which department or function is having a role in this process?, Where and when are customers involved in this process?, What are the specific drivers in the process that influence the outcomes?".
Nowadays, most of the MRO and manufacturing industries offer their services in an automated way. Similarly, KLM E&M has identified the standard steps followed during an MRO (aircraft, engine or components), and therefore designed processes that display all the required steps starting from the customer.

### 2.2.2 Improving customer satisfaction through process management

Productivity, reliability and products’ availability are the pillars of a company’s competitiveness, performance and sustainable business success, in the ever demanding work marketplace (Kronz 2006; Muchiri et al. 2011). More specifically, in the MRO industries, the maintenance managers need a good indication of the maintenance process’ performance and results in order to ensure that the whole plant performs within the target range. Therefore, process management through implementing performance measurement systems and metrics are necessary (Muchiri et al. 2011).

### 2.3 Business Process Management

Business process management is a management practice that uses business processes to achieve the goals of the organization, through ongoing improvement, performance management, end-to-end control of the business processes (Jeston et al., 2014; Hammer, 2010) and customer value fulfillment optimization (Conger, 2015).
As explained by Hammer (2010) the process management cycle (figure 13), derived from Plan Do Check Act cycle, starts with the generation of a process (bottom in the above figure); the understanding of the work the process accomplishes and the relation with the organizational strategy (Conger, 2015). At the next stage, this process needs to be continuously managed through setting critical metrics (Key Performance Indicators) that relate company requirements with customer needs and are compared to the targets that are set for each of those. Those targets are set based on the organizational needs, market competition, customer expectations and in case they are not met, further analysis should be performed in order to identify the root cause of the problematic performance (material, machine, method, manpower related). After the root cause identification, fixation takes place through choosing and implementing appropriate interventions. Finally, the post-intervention results are evaluated and then the cycle begins again (Hammer, 2010).

A process (or a process product or step) that doesn’t contribute to the overall organizational strategy is considered as waste and it needs to be removed, thus leaning is required in order to improve a process. Leaning or cleaning suggests simplifying or improving the remaining steps, using outsourcing, automation or co-production. Process management and improvement requires leaning – that is removal of unneeded steps for improvement, cleaning – that is the simplification and improvement of remaining steps, and greening – that is the potential use of outsourcing, co-production, or automation (Conger, 2015).

As depicted by Conger (2015), the steps that can be followed for the process improvement include business process mapping, waste identification and removal, problems identification, problems prioritization, problem root cause identification, alternatives analysis and process
redesign. For this purpose, techniques such as SIPOC, root cause analysis or value – added analysis can be used.

Another approach, as depicted by Kronz (2006) includes two principal tasks for the process managing: “evaluation, analysis and continuous monitoring of business workflows”, with the automated or manual data collection and evaluation compared to target values and “the aim of process controlling” that is the task-oriented process mapping, which leads to process transparency and evaluation. Those two principles can facilitate in identifying weak points and opportunities for subsequent process improvement. Finally, after the implementation of the improvement measures, the effects can be further analyzed and evaluated through process management (Kronz, 2006).

Additionally, Oakland (2007) denotes another approach for ongoing improvement through engaging the people involved that is based on process alignment. This approach starts with the organizational mission and vision, analysis of the CSFs (critical success factors) and transfer to the key processes. Hence, according to Oakland (2007) the entire organization is encouraged to work as a cross-functional group of people, who have a horizontal view of the business; understand how each department’s individual processes contribute and have an effect on customers’ satisfaction. Having a horizontal view, through the use of aggregating measurements reduces the risk to miss low value-adding activities, such as time lags during handshakes and makes it possible to identify dependencies and possible improvements (Willaert et al., 2006). In Oakland’s scheme (2007), process owners, responsible for the main, cross-functional processes, are entitled to ensure that employees can understand in which way, the work processes they perform can contribute the customer satisfaction.

According to Oakland, it is very crucial to understand the nature of a process. Hence, there is a sequence of steps in order to gather all the necessary information about the process. These steps include: definition of supplier-customer relationship, process definition and standardization, new process design or modification of the existing and finally identification of improvement opportunities for improving quality and increase production. In more details, the supplier-customer relationship can be identified by using the SIPOC model, the process definition and standardization is realized through process documentation with the use of flowcharts, the designing or modifying an existing process includes the process redesign in order to facilitate the process flow (how the process should be instead of how it is) and finally, identifying complexity or opportunities improvement is realized when a failure is observed (Oakland, 2007).

2.4 Performance measurement

Performance measurement represents the process of making an action quantifiable or in other words making efficiency and effectiveness of a process or action quantifiable (Amaratunga & Baldry 2002; Neely et al., 1995; Garg et al., 2012). Rouse et al. (2003) define performance measurement as the comparison between results and expectations denoting the importance of “learning to do better” objective. The performance status can only be controlled and checked
with the help of measurement. Performance measurement provides all the needed information to the manager in order to apply decision making effectively. The provided, quantifiable information is used in order to evaluate the progress compared to the goals and the objectives set (Parida, 2007); measure the customers’ satisfaction or the extent customer requirements are met – the organizational goal. Hence, feedback is provided and then corrective action may be applied where needed (Neely et al., 1995).

Performance measurement constitutes and incentive for good performance, since it doesn’t reward input or throughput but result. Hence, it is an incentive for output, or in other words an incentive for good performance. However, there has been some criticism on performance measurement by means of blocking innovation and ambitions, kills system responsibility and is static (Bruijn, 2002).

Performance measurement is realized through controlling a system of process oriented performance measures/metrics. This system links the process to the required business controlling aspects; effectiveness (customer satisfaction) and efficiency (quality, cost, turnaround time, delivery reliability) (Kronz, 2006). Before we proceed with the performance measurement systems currently used, a definition of performance must be given.

### 2.4.1 Definition of performance

Performance is an organization’s ability to implement a strategy and is expressed as an ability-and-motivation function. Performance can be examined from process, employee, safety, customer, financial, environment perspectives, thus including almost everything that can describe an organization (Parida, 2006).

### 2.4.2 Definition of performance measure or metric

A performance measure is the metric that quantifies effectiveness and efficiency (Neely et al., 1995; Garg et al., 2012) it is checked on a regular basis, it is compared to planned references (Meier et al., 2013) and is used in order to highlight a process’ weakness and to analyze it in order to identify the problem that causes the low indicator’s performance. The performance indicators that measure functions on the shop floor level are called Key Performance Indicators (Parida, 2006). In more details, in order to identify the root cause of the problems occurred within a process, the performance of the service delivery (or Service Level) should be measured. Hence, through understanding the status quo and thus becoming aware of possible organizational deficits, appropriate measures can be elaborated, subsequently implemented and evaluated and finally improvements based on current and past data can be defined (Meier et al., 2013). A performance measure is defined in quantitative or qualitative terms and evaluated compared to a reference target. Additionally, the three functions provided by metrics are control (of the performance), communication (of the performance internally to employees and managers and to external stakeholders). Finally, a well established system of metrics is capable of promoting improvement and intervention through gaps identification (Melnyk et al., 2004).
Performance measures can be classified based on different set of criteria. For example Meier et al. (2013) classifies the measures based on different service dimensions (eg. process), performance dimensions (cost, quality, flexibility), delivery types (repair, maintenance, spare parts) etc. The European standard for maintenance key performance indicators categorizes indicators in three types; economic, technical and organizational (En, 2011). Another categorization is the lagging indicators (mostly financial indicators that check whether the desired results were achieved) and the leading (that check the performance condition, whether the processes perform properly, leading to the desired results) (Muchiri et al., 2011; Parida et al., 2009). Most of the KPIs in the services sector include cost reduction, time-to-delivery, quality service, employee’s and customer’s satisfaction, financial benefits, efficiency etc. In more details, the time-to-delivery indicator includes waiting time, cycle time and service time among others (Sabry, 2014). The usage scenarios of a KPIs system range from management, controlling, process/IT management to process analysts, KPI managers offering corporate leadership, overall operational controlling, process monitoring and support among others (Kronz, 2006).

2.4.3 Definition of Performance measurement system

From the above mentioned, we can now conclude that a performance measurement system, is respectively an aggregation of entities which are observed as acting coercively (Rouse et al., 2003) and can quantify the effectiveness and the efficiency of the actions (Parida, 2006).

Historically speaking, the performance measurement systems was developed aiming to monitor and ensure that the organizational strategies are indeed pursued (Amaratunga et al., 2002) it provides the framework that defines how the organization’s strategy is formulated through the appropriate set of KPIs (key performance indicators) (Willaert et al., 2006) or in other words how the process delivers value to the end user/customer (En, 2011). The importance of the measurement systems lies in the fact that they promote better managerial decision making (Caplice et al., 2006) provides feedback and promotes continuous (Parida, 2006).

A measurement system should have certain characteristics that can determine its success. Such characteristics include comprehensiveness by means of capturing performance from different dimensions like delivery reliability and speed (eg. Optimized Production Technology or Just in Time\(^2\)), price or flexibility, quality (based on customers’ requirements and satisfaction) (Neely et al., 1995; Oakland, 2007), causally orientation by means of capturing the drivers of performance and not just the resulted ends and vertical integration by means of relating the overall organizational strategy to specific types of decision making for every organizational level (Caplice et al., 2006). Additionally, it should be consistent to organizational strategy in order to stimulate

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\(^2\) Based on Just In Time philosophy, it is waste if the goods are either produced or delivered too early or too late and Optimized Production Technology has the objective of optimizing production with the concurrent throughput time minimization (Neely et al., 1995).
action (Neely et al., 1995). Lastly, a measurement system should be well documented and metrics interrelations should be unambiguous (Kronz, 2006).

2.4.4 Performance Measurement frameworks

Performance measurement (PM) frameworks are generally categorized into 3 categories; traditional accounting based, multi-criteria and cause and effect relationship PMs. Traditional accounting (financial) based PM frameworks initially included financial aspects like Return on Investment (ROI) and Du Pont Pyramid of Financial Ratios. The main drawback of frameworks such this is that its cost analysis is related to past and thus it fails to predict future performance; its measures are short-termed (Parida, 2006) and say nothing regarding the future alertness (Norreklit, 2000).

Since the financial based PM frameworks lacked strategy alignment, more and more industries adopted a more balanced approach in identifying the suitable metrics (Cai et al., 2009). Therefore, multi-criteria PM frameworks that consider both financial and non financial performances, introducing thus a multi-dimensional framework of performance measurement were used instead. Components like data, action and analysis and criteria such as quality, efficiency, effectiveness, quality of work life, profitability, productivity, growth and excellence survival are also included here (Parida, 2006).

Plenty of frameworks following the above mentioned characteristics have been designed but the most well-known and broader-used is the balanced scorecard developed by Kaplan and Norton (Neely et al., 2000), used by more than 70 percent of the USA by the end of year 2001 (Garg et al., 2012). This framework integrates financial, customer, internal business, and innovation and learning perspectives; a mixture of both financial and non-financial types that makes corporate mission, vision and strategy clear (figure 14). In this framework the non financial perspectives are the drivers of the financial (Parida, 2006); the outcome measures are always related to the performance drivers, in a cause-and-effect relationship, thus building up a feed-forward control system (Norreklit, 2000). The criticism that Balanced Scorecards have received are due to the fact that they ignore people, competitors, suppliers and environmental or social issues (Garg et al., 2012), since they are narrowed to only display the performance of the internal system and even though they display a cause and effect relationship between different metrics (KPIs) they are weak in quantitative analysis of the complex intertwined relationships between KPIs (Cai et al., 2009).
The third category of PMs is the cause and effect relationship the results and determinants framework. This framework developed by Fitzgerald et al. identifies two types of performance metrics, those related to results, like financial performance and competitiveness and those related to the determinants of the results, like innovation, resource utilization, quality and flexibility in a function form where the former types are lagging indicators and the latter are leading (Neely et al., 2000; Parida, 2006).

However, there are several frameworks, which steer the focus to the horizontal material and information flows within the organization, i.e. the business processes. In those frameworks, the input measures are considered as the quantity and quality of flour and eggs while baking a cake and process measures are the oven temperature and baking time duration. Finally, outcome measures include the satisfaction felt after eating the cake (Neely et al., 2000). A list of all the PMs frameworks that have been developed are shown in the following table.

### Table 1: Performance Measurement frameworks (Parida, 2006)

<table>
<thead>
<tr>
<th>Model/framework</th>
<th>Measures/Indicators, Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sink and Tuttle (1989)</td>
<td>Efficiency, Effectiveness, Quality, Productivity, Quality of work life and innovation, Profitability/budget ability, Excellence, survival and growth,</td>
</tr>
<tr>
<td>Du Pont Pyramid</td>
<td>Financial ratios, Return on investment (ROI)</td>
</tr>
<tr>
<td>PM Matrix</td>
<td>Cost factors, Non-cost factors, External factors, Internal factors</td>
</tr>
<tr>
<td>Results and determinants matrix</td>
<td>Financial performance, Competitiveness, Quality, Flexibility, Resource utilization, Innovation</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>PM questionnaire</strong></th>
<th>Strategies, actions and measures are assessed, Extent to which they are supportive? Data analysis as per management position or function, Range of response and level of disagreement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Brown’s framework</strong></td>
<td>Input measures, Process measures, Output measures, Outcome measures</td>
</tr>
<tr>
<td><strong>SMART pyramid</strong> (Performance pyramid)</td>
<td>Quality, Delivery, Process time, Cost, Customer satisfaction, Flexibility, Productivity, Marketing measures, Financial measures</td>
</tr>
<tr>
<td><strong>Balanced Scorecard (BSC)</strong></td>
<td>Financial, Customer, Internal processes, Learning &amp; growth</td>
</tr>
<tr>
<td><strong>Consistent PM system</strong></td>
<td>Derived from strategy, continuous improvement, fast and accurate feedback, explicit purpose, relevance</td>
</tr>
<tr>
<td><strong>Framework for small business PM</strong></td>
<td>Flexibility, Timeliness, Quality, Finance, Customer satisfaction, Human factors</td>
</tr>
<tr>
<td><strong>Cambridge PM process</strong></td>
<td>Quality, Flexibility, Timeliness, Finance, Customer satisfaction, Human factors</td>
</tr>
<tr>
<td><strong>Integrated dynamic PM System</strong></td>
<td>Timeliness, Finance, Customer satisfaction, Human factors, Quality, Flexibility</td>
</tr>
<tr>
<td><strong>Integrated PM framework</strong></td>
<td>Quality, Flexibility, Timeliness, Finance, Customer satisfaction</td>
</tr>
<tr>
<td><strong>Integrated PM system</strong></td>
<td>Finance, Customer satisfaction, Human factors, Quality, Flexibility, Timeliness</td>
</tr>
<tr>
<td><strong>Dynamic PM Systems</strong></td>
<td>External and internal monitoring system, Review system, Internal deployment system, IT platform needs</td>
</tr>
<tr>
<td><strong>Integrated Measurement model</strong></td>
<td>Customer satisfaction, Human factors, Quality, Flexibility, Timeliness, Finance</td>
</tr>
<tr>
<td><strong>Comparative Business Scorecard</strong></td>
<td>Stakeholder value, Delight the stakeholder, Organizational learning, Process excellence</td>
</tr>
<tr>
<td><strong>Skandia Navigator</strong></td>
<td>Financial focus, Customer focus, Human focus, Process focus, Renewal and development focus</td>
</tr>
<tr>
<td><strong>Balanced IT Scorecard (BITS)</strong></td>
<td>Financial perspective, Customer satisfaction, Internal processes, Infrastructure &amp; innovation, People perspective</td>
</tr>
<tr>
<td><strong>BSC of Advanced Information Services Inc. (AISBSC)</strong></td>
<td>Financial perspective, Customer perspective Processes, People, Infrastructure &amp; innovation</td>
</tr>
<tr>
<td><strong>Performance Prism</strong></td>
<td>Stakeholders satisfaction, strategies, processes, capabilities, stakeholders contribution</td>
</tr>
<tr>
<td><strong>QUEST</strong></td>
<td>Quality, Economic, Social and Technical factors</td>
</tr>
<tr>
<td><strong>European Foundation for Quality Management</strong></td>
<td>Leadership, Enablers: people management, policy and strategy, resources; Processes, Results: people and customer satisfaction, impact on society; and Business results</td>
</tr>
</tbody>
</table>

### 2.5 Operational performance improvement theories

In literature, we can find many practices, theories or management styles that are related with the operational performance improvement. Among those, Total quality management (TQM) (Kaynak,
Background Research

2003), Just-in-time (JIT) (Monden, 2012), Reliability-centered maintenance (RCM) (Moubray, 1997) and Theory of Constraints (TOC) (Goldratt et al., 2004) are included. In the following paragraphs, a brief description of each of them will be given.

Reliability-centered maintenance “is a process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context” (Moubray, 1997). RCM is a methodology with specific structure that aims to maintain system function. The concepts it is based on include: there are failures that cannot be prevented and failures are not equally created. RCM is more oriented to safety, environmental and economical areas (Tsang, 1995).

Another management philosophy that is frequently applied in industries is the Total Quality Management, that promotes continuous improvement through utilizing the quality concept from resources’ acquisition to customer service (Kaynak, 2003). TQM is a style that promotes teamwork, integrity, training, leadership and cultural alignment with the customer satisfaction and focuses on quality implementation in all production phases.

Just in time is the production method of “produce the necessary units in the necessary quantities at the necessary time”. Implementing JIT leads to inventories’ elimination. However, it can only be implemented in a pull system rather than a push system, since it entails a conversely look at the flow of production (people of a process withdraw the necessary quantity of units at the right time from the previous process (Monden, 2012).

2.5.1 Theory of Constraints for the identification of performance bottlenecks

The Theory of Constraints (TOC) provides a standardized method for the identification of constraints (in manufacturing industry called bottlenecks) that prevent the organization’s goal realization (Goldratt et al., 2004) and promote continuous improvement. Based on TOC, the system should constantly improve the identified constraint until the limit is not a constraint anymore. Goldratt et al. (2004) hypothesizes that every system consists of interlinked activities, with one out of the total acting as a constraint for the entire system; it is the weakest link in the chain. TOC highlights the importance of focusing on the system’s constraints in order to achieve the desired performance levels (Cai et al., 2009). Therefore, TOC provides some tools that facilitate in realizing the “goal” of manufacturing companies; that is to make profit. Those tools include the five focusing steps (identify and eliminate constraints), the thinking processes (analyse and resolve problems) and throughput accounting (measure performance and guide management decisions). Some important definitions include:

-Throughput: the rate of money generation

-Inventory: the total investment cost for purchasing items that the system intends to sell

-Operating expenses: system’s expenses in turning the acquired inventory into throughput.
Based on the above mentioned definitions the goal of an industry is to “increase throughput while simultaneously reduces both inventory and operating expense” (Goldratt et al., 2004).

2.5.1.1 Benefits of TOC

TOC recognizes that every process has a single constraint and for the total throughput to be improved the identified constraints should be improved. Therefore, TOC provides total focus in eliminating the current constraint until it does not limit throughput, moving thus afterwards to the next constraint that facilitates in achieving the goal (make more profit) (Goldratt et al., 2004).

Benefits that accrue from the use of TOC include decrease of production waiting time (or lead time), quality improvement, profitability increase, inventory reduction (the flow of production becomes smoother), bottlenecks reduction and management, competitiveness improvement and continuous improvement (Management Accounting Committee, 1999; Goldratt et al., 2004).

TOC provides a set of tools to help achieve the goal. These tools include the five focusing steps, the thinking processes, throughput accounting and drum-buffer-rope (DBR). In the next section, a more detailed description of the five focusing steps will be given.

2.5.1.2 The Five Focusing Steps

This TOC tool is used for the identification and elimination of system’s bottlenecks. It follows a cyclical methodology as displayed in figure 15.

Step one is the identification of the constraint that limits the throughput and hinders the progress toward the realization of the goal. Identification of the constraint can be realized through real data analysis, observations (inventory piles) and questions in the shop.
Step two includes the constraint’s exploitation by using the total capacity at the constraint, which, most of the times, is wasted due to improper policy, bad scheduling or shop management. Several suggestions that can facilitate step two have been proposed, with “breaking batches”, “reduce internal setup time”, “use less efficient machinery” or “use quality control before constraint” among others.

Step three includes subordinating everything (policies, processes, decisions) based on the decisions taken in step two. In step 3, it is very common and useful to develop or change measurements in order to emphasize the bottleneck and triggering thus the management focus on them.

Step four includes elevating the constraint, by adding extra capacity in order to elevate the output generated by the constraint. The difference between step 2 and 4 lies in the fact that the latter necessitates additional purchasing (new machinery, employee more workers, instituting limited overtime, adding extra shifts, implement new technology etc.) until the constraint is eliminated.

Finally, step five entitles repeating the process for the other constraints identified or perhaps created after the decisions made in the previous steps.

The reason to use the five steps instead of other techniques proposed is that from a system point of view, constraints are the pacesetters, since no matter how fast the production of other components is, the constraint will always limit the performance of the system. The whole chain/the system of processes as a whole, is as strong as its weakest link; its slowest component (Management Accounting Committee, 1999).

2.6 Research in the field of maintenance performance
In the ever demanding world marketplace and in order to establish competitiveness, it is apparent, that high performance is necessary. Hence, ongoing improvement, process and performance improvement, productivity increase and better shop management are of great concern for all the industries. As a result, extensive research has produced methods, tools, techniques that can foster high performance and improve maintenance.

Scheduling rules, Theory of Constraints (TOC) scheduling rules, including DBR (Drum Buffer Rope), rods in job-shop maintenance (Golmohammadi 2015; Reményi et al., 2014; Simons et al., 1997), the lean manufacturing principles implementation (Motwani, 2003) and scheduling rules together with spares stocking policies to support a multi-item repairable inventory system (Scudder, 1984) have been extensively implemented according to literature. Additionally, many researchers have used simulation models in order to display or forecast input or production, like Betterton et al. (2009) who used discrete simulation in order to schedule and control the flow of products and Cobb (1995) who developed a GPSS/H simulation model as a tool to evaluate current maintenance performance. A computerized simulation model has also been developed by Gupta et al. (2003) for the aircraft line maintenance department of the Continental Airlines and finally,
simulation model as policy evaluation tool aiming to identify throughput improvements has also been proposed by Harvey et al. (1992).

Furthermore, a two level TOC-SCRS (Theory of Constraints – Supply Chain Replenish System) for a plant that produces different products in large sales volume (Wu et al., 2014), a model that proves how shop performance is affected by three workload control rule components (Fredendall et al., 2010) and an agent-based approach for production system control (Wiendahl et al., 1997) have been proposed. Additionally, optimization of joint products decisions can be achieved through an algorithm that is based on TOC (Tsai et al., 2007) and also multiple constraint resources can be solved with the use of a TOC-Based Algorithm (Wang et al., 2014). Another heuristic algorithm that can evaluate the feasibility of a mix of optimal production solutions has also been developed (de Souza et al., 2013) and finally, a multi-objective genetic algorithm that solves aircraft engine maintenance scheduling problem is also proposed by Kleeman et al. (2005).

Another field of research that offers solutions for performance improvement include protective capacity positioning and its relation with bottleneck shiftiness (Craighead et al., 2001), simulation model in order to solve the capacity planning problem (Andradóttir et al., 1997) and a maintenance grouping approach for system of different components when those are connected in series (Do et al., 2015). The material requirements planning system for aircraft maintenance and inventory control (Ghobbar et al., 2004), forecasting of the input logistical flows (Hees, 2009), cost reduction through inventory management improvement and material replenishment (Nijhoving, 2009) and outsourcing decision model for performance improvement in airlines MRO (Al-kaabi et al., 2007) have also been proposed.

2.7 Research framework

The research framework that structures the presented research is built upon the OPDCA cycle of ongoing improvement, combined with process management, process analysis and Theory of Constraints for the identification of performance constraints at Component Services, KLM Engineering & Maintenance. The realization of the framework steps is facilitated with a use of a range of proposed tools.

**OPDCA cycle**

The OPDCA cycle, is a version of the Deming PDCA cycle of continuous improvement. The steps indicated by the cycle include Observe-Plan-Do-Check-Act. The first step, which also constitutes an addition on the classic cycle, regards the definition and analysis of the current state in order to “grasp the current condition” (Knutson et al., 2014). The following step “Plan” regards the identification and the analysis of the constraint that halts the performance, whilst the next step “Do” concerns the development and the implementation of solutions/intervention plan that will eliminate the constraint. Subsequently, the “Check” step includes the evaluation of the results generated upon the implementation of the intervention plan and finally the “Act” step regards the standardization of the solution (Johnson, 2002). The OPDCA cycle provides the skeleton of the research framework that has been used in order to define the current situation at Component
Services, identify the opportunity for intervention in A&A Repair Shop and check the generated results.

**The essential Process Management Cycle**

Business process management is a management practice that uses business processes to achieve the goals of the organization, through ongoing improvement, performance management, end-to-end control of the business processes (Jeston et al., 2014; Hammer, 2010) and customer value fulfillment optimization (Conger, 2015). The process management cycle starts with the generation of a process, which entails the understanding of the current situation; the work the process accomplishes and also the relation with the organizational strategy (Conger, 2015). Thereinafter, proper metrics (Key Performance Indicators) that link the company’s requirements with customer needs are set and hence, when the targets of those KPIs are not met, further analysis is necessitated in order to identify the root cause of the problematic performance. After the root cause identification, fixation takes place through the implementation of appropriate interventions. Finally, the post-intervention results are evaluated and then the cycle begins again (Hammer, 2010). The process management cycle, which is based on the PDCA cycle of ongoing improvement, provided some additional steps that enhance the realization of each of the OPDCA cycle steps.

**Process analysis**

According to Oakland (2007), the process analysis includes a series of steps for the collection of all the necessary information about the process, including definition of supplier-customer relationship, process definition and standardization, new process design or modification of the existing (if needed) and finally identification of improvement opportunities for improving quality and increase production (Oakland, 2007). For the needs of the presented research, an evaluation of the current situation at Component Services KLM Engineering & Maintenance has been initially necessitated. Following the steps of process analysis and in more details through a deep review and understanding of the process performed at Component Services, the distribution of responsibility roles within and the identification and design of additional sub-processes included in the main process, the nature of the process; the current state has been easily defined.

**Theory of Constraints**

The Theory of Constraints (TOC) is one of the most broadly used methods for the identification of constraints that prevent the organization’s goal realization (Goldratt et al., 2004) and promote continuous improvement. The Theory of Constraints, developed by Goldratt, is based on the notion that every system has a constraint that should be constantly improved until it is no longer a constraint. Moreover, the five focusing steps of TOC include the identification of the performance’s constraint, the exploitation of it by using the total capacity at the constraint, the subordination and elevation of it and finally the repeat of the process for the identification of additional constraints. The five focusing steps is the tool used for the identification of the main constraint in A&A Repair Shop and subsequently for the development of the intervention plan of proposed solutions, through setting a Drum Buffer Rope and recommendations for the subordination of them.
For the realization of the research objective, the steps that have been followed throughout the research are presented in the research framework (figure 16). A combination of the OPDCA cycle of ongoing improvement, the essential process management cycle, process analysis approach and Theory of Constraints generated the proposed framework.
Background Research

Figure 16: Research framework

- Observe
  - Understand current condition
- Define current state of the process
- Map process and identify different process cases included
- Define process’ added value
- Define responsibility distribution per process step
- Performance observation on Connected Business Balanced Scorecard

PLAN

- Understand source of information gap
- Data analysis and observations (frequency tests, performance calculation and graphs, Simulation and GO GEMBA)
- Performance constraint identification

DO

- Develop intervention plan
- Calculate Drum Buffer Rope for the constraint elimination
- Define priority rules and propose models to increase productivity

CHECK

- Check results
- Simulation/measure the impact of the intervention plan
- If the results do not eliminate the constraint develop and check the impact of another intervention plan

ACT

- Fix the identified problem
- Implement the intervention plan, subordinate the constraint, improve process design and share the lessons learnt
- Repeat process from "Plan" for the identification of other performance bottlenecks

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**Observe**

The first step of the proposed framework includes all the required actions in order to understand the current state at Component Services. This step is really important, since it provides a stepping stone for the identification of the main performance constraint. A thorough understanding of the current situation facilitates in identifying the process' critical parts that may conceal bottlenecks and constraints. Therefore, this first step includes defining the current state of Component Services, in terms of the current process performed, the responsibility distribution per process step, the value that this process delivers to the end customer and the identification of different process cases that are included in the basic process. Additionally, for the complete understanding of the current state, this process step includes a study of the current performance metrics that are included in Component Services Connected Business Balanced Scorecard and moreover, a placement of those metrics within the process has been performed in order to make clear what is the nature of those KPIs, in terms of what they really measure.

The process of the Component Services has been retrieved from the ARIS system of KLM and for the design of both the different process cases and the metrics placement within the process, the design tool of Google Drawings has been used. Furthermore, for the responsibility distribution within the process performed at Component Services, the SIPOC model have been used in order to identify supplier’s and customer’s roles per process step, together with the input and output generated. Lastly, the value that the process delivers to the end customer has been identified through a series of semi structured interviews that have been held in KLM Engineering & Maintenance.

**Plan**

The second step of the proposed framework is of paramount importance, since it entails the identification of the main constraint-root cause that halts the performance. Therefore, this step uses the turnaround time repair KPIs included in Component Services Balanced Scorecard as an input for a data analysis of all the registered orders in Avionics & Accessories (A&A) repair shop from March 2014 until June 2015. The orders, which have been retrieved from the company’s SAP system, have revealed the cell, workstation and component that have the lowest performance, in terms of repair turnaround time. Complementary to the data analysis, a series of observations in A&A have taken place in order to identify possible symptoms of the bottleneck (eg. high inventory), policies and norms that may be applied and get a clear view of the repair process performed for the component that has the lowest performance; the actuators.

For the realization of this step, statistical tools together with the lean tool “Go Gemba” have been used. In more details, for the data analysis and subsequently the identification of the main constraint within the Repair Shop, frequency tests, performance calculations and graphs have been used. The findings of the data analysis have also been confirmed by the “Gemba” tool, the observations that have been performed in the action field; within the Repair Shop.
**Do**
The third step of the presented framework entails the development of the intervention plan that can lead to the elimination of the identified constraint. Therefore, this step includes a series of suggested solutions that can improve the performance in the repair shop. In more details, a Drum Buffer Rope; the fix number of actuators that the shop can handle, together with a priority repair rule for this component have been proposed. Additional models that can increase mechanics’ productivity in the repair shop have also been proposed.

For the development of the intervention plan, a background research has been performed in order to define which approach is more suitable for the identification of performance constraints within the repair shop. Additionally, a background research also facilitated in identifying and therefore proposing relevant models that can enhance the mechanics’ productivity in the repair shop.

**Check**
The fourth step of the proposed framework includes the evaluation of the results upon the implementation of the intervention plan. Therefore, the two additional sub steps that are included here concern the actual measurement of the impact of the intervention and in case the constraint is not eliminated, the development of a new intervention plan is necessitated. The impact of the suggested solutions on the inventory levels of the other types of components handled within the workstation has also been calculated.

For the needs of this step and since the proposed solutions that have been generated during the previous step have not actually implemented, the simulation tool has been used for the evaluation of the intervention’s impact. Hence, simulation revealed that implementing the Drum Buffer Rope and priority rules can indeed eliminate the identified constraint, offering thus capacity surplus for the repair of the other types of components.

**Act**
The final step of the proposed framework includes the actual fixation of the identified constraint, through the solution’s stabilization, the constraint’s subordination, process improvement or new design and sharing of the lessons learnt. Additionally, repeating the framework from the step “Plan” is also proposed for the identification of other constraints that may halt the process performance.

Since the proposed solutions have not been implemented in reality but tested through simulation, the realization of this step could not take place during the presented research. However, suggestions both for the implementation of the provided solutions and additionally for the subordination of all related decisions to the decisions that can eliminate the constraint have also been provided.
2.8 General usability of the framework and implementation restrictions

The presented framework consists of a series of steps that can guide the identification of performance constraints, through a deep exploration of the current process performed, together with a data analysis of the performance metrics. Additionally, this framework provides an intervention plan that includes setting a Drum Buffer Rope together with an order priority rule for the orders received. Since this framework is the outcome of a combination of different scientific approaches and methods, its applicability is not significantly limited.

The implementation of the proposed framework is only limited by a list of use criteria. Therefore, resembling the conditions under which this framework has been applied, all of the below mentioned use criteria should be met.

The framework can only be applied in industrial, push (not pull) flow shop processes that follow an acyclic route through the plant. This route should be a straight line which further means than no station should be visited more than once. On the other hand, as depicted in figure 17, job shop flows that work with customized products that follow different and not standardized routes based on the customer needs (Kumar, 1994) are excluded from the use of this framework. The push type of the process indicates that the flow of the orders is not based on the real demand, but rather to “Make to Stock”.

Figure 17: Flow shop vs. Job shop flow (own illustration)
Additionally, another essential criterion for the implementation of the presented framework is the simultaneous performance of different, hence standardized, flow shop, processes. The latter indicates the handling of different orders, e.g., the repair of different types of components, each of them following its own, standardized repair route.

The final use criterion specifies the scheduling rule under which the shop handles the received orders exclusively to be FIFO (First arrived, first handled), no matter what the type of the received order is. Moreover, the shop should share the total capacity among the orders. In more details, the latter means that the same workers are capable of handling different orders and not exclusively one specific type of them.

Complying with all the above described criteria can lead to the implementation of the proposed framework. It is of high importance to denote that the applicability of this framework exceeds the limits of the repair processes. Therefore, the presented series of steps can be implemented to various manufacturing and production processes that handle their orders under the same conditions as described above.

2.9 Conclusions on background research

The literature that has been reviewed and used in order to develop the presented framework is displayed in the table shown below. Moreover, the literature that regards the steps for process analysis, the essential cycle of process management combined with Theory of Constraints and the five focusing steps is included in this table. Additional literature that will be cited in the forthcoming chapters and justifies the use of the proposed tools per steps, such as SIPOC analysis and simulation is also included here. Finally, the literature that concerns the proposed models that can increase productivity in the repair shop is also included in table 2.

<table>
<thead>
<tr>
<th>Category</th>
<th>Title</th>
<th>Author</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process management: improving customer satisfaction</td>
<td>Development of maintenance function performance measurement framework and indicators</td>
<td>Muchiri, P.</td>
<td>2011</td>
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<tr>
<td>Performance measurement: definition of metrics</td>
<td>Performance measurement system design</td>
<td>Neely, A., Gregory, M., Platts, K.</td>
<td>1995</td>
</tr>
<tr>
<td>Performance measurement:</td>
<td>Development of a Multi-criteria Hierarchical</td>
<td>Parida, A.</td>
<td>2006</td>
</tr>
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<td>Connected Business Balanced Scorecard overview</td>
<td>Framework for Maintenance Performance Measurement Concepts</td>
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<td><strong>Performance improvement: models and theories (RCM, TQM, Just in time)</strong></td>
<td>Condition-based maintenance: tools and decision making, The relationship between total quality management practices and their effects on firm performance, Toyota Production System</td>
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<td>Tsang, A.H.C.</td>
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<td><strong>Performance improvement: Theory of Constraints</strong></td>
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<td><strong>Theory of Constraints: The five focusing steps</strong></td>
<td>Theory of Constraints (TOC) Management System Fundamentals</td>
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**Additional literature that is displayed in the following chapters**

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<tr>
<th>Semi – structured Interviews: Theory</th>
<th>Research Methods of Business-A Skill-Building Approach</th>
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<td>Sekaran, U., Bougie, R.</td>
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<td><strong>SIPOC Analysis: importance and methodology</strong></td>
<td>SIPOC Picture Book: A Visual Guide to SIPOC/DMAIC Relationship</td>
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<td>Rasmuson, D.</td>
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<td><strong>Simulation: theory and benefits in performance measurement</strong></td>
<td>Research Methods of Business-A Skill-Building Approach</td>
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<td><strong>Gemba: importance in constraints identification</strong></td>
<td>How to Go to the Gemba: Go See, Ask Why, Show Respect</td>
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<td>Shook, J.</td>
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<td><strong>Lost productivity: Manana attitude in repair shops</strong></td>
<td>Project management in the fast lane: applying the Theory of Constraints</td>
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<td><strong>Models for productivity increase: Pay for performance and profit sharing plans</strong></td>
<td>Compensation and Incentives: Practice vs. Theory</td>
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<td>Baker, G.P., Jensen, M.C. &amp; Murphy, K.J.</td>
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Based on the reviewed literature, a framework for the identification and elimination of performance constraints that comprises different scientific approaches and methods has been developed. This framework provides a series of steps, including understanding the current condition, the source of information gap, the development of an intervention plan, check the results upon intervention implementation and finally the actual fixation of the identified problem.

The implementation of the presented framework exceeds the limits of Repair Processes, similar to those performed in Component Services and can be therefore applied in various manufacturing and production push flow shop processes that follow an acyclic route through the plant, where a simultaneous performance of different, hence standardized, flow shop processes takes place under the FIFO scheduling rule of orders.
3. Observe: Understand current condition

KLM is a customer-centric company that aims to establish a leading position in the airline industry. Its main focus is customer satisfaction both for the aviation and the engineering & maintenance department. KLM E&M department is an important pillar of KLM, offering a variety of cutting-edge technology maintenance solutions to its customers. Therefore, ongoing process improvement is really crucial. Throughout this chapter, the current state at Component Services will be defined. The process and additional sub-processes (specified in the customer contracts) performed at Component Services will be explained and displayed, the added value delivered to the final customer will be defined and the performance metrics that are currently used will also be analysed.

3.1 Brief description of Component Services

As denoted earlier in this report, KLM E&M department offers aircraft, engines and components MRO solutions. The component services are performed in two distinct shops; BMSS (Base Maintenance Support Shops) that offers maintenance repair and overhaul services to airframes and components, such as carrier assies, wheels and brakes, engine parts and aircraft panels and A&A (Avionics and Accessories) that offer MRO services exclusively to components, including fuel and pumps, hydraulics, electro mechanical services, bottles and computers.

Figure 18: On the right a photo from A&A shop and on the left a Boeing 777 airframe in BMSS shop
3.1.1 Consumables-Rotables

In order to perform the maintenance procedures, different materials are needed. Basically they are categorized as consumables and rotables. The transfer of those materials within the Schiphol Oost Technical area is performed by the Logistics Center.

3.1.1.1 Consumables

Consumables are items that are not repairable and therefore used only once and then discarded. According to MARPA (Modification and Replacement Parts Association), consumables are items that belong to two distinct categories. The first one includes items that are not part of the engine, aircraft and propeller and generally used in order to support and to perform the maintenance including solvents, emery paper, cleaning agents, cutting oils, masking tape among others. These items are generally used to support and perform maintenance. On the other hand, consumable materials that are included in the second category can be a part of the aircraft, engine or propeller. Example of consumable materials that are included in this category are hydraulic fluids, greases, lubricating oils, adhesives, sealants, room temperature vulcanizing, lock-wire, silicone compounds, paints, and high temperature tapes (MARPA, 2012).

In KLM E&M Schiphol Oost, consumables are located in different buildings-hangars in order to efficiently service the maintenance processes. In more details, consumables are stored in Engine Shop (Building 410), VOC, H10, H11, H14, A&A (H11) and BMSS (H14). It is important to mention that H10, H11 and H14 are hangars in which Aircraft Maintenance takes place. Consequently, we can derive that maintenance processes performed in hangar 10, 11 and 14 can be supplied with consumables from shops that are located locally in those hangars. However, in case the consumables are not available locally, then they can be requested and supplied from other hangars, or buildings.
3.1.1.2 Rotables

Rotables (not repairables; repaired only several times, only a fixed number of repairs to be performed) are components that can be multiply repaired and reused. Examples of rotables may include sensors, valves, antennas, smoke detectors and pumps among others. The rotables that need to be repaired are called unserviceable rotables (US rotables), whilst those that have been repaired and are fully functioning are called serviceable rotables (SE rotables). Their repair process is initiated when the US rotables are shipped from the customer or the hangars where the maintenance takes place (H10, H11, H14) to the warehouse of the logistics center (MLC). Subsequently, they are shipped to the repair shops where MRO services take place (Engine Shop, A&A, BMSS). Upon repair completion, the fully SE rotables are shipped back in the MLC, where they are stored in order to maintain the pool availability. The above described flow of rotables forms a notional cyclical route, as displayed in figure 20. For time limitations and therefore, in order to narrow down the plethora of components under the scope of the presented research, the performance of rotables’ repairs will be analyzed and explored for the identification of constraints that halt the performance.
3.1.2 Customer Contract types at Component Services

Component Services basically offer two repair contract options to their customers; power by hour and time and material. Time and Material repair is invoiced per event and also offers two further options to the customers; availability or closed loop. With availability, the pool needs to maintain the agreed level of the stock defined in the customer contract and as a result provide this availability when needed, in an exchange. The second option, closed loop does not provide availability to the customers but the repair of the same unit (same serial number).

The second contract type, power by the hour (PBH) is invoiced per flight hour; for every hour the customer’s aircraft flies, the customer pays a monthly amount. The two options offered to the customers are also the same with the previous case, that is availability or closed loop. In the first case, the same unit is returned to the customer after repair (same serial number) whereas availability provides component availability to the customer, when needed.

Availability is offered against a fixed rate per Flight Hour or a fixed rate per aircraft per month. Finally, most of KLM customer contracts are based on the combination of repair on PBH in combination with availability.
### Table 3: Customer contracts offered by KLM Component Services

<table>
<thead>
<tr>
<th>Repair contract types</th>
<th>Repair options</th>
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<tr>
<td>T&amp;M repair invoiced per event</td>
<td>Availability offered via an exchange out of the pool</td>
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<td>Closed loop, same unit returned after repair. No availability</td>
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<tr>
<td>PBH (power by the hour)</td>
<td>Availability offered via an exchange out of the pool</td>
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<td></td>
<td>Closed loop, same unit returned after repair. No availability</td>
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### 3.2 Explore current process

The Component maintenance system of processes includes two distinct processes; to organize component availability and to provide component MRO. The first of the two entities the maintenance of the stock level that needs to be available for the customers, as defined in the contract. The second process includes all the required actions for the repair of the unserviceable component (figure 21).

In order to explore the current component services process, additional sub-processes that are already included in the main process have been identified and subsequently designed. Based on the above displayed process and moreover by taking into account the different contract types offered to the customers, three additional sub-processes derived from Component Services process can be designed; pool availability, Closed Loop and Time and Material.

In pool availability (figure 22), when a new customer order is received, KLM Component Services, pick a Serviceable Component from the warehouse, then ships it to customer, exchange it with...
the unserviceable component at the customer and then deliver the unserviceable back to the warehouse. From this location, the unserviceable part is delivered to the MRO shop, where repair processes are performed and upon repair completion the serviceable part is shipped and stored in the warehouse, maintaining thus the stock level of components’ availability. When the customer is KLM, the unserviceable part is immediately delivered to the MRO shop after exchange.

![Figure 22: Pool availability (own illustration)](image)

However, in some contracts, the repair of the same component removed from the customer can be requested. In this case there is no component exchange in customer, but only a removal of the component is performed. The very same component is then delivered to KLM Warehouse and subsequently to the repair shop. Upon repair completion the serviceable now component is delivered to KLM warehouse and then to the final customer (closed loop, figure 23).

![Figure 23: Closed loop (own illustration)](image)

Complementary to the closed loop sub-process, there may be cases where an initial evaluation of the used component takes place and decision whether it is possible to repair it or not is taken afterwards. The process of time and material is the same with closed loop (Time and Material) when repair is possible and the same with component availability, when repair is not possible (figure 24).

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5 A larger display of this figure is included in the Appendix F
6 A larger display of this figure is included in the Appendix F
Implementing Process Management at Component Services requires a deep evaluation of the process, in terms of what the process accomplishes and what is the added value of the process. Therefore, in this sub section the tools and methods that have been used in order to explore the process goal will be presented and analyzed.

### 3.3 Define Component Services added value

As indicated in the official KLM website, the focus of Component Services, is to respond to the specific needs of the customers, within the capability of current and future knowledge and the resources required, and to maintain a balance between the supplied product in relation to the price and quality of the product. Additionally, to provide a reliable, individual component, or a group of components for an aircraft/same type aircrafts or different types of aircrafts in which the component is in operation under similar conditions, under the type of usage the customer needs. Additionally, goal for the component services also is the ability to assess the offered repairs and modifications and decide whether and what to perform (not in case of AD-mandatory modifications), invest in human development and well-being, long term culture improvement, with respect and healthy norms and values that are explainable to all staff. However, and for the research requirements, interviews have been conducted in order to explore people’s perceptions regarding the goal of the Component Services process and eventually formulate it.

#### 3.3.1 Interviews

In order to define what is the added value that Component services deliver to the end customer a series of face to face, semi-structured interviews took place. Almost all the interviews were recorded and all of the recorded interviews had the full awareness and consent of the interviewees. Additionally, notes were also kept for the need of analysis. The reasoning behind using semi structured interviews as a method for data obtaining is that such an interview facilitates in exploring several factors related to the problem in question and offering considerable freedom to the interviewer in order to lead the discussion in different paths, trying to identify other “hidden” critical factors related to the situation (Sekaran, 2003).

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7 A larger display of this figure is included in the Appendix F
The interviews, which were held in KLM E&M buildings in Schiphol Oost were 15 and the topics covered included the goal of the component services process, the goal of MRO and availability included in the Component Services process, the added value offered to the customer, responsibility distribution within the process steps, what are people’s perceptions regarding the main performance constraints in the process and several times other questions that may arise during the conversation. The interviewees were employees in the Component Services and more specifically 1 shop mechanic, 1 cell manager, 2 production line managers, 2 customer interface managers, 3 supply chain managers, 2 data analysts, 1 material manager, 1 blackbelt and 2 group managers for supply chain and pool management. More information regarding the given questions will be found in Appendix.

3.3.2 Analysis and results

For the analysis of the results, the answers have been categorized into main coding names and subsequently, frequency test has been applied. Hence, for the question regarding the goal of the Component Services process most of the interviewees (57.14%) claimed “provide components' availability to customers” as the goal, with 28.57% claiming “customer satisfaction” and 14% “repair without cost: as the goal. Additionally, for the sub-process pool availability, most of the interviewees (80%) claimed “provide components' availability” as the goal, whilst the rest of them (20%) claimed “customer satisfaction” as the goal of this sub process. Furthermore, for the sub process “provide components’ MRO” the majority of the interviewees (71.43%) claimed “components’ availability to the customer” as the goal, whilst the rest of them (28.57%) claimed “provide components’ MRO services” as the goal. Last but not least, the interviewees were asked to depict the stage within the process that adds the value to the customers. As a result, the majority claimed that it is the “Maintenance, Repair and Overhaul process” that adds value to the final customers (71%), while the rest 29% denoted “Ship the right component to the customer”, which is referred to logistical services.

Based on the above mentioned analysis, we can conclude, that the main goal of the Component Services and the added value delivered to the final customer, as denoted by the people working in KLM E&M is “to provide component’s availability” to the customer. In other words, the goal of the process for KLM to be able to serve its customers, by repairing or delivering (depending on the type of contract) the right component, with the right specifications at the right time.

3.4 Responsibility per process step

For the deep exploration of the process performed at Component Services, defining the responsibility roles within the process is really important. Therefore, a SIPOC analysis (Rasmusson, 2006) has been performed in order to identify the supplier and customer per process step, the input and the output derived from each process step.

Define supplier-customer relationship

In this step, the internal stakeholders should be identified and the responsibility distribution should take place. Therefore, the SIPOC tool has been used, since it is a high level process
mapping tool that it is broadly and efficiently used in cases where the process in question needs to be improved (Rasmusson, 2006). With this tool, supplier, input, process description, output and customer per step can be defined. The findings are displayed in figure 25.

**Figure 25: SIPOC analysis for Component Services process**

The SIPOC analysis provided an analysis for the responsibility distribution per process step. Having a clear view of the supplier-customer relationships per process step and additionally, the transformation of input to output provides a deeper understanding of the process in question.

In more details, the process is initiated when the airline customer makes an order request (repair in case of closed loop or new component in case of pool availability) in the AERO System, which produces a picking slip together with a proforma invoice that includes the cost and other information regarding the order. Thereinafter, the Customer Interface creates the shipping slip of the order, the requested component is picked from the warehouse by using internal logistics and is subsequently shipped to the customer with the use of external logistics (pool availability). Subsequently, the exchange of the old with the new component or the removal of the old component is performed at the customer and the unserviceable (old) component, together with the form of complaint (reason of removal) is shipped back to the maintenance facilities of KLM, with the use of external logistics (KLM or customer). At this point, the line or base maintenance
delivers the Unserviceable component together with the complaint form to the Repair Shops of KLM (A&A or BMSS), that perform the needed repair processes of the component, based on the predefined turnaround time/day of delivery. The outcome of this procedure is a fully serviceable component that is either sent to the customer (closed loop) or to the warehouse of logistics center with the use of external or internal logistics respectively. In the latter case, with the use of internal logistics the serviceable component is stored in the warehouse in order to maintain the pool availability. Finally, the customer interface confirms the delivery of the component and the customer repair request or order is therefore closed.

3.5 Performance observations on CBBSC

Having a clear view of the current state of the process is a very important stepping stone for the identification of process constraints that may halt the performance. Therefore, an additional analysis of the currently used performance metrics should be performed. The identification of the main performance constraint will therefore be enhanced.

Key performance indicators (KPIs) are the performance metrics that relate the company’s requirements with the customers’ needs, whilst their scores are compared to a predefined target and hence, proper decisions are made if improvement is needed. In literature, there is a variety of performance measurement frameworks that have been proposed. Among those, the most broadly used is the Connected Business Balanced Scorecard (CBBSC), developed by Kaplan and Norton (Kaplan et al., 1996). The CBBSC framework is currently used in KLM E&M department. In the local intranet there is a real-time display of the process performance through the use of KPIs. As it can be observed in figure 26, KLM CBBSC is adjusted to the needs of the company but follows the main format as set by Kaplan and Norton. In more details “making the numbers” in KLM CBBSC represents the “Financial process”, in terms of operating income or capital employed; elements that contribute to the financial success of the company. Additionally, “Organizational development” represents “Learning and Growth”, with metrics such as training that depict the ability to change and improve. Furthermore, “Customer delight” in KLM CBBSC represents “Customer” of Kaplan and Norton, in terms of customer satisfaction or Service Level Availability; metrics that depict if value is delivered to the final customer efficiently. Finally, “Operational Excellence” represents “Internal business process”, basically in terms of turnaround times of MRO services; TAT metrics that show if the MRO process performs efficiently.
Approach

The CBBSC provides a complete display of all the performance metrics that are currently used at Component Services. The Connected Business Balanced Scorecard provides an up-to-date, real time performance indication and hence, it constitutes the most representative tool for the identification of performance constraints. However, before we proceed to the data analysis for the constraints’ identification, it is very crucial to understand the nature of the KPIs used, in terms of what they really measure and how those measurements can be displayed within the process at Component Services. Provided that there is a complete understanding of the current process and the KPIs used, in terms of what they really measure, proceeding with identifying the main performance constraints can be facilitated.

Therefore, for each sub-process of the Component Services process (pool availability, T&M and closed loop) the respective KPIs have been chosen from the CBBSC and located within the process design offering a more clear view of what they indeed measure. As depicted before, currently, Component Services uses turnaround time KPIs; that is the total time needed for the performance of each action depicted by the metric.

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8 The full list of the KPIs included in the CBBSC of Component Services can be viewed in Appendix F.
**TAT KPIs currently used**
The first case includes all the required actions for the maintenance of the stock level within the warehouse; pool availability. In this case, there is a list of current KPIs that have been identified and represented by red arrows in figure 27. All of them are TAT KPIs, which means that they measure the turnaround time, the time needed in order to return an item. Those KPIs include,

**TAT Respons availability:** The response time of KLM on received availability requests from customers.

**SL Pool third party:** The extent to which requests are handled according to the CS contract with a customer.

**SL US flow pool third party:** The extent to which components are sent back in time (according to the contract). Flow of US components from customers to E&M (reverse Service Level)

**TAT Repair OPS:** The time interval between the moment of dropping component (removed from aircraft) at “CIR IN” of its shop to end of repair of the component and the moment Tracking scan at CIR OUT of the shop.

**TAT Repair to Magazijn:** The time interval between the moment of issue/delivery (“drop”) of repaired component at CIR OUT of its shop and the moment it is received at a warehouse).

**TAT Vendor:** The time interval between the moment of the creation of the order and the moment the component is returned at LC. Where the transport time to and from vendor are excluded.

More particularly, if we deepen our analysis more in the MRO step (Provide Component MRO Service) we will identify three subsequent process KPIs; TAT Cir in, TAT Repair Shop and TAT Cir out, that all together form the TAT Repair OPS KPI, as it is displayed in the figure 27.

**TAT Cir in:** The time interval between the moment of dropping component (removed from aircraft) at “CIR IN” of its shop and the moment of transfer to shop handling. Opening hours of the cir are currently set at 7:00 till 16:00.

**TAT Repair Shop:** The time interval between the moment of transfer to shop handling and the moment of end of repair of the component.

**TAT Cir out:** The time interval between the end of the repair action of the component (crocos TWA or SAP HIST) and the moment first Tracking scan at CIR OUT of the shop. Opening hours of the cir are currently set at 7:00 till 16:00.
In the second case, closed loop (figure 28), the US components are taken out the aircraft, transported to the MRO Shop, repaired and then shipped back the customer. In the closed loop case, the customer is external and not KLM and since the logistics part is performed by the customer, no KPIs can be identified for this part. The KPIs for the closed loop included in CBBSC are as follows:

**TAT Repair OPS:** The time interval between the moment of dropping component (removed from aircraft) at “CIR IN” of its shop to end of repair of the component and the moment Tracking scan at CIR OUT of the shop.

**TAT Cir in:** The time interval between the moment of dropping component (removed from aircraft) at “CIR IN” of its shop and the moment of transfer to shop handling. Opening hours of the cir are currently set at 7:00 till 16:00.

**TAT Repair Shop:** The time interval between the moment of transfer to shop handling and the moment of end of repair of the component.

**TAT Cir out:** The time interval between the end of the repair action of the component (crocos TWA or SAP HIST) and the moment first Tracking scan at CIR OUT of the shop. Opening hours of the cir are currently set at 7:00 till 16:00.

The result KPI of the whole process is the **Service level Repair only flight hour contracts** that indicates the extent to which repair only flight hour items are handled according to the CS contract with a customer.

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9 A larger display of this figure is included in the Appendix
In the last case, Time and Material (T&M) the customer is external and not KLM. In this case, there is a list of current KPIs that have been identified and displayed in figure 29 by red arrows. All of them are TAT KPIs, which means that they measure the turnaround time, the time needed in order to return an item. Those KPIs include,

**TAT Non Pool to Repair:** The TAT of the delivery of the US component from the customer to the MRO Shop. The logistics is performed by the customer.

**TAT Repair OPS:** The time interval between the moment of dropping component (removed from aircraft) at “CIR IN” of its shop to end of repair of the component and the moment Tracking scan at CIR OUT of the shop.

More particularly, if you deepen our analysis more in the MRO step (Provide Component MRO Service) we will identify three subsequent process KPIs; TAT Cir in, TAT Repair Shop and TAT Cir out, that all together form the TAT Repair OPS KPI, as it is displayed in the following figure.

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**TAT Cir out:** The time interval between the end of the repair action of the component (crocos TWA or SAP HIST) and the moment first Tracking scan at CIR OUT of the shop. Opening hours of the cir are currently set at 7:00 till 16:00.

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\[10\] A larger display of this figure is included in the Appendix
**TAT Non Pool to Return:** The TAT of the delivery of the SE component from the MRO Shop to the customer. The logistics is performed by the customer.

The sum total of all the aforementioned turnaround time KPIs equals the result KPI of the whole process; **Service level CSO T&M.** This KPI is a service level, which measures the extent to which requests are handled according to the CS contract with a customer. This concerns the Time & Material repair process. The TAT performance of T&M equals the Service level of T&M.

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**3.6 Data collection, validity and reliability**

Validity concerns the degree to which any data collection method and measure manages to measure what it intends to do (Powell, 2006), whereas reliability refers to the degree to which a measure or data is error free (Sekaran, 2003). The data validity and reliability can be affected by several factors, including biases of the researcher/observer, data collection setting, sampling and inconsistent data collection methods among others. Nevertheless, using multiple measures can facilitate in increasing both the data validity and reliability (Powell, 2006).

For the needs of the presented research and in order to efficiently define the current state at Component Services, several internal meetings with the supervisors, informal and unstructured interviews with several employees took place. The validity of the presented results lies on the fact that several data collection methods have been used; including interviews, use of the company’s records and assessment by the participants and the supervisors. Additionally, the reliability of the presented results is ensured by the repeated confirmation of the findings as provided during the informal meetings and interviews.

In more details, in this chapter there has been an initial display of the flow of both the consumables and rotables in KLM E&M. The presented figures are the outcome of internal sessions and informal discussions with the KLM supervisor, who assessed and confirmed the

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11 A larger display of this figure is included in the Appendix
results. The customer contract types that have been presented in this chapter are the outcome of an unstructured interview with the Customer Interface managers of Component Services, also confirmed after reviewing the company’s records. Additionally, the current process performed at Component Services, as displayed in figure 21 has been retrieved from the local BPM-ARIS system of KLM that includes all the performed processes in KLM E&M. This process display has been used as the basis for the development of the additional sub-processes as defined by contract types (pool availability, closed loop and time and material). The design of the aforementioned sub-processes (figures 22, 23 and 24) and additionally, the design of the same skims also including the identified KPIs (figures 27, 28 and 29), are the outcome of several brainstorming sessions with the data analysts of the Component Services, who also assessed and confirmed the reliability of the presented figures.

During the chapter, the main goal and the added value of Component Services have been identified as “to be able to serve its customers, by repairing or delivering (depending on the type of contract) the right component, with the right specifications at the right time”. The reliability of this conclusion lies on the fact that it is the outcome of a frequency statistical test of the answers provided by a series of unstructured interviews with 15 KLM E&M employees, including 1 shop mechanic, 1 cell manager, 2 production line managers, 2 customer interface managers, 3 supply chain managers, 2 data analysts, 1 material manager, 1 blackbelt and 2 group managers for supply chain and pool management. For the needs of the SIPOC analysis (figure 25), several unstructured and informal interviews have been held, in order to identify the responsibility roles among the process steps. The identified responsibility roles were subject to repetitive review by the interviewees and therefore, the presented results, as included in the SIPOC analysis are the outcome of a progressive content assessment and confirmation.

3.6 Conclusions
Within this chapter the current state of Component Services has been defined. The process performed as a series of steps has been analyzed and additional sub-processes have been recognized and designed. These sub-processes include pool availability (maintaining the stock level in the warehouse), closed loop (the same component that is removed from the customer is repaired and delivered back to the customer) and time & material (an initial evaluation is performed in order to define whether the repair can take place or not). Additionally, process step analysis has also been performed for the identification of the responsibility roles. With the use of the SIPOC tool the supplier-customer relationship and the input-output transformation per process step have been displayed. Exploring and understanding the main process and sub-processes (as defined by the customer contract types) performed at Component Services, together with the identification of the responsibility roles, provides a deep process analysis that will facilitate in understanding where within the process the performance constraint lies and who is responsible for it.

Moreover, the current performance measurements used by Component Services have been explored through studying the Connected Business Balanced Scorecard. The relative Key
Performance Indicators have been subsequently located within the identified sub-processes in order to provide a more complete view of their nature; what they really measure.

Concluding, defining the current state of Component Services is the stepping stone for the identification of the main performance constraint. Having a good insight of the process, how it is performed and how it is measured facilitates in identifying information gaps that can lead to performance constraints.

Component Services measure the process performance in terms of turnaround time by using a list of KPIs that simply display the real time performance of each activity/process step. Since the aim of the presented research is to improve the maintenance process at Component Services, which also constitutes the activity (or process step) that adds value to the end customer, the relative KPIs will be explored. Therefore, the starting point of the data analysis for the identification of blockages will be the Repair process.

**4.1 Define repair performance at Component Services**

For KLM E&M department and more specifically for Component Services, performance is measured by a list of turnaround KPIs. Those KPIs measure the time of delivery to the customer. Hence, the orders that were delivered ON TIME or before the TAT set in the customer’s contract, increase performance, whilst delayed deliveries contribute negatively in the overall performance. For example, a Repair Shop turnaround KPI that performs 80% denotes that 8 out of 10 orders were delivered on time with the rest 2 to be late.

As depicted earlier, Component services is comprised by two repair shops; A&A and BMSS. The Component Services CBBSC offers separate and combined performance measurements for those two shops. However, even though the performance of BMSS shop is worse compared to A&A, the latter one has been chosen for this analysis, since initial steps of Process Management have already be taken there and also for time limitations. Indicatively, in figure 30, the separate and combined performance of BMSS and A&A for April 2015 can be displayed.

![Figure 30: Current KPIs identified in CS in Time and Material case](image-url)
It is really important to point out, that in the combined performance measurements, the percentage of the parts contributing to the total is taken into account as a weight. Equally important is for the reader to understand the difference between the Repair Shop and the Repair OPS. The start of the latter chronically coincides with Cir In and is completed with the completion of the Cir Out KPI, however this doesn’t mean that the Repair OPS is the sum of the three (Cir In, Repair Shop and Cir Out), but it is a different KPI measurement that is calculated independently of the rest three (figure 31).

4.2 Identify constraint
For the root cause analysis a mix of three tools and methods have been used. First of all, the essential process management cycle and the Theory of Constraints with the five focusing steps methodology have been combined with the lean technique GO GEMBA, in order to make close observations and evaluate the current situation and statistical data analysis and simulation formed the path of root cause analysis. The Theory of Constraints as the basis of analysis has been chosen since, as depicted in the literature review, it provides a standardized method for the identification of constraints that prevent the organization’s goal realization and promote continuous improvement. Based on TOC, the system should constantly improve the identified constraint until the limit is not a constraint anymore.

Set of criteria
During the first step of the constraints identification several criteria that would facilitate the research have been set. The below described criteria of data selection and analysis have been set for reasons related to time limitation of the research. Therefore, in order to narrow down the plethora of components repaired in KLM E&M, rotables repaired in A&A Repair Shop are under the scope of the presented research. Additionally, repairs performed during the period March 2014-June 2015 have been chosen for the needs of data analysis, since data from this specific time period is only displayed currently in the Connected Business Balanced Scorecard of Component Services KLM E&M. The list of criteria is as such:
Plan: Understand source of poor performance in A&A Repair Shop

1. The rotables (RA) components have been set as the objects of analysis. Rotables are components that can be repaired “infinite times” from a technical point of view, until they are totally useless and thus disregarded; there is not a predefined number that restricts the repair times as applied in repairable components. For this case, the customer is the pool of KLM and not an external one. Component services has several customers, each of those has a personalized contract with KLM. Within this contract, different Service Level agreements are set, based on the customer’s needs. For reasons related to research time limitations along with the fact that for Rotables the turnaround time is always constant (14 days), this type of components has been chosen.

2. The time period of the analysis has been set as March 2014 – end of June 2015. The reason that lies behind this criterion is that this is the timeframe of the available data on the Connected Business Balanced Scorecard of the organization.

3. A&A (Avionics & Accessories) has been set as the object of analysis, for reasons that were mentioned earlier.

The root cause of the analysis followed the path is displayed in figure 32.

![Figure 32: Root cause analysis path](image)

**Identify the Cell with the lowest performance**

Avionics and Accessories is one of the two repair shops of Engineering & Maintenance department of KLM. A&A consists of 8 different cells and each cell consists of each own workstations.

Cell 1 consists of one workstation: EK HIGH FREQUENCY

Cell 2 consists of three workstations: EH COMPUTERS_1, EHC COMPUTERS_2 and EHB COMPUTERS_4.

Cell 3 consists of two workstations: EM LOW FREQUENCY and EHA COMPUTERS_3

Cell 4 consists of three workstations; EB INDICATORS_2, EG INDICATORS_1 and EE AIRDATA

Cell 5 consists of two workstations: EWA FUEL & PUMPS and EWF HYDRAULICS ROT

Cell 6 consists of one workstation: EWB HYDRAULICS LIN
Plan: Understand source of poor performance in A&A Repair Shop

Cell 7 consists of two workstations: ES ELECTRO MECH. and ESA ELECTRO MECH.

Cell 8 consists of three workstations: EFA BOTTLES, EY GALLEY RELATED and EF BOTTLES

The starting point of the analysis is to find the cell with the poorest performance, which further means the cell with the highest turnaround time within A&A. Therefore, the performance for each of them has been calculated for the three KPIs; TATS Cir in, TAT Repair Shop (OPS), TAT Cir out and TAT Repair OPS.

Table 4: TAT REPAIR OPS for cells in A&A

<table>
<thead>
<tr>
<th>Cell</th>
<th>TAT Cir In %</th>
<th>TAT Repair Shop %</th>
<th>TAT Cir Out %</th>
<th>TAT Repair OPS %</th>
<th># Parts</th>
<th>Share %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell 1</td>
<td>84.4</td>
<td>74.7</td>
<td>92.5</td>
<td>62.2</td>
<td>1379</td>
<td>4.9</td>
</tr>
<tr>
<td>Cell 2</td>
<td>89.7</td>
<td>78.7</td>
<td>92.5</td>
<td>43.2</td>
<td>2294</td>
<td>8.2</td>
</tr>
<tr>
<td>Cell 3</td>
<td>89.2</td>
<td>84</td>
<td>94.2</td>
<td>55.2</td>
<td>4265</td>
<td>15.2</td>
</tr>
<tr>
<td>Cell 4</td>
<td>84</td>
<td>72.8</td>
<td>92.2</td>
<td>39.2</td>
<td>1551</td>
<td>5.6</td>
</tr>
<tr>
<td>Cell 5</td>
<td>79</td>
<td>56.1</td>
<td>82.5</td>
<td>59.7</td>
<td>1696</td>
<td>5.7</td>
</tr>
<tr>
<td>Cell 6</td>
<td>82.9</td>
<td>74.5</td>
<td>77.1</td>
<td>33.4</td>
<td>1607</td>
<td>5.4</td>
</tr>
<tr>
<td>Cell 7</td>
<td>79.9</td>
<td>73.2</td>
<td>70.7</td>
<td>30.8</td>
<td>3920</td>
<td>11.6</td>
</tr>
<tr>
<td>Cell 8</td>
<td>84.6</td>
<td>87</td>
<td>79.9</td>
<td>58.7</td>
<td>12188</td>
<td>43.5</td>
</tr>
<tr>
<td>Total</td>
<td>83</td>
<td>80</td>
<td>85</td>
<td>47.6</td>
<td>28029</td>
<td>100</td>
</tr>
</tbody>
</table>

The results displayed in table 4 depict that for TAT Cir In and Cir Out KPIs Cell 7 is the one with the poorest performance. However, for the TAT Repair Shop KPI, cell 4 performs poorer than 7. Taking into account that a. the TAT Repair OPS performance for cell 7 is poorer than 4 and also that b. cell 7 contributes more to the total of the parts repaired in the shop, we can conclude that Cell 7 is the one that performs poorer. Additional information regarding the data analysis displayed above can be found in Appendix.

Identify the Workstation with the lowest performance

The next step of the analysis is the identification of the workstation within cell 7 with the lowest performance compared to the others. For the purpose of this analysis, the TAT REPAIR SHOP (OPS) TAT KPI have been used. The reader should keep in mind that the TAT target for pool orders (rotables as components) is set as 14 days. This target has been calculated and defined as 14 days by the Engineering department in the past and is used as a norm since then. However, there have been many mechanics who argue that this calculation is outdated and therefore, new measurements have to be performed and a more realistic target should be calculated. The performance results are displayed in figure 33.
The performance within Cell 7 are as follows: ES ELECTRO MECH. workstation has a poor performance of 65%, while ESA ELECTRO MECH has a good performance of 97%. Therefore, we can conclude, that the Workstation ES ELECTRO MECH affects negatively the overall performance of the cell.

**Explore the reason of delay**

For every disturbance in the order delivery, there is a reason officially recorded in the system of orders. By using the statistical tool of frequency test, the most common reason for production disturbance and delay in delivery can be identified.

The reasons of delay in delivery as displayed in the system, together with a short description are as follows:

SHOP: skills/capacity or poor orders’ management  
TA: material unavailability  
UB: component outsourced to external vendor  
DA: rejected because of total cost of ownership or fail market value (when repair cost is bigger than the price of a 2nd hand, serviceable component and therefore replacement should take place instead of repair)  
PV: machine problems, missing manuals, lack of the right tool to use (machine & method problems)  
QT: Quote; waiting for the customer to reply to the cost offer made by the shop for a certain repair.  
MI: component is missing  
WB: component came in the shop, however is not recognized by the system; unknown component

Therefore, the results of the frequency test are as follows:
Plan: Understand source of poor performance in A&A Repair Shop

Figure 34: Reasons for delay within ES. ELECTRO MECH. workstation

Figure 34 depicts that the most common reason of delay within the workstation is the “Shop” (40% of total late orders), with “TA” as the second reason of delays (31% of total late orders). This figure reveals that in almost half of the total late orders, capacity, lack of skills or generally mismanagement of the repair orders is the reason of the delay.

Identify the component with the lowest performance

Cell 7 performs MRO services for a plethora of components; those components can be categorized into the following categories: sensor, relay, light, fan, ballast and actuator.

A sensor is an important aircraft component that is used for the control of the airflow and other uses. A relay is a component that is used as a switch, in order to control an electrical circuit. Lights also constitute a really important component in aircrafts, ranging from sidewalk lights, till wing, tail or assy and logo lights. Fan is also necessary for keeping the right temperature within the aircraft. Ballast is a material that facilitates in keeping the right aircraft.

An actuator (figure 35) can be either electrical or hydraulic and plays a vital role both for the movement and the flight control of an aircraft. In more details, an electrical actuator is a motor responsible for converting electrical signals into movement, while a hydraulic transforms the received fluid power into work, with the use of a piston. Actuators are basically used for the efficient operation of wheel brakes, landing gears and speed propellers but also for the flight control system of wing flaps and spoilers (of unfavorable air movement). An actuator transforms the electrical signals or the fluid power into movement through power that is then controlled and rotated by the actuating cylinder within the aircraft’s system (Simkins, 2012). The purchase cost of an actuator is estimated as ranging from $500 to $1000 (Apollo Valves, 2015), higher compared to the rest of the components repaired in Cell 7.
The next step of the data analysis is to identify the component that has the poorest performance. The performance scores per component are displayed in figure 36.

From the figure shown above, it can be concluded that the component that performs more poorly compared to the rest, is the “Actuators”, with a performance of 66%, then “fan” has a performance of 70%, “light” has a 74% performance, “relay” “sensor and “ballast” with a performance of 76%, 79% and 85% respectively.

Calculating touch and waiting time

For the identification of the root cause of the problematic performance of the actuators, 5 instances of actuators with high turnaround time (beyond the predefined). For the formulation of the sample, the statistical method of “simple random sampling” has been used in the population of all the late actuators from March 2014-June 2015. Further information about the random sampling performed will be found in Appendix. Sampling method has been used, since it would be

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12 Picture was retrieved from Google: http://www.stoneleigh-eng.com/pneumatic_actuators.html
impossible to analyse the data and construct the timelines for the total of the population of
unserviceable actuators for the above mentioned period for reasons related to time limitations.
Additionally, random sampling has been used since this method offers equal opportunities for
selection to the whole population, has minimized bias and can be easily generalized to the total
population (Sekaran, 2003).

**Analyzing 5 instances**

After choosing the five instances to be further analyzed, the touch time (the actual time spent for
the repair service) and the waiting time (time spent waiting and not performing repair) had to be
calculated in order to identify the root cause of the delay and the poor performance. More
information and explanations regarding the analysis performed for the sample can be found in
Appendix.

**Total touch time and touch time per actuator**

After analyzing the five aforementioned actuators’ repair instances the main conclusion is that the
touch time for each instance is just a really small percentage of the total TAT. In more details, the
touch time varies from 0.78-1.15% of the total time with the waiting time to be dominant, varying
from 98.85-99.22% of the total TAT, as depicted in the table shown below.

<table>
<thead>
<tr>
<th>Actuator 1</th>
<th>Actuator 2</th>
<th>Actuator 3</th>
<th>Actuator 4</th>
<th>Actuator 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Touch time (min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1,13%</td>
<td>0,78%</td>
<td>0,95%</td>
<td>1,15%</td>
<td>0,84%</td>
</tr>
<tr>
<td>Waiting time (min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>98,87%</td>
<td>99,22%</td>
<td>99,05%</td>
<td>98,85%</td>
<td>99,16%</td>
</tr>
<tr>
<td>Total time (min)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

However, it has been then identified, that the waiting time could be distinguished into Waiting
Time before repair (buffer time) and waiting time (within the repair process). Subsequently, the
calculations of the contribution of each one to the total time have been performed and the
findings are displayed in the following table.
Plan: Understand source of poor performance in A&A Repair Shop

Table 6: Touch time and waiting time before and within repair process per instance

<table>
<thead>
<tr>
<th>Actuator</th>
<th>Before repair process WT in d/h/min</th>
<th>Within repair process WT in d/h/min per time slot</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuator 1</td>
<td>13d13h2min 88.93%</td>
<td>17h35min 4.81% 3h14min 0.88% 1h42min 0.47% 18h26min 4.91%</td>
<td>15d7h55min</td>
</tr>
<tr>
<td>Actuator 2</td>
<td>6d13h18min 33.74%</td>
<td>18min 0.06% 20h23min 4.37% 2min 0.01% 9d1h41min 46.69% 2d22h30min 15.12%</td>
<td>19d13h</td>
</tr>
<tr>
<td>Actuator 3</td>
<td>22d11h57min 92.41%</td>
<td>1d20h21min 7.59%</td>
<td>24d10h26min</td>
</tr>
<tr>
<td>Actuator 4</td>
<td>24d9h22min 82.66%</td>
<td>27min 0.06% 5d2h19min 17.27%</td>
<td>29d13h42min</td>
</tr>
<tr>
<td>Actuator 5</td>
<td>33d10h44min 98.01%</td>
<td>36min 0.07% 3h11min 0.39% 12h29min 1.52%</td>
<td>34d7h11min</td>
</tr>
</tbody>
</table>

Simulation: Remove Waiting time before the Repair Process (Buffer time)

From the above mentioned analysis, it can be concluded that waiting time (WT) before repair is a crucial symptom of the constraint in the shop. However, in order to confirm this finding, we should also check if there is any relation between this finding and the performance. Therefore, we should check whether the performance of these 5 actuators can be improved if we could remove 100% of this waiting time. Simulation is a technique that can facilitate in determining the effects of certain changes. It can be thought as an experiment that is performed in a setting that represents the natural environment of the activities (Sekaran, 2003). The results are surprising, since the new TAT would have been considerably decreased (see Total TAT in the following table) and the SE components would have been delivered on time in these cases. Therefore performance could have been increased 100%.
Table 7: Simulation removing before repair process WT

<table>
<thead>
<tr>
<th></th>
<th>Before repair process WT in d/h/min</th>
<th>Total TAT</th>
<th>New TAT</th>
<th>On Time Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actuator 1</td>
<td>13d13h2min</td>
<td>15d7h55min</td>
<td>1d18h53min</td>
<td>YES</td>
</tr>
<tr>
<td>Actuator 2</td>
<td>6d13h18min</td>
<td>19d13h</td>
<td>12d23h42min</td>
<td>YES</td>
</tr>
<tr>
<td>Actuator 3</td>
<td>22d11h57min</td>
<td>24d10h26min</td>
<td>1d22h29min</td>
<td>YES</td>
</tr>
<tr>
<td>Actuator 4</td>
<td>24d9h22min</td>
<td>29d13h42min</td>
<td>5d6h20min</td>
<td>YES</td>
</tr>
<tr>
<td>Actuator 5</td>
<td>33d10h44min</td>
<td>34d7h11min</td>
<td>0d20h27min</td>
<td>YES</td>
</tr>
</tbody>
</table>

As denoted earlier, random sampling facilitates in generalizing the results of the sample to the total population. By using simulation, the applicability of the findings have also been tested in a greater sample of 58 late actuators; with the performance increasing 74% (43 out of 58 late actuators could have been delivered on time of the WT before repair could have been 100% removed). Additionally, the generalizability has also been checked with a sample of 9 other type late components (Actuator RAM, LIGHT and FAN) with the performance increasing 88.89% (8 out of 9 late components could have been delivered on time if 100% of the WT before repair could have been removed).

The result of the above described analysis is the identification of a symptom of the constraint that causes poor performance in Cell 7; that is Waiting Time Before Repair.

Identify the constraint - GO GEMBA
In order to identify the constraint that causes the symptom of Waiting Time before repair a lean tool has been used; GO GEMBA. GEMBA facilitates in understanding how the process works and where the problem really lies.
The GEMBA revealed the mechanics’ perceptions regarding the maintenance process, the main constraints and the process of repair was also explained. Several policies and norms within the shop have also been identified.

The most important findings will now be presented. The standard procedure entitles that when the US component arrives at the MRO Shops the specialist scans the code of the component and automatically the 4 Ms are planned. In case a material that is needed for the repair is not available, then a new order has to be placed. Meanwhile, and until the ordered materials are delivered in the shop, the US components just lie in the shop, adding thus considerable delay.

In A&A more specifically, the main production problems that are identified by the employees (mechanics and data analysts) included material as one of their problems, however, most of the people identified the “Shop” as a problem, confirming the findings of the data analysis. Additionally, based on mechanics’ perceptions the reason of the poor performance included high input of unserviceable components and capacity deficiency (manpower).

Most importantly though, GEMBA revealed that the cell encounters a big problem with high inventories; there were many unserviceable parts (including actuators) that were located on the cell selves, waiting to be repaired.

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13 (Shook, 2011) The picture is retrieved from Google: http://quality-on.blogspot.nl/2014/08/gemba-walks-are-you-going-to-see-or-to.html
In order to confirm that indeed, the high inventories are a symptom of the constraint, a data analysis has been performed. For the period March 2014-June 2015, the number of US components that are accumulated on the shelves has been calculated. The revealed result is that if we assume that on March 2014 the inventory before repair was 0, based on the inflow and outflow real cell data, on June 2015, the inventory reaches the point 67; that means that as time passes by, more and more inventory (Unserviceable actuators) accumulates.
Plan: Understand source of poor performance in A&A Repair Shop

Based on Theory of Constraints and lean manufacturing, an increase of inventory usually determines a phenomenon before the bottleneck/constraint; since inventory is handled by the mechanics we now know that the constraint in our research is related with the orders management.

To confirm the finding that the main constraint within cell 7 is poor order management, the capacity of Cell 7 should be firstly checked. The reader now should recall that when the “Shop” is displayed as the reason of the disturbance (late turnaround time) in the order delivery, therefore it is either the lack of capacity /skills or a mismanagement of the repair orders that caused this disturbance.

**Capacity in Cell 7 for actuator repairs**

Based on the working list that is currently used, in cell 7 there are 11 mechanics that perform component repairs. However, not all of those mechanics are capable to perform actuator repairs. Therefore, based on their given skills there is a number of 4-6 mechanics (this number changes according to the monthly working schedule) who can perform the actuator repairs. Since their skills are unquestionable (they are displayed in the working list), calculating the capacity (net man-hours) is necessitated.

For the period September 2014-May 2015 the net man-hours of the mechanics that perform actuator repairs is calculated and compared to the total hours needed for the inflow of actuator repairs. This period has been chosen based on the availability of the working schedules. In the next chapter, the total time needed for an actuator repair will be calculated as 6.5 hours. However, this calculation will be now used in order to confirm that the root cause of the poor performance is the inefficient order management.
Figure 40, displays that during the period September 2014 – May 2015 cell 7 had both the capacity and skills to perform the actuator repairs. Therefore, not proper order management can be concluded as the main constraint / root cause of poor performance in cell 7.

4.3 Conclusion
Throughout this chapter, a data analysis has been performed for the identification of the performance constraint in A&A repair shop. The starting point of this analysis is defining what performance is within the Component Services Repair Shops and how is repair performance displayed through the relevant KPIs. Thereinafter, a performance data analysis has been performed in order to identify the cell, the workstation and finally the component that has the lowest performance within A&A repair shop.

Subsequently, a calculation of the waiting time before repair (buffer time), waiting time within repair and touch time has been performed, revealing thus a symptom of the performance constraint; long waiting time combined with high inventory of unserviceable components. Therefore, the main constraint has been revealed; poor repair orders’ management within the shop that causes high inventory accumulation.
5. **Do: Develop intervention plan with DBR and repair priority in A&A**

In this chapter, the intervention plan will be developed and presented through a set of proposed solutions. Appropriate calculations of the number of actuators that the shop can handle, together with a priority rule will be presented. Additionally, models that can increase the productivity in the shop will also be provided.

### 5.1 Exploit constraint

Before we proceed with the constraint exploitation, a further understanding of the repair process of actuators is needed. Besides, Performance improvement cannot take place if the process in question is not deeply explored.

**Design and understand Repair process**

Going Gemba, discussing with people, asking questions and observing things facilitated in understanding how the repair process is performed and therefore design it, as it can be seen in the following pictures.

Before we provide a description of the repair process per step, the buffer time before and after the repair together with the handshakes between the Customer Interface (CIRO) and the cell should be displayed.

![Handshakes and buffer time](image)

**Figure 41: Handshakes and buffer time**

For the needs of the described analysis, the part that starts with the handshake between CIRO and Cell and ends with the handshake between Cell and CIRO is of our interest. From the picture shown above, we can derive that there is an initial buffer time, which represents the waiting time before repair, thereinafter the repair process is performed and at the final step responsibility is
transferred to the CIRO with the above displayed handshake. A description of the repair process (figure 42) will now be given.

![Figure 42: Repair process for actuators](image)

The initial check basically includes the paperwork that has to be performed in order to proceed with the general repair. This entitles the check of the component’s part number from the job card, check the complaints/the reasons of removal and the past repairs. Additionally, it includes downloading the manuals needed to perform this repair from the system, based on the part number and filling the digital maintenance report.

Disassemble, entitles the disassembly of the actuator. The level of disassembly depends on the repair that needs to be done, as indicated in the manual.

The repair consists of a sequence of other steps; cleaning, repair and testbench. The repair sub-step which is included in this step is the most important step of the whole repair process, since it is the one that delivers value to the final customer; it is this step that makes a component operable again. After disassembly and before the repair takes place, some parts have to be cleaned. After the repair, before assembly, the mechanic should test the actuator/or the part that was repaired by using the testbench; a power simulator. Afterwards, the mechanic can conclude whether the repair is successful or not. If yes, then assembly takes place.

The final check, which is the final step in the repair process, is performed in the CROCOS system and includes basically all the paperwork that accompany the SE component, in terms of “release to service”, close the digital maintenance record (DMR) and deliver the SE component to the CIRO. At this point the repair process, as performed in the repair shop is completed.

From the above mentioned, the repair route can now be designed (figure 43). As it can be concluded, Initial check includes Input check, Testbench, Define repair, the Disassemble includes itself, the Repair step includes Cleaning and Repair, Assemble also includes itself and finally the Final Test includes Testbench and Final Check.
Each of the steps of the repair route has a predefined duration that is displayed on the job card that accompanies the unserviceable component to be repaired. Based on those predefined time duration, we can therefore calculate the duration of the touch time of the repair process, as it follows. Some additional information regarding the measurement of the process can be viewed in Appendix.

Table 8: Time duration per repair step

<table>
<thead>
<tr>
<th>Step</th>
<th>Activity</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial check</td>
<td>Input check</td>
<td>6 minutes</td>
</tr>
<tr>
<td></td>
<td>Testbench</td>
<td>60 minutes</td>
</tr>
<tr>
<td></td>
<td>Define repair</td>
<td>5 minutes</td>
</tr>
<tr>
<td>Disassemble</td>
<td>Disassemble</td>
<td>60 minutes</td>
</tr>
<tr>
<td>Repair</td>
<td>Cleaning</td>
<td>10 minutes</td>
</tr>
<tr>
<td></td>
<td>Repair</td>
<td>60 minutes</td>
</tr>
<tr>
<td></td>
<td>Testbench</td>
<td>60 minutes</td>
</tr>
<tr>
<td>Assemble</td>
<td>Assemble</td>
<td>60 minutes</td>
</tr>
<tr>
<td>Final test</td>
<td>Testbench</td>
<td>60 minutes</td>
</tr>
<tr>
<td></td>
<td>Final check</td>
<td>24 minutes</td>
</tr>
</tbody>
</table>

From the time durations given in table 8, we can now calculate the touch time per repair for an actuator as:

\[
\text{Touch time} = 6 + 60 + 5 + 60 + 10 + 60 + 60 + 60 + 60 + 24
\]

\[
= 405 \text{ minutes or 6 hours and 45 minutes}
\]

The above described process includes only the repair steps, however, before the initial check and after the final test of the serviceable part, a handshake between the cell and the Customer Interface (CIRO) is performed, as indicated by the vertical arrows in the following picture. The
handshake shifts responsibility to the next actor, which means that after CIRO performs the check and delivers the US parts in the cell, by locating them on the shelves, the responsibility is shifted to the cell. This is a very important observation, since it practically means that the cell is responsible for the creation of the constraint and not the CIRO. A representation of the repair process, the handshakes with the CIRO and the KPIs used by the Connected Business Balanced Scorecard for the repair shop can be displayed in figure 44.

**Figure 44: Handshakes identified before and after Repair process and KPIs used**

*Calculate constraint’s capacity*

In the book “The Goal”, when Alex Rogo identified that the main constraint in his production line was the machine NCX-10, he started to implement some changes in the production process in order to exploit the full, current capacity of his bottleneck. In our research, we have identified that our constraint is the manpower/human capacity, causing constraint phenomena like high inventory of orders to be repaired and high waiting time before repair.

In order to exploit the constraint identified, we need to calculate the capacity of the constraint. For this reason, some facts regarding the cell are given below:

- For every calculation that will follow and regard the actuators, the touch time that will be used is 6 hours and 45 minutes, as calculated in the previous section.

**Figure 45: Repair duration of an actuator**
b. Based on the working schedule, we know that in the cell 7, there are 4 mechanics that can work with actuators. However, they also work with other components too.

c. There is only one working shift from Monday until Friday (Saturday and Sunday are not working days). That means that there are in total 5 working shifts per employee (holiday leaves and sickness is not included)

d. Out of the 8 hours of shift, 6.5 hours are the real production hours. In other words, the gross available production hours are 8 per day per mechanic but the net are only 6.5 since coffee/lunch breaks etc. are excluded.

Based on the above mentioned information we can now calculate the capacity of the manpower (M) on a weekly basis; that is

\[ M(\text{total}) = 4 \times 5 \times 6.5 = 130 \text{ hours per week or } 7800 \text{ minutes} \]

This finding can be translated into number of actuators (A)

\[ A(\text{week}) = \frac{7800}{405} = 19.26 \text{ actuators per week}, \]

or approximately 4.8 actuators per week per mechanic,

\[ A(\text{month}) = 19.26 \times 4 = 77.04 \text{ actuators per month} \]

Based on the data regarding the number of orders in the set period (March 2014-June 2015), the number of actuator orders ranges from 23 to 63 per month and is not constant. However, it is much less than the number of actuators the mechanics can repair on a monthly basis, which indicates that there are available hours (manpower) for the repair, even though those mechanics also work with other components as well. However, we can conclude that manpower doesn’t seem to be a constraint, strengthening thus the conclusion from the previous chapter that the main constraint is the management of the orders.

5.2 Setting Drum Buffer Rope (DBR) and priority rules

Currently, Cell 7 in A&A works with the FIFO method for the order repairs; that is First In, First Out for a rather “push” process of repairs, since the CIRO delivers all the unserviceable components to be repaired in the cell, without any restriction on the number of components. However, following the steps of Theory of Constraints and the data analysis, after having identified “Herbie”, we need to set a DBR that renders the process to “pull” rather than “push”\(^\text{14}\) that is now.

Based on Theory of Constraints, when the resources (eg. people) are limited, the most limited one is set as “Drum” determining the pace of the entire system. However, the constraint should never lose a minute of its capacity; should always be busy working and not waiting for other parts to complete the repair/manufacturing process. Therefore, a drum schedule should be established, that maximizes the throughput of the constraint. Additionally, it is really important not to

\(^{14}\) The “Push type” is not based on the real demand, but rather to “Make to Stock”. On the other hand the “Pull type” is based on real demand or in other words, “Make To Order”. 
introduce new inventory when the system is still busy, that means delivering new orders only when the constraint is finished with the previous ones; this is the rope.

In order to implement DBR method in cell 7, priority rules should be set. For example, since actuators is the component that performs poorer compared to the other components the shop handles and also because of its high importance in the aircraft operation and purchase cost, priority tags could be placed on them. In other words, in this case actuators should have a priority in the repair process.

Using the calculations of the previous chapter, implementing DBR means that we set the “Rope” as the capacity of our constraint; that is 77 actuators per month. That means, that the number of orders to be delivered, using the full capacity of the Cell is 77 actuators per month; this is the number of actuators that can be delivered from the CIRO in the cell per month.

**A bottleneck creates another bottleneck**

It is really important to keep in mind that the mechanics who work with actuators, also work with the other components. Therefore, if they spend most of their net working hours on actuators, another bottleneck with another component may be created. As a result, setting DBR of actuators as 77, with the maximum capacity used is not efficient.

For the time period March 2014-June 2015, the total orders per component have been calculated (figure 46).

![Figure 46: Number of orders per component](image)

From the figure shown above, we can conclude that half of the orders delivered during the set period are actuators (1342 orders for actuators), with lights contribute with 34% to the total orders, 7% for the fan, 5% for the sensor, only 2% for ballast and finally, only 1% for relay.
Therefore, by following this identified pattern of the total orders delivered to Cell 7, we can set a priority rule for actuators, since they perform poorest compared to the other components that however, will not create another bottleneck. As a result, mechanics can devote half of their working hours to actuators and then the rest of them to the other components. By using simulation we can now calculate the inventory level of Unserviceable components, if we take into account that mechanics use half of their capacity for actuators and the rest for the other components. That means that mechanics repair now:

\[ A = \frac{77}{2} = 38.5 \text{ or } 40 \text{ (rounded up)} \]

However, with the simulation we can now see that if we set DBR as 40, inventory still goes up (see blue line in figure 47). Therefore, we can also simulate the inventory level for setting DBR as 45 or 50. Observing the results in the following figure, we can now conclude, that setting DBR as 50, is the best solution for keeping inventory levels low.

**Figure 47: Simulation for DBR=40, 45, 50 and 77 actuators**

With a DBR of 50 actuators, mechanics should repair:

\[ A = \frac{50}{4} = 12.5 \text{ actuators per week or} \]

\[ A = \frac{12.5}{4} = \text{approximately 3 actuators per mechanic} \]

We can now calculate the time devotion per mechanic as such:

\[ M = 3 \times 6.5 = 19.5 \text{ hours per week out of the total of } 6.5 \times 5 = 32.5 \text{ hours} \]
In other words, by using a DBR of 50 actuators per month, each mechanic should repair 3 actuators per week, which is 3 days out of the 5 working days and as a result, the rest 2 days he can dedicate it in repairing the other types of components. As a result, the inventory of unserviceable components to be repaired will be lowered, ensuring thus that no other bottlenecks will be created for the other components. In order to ensure that each mechanic will follow the above mentioned rule, performance KPIs for each mechanic could possibly be set.

5.3 Increase productivity

With the DBR set as 50, based on simulation performance should be increased for actuators. However, if high inventory persist, then the problem certainly is not orders management, since there is availability of working hours but rather productivity. In this case, KLM should additionally implement some models to increase cell’s productivity, by offering incentives. These incentives include pay for performance and profit sharing models.

Lost productivity

“There will always be work to do tomorrow, there will always be tomorrow in which to do work.”

Based on Manana attitude, you don’t have to hurry today on work, since work will also come tomorrow and the day after.. Manana is mostly caused by lack of incentive to finish your work quickly. This attitude is very common in standardized, routine works, like the manufacturing or repair industries. Similarly, in KLM the repair process is standardized enough, as we explained earlier (scan of US component, disassemble, repair, assemble, test). This implies that there is little satisfaction in completing the routinized work, it discourages people from having the enthusiasm and “the kick that moves work ahead quickly” (Newbold, 1988).

Pay-for Performance

Economic compensation models assume that high performance necessitates high effort. Therefore, providing incentives to the employees increases the performance. Incentives can be given through a well-established reward system that offers compensation to the workers, increasing thus their expected utility and therefore their productivity. Rewards can be praise from superiors, future promotion, feelings of self-esteem, cash rewards etc. (Baker et al., 1988).

The above mentioned reward system could be implemented in A&A cell through objective performance measurement and evaluation systems. In more details, the performance of each mechanic could be measured in number of orders completed and then the respective reward system can be applied, as the theory implies.

Profit sharing plans

In profit sharing, the worker’s compensation is tied to the total organizational performance. Based on literature, profit sharing is more effective compared to the previous model. Profit sharing includes stock ownership, team bonuses and cash flows accrued from the organization’s profits (Baker et al., 1988).
The goal of KLM Component Services, as identified through this research is to provide availability to the customers; in other words to provide the customer with the right component, at the right time. This goal cannot be realized if the performance is not acceptable.

It is typical for big organizations, including KLM, that there is inconsistency among different departments. In most of the organizations, people with similar skills are grouped together, focusing thus on their tasks and fostering a vertical view that hinders the effective operation of the organization’s ability. In this case, there isn’t clear understanding of the interrelations between the different departments in how they do affect the performance of the total process and the company; how their individual works can affect the customer’s satisfaction (Oakland, 2007). This is also an observed problem in KLM that needs considerable attention. By establishing profit sharing plans together with introducing process management for the improvement of the repair processes, the workers gain an incentive to increase their performance. As a result, worker’s increased performance can increase the organization’s performance which creates more customer satisfaction and thus more profits to share.

**Overtime and outsourcing**

Overtime and outsourcing are two methods that are currently used by KLM, when the input of unserviceable components is really high. The former one is rarely used and the latter one is more frequently used. However, for the latter case, appropriate management of the relation between the repair shop (KLM) and the external vendor should be performed, since it is common that the external vendors do not abide by the set turnaround time. In the case of KLM and in the Connected Business Balanced Scorecard currently used, the performance of the external vendors is measured (TAT Vendor) but performs poorly. For this reason, practices like constant communication should be used. However, this is beyond the interests of this research.

### 5.4 Conclusion

Following the proposed framework and more specifically the step “Do” that entails the development of the intervention plan, a Drum Buffer Rope has been set. In more details, it is calculated that with full capacity, the workstation can repair 77 actuators per month. However, this calculation isn’t useful, since it may create additional bottlenecks with the other components repaired in the workstation. Therefore, the orders that regard other components have also been calculated and taken into account. The pattern of the number of orders for the predefined period (March 2014-June 2015) has therefore been identified and the DBR has been set based on this. In more details, from the orders data per component, it has been calculated that 50% of the total orders were actuator repairs. With the use of simulation, the number of actuator that is close to 40 (approximately 77/2) and limits the inventory has been identified; this number is 50 and creates an inventory of 6 unserviceable actuators after the period of 16 months. With this result, the proposed solution is as such: “Every mechanic (total 4 mechanics working with actuators) should repair 3 actuators per week, which means that the 3 out of 5 working days should be dedicated in actuator repairs. The rest two of them, the mechanic can work with the other components. Therefore, actuators have priority compared to the other components”.

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In order to ensure that each mechanic will follow the above mentioned “rule”, models that can increase the productivity and the motivation to work on the repairs, such as pay-for-performance and profit-sharing are also proposed.
6. **Check: Simulate inventory level upon intervention implementation**

6.1 **Measure the impact of intervention**

The data analysis of the repair turnaround KPI of A&A repair shop, revealed that the main constraint that halts the performance in the shop is a rather poor order management. Therefore, throughout the previous chapter, an intervention plan that can eliminate the identified constraint has been developed and presented. This set of solutions included setting a Drum Buffer Rope; a fix number of actuators that the shop will handle on a weekly basis as 12.5 actuators per week. Based on the current capacity, it has subsequently been calculated that each mechanic should repair 3 actuators per week, which equals 3 working days. Therefore, in order to prevent the development of another bottleneck, the mechanics can work the rest days of the week with other components. However, a priority rule for actuators’ repair has been proposed. Moreover, in order to increase mechanics’ productivity, pay for performance and profit sharing plans models have been proposed.

In this step of the presented framework, an evaluation of the results upon the implementation of the intervention plan is performed. During the action research performed at Component Services KLM E&M, the list of the above mentioned solutions has been proposed but not implemented. Therefore, the impact of the intervention plan cannot be evaluated with real data.

However, during the calculations performed in the previous chapter and in order to confirm the efficiency of the proposed solutions, simulation has used. Hence, the inventory level of unserviceable actuators, the main phenomenon of the identified constraint has been simulated and this analysis has showed that the inventory level of actuators would have been dramatically decreased if the proposed DBR was implemented in March 2014.
Check: Simulate inventory level upon intervention implementation

The findings displayed in figure 49 confirm that by setting the DBR of 50 actuators per month on March 2014 (11 unserviceable actuators as an initial inventory), the level of the unserviceable actuators would have been decreased, almost 50% by June 2015 (6 actuators). The magnitude of this result can be observed when compared to the real inventory levels. Figure 49 depicts that the inventory of US components reached the number 67 at the end of June 2015, or in other words the inventory level had been increased almost 500% from March to June. Therefore, implementing the DBR as 50 could not only prevent the increase of inventory but also decrease the inventory almost 50%.

It is very important to mention here that in order to check the efficiency of this solution the process is still considered to be “push” and not “pull” during the simulation. The reason is that the impact of the intervention on the constraint’s symptom cannot be explored unless we use the symptom and real data, the real flow of US actuators in the repair shop. Simulating the inventory level with the proposed DBR confirmed that the implementation of the proposed intervention plan will decrease inventory and therefore, eliminate the identified constraint. This finding indicates the completion of the “Check” step of the proposed framework.

The finding of this simulation is very important for another reason as well. Figure 50 provides an overview of the inflow of US actuators from March 2014-June 2015 and the simulated inventory with the DBR of 50 actuators.
This figure depicts that for the series of months June-November 2014 and May 2015 the inventory level is below zero. Obviously this is not realistic but it is indeed important since it provides additional capacity for the repairs of the other components handled by the workstation. In those cases, the inventory level of actuators is zero and therefore the inventory level of the other Unserviceable components could be decreased. Hence, more repairs are performed in the repair shop and more serviceable components are delivered to the warehouse. This could lead to a possible decrease of additional cost at Component Services, since no purchase or rent of additional components could be needed, since the components’ availability is efficiently maintained.

6.2 Check the impact on other components

In order to check the impact of the DBR of 50 actuators with repair priority on the rest of the components repaired in cell 7, a calculation of the net man-hours available after the DBR repairs, compared to the real man-hours needed for the repairs of the rest of the components has been performed. The data that were used for this calculation have been retrieved from the working schedule of the mechanics in Cell 7, whereas the repair orders received in cell 7 have been retrieved from the SAP system the company uses. It is really important to point out here, that for the calculation of the man hours needed for the rest of the components, the norms as given by the Engineering Department have been used. In more details,

- The light repairs (all the types) have been considered as a 3.6 man hours process
- The relays repairs (all types) have been considered as a 3.5 man hours process
- The fan repairs (all types) have been considered as a 6 man hours process
- The sensor repairs (all types) have been considered as 6 man hours process
Moreover, it is of high important to point out that cell 7 performs repairs of a great plethora of components. During the presented research, there has been an attempt to categorize all the components into the above mentioned categories. However, there might be some categories that have not been taken into consideration in this calculation; therefore the presented table should be reviewed with caution.

**Table 9: Man hours available and needed for component repairs**

<table>
<thead>
<tr>
<th></th>
<th>Net man hours available</th>
<th>Total man hours needed for repairs</th>
<th>Man hours needed for actuator repairs</th>
<th>Man hours needed for repair of the rest of components</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>September 2014</strong></td>
<td>1752.84</td>
<td>855.3</td>
<td>149.5</td>
<td>705.8</td>
</tr>
<tr>
<td><strong>October 2014</strong></td>
<td>1805.49</td>
<td>1050.5</td>
<td>312</td>
<td>738.5</td>
</tr>
<tr>
<td><strong>November 2014</strong></td>
<td>1558.44</td>
<td>942.8</td>
<td>182</td>
<td>760.8</td>
</tr>
<tr>
<td><strong>December 2014</strong></td>
<td>1432.89</td>
<td>1097.3</td>
<td>325</td>
<td>772.3</td>
</tr>
<tr>
<td><strong>January 2015</strong></td>
<td>1683.5</td>
<td>1083.1</td>
<td>325</td>
<td>758.1</td>
</tr>
<tr>
<td><strong>February 2015</strong></td>
<td>1764.75</td>
<td>1005.2</td>
<td>325</td>
<td>680.2</td>
</tr>
<tr>
<td><strong>March 2015</strong></td>
<td>2055.625</td>
<td>1067.6</td>
<td>325</td>
<td>742.6</td>
</tr>
<tr>
<td><strong>April 2014</strong></td>
<td>1838.688</td>
<td>867.5</td>
<td>325</td>
<td>542.5</td>
</tr>
<tr>
<td><strong>May 2014</strong></td>
<td>1360.125</td>
<td>626.1</td>
<td>325</td>
<td>301.1</td>
</tr>
</tbody>
</table>

Table 9 displays the real total available man hours in Cell 7 from the period September 2014-May 2014. Additionally, the total man hours needed for the actuator repairs have been calculated based on the DBR of 50 actuators and the inventory level as displayed in figure 47. Moreover, the man hours needed for the repairs of the rest of the components have been calculated based on the given norms. A comparison of the net available hours, net hours needed for actuator repairs, net hours needed for the rest of the repairs and the total of the last two is provided by the following graph.
Figure 51 confirms that through setting a DBR of 50 actuators per month with a repair priority, there is still enough capacity for cell 7 to perform the repairs of the rest of the components. Once more, it should be pointed out, that the presented results should be reviewed with caution, since there might be component types that have not been included in the calculations.

6.2 Develop new intervention plan – Elevate constraint

In case the implementation of the intervention plan has no significant impact on performance (it doesn’t improve the process performance), then another intervention plan should be generated. Therefore, the steps of the proposed framework from “Do” should be repeated. Following the five focusing steps of Theory of Constraints, if performance improvement in the bottleneck is not observed then additional people, machines, tools or training should be performed. However, based on the presented analysis and with the help of simulation tools, we concluded that if cell 7 sets a DBR of 50 actuators per month based on its capacity, together with priority rules the level of inventory will be decreased. Hence, constraint elevation is not needed.
6.3 Conclusions
Following the presented framework, an evaluation of the intervention plan has been performed with the use of simulation. Hence, the inventory level of unserviceable actuators has been calculated, taking into account that the proposed DBR as 50 actuators per month is implemented. The result of this simulation is that the level of unserviceable inventory could have been decreased almost 50% by the end of June 2015, if the DBR had been implemented in March 2014. For the needs of simulation, the real inflow of unserviceable actuators for the period March 2014-June 2015 has been used. The impact of the proposed DBR and priority rule has been calculated with the use of simulation. The results display that by setting the DBR of actuator repairs as 50, provided that there is a priority in actuator orders, there is enough capacity to perform the rest of the component repairs in Cell 7. In case the results of the simulation had not showed a significant improvement in inventory levels, then another intervention plan should be developed and implemented.
7. Act: Redefining the relation between pool and repair shop

This last step of the proposed framework includes the real implementation of the intervention plan, the constraint’s subordination, process design improvement and sharing the lessons learnt. The intervention plan developed and checked throughout the previous chapters has not actually been implemented at Component Services and A&A repair shop. Therefore, this final step of the proposed framework suggests the implementation of it and provides some additional suggestions that can facilitate in it.

7.1 Subordinate constraint

Based on the five focusing steps of Theory of Constraints, in order to ensure the efficiency of the solutions proposed in chapter 5, subordinating every decision to exploit the constraint is necessitated. This suggests that the use of the constraint should not be limited by any means. In the DBR setting, there should be proper communication with the CIRO and the pool, so as for the right amount of US actuators to be delivered to the cell on a monthly basis. However, this is a challenge for KLM, since the relations between the pool and the shops are unclear.

In more details, the relation between the warehouse/pool and the repair shops should be redefined and the repair process should be rendered to “pull” instead of “push” which currently is. Moreover, implementing the models for the productivity increase, as proposed in chapter 5, requires universal approval and careful design and implementation from the KLM stakeholders involved. Additionally, proper metrics that measure the mechanics’ performance and productivity should also be developed and objectively checked for the needs of the models.

Redefining the relation between pool and repair shops

Within the relation between the pool and the repair shops the pool is the customer, since the shops provide it with the SE components. The unserviceable components that need to be repaired
are initially located in the warehouse and afterwards delivered to the repair shops. However, the Pool does not check if the shops have the capacity to perform the repairs but rather assumes that the shops are always capable to proceed with the repairs. Additionally, the pool availability, or in other words the warehouse’s needs for serviceable parts is never checked. The latter means that every unserviceable component delivered to the warehouse is immediately shipped to the repair shop, no matter if this repair is necessary for the maintenance of the pool stock level.

If we recall figure 2 (displayed above) when the customer requests a new component, a SE (serviceable) component is picked from the CS warehouse and then delivered to the customer. This component can be picked from the pool of the warehouse (from the available stock), or if there is no availability, KLM rents or purchases a new one from an external vendor, which adds excessive cost. Subsequently, the unserviceable (US) component is removed from the aircraft and exchanged with the SE one and then shipped to the CS Warehouse. From this location it is then delivered to the Repair Shops that perform the MRO Services and upon repair completion the now SE part is shipped back to the CS warehouse, maintaining thus the stock level.

However, since there is no forecast of the customers’ supply needs from the pool, every US component is supposed to be immediately repaired in order to maintain the stock level. Nevertheless, this is not effective, since the inventory of US components becomes an inventory of SE components located in the warehouse. Therefore, a more dynamic approach is needed by aligning the supply and demand needs.

**Inventory management at Component Services**

It is very important for the pool (CS Warehouse) to define a stock level, a marginal spare support inventory level (ml) for all the critical components; components that have high cost of purchase or are critical for the proper aircraft operation. This inventory level could be determined either by the number of the predefined, expected aircraft’s checks of every customer, or as Daniel et al. (2010) denoted, driven by minimizing the total backlog cost expected among the requests. The latter means that availability of components with a high cost of purchase should be prioritized compared to those with lower cost.
The intervention plan developed and presented in chapter 5 and simulated in chapter 6 proves that setting a DBR of 50 actuators on a monthly basis or 12.5 actuators on a weekly basis is efficient enough to decrease the levels of US inventory of actuators; a symptom of the identified constraint in A&A Repair Shop. However, beyond this proposed solution, the inventory management of Component Services pool should be redefined. Driven by cost minimization and thus setting a marginal spare support inventory of SE components necessitates a proper alignment of the repair orders. Since an actuator has a high cost of purchase ($500-$1000) and is a critical part of an aircraft compared to the rest of the components repaired in Cell 7, a marginal spare support inventory of SE actuators is necessary. Therefore, if the actuators’ pool level (al) is higher compared to the marginal one, the FIFO rule of repairs can be of use in cell 7. On the other hand, in case the inventory pool level is lower compared to the marginal, priority rules in the actuators’ repair orders should be applied based on a DBR that is defined by the number of SE actuators that need to be repaired in order to maintain the needed marginal inventory level. However, proper repair planning is necessary in order to satisfy the repair needs of the rest of the components repaired in Cell 7.

\[ al > ml \rightarrow FIFO \text{ rule} \]

\[ al < ml \rightarrow \text{prioritized actuators’ repairs, with} \]

\[ DBR = (ml - al) \text{ properly aligned to the repair needs of the other components} \]

**Setting buffers in the pool**

Additionally, establishing proper buffers in the pool is necessary for the storage of the unserviceable components that their repair is not yet needed. Those buffers can function as a feeder of the Repair Shops based on the needs for the maintenance of the marginal spare inventory level. By establishing buffers in the pool, the repair process is rendered as “pull”, since the Cell/Workstation pulls the amount of parts that need to be repaired. Figure 5.3 displays the above described proposal for the inventory management at Component Services.
7.2 Repeat process
The final step of the 5 focusing steps entitles repeating the process in order to identify new bottlenecks and subsequently eliminate them. Therefore, implementing the proposed framework in A&A again can reveal new constraints that burden the performance of the shop. Additionally, since the proposed framework has only been applied in one of the two repair shops, implementing it in BMSS Repair Shop is also necessitated. However, the proposed framework for BMSS could be implemented from the second step “Plan”, since proper analysis of the current state at Component Services has already been performed during the first step “Observe” of the presented research. It is important to point out here, that the suggested solutions provided in chapter 5 can only be applied in repair processes that resemble the actuators’ repair process and are performed under the same repair conditions. Similarly,

In more details, the solutions can be applied:

a) In repair processes that follow the route:
   Initial Check $\rightarrow$ Disassemble $\rightarrow$ Repair $\rightarrow$ Assemble $\rightarrow$ Final test
b) In repair cells that the mechanics do not repair only one type of components but rather a plethora of types.
c) The repairs are basically performed according to the FIFO rule (First In First Out), aside from the late orders who are offered priority.

Implementing the proposed framework in the two repair shops, identifying thus the basic performance constraints and eliminating through implementing the proposed intervention plan could lead to performance improvements.

7.3 Conclusions
Following the steps of the established and presented framework, this research resulted in proposing an intervention plan that can eliminate the identified constraint within Component Services KLM E&M and more specifically A&A repair shop. The proposed solutions have not been implemented and therefore, in this final step, their implementation is suggested.

The implementation of the intervention plan necessitates some additional actions that need to be taken. First and foremost, setting the DBR of 50 actuators per month, or in other words rendering the repair process to “pull” rather than “push” requires the coordination of different stakeholders within KLM Engineering and Maintenance. The latter necessitates the redefinition of the relationship between the pool (warehouse) and the repair shops, the establishment of a “buffer” in the pool or in the repair shop that is “pulled” by the workstation.

Additionally, for the implementation of the proposed models that can increase the mechanics’ productivity, coordination of the relevant KLM divisions is necessitated for the proper design and implementation. Moreover, a universal approval in both the repair shops should be ensured together with the establishment of objective metrics that can measure the productivity and the performance of the mechanics.
Beyond the proposed solution, the inventory management and the repairs ordering at Component Services is proposed to be re-examined, since a more dynamic approach between the supply and demand of serviceable components is needed. Therefore, establishing two indicators is proposed; a) a marginal spare support inventory level for critical parts (such as actuators) driven by minimizing the total backlog cost expected among the requests or by the number of the predefined, expected aircraft’s checks of every customer and b) their respective actual pool inventory levels. In case the marginal inventory level is higher than the actual, priority should be given in the repairs of the critical parts, such as actuators. In this case a proper DBR should be set taking though into account the repair needs of the rest of the components repaired in the same cell. On the other hand, in case the actual level is higher than the marginal level, the FIFO rule in repairs can be applied. Defining and monitoring such indicators necessitates the establishment of proper buffers, where the unserviceable critical parts (actuators) that do not need repair yet can be located.

Finally, the repeat of the proposed framework is also necessitated for the identification of additional bottlenecks within A&A Repair Shop and BMSS. Provided that the main bottlenecks within the two repair shops are revealed and subsequently eliminated, performance improvement at Component Services may be achieved.
Conclusions and Recommendations

This last chapter of the thesis report presents all the main conclusions and recommendations that have been derived from the conducted research. Moreover, it presents research reflections, research limitations and suggestions for future work.

8.1 Research summary and conclusions

Technology, market internationalization and increasing competitiveness have an unquestionable influence on industries and on customers’ needs. Therefore, ongoing process performance improvement should be a priority for all types of industries. For Aviation MRO industry, performance improvement can only be realized through the identification and the subsequent elimination of performance constraints, root causes that are related to the 4 Ms (manpower, machine, method and material) and halt the performance. Similarly, for KLM Engineering and maintenance, maintenance process improvement is of paramount importance. Therefore, several projects have been initiated, aiming to identify performance constraints within the repair processes.

The research objective is to design a framework that can identify the main turnaround time performance constraints at Component Services when applied. This framework provides a decomposition of process steps in order to identify the relations with the ingredients of a process (manpower, machine, method and material) that halt the performance. Therefore, the root causes of poor performance can be identified and suggestions for their elimination have also been provided.

The research question that will facilitate in developing a framework appropriate for the identification of performance constraints within Component Services is as follows:

“How can the performance of an MRO process be improved, in terms of turnaround time?”

For the needs of the research question a data analysis has been performed in order to explore the root cause of the poor performance in A&A Repair Shop at Component Services KLM E&M. This analysis revealed the poor or inefficient repair order management of actuators as the main constraint. Hence, a Drum Buffer Rope as 50 actuators on a monthly basis or 12.5 actuators per week, together with priority for actuator repair orders has been proposed for the improvement of the MRO process performance, in terms of reducing the inventory level of unserviceable actuators. Additionally, a redefinition of the relation between the pool and the Repair Shops is recommended for the performance improvement, in order to establish a more dynamic inventory management through aligning the components’ demand and supply, leading thus to cost decrease at Component Services.

Additional sub-questions that facilitated the conduct of the presented research are given below.
Conclusions and Recommendations

1. What can we learn from literature, regarding the process performance improvement and bottlenecks’ identification?

An extensive background research that has been conducted provided useful information regarding methodologies and approaches that can be used for the performance improvement and the performance constraints identification. This background research facilitated in the development of the proposed framework for the identification of the main performance constraints within Component Services and more particularly A&A repair shop. The presented framework uses as a base the OPDCA (Observe, Plan, Do, Check, Act) cycle of ongoing improvement combined with the essential process management cycle and analysis approach and the Theory of Constraints. A proposed intervention plan that includes setting a Drum Buffer Rope, a priority rule and additional payment models that can increase the performance of the mechanics have also been provided after the conduct of the relevant background research.

2. What is the current process performed at Component Services KLM Engineering & Maintenance?

The Component maintenance system of processes includes two distinct processes; to organize component availability and to provide component MRO. The first of the two entitles the maintenance of the stock level that has to be available for the customers, in case of repairs, as defined in the contract with the customer. The latter one includes all the necessary actions for the repair of the unserviceable components. In order to explore the current component services process, additional sub-processes that are already included in the main process have been identified and subsequently designed. Moreover by taking into account the different contract types offered to the customers, three additional sub-processes derived from Component Services process can be designed; pool availability, Closed Loop and Time and Material.

In pool availability, when a new customer order is received, KLM Component Services, pick a Serviceable Component from the warehouse, then ships it to customer, exchange it with the unserviceable component at the customer and then deliver the unserviceable back to the warehouse. From this location, the unserviceable part is delivered to the MRO shop, where repair processes are performed and upon repair completion the serviceable part in shipped and stored in the warehouse, maintaining thus the stock level of components’ availability. When the customer is KLM, the unserviceable part is immediately delivered to the MRO shop after exchange.

However, in some contracts, the repair of the same component removed from the customer can be requested. In this case there is no component exchange in customer, but only a removal of the component is performed. The very same component is then delivered to KLM Warehouse and subsequently to the repair shop. Upon repair completion the serviceable now component is delivered to KLM warehouse and then to the final customer (closed loop).

Complementary to the closed loop sub-process, there may be cases were an initial evaluation of the used component takes place and decision whether it is possible to repair it or not is taken
Conclusions and Recommendations

afterwards. The process of time and material is the same with closed loop when repair is possible and the same with component availability, when repair is not possible.

3. **How is responsibility distributed within this process?**

The responsibility distribution has been identified with the use of a SIPOC (supplier-input-process-output-customer) analysis that is displayed in figure 25.

![SIPOC analysis for Component Services process](image)

The SIPOC analysis provided an analysis for the responsibility distribution within Component Services and revealed the supplier-customer relationships per process step.

In more details, the process is initiated when the airline customer makes an order request (repair in case of closed loop or new component in case of pool availability) in the AERO System, which produces a picking slip together with a proforma invoice that includes the cost and other information regarding the order. Thereinafter, the Customer Interface creates the shipping slip of the order, the requested component is picked from the warehouse by using internal logistics and is subsequently shipped to the customer with the use of external logistics (pool availability). Subsequently, the exchange of the old with the new component or the removal of the old component is performed at the customer and the unserviceable (old) component, together with
the form of complaint (reason of removal) is shipped back to the maintenance facilities of KLM, with the use of external logistics (KLM or customer). At this point, the line or base maintenance delivers the Unserviceable component together with the complaint form to the Repair Shops of KLM (A&A or BMSS), that perform the needed repair processes of the component, based on the predefined turnaround time/day of delivery. The outcome of this procedure is a fully serviceable component that is either sent to the customer (closed loop) or to the warehouse of logistics center with the use of external or internal logistics respectively. In the latter case, with the use of internal logistics the serviceable component is stored in the warehouse in order to maintain the pool availability. Finally, the customer interface confirms the delivery of the component and the customer repair request or order is therefore closed.

4. What is the added value that this process delivers to the final customer?

As denoted by the people working in KLM E&M, the main goal of the Component Services and the added value delivered to the final customer, is “to provide component’s availability” to the customer. In other words, the goal of the process for KLM to be able to serve its customers, by repairing or delivering (depending on the kind of contract) the right component, with the right specifications at the right time.

In order to identify the adding value delivered to the customers, semi-structured interviews took place. The interviewees were employees in the Component Services and more specifically 1 shop mechanic, 1 cell manager, 2 production line managers, 2 customer interface managers, 3 supply chain managers, 2 data analysts, 1 material manager, 1 blackbelt and 2 group managers for supply chain and pool management. Even though the employees’ positions varied, the “Goal” of the process was easy to be defined, since the majority of the interviewees (57.14%) claimed “provide components’ availability to customers” as the goal. Therefore, the goal of the process has been set as “to provide component’s availability” to the customer. In other words, the goal of the process for KLM is to be able to serve its customers, by repairing or delivering (depending on the kind of contract) the right component, with the right specifications at the right time.

5. How is process performance currently monitored at Component Services KLM Engineering & Maintenance and more specifically, what are the KPIs that check the maintenance performance?

For the needs of this sub-question, an overview of the current performance measurement system of Component Services, KLM E&M has been provided, with the use of the Connected Business Balanced Scorecard for Component Services. The performance is monitored with a use of several key performance indicators (KPIs) that relate the company’s requirements with the customers’ needs, whilst their scores are compared to a predefined target and hence, proper decisions are made if improvement is needed. KLM CBBSC is comprised by 4 categories of performance metrics, including “making the numbers” (elements that contribute to the financial success of the company), “Organizational development” (with metrics such as training that depict the ability to
The fourth category of performance metrics regards the “Operational Excellence”. The focus of the presented research has been on this last category, since it includes all the metrics that monitor the maintenance performance. Those metrics are basically turnaround time KPIs that measure if the Maintenance Repair and Overhaul process performs efficiently; delivers the process' output on time.

Moreover, for pool availability the KPIs used include:

**TAT (turnaround time) Respons availability:** The response time of KLM on received availability requests from customers.

**SL (Service level) Pool third party:** The extent to which requests are handled according to the CS contract with a customer.

**SL US (unserviceable) flow pool third party:** The extent to which components are sent back in time (according to the contract). Flow of US components from customers to E&M (reverse Service Level)

**TAT Repair OPS:** The time interval between the moment of dropping component (removed from aircraft) at “CIR IN” of its shop to end of repair of the component and the moment Tracking scan at CIR OUT of the shop.

**TAT Repair to Magazijn:** The time interval between the moment of issue/delivery (“drop”) of repaired component at CIR OUT of its shop and the moment it is received at a warehouse.

**TAT Vendor:** The time interval between the moment of the creation of the order and the moment the component is returned at LC. Where the transport time to and from vendor are excluded.

More particularly, if we deepen our analysis more in the MRO step (Provide Component MRO Service) we will identify three subsequent process KPIs; TAT Cir in, TAT Repair Shop and TAT Cir out, that all together form the TAT Repair OPS KPI.

**TAT Cir in:** The time interval between the moment of dropping component (removed from aircraft) at “CIR IN” of its shop and the moment of transfer to shop handling. Opening hours of the cir are currently set at 7:00 till 16:00.

**TAT Repair Shop:** The time interval between the moment of transfer to shop handling and the moment of end of repair of the component.

**TAT Cir out:** The time interval between the end of the repair action of the component (crocos TWA or SAP HIST) and the moment first Tracking scan at CIR OUT of the shop. Opening hours of the cir are currently set at 7:00 till 16:00.

For closed loop, the KPIs used include:
Conclusions and Recommendations

**TAT Repair OPS:** The time interval between the moment of dropping component (removed from aircraft) at “CIR IN” of its shop to end of repair of the component and the moment Tracking scan at CIR OUT of the shop.

**TAT Cir in:** The time interval between the moment of dropping component (removed from aircraft) at “CIR IN” of its shop and the moment of transfer to shop handling. Opening hours of the cir are currently set at 7:00 till 16:00.

**TAT Repair Shop:** The time interval between the moment of transfer to shop handling and the moment of end of repair of the component.

**TAT Cir out:** The time interval between the end of the repair action of the component (crocos TWA or SAP HIST) and the moment first Tracking scan at CIR OUT of the shop. Opening hours of the cir are currently set at 7:00 till 16:00.

The result KPI of the whole process is the **Service level Repair only flight hour contracts** that indicates the extent to which repair only flight hour items are handled according to the CS contract with a customer.

For Time and Material (T&M) the KPIs currently used include:

**TAT Non Pool to Repair:** The TAT of the delivery of the US component from the customer to the MRO Shop. The logistics is performed by the customer.

**TAT Repair OPS:** The time interval between the moment of dropping component (removed from aircraft) at “CIR IN” of its shop to end of repair of the component and the moment Tracking scan at CIR OUT of the shop.

More particularly, if you deepen our analysis more in the MRO step (Provide Component MRO Service) we will identify three subsequent process KPIs; TAT Cir in, TAT Repair Shop and TAT Cir out, that all together form the TAT Repair OPS KPI.

**TAT Cir in:** The time interval between the moment of dropping component (removed from aircraft) at “CIR IN” of its shop and the moment of transfer to shop handling. Opening hours of the cir are currently set at 7:00 till 16:00.

**TAT Repair Shop:** The time interval between the moment of transfer to shop handling and the moment of end of repair of the component.

**TAT Cir out:** The time interval between the end of the repair action of the component (crocos TWA or SAP HIST) and the moment first Tracking scan at CIR OUT of the shop. Opening hours of the cir are currently set at 7:00 till 16:00.

**TAT Non Pool to Return:** The TAT of the delivery of the SE component from the MRO Shop to the customer. The logistics is performed by the customer.
The sum total of all the aforementioned turnaround time KPIs equals the result KPI of the whole process; **Service level CSO T&M**. This KPI is a service level, which measures the extent to which requests are handled according to the CS contract with a customer. This concerns the Time & Material repair process. The TAT performance T&M equals the Service level T&M.

6. **Which are the critical parts within the maintenance process that affect the process performance?**

In order to identify the main constraint within the maintenance process that halts the performance, a data analysis has been performed. Moreover, the performance of the turnaround time (TAT) Repair Shop KPI has been analyzed for the Avionics & Accessories Repair Shop (A&A) of Component Services for rotatable orders (components that can be multiply repaired and used again) of the period March 2014 - June 2015. This data analysis revealed that cell 7, workstation ES ELECTRO MECH (of cell 7) and actuators (component repaired in ES ELECTRO MECH) have the lowest performance in A&A Repair Shop. Proper calculations of the buffer time (waiting time before repair), touch time and waiting time within repair have been performed, revealing a symptom of the constraint, which is high buffer time within the cell. The lean tool going Gemba, or in other words a number of observations within the cell that have been performed, confirmed the finding of the data analysis (high buffer time) indicating high inventory of unserviceable actuators. Therefore, poor order management has been identified as the constraint of the process performance.

7. **What are the suggested solutions that can eliminate the identified bottlenecks within the maintenance process at Component Services KLM Engineering & Maintenance?**

The intervention plan that has been developed and thus proposed includes setting a Drum Buffer Rope of 50 actuators’ repairs per month or 12.5 per week. The time duration of the repair process together with a simulation of the inventory levels of unserviceable actuators have been taken into account for the calculation of the DBR. Based on the current capacity in cell 7 and workstation ES ELECTRO MECH, implementing the intervention plan entails that the mechanics should devote 3 working days on actuators’ repairs and the rest 2 on other components repairs, setting thus a priority rule for actuators’ repairs.

Additionally, based on scientific research, payment and incentive models that can increase the productivity in the shop, including pay for performance and profit sharing plans have also been suggested. The former one necessitated the implementation of objective performance evaluation systems that can measure each mechanics’ performance through setting respective KPIs. Thereinafter, a respective reward system based on their performance can also be applied. On the other hand, profit sharing models (worker’s compensation is tied to the total organizational performance) will offer an incentive to mechanics to increase their performance.

The efficiency of the proposed intervention plan has been tested with the use of simulation. Moreover, the inventory levels of unserviceable actuators have been simulated taking into account the DBR of actuators as 50 per month. The outcome of the simulation revealed that the inventory would have been decreased almost 50% by the end of June 2015, provided that the DBR
Conclusions and Recommendations

was set and used as 50 from March 2014. Complementary, the impact of the proposed solution has been simulated, confirming thus that the development of other performance bottlenecks regarding other types of components is indeed prevented, since a capacity surplus has been calculated, offering thus sufficient time for the repair of the rest of the components within cell 7.

8. How can the suggested solutions be implemented at Component Services Engineering & Maintenance?
The implementation of the proposed solutions necessitates a number of additional suggestions that accrue from the intervention plan. First of all, the implementation of the DBR as 50 actuators repairs per month necessitates rendering the repair process to “pull” instead of “push” which currently is. Additionally, a redefinition of the relation between the repair shops and the warehouse (pool) is really essential, since a more dynamic approach between the demand and supply of components should be established and therefore the excessive cost at Component Services can be decreased. Defining two new metrics based on customers’ historic demand data or driven by minimizing the total cost is recommended; a marginal spare inventory level (for critical components) and their actual pool level. Based on those metrics the respective order management is proposed; a proper DBR (calculated in accordance to the demand) and priority in case spare critical parts are needed and the FIFO rule when there is spare parts surplus. For the needs of this proposed solution, establishing proper buffers in the warehouse for the location of the unserviceable critical parts that do not need yet to be repaired is recommended.

Moreover, implementing the models for the productivity increase requires universal approval and careful design and implementation from the KLM stakeholders involved. Additionally, proper metrics that measure the mechanics’ performance and productivity should also be developed and objectively checked for the needs of the models.

8.2 Research reflection
In this research, a framework that combines the basic process management steps as depicted by the OPDCA cycle of ongoing improvement and the essential process management cycle, together with process analysis, intertwined with the Theory of Constraints has been developed and presented. The aim of this research is the identification and elimination of performance bottlenecks within Component Services KLM Engineering & Maintenance and more specifically within Avionics & Accessories Repair Shop. For each of the defined steps additional tools, such as SIPOC analysis, interviews, data analysis through frequency tests, simulation and the lean tool “Go GEMBA” that can facilitate the implementation of the presented framework are also proposed.

For the completion of this research, the contribution of the Management of Technology curriculum is of high importance, since the program provides the required knowledge for the improvement of the technology’s quality. Moreover, it addresses challenging questions to organizational settings regarding the technologies that are needed per business case and how to increase quality by improving the current state, how to use technological opportunities in order to affect the vision/mission and strategy, whether to use its own research capabilities or collaborate
with external partners. The contribution of the knowledge acquired throughout the past two years has been of paramount significance for the completion of the presented research.

The design and conduct of this action research has been facilitated through studying the relevant literature that has been provided by the Management of Technology master program. Hence the steps that had to be followed were easily identified. However, transferring knowledge from theory into practice was a big challenge, since Component Services KLM E&M is a considerably large division, including two repair shops that further include several cells and workstations, each of those offering repair services over a plethora of components. Therefore, defining the current state, understand how the main process is performed and measured required considerable time.

Additionally, theories and approaches including the essential process management cycle, process analysis, ongoing improvement, Theory of Constraints and lean tools that were studied during the attendance of the master program were transferred into practice in this research. Since some initial steps of process management have already been realized in KLM E&M, transferring the acquired knowledge into practice was facilitated.

Most importantly, the interaction with several employees of KLM contributed decisively to the implementation of the presented framework. The knowledge gained during the interviews and the observations that took place in the A&A repair shop enhanced both the understanding of the current state at Component Services and the identification of the performance constraint. Moreover, the continuous communication with the employees and mechanics of KLM E&M during the informal discussions and interviews regarding the problems concealed within the maintenance processes and the need for improvement created more commitment and increased their motivation for change, improvement and consistency among the different divisions.

The experience that was gained throughout this research is of paramount importance. Transferring the theory that I have acquired during the attendance of the Management of Technology master program into practice was really important for realizing my current capabilities and developing new ones. Most importantly, this research project made me realize how theory can enhance improvement when implemented, how necessary theory is in a real setting.

8.3 Research recommendations and limitations
The presented framework develops and proposes an intervention plan for A&A repair shop that can eliminate the identified performance constraint. In this section the recommendations and the limitations will be presented.

Framework
The presented framework offers a roadmap for the identification of performance constraints and proposes an established intervention plan for the elimination of those. However, there are certain use criteria that limit its implementation. First of all, the performance constraint identification is the outcome of a data analysis performed for turnaround time KPIs. In more details, quality or cost metrics have not been tested with the implementation of this framework. Hence, further
Conclusions and Recommendations

research is needed in order to explore the applicability of both the developed framework and moreover of the proposed solutions for cost and quality KPIs.

Additionally, the developed intervention plan can only be implemented in industrial (not repair exclusively but also manufacturing and production processes), push (not pull) flow shop processes that follow an acyclic route through the plant. Hence, the implementation on job shop flow processes is recommended.

Furthermore, the developed intervention plan can only be implemented in repair stations where capacity is shared among the orders, which are handled with the FIFO scheduling rule. Hence, further research is necessitated for the implementation of the intervention plan in conditions that differ from the above described; scheduling rules other than FIFO and not shared capacity.

Component Services

The presented framework for the identification of performance constraints has been developed during a research conducted in A&A repair shop. Based on the simulation results, the inventory of unserviceable actuators can be decreased offering thus capacity surplus for the repairs of the other components handled by the workstation. The latter could lead to their inventory decrease and hence to the delivery of more serviceable components to the warehouse, providing thus more availability and simultaneously leading to cost decrease at Component Services, since the purchase or rent of new components for customers’ compensation may be therefore prevented.

Beyond this proposed solution, the inventory management and the repairs ordering at Component Services is proposed to be re-examined, since a more dynamic approach between the supply and demand of serviceable components is needed. As a result, defining two new indicators is proposed; a) a marginal spare support inventory level for critical parts driven by minimizing the total backlog cost expected among the requests or by the number of the predefined, expected aircraft’s checks of every customer and b) their respective actual pool inventory levels. In case the marginal inventory level is higher than the actual, priority should be given in the repairs of the critical parts, such as actuators. In this case a proper DBR should be set taking though into account the repair needs of the rest of the components repaired in the same cell. On the other hand, in case the actual level is higher than the marginal level, the FIFO rule in repairs can be applied. Defining and monitoring such indicators necessitates the establishment of proper buffers, where the unserviceable critical parts (e.g. actuators) that do not need repair yet can be located.

Therefore, additional research is recommended in order to in order to explore the impact of the proposed intervention plan on the pool availability and cost decrease and to analyze historical data of demand and prioritize the components. Moreover, proper analysis should be performed in order to set the DBR that drives the order repairs in case the marginal inventory level of spare parts is higher than the actual.

Furthermore, the implementation of the intervention plan and the inventory management recommendations necessitates some additional actions that are recommended. First and
Conclusions and Recommendations

foremost, setting the DBR of 50 actuators per month necessitates rendering the repair process to “pull” rather than “push”. This requires the coordination of different stakeholders within KLM Engineering and Maintenance, in terms of redefining the relationship between the pool (warehouse) and the repair shops. For this case, the development of a “buffer” in the pool or in the repair shop that is “pulled” by the workstation is recommended.

Additionally, for the implementation of the proposed models that can increase the mechanics’ productivity, coordination of the relevant KLM divisions is necessitated for the proper design and implementation. A “universal” approval in both the repair shops should be ensured together with the establishment of objective metrics that can measure the productivity and the performance of the mechanics.

Finally, implementing the framework in BMSS repair shop is also proposed, for the identification of constraints related to the 4 Ms that may halt the performance. Identifying and eliminating the performance constraints within the two repair shops, may lead to performance increase at Component Services and thus a relative research is proposed to be conducted.

**A&A Repair Shop**

Based on the presented simulation results in chapter 6, using the DBR of 50 actuators per month can offer sufficient capacity, in terms of available personnel, for the handling of the repair orders regarding other types of components. Taking into consideration the repair norms as defined by the Engineering Department, together with the inflow of all types of Unserviceable components, compared to the cell’s capacity as indicated in the working schedules, the findings confirm that there is capacity surplus for the repair of the rest of the components in workstation. However, this result is limited to the fact that it is calculated based on the repair norms as defined by the Engineering Department and not based on the real repair times and also since the cell handles a plethora of components, there might be component types that have been unintentionally omitted. Hence, more research is recommended.

Additionally, repeating the process steps defined by the presented framework in A&A Repair Shop is also suggested for the identification of additional bottlenecks that may halt the performance. Therefore, further research may be needed for the provision of proper solutions, in case the conditions of the identified constraints do not allow the implementation of the intervention plan developed during the presented research.

**Actuators**

The implementation of the presented framework revealed the main performance constraint in A&A Repair Shop, Cell 7 and workstation ES ELECTRO MECH as the actuator component. The repair rule proposed is: “Every mechanic (total 4 mechanics working with actuators) should repair 3 actuators per week, which means that the 3 out of 5 working days should be dedicated in
actuator repairs. The rest two of them, the mechanic can work with the other components. Therefore, actuators have priority compared to the other components. With a use of simulation, the inventory of unserviceable actuators has been calculated and compared to the real inventory. In more details, setting a DBR of 50 actuators per month on March 2014, together with a priority rule for actuator repairs could have decreased the inventory almost 50% by the end of June, whilst the real inventory has been increased almost 500% by the end of June.

However, during the development of the implementation plan the touch time of the actuators’ repair (6.5 hours) has been calculated based on the norms that the engineering department developed in the past, regarding the duration of each process step. Therefore, real time measurements need to be taken through observations and subsequently should be taken into consideration for setting a more realistic DBR for actuators repairs.
References


References


Appendix

Appendix A: KPIs performance calculation per cell

For all the cells within the A&A Repair shop, a calculation of the KPIs performance for each cell has been performed. The results of TAT CIR IN, OUT, Repair Shop (OPS), together with a table that compiles all the calculated results are given below.

The **TAT CIR IN** of all the cells has been analysed in order to identify in which one most of the delay is observed.

![TAT CIR IN Chart](image)

**Figure 52: TAT CIR IN for cells in A&A**

From figure 53, it can be concluded that the most delayed cell for the TAT CIR IN indicator is cell 7, with 71% on time deliveries.

Thereinafter, the **TAT REPAIR SHOPS (OPS)** has been analysed in order to identify in which one most of the delay is observed.
From figure 54, it can be concluded that the most delayed cells, concerning the TAT REPAIR SHOPS (OPS) indicator are both cell 4 and 7, with 73% on time deliveries.

Finally, the TAT CIR OUT has been analysed in order to identify in which cell most of the delay is observed.
Again, the most delayed cell, concerning the TAT CIR OUT indicator is cell 7, with 71% on time deliveries. The TAT REPAIR OPS has been thereinafter calculated for each cell and then those findings have also been compared with those produced in the first place. Calculating the TAT REPAIR OPS made it clear, that even though both cells seemed equally late (73% TAT REPAIR SHOPS (OPS)), cell 7 had a TAT REPAIR OPS of 30.08% compared to 39.2% of the cell 4. As a result, it has been concluded that Cell 7 is the most delayed cell in A&A.

<table>
<thead>
<tr>
<th>Table 10: TAT REPAIR OPS for cells in A&amp;A</th>
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<tbody>
<tr>
<td><strong>CELL</strong></td>
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<td>CELL 7</td>
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<tr>
<td>CELL 8</td>
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<tr>
<td>Total</td>
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</tbody>
</table>

# parts 22294 28029 22638

Share % 4.9 8.2 15.2 5.6 5.7 5.4 11.6 43.5 100
Appendix B: Random sampling

For the random sampling a scoping of the instances has been performed, in order to deepen the analysis more and identify the constraint. For this reason, a plot of the late days for all the Actuators for the period March 2014 until June 2015 has designed. From this plot, it can be concluded that most of the instances have a number of delayed days ranging from 1-20 days. From this point, it has been clear that the instances that would be deeper analyzed should be included in this sample. As a result, five instances have been randomly chosen; 1 day of delay, 5 days of delay, 10 days if delay, 15 days of delay, 20 days of delay.

![late days](image)

Figure 55: Repair process for actuators

The job cards that are given to the mechanics for performing the repair, offer a time indication for each repair step; this is just an indication, the process step can last longer or shorter; can be interrupted and resumed. The current data that is available provide the time indication per process step and the time that the process step was completed. Based on this information, the start time has been calculated. Thereinafter, the touch time and the waiting time per instance have been calculated.
Appendix C: Analysis of five late actuators

Actuator 1: 1513050z (TAT=15 days/1 day of delay)

The TAT of actuators for the pool order is set as 14 days. This TAT also includes transportation from the Warehouse in the Logistics Center to A&A repair shop and back. For the 1st instance, the figure of the process steps as performed based on the official data is as follows.

![Diagram of Actuator 1 process steps](image)

Based on figure 57, calculating the touch time and the waiting time revealed that the touch time is just a really small percentage of the total TAT. In more details, if we take into account that the total TAT is **15 days, 7 hours and 55 minutes**, the touch time is only **2 hours and 26 minutes**, compared to **365 hours and 29 minutes of waiting time**. However, we should also keep in mind, that in reality, all the process steps follow a sequence and are not performed in a parallel way, as depicted by the dataset. For this reason, the total touch and waiting time if the steps were followed as a sequence have been also calculated. In this case, the total touch time is **4 hours and 10 minutes**, compared to **363 hours and 45 minutes of total waiting time**; still the difference is really significant.

Actuator 2: 5318425z (TAT=19 days/5 days of delay)

The same analysis has been realized for the second instance; 5318425z, with the total TAT of 19 days which equals 5 days of delay.
Based figure 58, calculating the touch time and the waiting time revealed that the touch time is still just a really small percentage of the total TAT. In more details, if we take into account that the total TAT is **19 days and 13 hours**, the touch time is only **2 hours and 48 minutes**, compared to **466 hours and 12 minutes of waiting time**. However, if we take into account again that all the process steps follow a sequence and are not performed in a parallel way, the new total touch time is **3 hours and 40 minutes**, compared to **465 hours and 20 minutes of total waiting time**; still the difference is really significant. Additionally, as it is depicted in the above figure, in this specific case there is a “TA” disruption during the 7th day of repair that was ended after almost 6 days. This disturbance contributed with a total of **5 days, 20 hours and 11 minutes** to the total waiting time.

Actuator 3: **5409868z** (TAT=24 days/10 days of delay)

For the third instance; **5409868z**, with the total TAT of 24 days which equals 10 days of delay the figure designed is as follows.
Based figure 59, calculating the touch time and the waiting time revealed that the touch time is again just a really small percentage of the total TAT. In more details, if we take into account that the total TAT is 24 days, 10 hours and 26 minutes, the touch time is only 2 hours and 8 minutes, compared to 584 hours and 18 minutes of waiting time. However, if we take into account again that all the process steps follow a sequence and are not performed in a parallel way, the new total touch time is 6 hours and 45 minutes, compared to 579 hours and 41 minutes of total waiting time; still the difference is really significant.

Actuator 4: 5270228z (TAT=29 days/15 days of delay)

For the fourth instance of analysis; 5270228z, with the total TAT of 29 days which equals 15 days of delay the figure designed, based on the formal system data is as follows.
Appendix

Figure 59: Actuator 4-5270228z, 15 days of delay

Based on figure 60, calculating the touch time and the waiting time revealed that the touch time is again just a really small percentage of the total TAT. In more details, if we take into account that the total TAT is 29 days, 13 hours and 42 minutes, the touch time is only 3 hours and 34 minutes, compared to 708 hours and 8 minutes of waiting time. However, if we take into account again that all the process steps follow a sequence and are not performed in a parallel way, the new total touch time is 6 hours and 45 minutes, compared to 704 hours and 57 minutes of total waiting time; again the same pattern is occurred as the touch time is really small compared to the waiting time.

Actuator 5: 5770736z (TAT=34 days/20 days of delay)

Last but not least, the same analysis has also been performed for the fifth instance; 5270228z, with the total TAT of 34 days which equals 20 days of delay. The produced figure is as follows.
Again, the analysis revealed that the touch time is again just a really small percentage of the total TAT. In more details, if we take into account that the total TAT is 34 days, 7 hours and 11 minutes, the touch time is only 4 hours and 11 minutes, compared to 819 hours of waiting time. However, if we take into account again that all the process steps follow a sequence and are not performed in a parallel way, the new total touch time is 6 hours and 55 minutes, compared to 816 hours and 16 minutes of total waiting time.
Appendix D: Time duration per process step

It is important to point out, that some of the process steps were performed in a parallel way, based on the official data. However, this is not possible, as each step requires the completion of the previous one in order to be performed. As a result, the real touch time of the process step might be different than the one calculated before. By taking into account the standard process steps’ durations as given in the job cards, calculating now the real touch time per process route can be realized. This touch time per repair route can be seen below.

Table 11: Real Touch time per process route

<table>
<thead>
<tr>
<th>Duration per process step (min)</th>
<th>1513050Z</th>
<th>5318425Z</th>
<th>5270228Z</th>
<th>5409868Z</th>
<th>5770736Z</th>
</tr>
</thead>
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<td>41</td>
<td>36</td>
<td>71</td>
<td>71</td>
<td>67</td>
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</tr>
<tr>
<td>30</td>
<td>45</td>
<td>60</td>
<td>60</td>
<td>20</td>
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<td>105</td>
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<td>130</td>
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<td></td>
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<tr>
<td>54</td>
<td>54</td>
<td>84</td>
<td>84</td>
<td>34</td>
<td></td>
</tr>
</tbody>
</table>

| Real touch time (h/min)         | 4h10min  | 3h40min  | 6h45min  | 6h45min  | 6h55min  |

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Appendix
Appendix E: Interview questions
The interviews that have been conducted in Component Services aimed to reveal employees’ perceptions regarding the goal of the Component Services process, the step that creates the added value for the customer, the responsibility distribution within the process and the identification of possible bottlenecks and respective intervention plans that could eliminate them. The interviews were semi-structured, that means that there has been a list of predefined, standard questions used but also some additional questions adjusted to the background and position of each interviewee. The list of the standard questions that were used during the interviews is given below:

1. What is the GOAL of the process? What is the goal of the availability and component MRO
2. Where do you think that within the two parallel processes the added value is placed?
3. Where do you think that the main bottleneck is placed, within the process, or pool availability?
4. Who is responsible for each phase within the process?
5. How do you see this process? What would you change in the process? What is the input and the output of each phase in terms of TAT, cost, quality? What should be the outcome of each phase?
6. How do you check the performance of the pool availability process? What indicators or KPIs do you use? TAT, quality and cost KPIs internally and externally (outsourcing MRO to external vendors). Are there any KPIs that you check and measure the efficiency of the handshake? What is the agreement between the Shops and the Pool? Who works with availability and who with TAT? How do you see the handshake with the component of MRO? In what terms do you check the efficiency of the handshake? The same with Aircraft Maintenance (AM) and Engine Services (ES). Is there a Service Level, TAT agreed between Component Services and AM/ES?
7. How do you define KPIs and in what ways do you check?
Appendix F: Component Services Process figures (figures order is Component Services, Pool availability, Closed loop, Time and Material) and CBBS
### Making the Numbers
- Production Result Repair and Staff: 128 +
- Current Operating Income: 23 +
- Capital Employed: 166 +
- Absenteeism: 90 +
- Warranty Monitor: 90 +
- Factuur Verschillen Lijst: 90 +
- Loan & Borrow: 90 +
- Non Trace SAP orders: 90 +
- TAT PR to PO: 3 +
- GAB Process Measurement: 90 +

### Organisational Development
- Training: 165 +
- Holiday & Compensation Leave: 30 +
- FTE: 603 +

### Customer Delight
- Customer Satisfaction: 8 +
- Service Level Availability: 0 +
- SL us flow pool third party: E5 +
- SL CSD T&M: 60 +
- SL pool third party: 50 +
- Invoicing Quality: 15 +
- Invoicing Speed: E6 +
- SL repair only flight hour contracts: 78 +
- TAT R4M: 30 +

### Operational Excellence
- Stuurtax (BMSS / A&A): 89 +
- System Implementation Score: 0.1 +
- TAT Nonpool to REPAIR: 33 +
- TAT REPAIR (OPS): 42 +
- TAT Response Availability: 59 +
- TAT REPAIR to T&M (NON POOL): 100 +
- TAT REPAIR to MAGAZIN (POOL): 81 +
- TAT CIR OUT: 71 +
- TAT VENDOR: 50 +
- TAT Repair Shop (OPS): 84 +
- TAT CIR IN: 80 +
- TAT VO to REPAIR: 86 +
- TAT VO (US): 99 +
- TAT VO (SE): 76 +
- TAT HRM delivery: 87 +
- % available direct from own stock: 60 +
- Recovery Costs: 1 +
- Productivity (Utilization): 46 +
- Non Conformities: 0 +
- Deferred Defects: 15 +
- TAT Equipment: 62 +
- Inkoop Ruffartikelen: 20 +
- Stuurtax Line 1: 90 +
- Stuurtax Line 2: 90 +
- Stuurtax Line 3: 90 +
- VC Planoceus: 90 +
- Time to Quote: 56 +
- Quote versus Realisation: 56 +
- Process Speed BRR: 56 +
- TAT DMU: 56 +

### Safety Management
- Audit Findings: 1 +
- Technical Occurrences: 1 +
- SHE Occurrences: 1 +

### Sustainable Growth
- Margin Time and Material: 809 +

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