Improving the Outbound Logistics Process at KLM Engineering & Maintenance

An algorithmic approach to improve the process in terms of personnel’s capacity

Stefania Porozantzidou
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by

S. Porozantzidou

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Information

Author                     Stefania Porozantzidou
Student Number             4313828
Email                      S.Porozantzidou@student.tudelft.nl
                          stefaniprz@gmail.com
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Academic Information

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Graduation Committee

Chairman                   Prof.dr.ir. Marijn Janssen (Information & Communication Technology and Governance)
1st Supervisor TUDelft     Ir. Marcel W. Ludema (Transport Policy and Logistics Organization)
2nd Supervisor TUDelft     Dr.ir. Zofia Lukszo (Energy and Industry)
External Supervisor        Bastiaan Kroes (Leans Six Sigma Blackbelt KLM Engineering Maintenance, CS Logistics)

An electronic version of this thesis is available at http://repository.tudelft.nl/.
With this report of my graduate project at the Logistics Center of KLM Engineering & Maintenance, I complete my Master of Science degree in Management of Technology at Delft University of Technology in the faculty of Technology, Policy and Management.

The research regards to an algorithmic approach towards the improvement of the outbound Logistics process within the Logistics Center of KLM Engineering & Mainentance. After the suggested algorithm's development its application requires an extensive analysis to collect realible and representative data to simulate the process, run and test several scheduling scenarios.

The project could not be able to be completed without the supervision and support of several people to whom I would like to express my gratitude.

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Summary

Abstract

Within this report, a process improvement framework is developed and applied in the case of the outbound Logistics process at KLM Engineering & Maintenance. The methodology proposed for the improvement of the process includes a synergy of three different, but related theories: Lean, Six Sigma and Engineering Design. The integration of their critical steps are followed in order to develop improvement recommendations. These are to define the current state and the existing point, measure the process performance in terms of the predefined performance metrics making use of reliable data, develop and analyze improvement techniques. In the context of the analysis phase and due to certain limitations, a specific work scope has been chosen and an algorithmic approach has been applied in order to develop personnel’s scheduling scenarios, test and evaluate them in terms of Turnaround Time, Quality and Cost. Next the improvement step includes the proposal of feasible solutions based on the analysis performed. Finally, the control phase helps the continuous improvement of the outbound Logistics through performance management tools.

Situation

The outbound Logistics process concerns the activities of receiving the unserviceable components at the Logistics center, performing an administrative inspection and delivering the components to the repair vendors, who are accountable for their test, repair and overhaul. The operation of the Logistics center, including the outbound Logistics has the form of a job shop, where jobs (tasks) consist of a number of operations that need to be performed on different machines (or in this case different type of employees). In the current state the Logistics process' quality is not possible to be clearly defined and in the meanwhile the Logistics center is unable to meet the time requirements of the components’ deliveries to the repair vendors, therefore, poor performance has been recorded and inefficient process steps have been suspected.

Problem

The main objective of the project is "to control the incoming goods within the Logistics center and provide their right delivery to the customers". This objective can be achieved by creating the following sub objectives: to analyze the current performance of the outbound Logistics, define the problem and improve it by suggesting a set of solutions. In order to complete objectives mentioned, the following main research question has to be answered.

"How to improve the outbound Logistics process within the Logistics Center at KLM Engineering & Maintenance in terms of Quality, Turnaround Time and Cost?"

Several sub questions have been formed in order to facilitate the project’s execution and give an answer to the main research question stated above. The questions presented below have been created in such way that the actions taken to answer them follow the academic approach’s steps.

RQ1: What is the current outbound Logistics process within the Logistics Center at KLM Engineering & Maintenance?

RQ2: What can we learn from literature regarding to the improvement of Logistics processes?
RQ3: What are the selected KPIs and data to measure the performance of the outbound Logistics process?

RQ4: What is the performance of outbound Logistics process?

RQ5: What are the suggested solution areas for the future outbound Logistics process within the Logistic center at KLM Engineering & Maintenance?

RQ6: How can the outbound Logistics process within the Logistics center at KLM Engineering & Maintenance be simulated and tested in respect with its manpower performance?

RQ7: How can the improvement strategies be implemented?

Approach

After having introduced the main problem, for the purposes of the research a specific methodology has been followed. Literature review has helped decide which tools and techniques have been applied successfully in similar past projects. The framework developed for this research is compromised by a combination of three useful methodologies. Lean, Six Sigma and an Engineering Design have been integrated and have formed a unique academic framework. The benefits from this synergy have been to create a flexible and adjustable approach, while achieving unprecedented improvements and facilitating the organizational communication.

Define

The first step of the approach has been to make the detailed description of the company and the process' current state. KLM Royal Dutch Airlines is the oldest operating airline in the Netherlands and includes three core businesses: Passenger Transportation, Cargo Division and Engineering & Maintenance. The project is conducted for the later unit of KLM, whose main business is to provide Maintenance, Repair and Overhaul services to its internal or external costumers. KLM Engineering & Maintenance is divided in three departments: the Aircraft Maintenance, Engine Services and Component Services. The Logistics center of KLM Engineering & Maintenance belongs to the Component Services' division.

The overall operation of the Logistics center is decomposed into five units: the expedition, the customs, outbound and inbound Logistics and the warehouse. During Aircrafts' maintenance, several components that need to be tested, repaired or overhauled are extracted from it and sent to KLM Engineering & Maintenance Logistics center that is accountable for delivering the components to the contracted repair vendors, either internal or external (Outbound Logistics). After being processed by the repair vendors the components are once again sent to the Logistics Center where are stored or (in certain cases) delivered directly back to the aircraft (Inbound Logistics). In the meanwhile, the appropriate components from the warehouse are selected to replace the ones extracted from them. Separate type of employees are assigned to performed the customs formalities.

As the focus of this project has been in the outbound Logistics, the tasks performed in this process has been presented and defined in order to identify the bottlenecks that undermine the process' performance. The main tasks of the outbound Logistics start from the moment that the unserviceable components have been separated from the expedition personnel, passed (if needed) though import and have been placed in an area in the Logistics center, where a buffer is created. The physical inspector, the first type of employees, picks one
components at a time from this buffer. His/her task includes checking the data and information in the forms that are sent with the component and on the physical component itself. The output of the physical inspector's task is one single document including verified information and data related to each component that facilitates the creation of the repair order. There are cases in which there are either missing, wrong or indistinguishable information, or components that are not supposed to follow the outbound Logistics. In these case the components are placed to a special buffer for extended inspection. Another buffer exists in the Logistics center, where physical inspectors place the components that have completed. The repair administrator is the next type of employees, whose assignment is to create a repair order for each component that is located in the second buffer. After picking the component in first in first out priority. The repair administration includes configurations in the systems and cross checking data and information so as the correct repair order is created. After completing this task the repair administrator dispatches the component to a place where expedition personnel and export deal with final task before the components leave the Logistics center and are transported to their respective repair vendors.

Value stream mapping sessions and focus groups in combination with personal observations of the process, have resulted to identifying several problematic areas in the process flow. The main problem of the outbound Logistics is the inefficient process that undermines the overall performance of the Logistics center in terms of quality, turnaround time and cost. Searching in theory and investigating in the real field, the root causes of this problem have been listed and summarized in a fishbone diagram. The causes are included in six categories: Method, Material, Man, Machine, Environment and Suppliers/Customers. For each of these categories, features have been attached which might negatively influence the overall process' performance.

In order to make the outbound Logistics performance measurable, performance metrics have been defined, known as Key Performance Indicators (KPIs). The most critical KPIs recognized in the outbound Logistics describe the turnaround time requirements in terms of the critical buffer in the end of the day and the total operating cost of the outbound Logistics process. Turnaround time regards to the maximum time of the component's flow in the outbound, from the moment that is received in the expedition to the time that is ready for delivery to the repair vendors. 48 hours is the Turnaround Time based on the agreements with the company's contracted customers. For the purposes of the project quality has been separated in internal (process quality) and external (components quality). Poor process quality refers to the features that create waste in the process and undermine its performance. Unnecessary transportation and movement, long waiting times and over processing due to components defects are some of the recognized wastes in the process. Further, components quality can be described by the condition of the components that are delivered in the Logistics center. Missing, wrong data and/or other issues that might influence the normal process flow of the outbound Logistics can be considered as components quality factors. The lack of employees personal development and motivation have been aspects that can be considered as waste influencing the process' performance. For the purposes of this project, quality has been quantified in terms of waste within the process and measured as the number of components situated in the critical buffer, that is the temporary storage, between the tasks. More than 25 components for four subsequent shifts, mean that the buffer has reached its limit and the employees are unable to handle to components and deliver them to the repair vendors on time. Therefore, waste, or poor quality has been identified. The KPI concerning to the cost is the result of the previously mentioned factors, Turnaround Time and Quality. In more details
delays in turnaround time and poor quality either internal or external can possibly result to excessive costs.

**Measure**

The next step after having defined the elements included in the outbound Logistics is to measure its performance and present the results, so as to develop improvement solutions. Performance measurement requires the collection of reliable and consistent data. A data collection plan has been applied. Information about the components location and date has been retrieved from tracking system and summarized to create several graphs of the component's turnaround times. Moreover, personal measurements have been conducted while joining shifts with the employees and following the components' flow. The later task has given information regarding to the components' quality (external quality) and their impact on the final turnaround time. The measurements justified the poor performance of the outbound Logistics process. Therefore problematic areas, including late deliveries and several quality issues that delay the employees' task, have been notice.

**Analyze**

The analysis follows the performance measurement. According to the theory and literature on past projects in Lean Six Sigma have helped develop a set of solutions that would solve the root causes of the problematic areas in the outbound Logistics.

The solutions propose tasks that need to be performed in order to elaborate on the data requirements for completing a repair order and thus, having a component ready for delivery and set up strict rules and a standardized way of working. Having the previously mentioned in place, the contract details and agreements with the customers can be revised, so as every component can only be sent and accepted in the Logistics center with the important information and correct condition.

Communication among the employees, supervisors and managers in a daily basis is very essential for the personnel's assistance in their tasks, motivation to work, involvement in the process and accountability for the result. Frequent communication can enhance the process quality and therefore influence the turnaround time.

Forecasting the daily incoming workload of unserviceable components in the Logistics center is a task that has to be performed in order to evaluate the personnel's capability and make sure that every day enough personnel to handle the deliveries is working. Taken into consideration historical data and the company's potential in future growth have helped analyze the yearly, monthly, daily and hourly workload. Personnel's scheduling is an aspect that needs to be further investigated and analyzed.

A future state design of the outbound Logistics has proposed the combination of the tasks performed in the process. In other words only one type of employees should perform the physical inspection and directly after the repair administration. In that way the in between buffer (buffer 2) has been immediately removed. Further research has been performed so as to check the personnel's capability to handled the forecasted workload in the future state.

A final step for the improvement of the outbound Logistics is the introduction of performance management techniques. The existing tracking system and future RFID system can be employed to retrieve information about the process' workflow and create reliable performance reports any time needed. Performance management techniques can
automatically identify possible bottlenecks within the process and on time corrective action can guarantee continuous improvement of the outbound Logistics.

Another solution for providing more efficient Logistics services that perform better in terms of quality, Turnaround Time and cost recommends outsourcing the business of the Logistics center. Extend cost benefit analysis and investigation need to be conducted so as to decide whether or not the solution proposed can benefit the overall company.

Due to certain limitations and/or lack of authorization and time constraints the solutions and their execution plans have only been proposed but not applied in the actual working field. Nevertheless, extreme focus has been given to the personnel's scheduling. Insufficient or excessive number of employees in some cases have either caused big delays, or expensive unused personnel. Scheduling has to be programmed according to the process needs, the expected incoming workload, the available time to complete the task and operational daily cost.

Literature has shown that simulation is a suitable tool to visualize the process. In terms of simulation an algorithmic approach has been followed to create a calculation model in which several scheduling scenarios have been first tested and then evaluated and compared to give to the one that scored the best results. The algorithm developed for this project, in its general form can be used in any supply chain system that is modeled in a job shop model.

Data regarding to the physical inspectors' and repair administrators' handling times, the number of components delivered in the outbound Logistics in every shift have been retrieved from the data analysis and used in the calculation. Scheduling scenarios included different combinations and number of employees in every shift, skipping in some cases the most expensive shift (evening and weekends).

All the figures and scenarios presented above have been applied in the calculation model for the two version of the outbound Logistics (current and future state, as presented previously). The deliverable of the calculation model has been the number of uncompleted components in the critical buffer and the operational cost of the personnel employed in every shift. Analysis of this figure implies the percentage of on time deliveries to the repair vendors of the existing daily workload by the number of employees suggested in every tested scenario.

**Improve**

The results have shown that for short term implementation in the current state of the Logistics center weekend shifts can be removed from the weekly schedule. This change has not influenced the components' on time delivery whilst providing an economic solution. Moreover, in long term the second version of the outbound Logistics proposed in this project present comparative better results. Only for this case full time and weekend shifts have been included so as to provide on time deliveries any time and minimizing the cost for the company.

**Recommendation**

In the end of the report several recommendations have been presented. The complete set of solutions has been the result of brainstorming sessions for which cooperation of multiple people was required. The solutions proposed for this project include action plans for further research and future projects. A list of data requirements for a component ready for delivery, based on which the standard way of working can be defined, has been one of the initiatives
of the project. Moreover, a future project would recommend the redefinition of strict contract details, including the data requirements from the Logistics center to its customers, that has been researched in the previous steps. Communication would play a very critical role in the process efficiency. Good communication among employees, supervisors and managers can contribute to the employees’ involvement and motivation to be a part of a healthy and social working environment. Moreover, regular meetings and trainings regarding to changes in the process are suggested as they would add significant value for people. Clear definition of the expected workload has been investigated and used for the personnel’s new scheduling proposal. Having completed the research for the previous action plans, the future state design of the outbound Logistics has been introduced and finally performance management techniques have been proposed aiming to the process’ control and continuous improvement.

Another different proposal for the Logistics center has been the outsourcing the Logistics’ of KLM Engineering & Maintenance. Extended research should be performed to evaluate the costs and benefits out of this action.

Due to certain limitations and constrains, the implementation of the complete set of solutions could not be realized in the context of this project. Nevertheless, according to the chosen scope, the best personnel’s scenarios have been suggested. Finally, further research and cost benefit analysis must be made for other alternatives aiming to the process’ improvement, such as outsourcing the entire Logistics process.

**Contribution**

The research has an added value for the company, literature and society. First, the success of the project and its result are very important once implemented in the real field. Based on the outcomes stated in this report, the outbound process can be improved. Furthermore, the methodology proposed for this project can be followed for similar processes within the Logistics center (Inbound Logistics) and for the entire supply chain as well. Besides the methodology that combines Lean, Six Sigma and Engineering Design, the algorithm’s development has been the main scientific creation for the company. The theory and knowledge which lies behind its function is transmitted to the company’s supervisor and the company’s specialists, who can share and spread it to other departments of KLM Engineering & Maintenance. Significant has also been the contribution of the project in literature. The proposed methodology and its exact application in a process similar to the outbound Logistics has been a novelty. Moreover, the framework developed for the creation of the algorithm and calculation model can be used in other projects and further researches.
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1. Introduction

1.1 Introduction to KLM Engineering & Maintenance

KLM Royal Dutch Airlines, the oldest operating airline in the Netherlands, was founded in 1919 and since then is a very important worldwide employee in aviation. KLM is a part of AIR France - KLM group since 2004 and owns KLM Cityhopper (KLM, n.d.), Transavia.com and Martinair.

KLM Engineering & Maintenance (E&M) is one of the core units of AIR France - KLM group, besides KLM Passengers and KLM Cargo. KLM Engineering & Maintenance can be considered a separate company interrelated with KLM Royal Dutch Airlines. The main business of KLM Engineering & Maintenance is to provide Maintenance Repair and Overhaul (MRO) services that guarantee air safety, managing aircraft operation management, and cost minimization. The company's objective is to become the world largest provider of MRO services for aircrafts. Within KLM Engineering & Maintenance there are several operating departments that are responsible for the implementation of their skills for serving the company's goals and its customers' needs. There is a united organization responsible for strategy, marketing, business development, sales force and external communication.

The research was conducted within the Logistics department of KLM Engineering & Maintenance, which is accountable for handling the aircrafts components and is the only entrance and exit of components at KLM Engineering & Maintenance, more specifically the Logistics center provides:

- import and export custom formalities
- warehouse for the serviceable aircraft components
- administration of repaired deliveries (Inbound Logistics)
- administration of repair orders (Outbound Logistics)

The figure below (Figure 1) shows the components’ flow through the Logistics center. As it is shown, the main operation of the Logistics center is divided into two streams that flow in parallel. The two flows are distinguished according to the type of components that enter the Logistics center: serviceable and unserviceable. Unserviceable components are supplied to the Logistics center from internal (KLM) or external customers (other airlines e.g. Jet, Virgin etc). This type of components regards to those that are in need to be tested, repaired, overhauled or in other words are unserviceable (“dirty”) and inappropriate to fly with the aircraft. The reason of removal and the complaint of the components operation are identified by the aircrafts engineers during the regular or not checks, so the component arrives always with a repair description in the Logistics center. The Logistics center is accountable for their right administration (outbound) and their right delivery to the repair vendors. Meanwhile serviceable components arrive at the Logistics center and follow the inbound process. Serviceable components are the ones that return to the Logistics center form the repair station as serviceable (“clean”), that means well-functioning. Right administration is completed by the employees so that the component can be formally and securely stored in the Logistics Central Warehouse. As these processes flow, the Logistics center is once more
1. Introduction

responsible for supplying their customers with serviceable components from their stock as requested.

![Diagram of KLM Engineering & Maintenance Supply Chain](image)

**Figure 1: KLM Engineering & Maintenance Supply Chain**

The scope of the research has been on the outbound Logistics that includes the activities for handling the outbound flow at the Logistics center, such as receiving, inspecting, administrating and dispatching components to the repair vendors. The outbound flow consists of all the packages that arrive from other KLM units or external parties, after the regular or not checks of aircrafts that require test, repair or overhaul. As it has been mentioned the outbound Logistics is accountable for the right delivery of the unserviceable components to the repair vendor (Figure 1). Right delivery includes several factors, such as safe transportation, undamaged component, right paperwork included, right destination and right time so that it can meet the contract requirements.

In the context of a project that has been launched within different departments of KLM Engineering & Maintenance at December 2014, a question had been raised regarding to the overall performance of MRO services of KLM Engineering & Maintenance. Attention has been given to the Logistics center, as several defects were identified that resulted to inefficient Logistics processes. Thus the objective has been: "To control the incoming goods within the Logistics center and provide their right delivery to the customers". Therefore the aim of this
research is to recommend to KLM Engineering & Maintenance an improvement strategy for the Logistics process with a major focus on the outbound Logistics.

1.2 Problem Description: Waste within the Logistics Process
The managers of KLM Engineering & Maintenance Logistics center evaluated the current Logistics process within the Logistics center as inefficient. The main cause of the inefficiency in the process lies to the fact that little is known about the performance of the outbound Logistics sub processes. The lack of standardizations makes the process execution and every decision making related to that, difficult to perform and impossible to give correct results. Therefore, in this research three main abnormalities have been identified that can also be considered as the most important performance indicators. Quality, Turnaround Time (TAT) and Cost are the variables that need to be taken into consideration when referring to process performance and in the current state are underperforming in the Logistics center at KLM E&M. Results from analysis and observations have shown that the existing state in the Logistics center presents several inefficiencies in the overall process, which have been elaborated in the following chapters. According to Lean theory, the first and most important step is to recognize the problem while observing and being a part of the process (Hines, 2000), (Six, 2015).

The identified defects can be seen in the fishbone diagram below (Figure 2). For the construction of the diagram, several observations and informal interviews with employees, supervisors and managers have been conducted. The root causes belong to the following fields; four of them concern the 4 M’s (Method, Material, Machine, and Man) and the rest present problematic areas in the internal environment and external factors which the customer or the supplier. The root causes that result in failing to meet the company’s TAT, Quality and Cost requirements, can be separately analyzed, processed and improved (Hackman et al., 1995), (Ishikawa, 1976). Several causes have been identified. The data analysis performed in Chapter 4 has shown the most critical focus areas that can be recognized out of this diagram below.
In order to proceed into further research and to provide a better definition of the existing problem in the Logistics center, detailed definitions of what Quality, Turnaround Time and Cost stand for the outbound Logistics in KLM Engineering & Maintenance have been provided.

**Quality Definition**

Quality is a very broad concept in theory and in business as well. However, its definition though has been narrowed to the KLM’s needs when it comes to examining the root causes of its underperformance and suggest improvement strategies. Quality mostly concerns to the process’ quality, which has a great impact on the overall performance. Bad quality according to Lean theory can be described as waste that needs to be removed from the process. The following list presents what is the waste in the outbound processes in the Logistics center (Karlsson et al., 1996), (Hines et al., 2000), (Six, 2015), (Kroes, 2015).

- Transportation: Internal transportation
- Movement: Walking, search
- Waiting: Waiting for answers, decision etc.
- Defects: Component processed multiple times
- Personal Development: Employees knowledge, training and motivation
- Buffers: Temporary storages

However, little is known about the performance of the outbound process in real figures. One of the outcomes of the research is to come up with certain performance measurements for the quality of the outbound Logistics processes.

All the previously mentioned definitions of waste have been found in the outbound Logistics. Nevertheless, their quantification has been a difficult task to perform, due to time constrains.
or inability to measure. For example, internal transportation and movement are not the most significant quality factors, but they have been proven to be inefficient, such less meters and/or time spent in dispatching the component could have been saved if the infrastructure were differently designed. Waste regarding to waiting for answers and decisions and defects that require one component to be processed multiple times, can be explained by the components' condition and their correct papers when delivered in the Logistics center. After extended research and measurements it came as a result that there have been cases when defected components with missing data, incomplete information, wrong packaging etc., have had great impact on the process' quality, causing long waiting times for decision, over processing and failed FIFO (First In First Out) prioritization. Personnel's development is another factor that could not be quantified to measure its influence on the process' quality. However, research has shown that employees’ insufficient training, knowledge, lack of involvement and motivation to work can have a negative effect on the process overall performance.

**Critical Buffer**

One form of waste that has been clearly defined, quantified and used for the performance measurement has been the critical buffer. The buffers are temporary storages, where the components are placed after one task is completed and before the next one starts. The critical buffer regards to the second buffer in sequence, which is created after the physical inspector's task. It can be measured by the number of uncompleted components by the repair administrators at the end of their shift. Extended research has been conducted in order to define the exact critical buffer's level based on the average workload, the personnel's capability and the turnaround time requirements defined in the contracts.

**Turnaround Time Definition**

Turnaround time (TAT) is the total amount of time needed to complete a task (Silberschatz et. al, 2008). In more details, the maximum time of the component's flow in the outbound, from the moment that is received in the expedition to the time that is ready for delivery to the repair vendors, is the turnaround time that is required for a component. The turnaround time is a predefined number of 48 hours stated in the agreements with every contracted costumer of KLM Engineering & Maintenance. However, the Logistics center fails to achieve the predefined turnaround time stated in the contracts, in many cases, causing many variations in the completion time. The improved process included suggestions contributing to meeting and stabilizing the completion time of the entire outbound process, assuring that every component’s delivery meets the time constraints (Six, 2015).

**Cost Definition**

For this research the cost has been considered to be the result of the two previously mentioned factors, quality and turnaround time. In order to check the performance results and translate it into cost; the main interest of managers and the higher levels in hierarchy of the company, in the research cost attributes have been attached in the KPIs definition as well. The operational cost from the personnel's employment has been taken into consideration, scored among several improvement alternatives and used as a determining factor for the best possible scenario's selection. Another aspect of the cost definition in the project refers to the cost saving that is related and connected to the improvement of quality and turnaround time through the process’ redesign. In other words, the attempt of improving
the Logistics processes in terms of quality and turnaround time will eventually lead to cost minimization (Ruffa et al., 2000).

1.3 Research Questions
The company's initiative is "To control the incoming goods within the Logistics center and provide their right delivery to the customers". For this research, knowledge and expertise in the field should be obtained, that can be triggered by the main research question that is mentioned below.

"How to improve the outbound Logistics process within the Logistics Center at KLM Engineering & Maintenance in terms of Quality, Turnaround Time and Cost?"

A combination of methodologies is used for the purpose of the objective in question. At this point there should be a clear distinction between the two basic cores of the work that has to be done. Although the biggest part of the assignment is considered to be mainly a design project, an extended research and analysis has been performed first in order to define the critical KPIs. After having gathered the complete set of reliable data and proposed a set of possible solutions, the design phase has taken place. The project's scope has been narrowed down and shifted to analyze further and provide suggestions for one of the solutions. This phase concerns the design of an algorithm that simulates the outbound Logistics process and aims to test several alternatives and score their performance resulting to the best improvement strategy and its proposal to the company.

The following questions have helped structure the research, define better and realize the design objective. The methods that have been used in answering the questions have been included in the description above them.

RQ1: What is the current outbound Logistics process within the Logistics Center at KLM Engineering & Maintenance?

The process flow map that includes every critical task has been created in order to present the current state in the outbound Logistics in the Logistics center. This has provided an overview over the existing processes, the bottlenecks and defects that have resulted in poor quality, variations in turnaround time and therefore, additional costs. In chapter 2 there has been a detailed description of the current process, important elements and variables have been explained as well helping the reader to get a good insight of the situation in question. Observations, unstructured interviews and group sessions have been conducted to define and present reliable information concerning to the current process.

RQ2: What can we learn from literature regarding to the improvement of Logistics processes?

After getting a good insight of the current Logistics processes of KLM Engineering & Maintenance and identifying what the main problem has been and its root causes, an extended literature review has provided a better understanding and knowledge about tools and methods that have been used for organizing processes similar to the outbound Logistics within the Logistics center at KLM Engineering & Maintenance. The value and use of process management in Logistics centers and the engineering redesign of Logistics processes have been the keywords of this research that helped in the process improvement of the case in question. Multiple theories had been found in literature for process improvement. Lean, Six Sigma and Engineering Design have been integrated from the purposes of the research. Study cases and other literature have helped come up with solutions towards improvement.
Finally, features form the existing algorithmic approaches for the personnel's scheduling have been used for the calculation model's development. Chapter 3 cites the literature that has been used and the knowledge that has been obtained from scientific papers and academic work for the construction of the project in question.

**RQ3: What are the selected KPIs and data to measure the performance of the outbound Logistics process?**

One of the most critical tasks of the research has been the data collection. Attention had been given in acquiring the right data for modeling the processes. Inside knowledge from experts, observations and measurements have been performed to collect the useful data. Joining shifts and taking detailed notes in every step led to the correct and reliable data's acquisition. Data has been properly categorized and analyzed statistically in order to proceed to further steps in the research. The collected data and their analysis have been further used for the process’ simulation and testing. Due to the problem definition the performance metrics based on which the process has to be improved, have also been the critical KPIs: Quality, Turnaround Time, Cost.

**RQ4: What is the performance of outbound Logistics process?**

As it has been mentioned before, little was known about the performance of the outbound Logistics process’ quality and the reason of huge variation in TAT. Therefore, the performance of the outbound Logistics had to become measurable, by the definition of the critical Key Performance Indicators (KPIs) related to these processes.

According to the fishbone diagram (Figure 2) the most critical factors that cause defects in the process are the 4 M’s, the environment and the suppliers/customer, which have been attached to the KPIs during their definition. In that way the overall existing performance could measured and better results in Quality, Turnaround Time and Cost could be achieved when steering one or more of these factors. Information that is available in different systems has been used to define the critical KPIs, measure the overall performance of the outbound Logistics and therefore improve the processes within the Logistics center. Chapter 4 is dedicated to the data gathering and analysis for the process’ performance measurement.

**RQ5: What are the suggested solution areas for the future Outbound Logistics process within the Logistic Center at KLM Engineering & Maintenance?**

Certain initiatives had been defined for the improvement of the outbound Logistics. The initiatives have been categorized according to the 4 M’s that compromise the process' internal factors of inefficiency and the external factors that are the environment and suppliers/customers. The factors presented in the fishbone diagram (Figure 2) can be adjusted according to the company’s requirements in respect to Quality, Turnaround Time and Cost. For each initiative several people are accountable, whose communication and interconnection is very essential to the success of the general goal. After research and analysis the respective initiatives have been defined.

The first step of the design phase has been to identify solution areas and define actions according to the initiatives, throughout the data analysis and brainstorming meetings. For each of the discussed initiatives, a set of solutions has been suggested for the process' improvement. Finally, a new process flow (Hines et al., 1998) has been created in order to make a representation of the new design of the outbound processes in the Logistics center. The research has obtained a design driven characteristic and for that purpose the
recommended steps of the Engineering Design have been followed (Dym et al., 2013). For every solution, the new design had to be tested and compared to the current state, so as to give the best improvement alternative over the process.

Active contribution to the company’s internal meetings, which have be scheduled in order to come to an agreement for the desired future state map had been given. The future state has been derived from internal sessions and brainstorming among managers, Blackbelts and employees within the Logistics center. Several meetings have taken place in order to make a clear definition of the current state situation, define the defects and finally come up with requirements for the future state based on the company's objectives. Gathering information regarding the existing process by interviewing managers and employees in the Logistics center, joining shifts with them and internal reports that are available in the intranet was one of the most critical tasks of the research. Participation has played an important role in giving the proposed method a scientific character. Chapter 5 presents the solution areas that have been identified, throughout the previously mentioned process. Moreover, the existing limitations and constrains have been explained, justifying the reason why the scope of the project is narrowed down to one specific solution that concern the personnel’s scheduling.

RQ6: How can the outbound Logistics process within the Logistics center at KLM Engineering & Maintenance be simulated and tested in respect with its manpower performance?

The outbound Logistics is too complex to analyze in a numeric way and time constrains have not allowed to perform a real time execution. That has been the reason why an algorithm has been developed that simulates the actual outbound Logistics process. In its general form the constructed algorithm can represent any similar process with successive steps and different types of employees per task or flow shops. The calculation model created out of the developed algorithm can identify the bottlenecks within the process and measure the overall performance in respect with the KPIs that have been defined in the previous stages of the research. Manpower was a variable that has been tested in respect with cost and turnaround time. Moreover, the simulation model can be used either for understanding the behavior of the system or for evaluating various strategies for its operation.

One of the most critical parts of the project has been the calculation and testing applying the developed model. After having created a reliable set of data from the data analysis in chapter 4, several scenarios regarding the personnel's scheduling have been tested. After the simulation and the scenarios testing the best alternative has been proposed. The literature review together with consultation from managers and the supervisor helped develop a complete improvement strategy towards the improvement of the outbound Logistics.

Chapter 6 introduces the algorithm in its general form and explains the calculation model that had been used to simulate the existing outbound process of the Logistics center. Finally, its application and the results have been presented in the end of the chapter.

RQ7: How can the improvement strategies be implemented?

The final conclusion of the research has been presented in Chapter 7. An overview of the used methodology and the complete set of the recommendations and how can these implemented in the case of the outbound Logistics, compromise the proposal for the improvement of the outbound Logistics.
1.4 Research Methodology

The project in question is considered an action research that has been performed in the Logistics center of KLM Engineering & Maintenance. The action research regards to the real time participation of the researcher in the company's business, not only as an observer but as an active member in the decision making (Eden et al., 1996). Valuable input and proposals had been given at the internal meetings that have been held together with the company's supervisor. Although this type of research is not always scientifically valid, it has been enhanced and supported by academic research and tools. The use of Lean Six Sigma principles has helped to achieve this task and approach the problem in a scientific way (Daniel, 1997). According to research, solving this problem with an algorithmic approach and the use of a calculation model would fit best for analyzing, measuring and coming up with a new design for the Logistics improvement. Information from contracts with customers and internal target rules have been used to define the KPIs related to Turnaround Time and Quality in respect to the 4 M's, which had been further compared with the performance of the suggested design, set the targets for the improved future state and finally develop improvement strategies.

For the purposes of this research triangulation and action research had been used. The triangulation regards to the data collection and includes literature review, interviews and observations. Moreover, action research for businesses has been performed, according to which scientific knowledge from the literature review and trainings within the company, actions in the decision making and suggestions have been applied (Eden et al., 1996). The figure below (Figure 3) presents the design methodology that has been followed for the research and the link between the research questions and the methods that have been used to answer them.
1. Introduction

Lean, Six Sigma and Engineering Design

Lean

Lean regards to a theory and a way of thinking, whose main goal is to remove the waste from the process, so that every task is value adding. Value adding process is from the customers’ perspective. Lean Theory is based on four pillars (Figure 4) that need to be taken into consideration in order to achieve Lean in business and aims towards continuous improvement (Hines, 2000), (Six, 2015). The Lean steps have been basically used for the problem's definition and data collection. Observations, measurements and being part of the process are proposed in Lean theory and applied in the existing project.
1. Introduction

Six Sigma

Six Sigma proposes a five phases approach for improving the Logistic in businesses known as DMAIC (Define- Measure- Analyze- Improve- Control) (Figure 5). Six Sigma is a tool that strives to identify and remove the causes of defects and errors in a process. Several management and statistical methods are used to create a dedicated infrastructure of people within the organization who contribute to the process’ performance. Literature search in academic papers and reports prove that the proposed approach will lead to the desired results. Similar problem solving approach is used in this research (Nanova et al., 2012). Useful statistical tools from Six Sigma theory have been utilized for the data analysis which has led to the bottleneck's identification.

Although Lean and Six Sigma are two different theories, their principals can be combined for the operation of businesses to achieve better results. For more than five years KLM Engineering & Maintenance has engaged Lean Six Sigma approach to its philosophy and way of working. Advantages from Lean Six Sigma application are multiple, including increased efficiency, development of effective people, decreased cost and increase in revenues and can benefit the entire business (Daniel et al., 1997).
1. Introduction

**Engineering Design**

A structured methodology has been followed according to the Engineering Design (Eden et al., 1996). This process includes several steps that can be integrated with the Lean Six Sigma theory so as to meet company’s principles. The figure below (Figure 6) presents the steps that have been recommended for the research (Dym et al., 2005). The Engineering Design has been mainly used for the deepest level of the project’s scope, which is the design and application of certain solutions.

![Figure 6: Engineering Design Process Steps (Dym, 2005)](image)

**Lean, Six Sigma and Engineering Design**

As shown below, all three strategies use similar milestones in some cases in a more explicit way while in some other more direct and straightforward. Therefore, the design approach that has been developed for the project in question, integrates the principles of Lean Six Sigma and Engineering Design. The most critical steps of the theories have been combined and incorporated to produce an efficient design framework (Figure 7). The integration of these three approaches can provide results that exceed the benefits of each individual approach. Their combination can achieve unprecedented improvements and facilitate the organizational communication, when different departments are accountable for different problem-solving methods. While Lean Six Sigma applies tools like Likert scales, surveys, interviews and focus groups, aiming to customer satisfaction, the Engineering Design focuses more on earnings and feasibility to implement. Therefore, Lean Six Sigma benefits from customer communication helps the approval and design making of proposals by Design. As far as the data collection, Lean Six Sigma develops and analyzes process map, creates formal data collection plans and measurements. On the other hand Engineering Design only declares the need and importance of data collection. Moreover, Lean Six Sigma makes use of specific frameworks (SIPOC) to overview the process and the define the problem, while Engineering Design uses that frameworks for the process analysis. Engineering Design develops execution plans for the implementation following best practices, whereas Lean Six Sigma is more disciplined when it comes to implementation. Finally, Lean Six Sigma applies control plans to
ensure the correct implementation and corrective action plan in cases that the execution does not perform as planned. The features mentioned above include several elements with which the Lean Six Sigma can enhance and improve the Engineering Design approach. The integration of the mentioned methodologies can assure that every important information is taken into consideration during the implementation phase and can guarantee its successful execution.

There are multiple tools to address issues in the design of engineering systems. The benefits of creating and implementing a new framework, which integrates the principles of the three mentioned theories, are multiple. The application of Lean Six Sigma concepts in an Engineering Design can result to an adaptable and flexible framework. The integrated approach applied for this research provides a better visualization of the process, its interaction with its elements and helps identify the bottlenecks leading towards continuous improvement. The basic framework of Lean Theory (PDCA) is taken as a beginning. Thereafter, elements and proposed actions from Six Sigma and Engineering Design are adopted and combined in order to enhance the methodology and have more flexibility in the actions and decisions taken.

The steps that have been followed to accomplish the design objective are given in the proposed design framework and are described by the DMAIC phase in a more explicit way that was closer to Engineering Design and Lean approach (Figure 8). The framework begins with the "Define" phase, which is common for the three approaches and includes the definition of several elements related to the problem. The "Measure" and "Analyze" step can be correlated to the "Plan" phase of the Lean theory and "Background Research", "Data Requirements" and "Solutions" of Engineering Design. In these steps the performance measurement and a complete set of solutions is developed. Part of the solution regards to scoping among the solutions due to limitations and applicability in the project. For the purposes of the Analysis phase, the process’ simulation through a calculation model and an algorithmic approach has helped create a prototype of the process. Further, the "Improve"
step of the developed framework, corresponds to the "Act" phase of Lean theory and "Prototype" phase of the Engineering Design. The improvement phase, regards mainly to the selection of the best scenario resulted from the calculation model and finally suggest the strategy towards improving the outbound Logistics. In the end, the "Control" step, "Check" and "Test and Redesign" steps respectively to the other theories, require the development of a control plan that would guarantee continuous improvement of the process.

![Figure 8: Research Approach](image)

**Define**

The first phase of the proposed approach included a set of definitions. These definitions help have a clear overview of the existing process and its essential features. The current state of the outbound Logistics is studied in details. Observations, interviews and joining shifts on the floor result in the understanding of the current process. Several diagrams visualize the outbound Logistics, the tasks performed, their input and output and the mechanisms employed in every step.
Further, extended research on the floor, focus groups and value stream mapping sessions (see Appendix Interviews, Observations and Internal Sessions) resulted in identifying the main problem within the outbound Logistics.

The critical KPIs have been defined through Literature. Having studied and researched in similar cases in books and papers have contributed in understanding which important performance indicators could be taken into consideration for this project. Quality, Turnaround Time and Cost are the main performance indicators that can help measure the overall performance of the outbound Logistics.

At the end of the definition phase and after having defined the existing process, the critical KPIs have helped identify the problematic areas and bottlenecks that undermine the performance of the existing outbound Logistics process. Additional value stream mapping sessions, focus groups and internal sessions with employees, supervisors and managers have helped define the causes and root causes of poor quality, delayed turnaround time and excess operational costs.

**Measure**

The following step includes the performance measurement of the current state in the outbound Logistics. First, a data collection plan is required in order to gather the correct, reliable and consistent information and measure the process performance in terms of the critical KPIs. A combination of personal measurements for real timings, information from tracking systems and internal reports include the sources of the data needed.

Statistical tools have been used to measure the performance and create meaningful plots, table and diagrams presenting the process' performance. The comparison of the results from this action with the KPIs point out the problematic areas within the process.

Taken into consideration the problematic areas and realizing how these can be solved, contributing to the overall improvement of the process; several solutions have been developed and proposed. Scoping on a single solution based on the feasibility of creating and testing a complete action plan, leads to following the next steps of the process.

**Analyze**

This phase includes the analysis of the chosen solution of focus. The personnel’s scheduling has been proven to contribute to a more efficient process flow in terms of quality, turnaround time and cost. The development of the algorithm that simulates the process and test certain scenarios concerning to the personnel scheduling has been a part of the analysis phase.

Next the application of the calculation model, using data and information from the performance measurements is an essential part of the analysis. Several scenarios of scheduling combinations that include different number of employees' emplacement and therefore, different operational costs.

Finally, the calculation model presents results for every scenario in terms of the KPIs and critical performance indicators. On time delivery scores, based on the required turnaround time, and overall cost of every scenario are summarized in tables and presented in graphs.

**Improve**
The improvement phase requires the selection of the scenario with the best results, in terms of on time deliveries and cost. Finally, this step provides a complete recommendation with every feasible solution that can be implemented for the improvement of the outbound Logistics process.

**Control- Sustain**

This final step is left out of the project's scope. Nevertheless, action plans for the process control and its performance sustainability have been proposed. Performance management techniques and topics for further research projects have been briefly analyzed.

**1.5 Deliverables**

*Set of solutions for the problem*

As it has been mentioned the research objective is to develop a future state of the outbound Logistics process with less waste. A set of solutions has been the result of several internal meetings, interviews and literature based on the data analysis that has been performed and has identified the problematic areas within the process (Appendix B Interview, Measurements and Observations). In general the new process should include more standardized steps that perform more efficiently in comparison to the current state. The deliverable has included a combination of solutions that could be implemented simultaneously and regarded in different aspects of the problem. However, due to constrains and limitations the deliverable is described only in terms of an action plan for further and additional projects.

*Personnel’s Scheduling*

Out of the several set of solutions further research has been conducted in the Personnel’s scheduling. The personnel’s capacity for ensuring the right and on time delivery based on the incoming goods workload has been approached by simulating the process and testing several possible scheduling scenarios. The model for realizing the simulation has been created based on the algorithm developed and introduced for the purposes of this research. The following figure (Figure 9) represents the design methodology for the simulation. Law’s (Law, 2003) steps for a simulation study have been taken as a guide map for the work done in Chapter 6. Different scenarios have been tested using the calculation model and assessed based on cost minimization and time constraints. Finally, based on the calculation's results, the best scenario for the company has been proposed and in the end a complete proposal for the improvement of the outbound Logistics process has been suggested.

![Figure 9: Simulation’s Design (Law, 2003)](image)

**1.6 Scientific Contribution**

The contribution of this research has been divided in three separate fields: scientific, managerial and societal.
1. Introduction

First, the research is related to a managerial aspect of KLM Engineering & Maintenance and contributes to its business by making a quantitative and scientifically proved recommendation for the improvement of the Logistic processes. Moreover, the algorithm developed to simulate the outbound Logistics process can be adjusted to simulate the entire supply chain of KLM Engineering & Maintenance and therefore identify any existing bottlenecks and improve the company’s process.

By applying an algorithm and a calculation-simulation model for measuring the current state and testing several scenarios for the improved future state, the research acquires a scientific character as well. The literature review justifies that little is known in Lean Six Sigma theory regarding to the use of algorithms to simulate the Logistics process, the creation and use of scenarios to test their performance. Therefore, this research introduces a slightly altered version of Lean Six Sigma approach that makes use of an algorithmic approach to simulate the process identify the bottlenecks and improve it by suggesting the best scenario that is tested. Moreover, the research provides a scientific contribution on improvement strategies by stimulating the personnel's occupation.

The societal relevance regards to providing right services to the customers. One of the biggest goals of KLM Engineering & Maintenance is to become the world leader in MRO business. This could be accomplished by integrating the Seven Rights of Logistic to its business (Right product, Right place, Right time, Right price, Right quality, Right quantity, and Right customer) (Robeson, 1994). The improvement of the outbound Logistic processes in the Logistics Center is a great contribution towards this goal and could also be extended to serve the needs of the entire Logistics chain.

1.7 Research Outline

The report has been structured based on the methodology and the steps that have been taken chronologically. The following chapter introduces the reader to the company. Every background information, terminology and details concerning KLM E&M, its Logistics center and the outbound process that has been the main focus of the research are stated in the second chapter. Chapter 3 cites the literature that has been utilized in order to gain better knowledge over the performance indicators and metrics, understand the theory behind the research that was followed, and justify the reason why simulation is a very useful tool for the project in question. Data analysis is a very big part of the research. Chapter 4 first describes the indicators and metrics that were essential for performance measurement. In following sections, the used methods for conducting the data analysis and collecting reliable information are explained. Lastly, the results from the data analysis justify that the process shows big margins of improvement. A combination of brainstorm meeting and knowledge from literature results to several solution areas, which are listed and described thoroughly in Chapter 5. Chapter 6 includes the process’ simulation. First there is the formal statement and explanation of the algorithm and the calculation model that has been developed for the needs of the project. Thereafter its application for the outbound Logistics process is performed by creating the set of input data and scenarios to be tested. The results analysis and the selection of the best scenario conclude the chapter. The one that minimizes the total cost and leaves no uncompleted components in the end of multiple subsequent shifts, meaning that the time requirements are met, is the best scenario. Finally, chapter 7 concludes the project and provides recommendations for further research.
2. Outbound Logistics Process Overview

This chapter presents the activities, actors, and parties that are involved in the outbound Logistics process at the Logistics Center of KLM E&M. First a general view of the company's design is presented in Section 2.1. The terminology is explained in the Section 2.2 and Section 2.3 provides an insight of the supply chain of the components that arrive and leave the Logistics Center. Further in Section 2.4 a Value Stream Map is employed for the detailed representation of the outbound Logistics process and finally Section 2.5 explains the personnel's scheduling at the Logistics Center. The summary and the conclusion of this chapter are stated in Section 2.6.

2.1 Background of KLM

This Section provides an introduction to KLM, the main business of KLM Engineering & Maintenance and its department of Logistics Center.

2.1.1 KLM Royal Dutch Airlines

KLM Royal Dutch Airlines, the oldest operating airline in the Netherlands, was founded in 1919 and since then is a very important worldwide employee in aviation. KLM is a part of AIR France - KLM group since 2004 and owns KLM Cityhopper (KLC), Transavia.com and Martinair.

KLM is the largest airline in the Netherlands that carries about 23 million passengers and half a million tons of freight annually (KLM, n.d.). Three are the core business of the KLM: Passenger Transportation, Cargo division, and Engineering & Maintenance (E&M) which is the main focus of this research.

2.1.2 KLM Engineering & Maintenance

As mentioned above KLM Engineering & Maintenance is one of the core units of AIR France-KLM group. The main business of KLM Engineering & Maintenance is to provide Maintenance Repair and Overhaul (MRO) services that guarantee air safety, managing aircraft operation management, and costs minimization to both internal and external clients. The company has around 5,000 employees and acquires a large portfolio of activities provided by three departments: Aircraft Maintenance, Engine Services and Component Services.

The activities of Aircraft Maintenance include Line Maintenance and Base Maintenance of aircrafts that 80% of the cases come from internal customers. Line Maintenance is an unscheduled maintenance on aircrafts that are in service, either on-site or in a hangar. Base Maintenance is scheduled and more thorough maintenance; it takes place in a hangar on aircrafts that are out of service.

Engine Services provides maintenance, repair, and overhaul (MRO) services on four types of aircraft engines that are all produced by General Electric. Approximately 250 engines are repaired every year of which 40% are engines from internal customers and the rest come from third parties (internal report, Castro et al., 2010).

The Component Services is accountable for supplying serviceable components to both internal (KLM) and external customers (see Appendix A List of Customers). Component
Services delivers repair & overhaul services for components, maintains the warehouse of components in stock, and provides the internal transportation of components at Schiphol between the 6 maintenance units of the three business units of Engineering & Maintenance and the Logistics Center.

The company's objective is to become the world largest provider of MRO services for aircrafts. The aforementioned operating departments are responsible for implementing their skills for serving the company's goals and its customers' needs. There is a united organization responsible for strategy, marketing, business development, sales force and external communication.

The research is conducted within the Logistics Center of KLM Engineering & Maintenance Component Services. Its detailed overview is presented in the next section.

2.1.3 Logistics Center of KLM Engineering & Maintenance

This section provides a detail description of the operational process that is performed in different areas within the Logistics center, as depicted in the sketch of the following section (Figure 16). The description will follow the components' physical route in the Logistics center.

**Expedition**

The expedition is the only entrance and escape of the components to the building. The expedition personnel are responsible for the transportation of the components within the Logistics center. Several incoming components' final destination is not in the Logistics center. These are directly, sometimes after import clearance activities, send for transport. The personnel in charge is also accountable that every component that enters the Logistics center keeps flowing or is located in the correct lane for further transport. Incoming custom clearance goods are first handled by the import department that will be soon replaced by an external company outside the Logistics center.

**Shop VC**

After these custom clearance administrative activities, the goods are offered to the expedition for (internal LC) transport. Shop VC performs the administrative activities required to send and receive components for/from external repair. Shop VC outbound ensures the right documentation and the right vendor information for goods to be send to vendors. Shop VC inbound inspects all incoming components (new, internally repaired and externally repaired) for the correct permits and licenses after which the components are declared serviceable.

**Warehouse Logistics Center**

When finishing their processes, the goods are offered to the expedition for internal LC transport. MLC (Warehouse Logistics Center) is the only KLM Engineering & Maintenance component warehouse in the Schiphol-Oost area. Ordered components are picked, administratively booked out the warehouse and offered to the expedition for internal LC transport. Export, outbound goods with a destination outside the European Union are custom cleared for export and pick up by KLM Cargo.

2.2 Terminology for the Logistics Center

Some important terminology should be explained, before going deeper into the Logistics process at the Logistics Center. The terminology can facilitate the reader to understand the basic operation of the Logistics center and connect it with the analysis that has been performed for the research.
IT systems

IT systems are necessary for the successful administration of components in the Logistics center. Their interface links administrative and logistics procedures and helps the stakeholder keep track and extract valuable information regarding the components.

SAP is one of the most essential systems and is widely used in every organization’s core business. Most of the administrative work in the Logistics center is completed in SAP system that is used in various formats to create material orders (Shop order, Purchase order, Repair Orders, Warranty Orders and Material documents).

The following Logistics information can be found in SAP orders

- DV: Date and Time stamp product delivered at Vendor (for Repair parts)
- PV: Date and Time stamp product picked up at Vendor.
- CR: Date and Time stamp product cleared for (inbound) customs
- DM: Date and Time stamp product delivered at KLM Engineering & Maintenance logistics center.
- GR: Date and Time stamp “goods received” by the KLM Engineering & Maintenance department which placed the order

Component Services uses Crocos to register components’ information regarding their life cycle and logistics status. Crocos is a system that provides identification for every component in its data base. Information about its physical location is always available in this system, helping the warehouse and inventory management process. Moreover, Crocos provides notifications about the components’ necessary checks and automatic registration of a component’s removal, request for installation or placement in the warehouse. The main input data that is required from Crocos is the component’s unique label number that is attached in its package.

Another useful system that provides track and trace information is the Tracking system. Its interface with SAP and Crocos give reliable data regarding the physical location of the component, information about its origin and destination. A tracking sticker with a unique barcode indicating the component’s final destination can be created by the Tracking system. Regular scans in specific scanning points within the Logistics center are required in order to update the system about the internal component’s flow and define turnaround time in each process. Thus, monitoring, track and trace becomes more reliable and consistent data can be extracted by this task.

Purchase Order

A Purchase Order (PO) is attached to every component that is accepted in the Logistics center. A PO is created by the corresponding department that orders the product. A PO is registered in SAP, the ERP system used all the departments in KLM Engineering & Maintenance. It can be considered as the identification by which an order is followed. The PO is created at the start of a purchase or external repair process.

During aircrafts’ maintenance, all parts are technically inspected and in case an inspector decides that a component requires an external repair, test or overhaul that means it is no
serviceable, he/she creates an order and SAP automatically creates a PO. The component is further transported to the Logistics Center and passes through the outbound, where all the necessary administration and formalities are conducted, and finally is sent to the vendor. In the meanwhile, the Logistics center is responsible for supplying the aircraft with a serviceable component from the warehouse’s stock.

Multiple confirmations in information systems (SAP, Crocos, Scarlos) are made throughout the entire process in the information systems, based on this PO number. The component is tracked using its PO and the vendor sends it back with the same PO once it is successfully repaired. The component arrives at the Logistics Center again as serviceable this time and goes through the inbound process where it is inspected and attached with a confirmation in SAP. A serviceable or clean component is the one that has been process by the repair vendor, who fixed and solved and tested any trouble or damage that was attached, giving, thus to the component a serviceable label. At this time the financial process starts: the costs for the repair are included on the bill of the owner of the engine and the vendor gets paid in case all parts of the PO have received a GR confirmation in SAP. If a vendor is unable to deliver all parts of a PO in one instance, it delivers the parts of the PO in multiple instances by partial deliveries.

**Component’s Unique Characteristics**

Every component that is delivered at the Logistics center comes in a package from the respective customer. An invoice is attached to each package with all the required data such as the order number, the client number and a description regarding the component’s reason of removal.

Each component has a unique part number that compromises its international identification document. Certain types of components are serialized meaning that every unit of that component type has a serial number that indicates its lifecycle and every test repair or overhaul registered in it. Every component is registered in SAP so that the Repair Administrators in the Logistics center can follow the component and attach all the necessary paperwork to it.

The Repair Administrators in the Logistics center make sure that the component is sent to the repair station with all the necessary information and paperwork. A repair order and perform invoice should be performed without any mistakes for the successful completion of the outbound process.

**Certificates**

Every component that belongs and has been used in an aircraft must have a certificate that contains all information regarding the unit. The part and serial number, the production date, the repair vendor, the maintenance, test/repair/ overhaul history of the component must be included in the certificate. It is a proof of quality acquired by the national aviation authority (American FAA or European EASA). The authority provides license to manufacturers that produce components according to their regulations and allows them to sell them. The certificates are useful for the MRO businesses. KLM Engineering & Maintenance has licenses from several aviation authorities including FAA, EASA, CAAC (China) and CAA (UK). The origin country of each component’s owner, and not manufacturer, determines the required certificate. Only components with validated certificates can be used.
2. Outbound Logistics Process Overview

Employees at the Logistics Center

There are several types of employees in the Logistics center, each of them responsible for separate tasks in the process.

General Expedition personnel receive packages from the import with the necessary papers needed including the components information needed to make it known in the system (Crocos) that the component arrived in the Logistics center. After updating the system, they are responsible for making a distinction between serviceable and unserviceable components and transport them to the proper places within the Logistics center attaching a tracking sticker to the package.

Physical Inspectors are responsible for checking the condition of dirty components. Certificates, paperwork and damages on the component are checked and reported by the employees. After performing a thorough check about the physical condition of the component, the inspector validates whether the data that are reported in the Invoice correspond to the id plate and creates a form with all the correct information that can be used further in the process.

Repair Administrators are more skilled personnel that are responsible for the administrative work in the computer. Certain data, besides the physical component, are required and need to be inserted in the appropriate system (Crocos, SAP), so as to register the components purchase and/or repair order and create the paperwork in order to send the right component to the right repair vendor.

Component's streams - Pool, Forward exchange, Closed Loop Amsterdam

The Logistics Center of KLM Engineering & Maintenance, accepts components from multiple customers all over the world. Thus, different contract details describe the agreements with every customer, concerning the turnaround time of the components, the compatible repair vendors etc. Moreover, different configurations and different systems are used for every customer. Therefore, there has been a clear distinction between three main streams in the delivered components; Pool, Forward Exchange (FE) and Closed Loop Amsterdam (CLA). A unique barcode is attached to every component, according to the type of stream that each it belongs and is located in the respective place in the Outbound Logistics and handled by different type of employees.

Components that belong in the Pool and Forward Exchange stream have a barcode initiating with "SPLVC" and are placed together in the same lane. Only when the components data (code number) is visible the physical inspector can make a distinction between Pool and FE components. From that time the appropriate employee can handle the components that are assigned to this stream.

Closed Loop Amsterdam components are separated from the rest as they are assigned with barcodes starting with SPLCLA and are placed from the expedition to a different lane. Therefore the CLA employees can easily distinguish their components and handle them correctly.

2.3 Current State of the Outbound Logistics Process

This chapter provides a detailed description of the current state in the outbound Logistics. The physical flow of the components from the moment that are delivered in the Logistics center until the moment that they are out for delivery in the repair vendors and all the critical
2. Outbound Logistics Process Overview

tasks that are completed in between are presented in section 2.3.1. The section 2.3.2 provides a visual description of the design layout and section 2.3.3 makes an introduction to the employees scheduling that will become one of the main solution topics in the following chapters.

2.3.1 Description of the Outbound Logistics Process

This section elaborates on the outbound process that is the flow that unserviceable components follow within the Logistics center. The following IDEF0 (Integrated Computer Aided Manufacturing DEFinition for Function Modeling) diagrams have been designed in BPwin to model, describe and visualize the activities that take place in the Logistics Center. The diagrams include a rectangular box that represents the main activity of the outbound Logistics process that is "to Provide Outbound Logistics" (Figure 10). The arrows that are used have a different meaning based on their position and direction with respect to the main box. Input and output are presented in the horizontal arrows that point in and out of the main box. The vertical arrow that comes from the top of the main activity's box declares the elements that control the activity in order to give the desired output, while the arrow coming from the bottom to the main box represent the mechanism, operators and software that is used to complete the activity and process the input to deliver the output. The main activity is decomposed to several sub activities that represent the tasks performed in the Logistics center to complete the outbound process (Figure 11). The sub activities are further decomposed and visualized to the deepest level in the following figures (Figures 12-15). The diagrams visualize subsequent steps that represent the physical flow of the unserviceable components in the outbound Logistics process. Therefore, the time distance between the diagrams is of great importance and has been identified during the data analysis. This action helps gain a general view of the normal timeframe that is needed to complete the process without any waste and/or defects.

Figure 10: Outbound Logistics Process
First the component is dropped off at the Expedition of the Logistics center and goes through Import. In case of domestic components’ the import makes the package custom free or else custom taxes should be issued. After the component is transported to shop VC where there is a buffer waiting for physical inspection and repair administration. Then the component goes through export and is finally left to the expedition waiting to be picked and transported to the repair vendor (Figure 12).

![Diagram: Provide Outbound Logistics](image)

**Figure 11: Provide Outbound Logistics**

**Receiving incoming goods**

The process of receiving packages at the Expedition is designed to facilitate receiving the component and divided them based on whether they are unserviceable and need to go through outbound or serviceable, which follow the inbound flow. This process is performed by the expedition employee.

Components are delivered at the expedition several times per day by different delivery services. Most of the times unserviceable components come from the Hangars located in Schiphol Oost technical area, from France via the shuffle or are sent by external customers. Serviceable components arrive at the expedition from several repair vendors and customers domestic or not. Based on the origin of the delivered package, it must go through import which issues the Customs Release notice in SAP including all the necessary information for the expedition employee to update the system and make it known. The employee creates a tracking sticker that indicates the final destination of the component in the Logistics center. The next task is to determine the route that the component will follow within the Logistics center. Some serviceable components are sent directly to the customer, whereas others need to go through the Logistics center’s process either to be stored at the warehouse or to be delivered to customers as well. The later needs to be separated from the others and transported to the correct location in the inbound section of the Logistics center. As for the
2. Outbound Logistics Process Overview

Unserviceable components, they have to pass through the outbound process and be handled administratively before sent to the respective repair vendor. These components are transported to the shop VC where they are placed in different lanes if they are coming from CLA (Jet airways, Air Morocco) or not customers. After identifying the component and its destination, the employee loads the packages into a cart and transports them to the respective place in Logistics center. A critical step in this task is to scan the tracking sticker in each phase so that the relevant information, regarding to the time and location, can be obtained. The following figure (Figure 12) represents the process of receiving components in the Expedition. The processes described above compromise the outbound process that the component goes through in order to be sent to the repair vendor.

![Figure 12: Receive Incoming Goods](image)

**Physical Inspection**

The physical inspector is responsible for assuring the quality of the received unserviceable component. The employee takes the components out of the buffer in Shop VC according to FIFO priority, although the rule is not always followed (See Section 3.1.1). Two parallel streams are working simultaneously for handling CLA and other components. The reason of that lies to the fact that different customers, thus different contract, have separate requirements and demands. Therefore, expertise should be acquired for CLA customers. Nevertheless, both employees guarantee that the component meets the quality requirements and has the right certificate and documentation according to the aviation authorities for flight. The visual inspectors open the packages check for the documents and verifies that the components is delivered without any damage other than the reported in the enclosed invoice. There is no technical inspection performed at this step, as the component that arrives at the Logistics center must be accepted only with the relevant description and reason of removal that is written by expert technicians. If the component is in the proper condition, the physical inspector fills in a form with all the information that can be obtained from the
components id label (serial/part/following number etc.). Dimensions and weight of the package are also reported in this form that facilitates and saves valuable time for the repair administrator, who uses these data as an input for making the correct order. After completing the check and reporting the components data, the employee places the packaged to a buffer, from which it will be picked for further handling (Figure 13). A physical's inspector handling time lasts on average for 15 minutes. Detailed figures of the physical inspector’s handling time can be found in the Data Analysis performed in Chapter 4. The following Section 2.3.3 describes the physical inspectors' scheduling and their average production rates.

In cases of missing data in this step, or any defects that may be encounter and cannot be solved by the physical inspector, the components should be left to the scoping buffer. From there the component follows another process for the clarification of the problems that have been reported in the physical inspection phase.

![Figure 13: Physical Inspection](image)

**Administrative Inspection**

The repair administrator is accountable for checking the certificates and documents that are sent in the package. He/she is picks components from the buffer following again the FIFO priority rule. The repair administrator in general verifies the information on the certificates in accordance with the data obtained by SAP and on the physical component as it is reported in the previous step by the physical inspector. Then the employee matches the requests with the PO and. In the respective systems, SAP and Crocos the repair administrator determines the work scope and the repair vendor that is accountable for each component. The final step is to Perform Invoice with all the necessary data and description regarding to the component for each repair vendor. A list of the data requirements that need to be included in the package before being sent to the repair vendor is presented in the Appendix.
completing the administration a new tracking sticker is matched to the previous one and attached in the package. The sticker is scanned in the current location. All printed paperwork should be packed in the package and a last visual inspection is required. The employee transports the component to the drop point, from where it is picked by the runner and placed to the expedition area. It is essential that the sticker is again scanned so that it is known in the system that the component is left and picked from the specific location (Figure 14). On average the physical inspector’s task takes up to 20 minutes (see Chapter 4). Section 2.3.3 cites an overview of how the personnel is managed in the outbound Logistics based on their production rates.

![Figure 14: Administrative Inspection](image)

In cases of troubles, missing or incorrect data the repair administrator should dispatch the component to the troubleshooting buffer for further inspection. A list of all the possible problems that could be encountered in this phase is shown in Appendix A Process Sidesteps.

### Export and Transportation

After completing the necessary inspection and administration in each component, a buffer is created in the expedition area, where the components are left until they are further processed for export formalities. Thereafter, a batch of packages waits for trucks to arrive. In this area loads of packages are placed including those that are unserviceable and need to be sent to repair vendors and clean ones that are requested by customers. Almost every half an hour there are truck arrivals, which collect the packages. Proper separation and handling should be performed so that the right component is dispatched to the correct truck for transportation.
Scoping and Troubleshooting

Scoping and Troubleshooting processes are out of the scope of this research. However, a brief description is provided in order to understand better the entire process. The processes' diagrammatic representation is cited in Appendix B Side Step Processes (Figure 35 and Figure 36). Both sub processes include sidesteps of the main process flow that is required only when the employees handling the components encounter issues in identifying a component's data that are necessary for completing their task. It is common, that the customer sends a component with insufficient information about its condition or indistinct data that are required for its configuration in the system. Some of these issues can be solved easily by checking in the system by the employees that have access to it. Nevertheless, this is not always the case. In some cases further investigation is needed and therefore the components need to follow the sub process to complete and solve the issue without delaying the normal flow of the other components. The employees that are responsible for scoping and troubleshooting try to give solution to the issues as soon as possible and return the component to the normal flow with all the complete information needed. Around 5 per cent of the incoming unserviceable components end to Scoping or Troubleshooting ranks every day.

The following figure (Figure 15) visualizes the main process steps that compromise only the Outbound Logistics. This representation will be the milestone for the analysis, whereas more attention will be given to the "Physical Inspection" and "Repair Administration", as they are the more essential activities of the Outbound Logistics and most of the defects occur. In the Appendix C Outbound Logistics Critical Areas, there are some photos visualizing areas where the critical task and the in between buffers are performed.

![Figure 15: Main Process Steps](image)

Conclusion

The section provided a detailed description of the outbound processes in the Logistics center. Four are the main stages that the component passes through in the outbound after being delivered from the customers and before being transported to the repair vendors.

The unserviceable component is received in the expedition and goes through import if necessary. A new tracking sticker is created by the employee and then is dispatched to Shop VC where physical inspection takes place. Administrative inspection assures that the component acquires the correct paperwork and Perform Invoice is issued. Tracking sticker is created and regular scans make sure that the components flow is recorded in the systems for monitoring its route and counting the overall performance of the process in terms of time.
Two sidesteps are added in the outbound process, which occur in cases of problematic orders and any kind of defects in the delivered component, see Appendix B Sidestep Processes (Figure 35 and Figure 36).

2.3.2 Design Process Lay-out of the Logistics Center

The outbound Logistics process is design in similar ways as other MRO Logistics centers. As it is mentioned, KLM practices Lean Six Sigma in organizing its businesses (Section 3.4). A Kaizen event should be performed for the re organization of the Logistics center and therefore the improvement of the process's performance (Hines, 2000), (Six, 2015). The Kaizen event requires the whole department focused for a certain period of time on improving the entire process, including re constructing the lay out. The aim of this task is to redesign the entire Logistics process, in order to come up with a normal flow of the components, minimize the buffers and thus contribute to the quality and turnaround time improvement. Significant input for the Kaizen event is given by the researcher after analysis of the outbound. The current lay out of the Logistics center is depicted in the sketch below (Figure 16). The arrows and the number in sequence follow the physical flow of the component in the outbound Logistics process. Moreover, the points where scanning is performed using every component's unique barcode to insert its location in the tracking system are depicted in this figure. The scanning points and their actions performed are described in the Appendix E Scanning Points (Table 23) and are very important for monitoring the workflow and contribute to the performance management.

![Figure 16: Current State Design Lay out and Scanning Points](image-url)
2. Outbound Logistics Process Overview

2.3.3 Process Overview

This section describes some important elements that influence the process flow in the outbound Logistics. Due to the employee's production rates, their scheduling is explained in order to meet the turnaround time requirements. Moreover, the dispatching rules that are used are explained in details in the last paragraph.

Personnel's Scheduling

The employees' scheduling within the Logistics center can result in significant cost savings. Therefore, good planning and personnel's management is very essential for accomplishing the Lean in the Logistics center. This section describes briefly the existing employees scheduling that work for the outbound Logistics.

There are three groups of employees working in the Logistics process (Section 2.2 Employees at the Logistics Center); the General Expedition personnel, the Physical Inspectors and the Repair Administrators. Nevertheless, detailed analysis have been performed for the two types of employees the Physical Inspector and Repair Administrator, who work only for the outbound Logistics and influence the process' performance.

At the Logistics center the scheduling is based on a 7x2 roster. That means that the operations run seven days a week in two shifts (day and evening), because the Logistics center is responsible for receiving and delivering components to customers when needed. The aircraft MRO business requires services any time and any day of the year (24/7/365). Every day can be divided into two shifts; the day shift (7:00-15:00) and evening shift (15:00-23:00). Each shift is 8hours (480 minutes), however, due to overlapping, lunch/dinner and coffee breaks and any other reasons the real productive shifts time has been calculated to be 6.5 (390 minutes).

Production Rates

As it has been mentioned the average handling time of physical inspector is 10 minutes; that means that his/her production rate would be around 39 components per shift. The same for the second type of employee; 20 minutes are required for a repair administrator to completed their task, therefore, 19 components per shift are their average production rate. The calculations above result to the fact that the production rate of physical inspector is twice of the repair administrator's. As a result, for a normal process flow in the outbound Logistics the number of repair administrators is expected to be at least twice than the physical inspectors. However, the outbound Logistics personnel's scheduling is complex to described since there is no standardization. Generally, the employees are dispersed in shifts that at least 6 repair administrators (4 day, 2 evening shift) and 3 physical inspectors (2 day, 1 evening or 3 day shift) are working every day including weekends. That has been the main reason why in this research extreme focus has been given to the personnel's scheduling (Chapter 6).

Priority Rules

FIFO is used in the Logistics center as it is an efficient tool for minimizing the components' average flow time (Jayamohan, 2000). However, this is not always the case. Customers' satisfaction and their components' due date, defined in the contracts, are final factors that determine the components’ priority (Philipoom, 2000). Most of the times employees deliberately choose components with emergency request or components that are left in the solved scoping buffer. This fact might facilitate the overall turnaround time performance of
the outbound since components with high importance are eventually handled in time, but one the other hand it might create extra delays for other components.

2.4 Conclusion
This chapter explained the physical flow of the unserviceable components delivered in the Logistics center. A general description of the Logistics center is provided. Important terminology has also been provided to help the reader follow the internal vocabulary. Moreover, the critical steps, employees and systems which comprise the entire chain of outbound Logistics have been described in details. Finally, the representation of the process has been depicted in a process flow diagram and the design of the Logistics center has been provided in order to visualize and gain a better insight and overview over the environment that has been examined.

All the components that arrive in the Logistics center are accepted in the expedition. Trucks arrive multiple times in a daily basis without following a fixed schedule. The personnel in expedition make a distinction between serviceable and unserviceable components by their label and sender. Thereafter, they create tracking stickers with unique barcodes for every component and transport the components in the correct lane of the Logistics center.

The unserviceable components are placed in the outbound Logistics, where various tasks are performed to complete the components' handling and create the correct order for the correct repair vendor. Two different types of employees are working for the outbound Logistics. The physical inspector that checks the physical condition of the components and completes a form with every required data and information found on the component or the papers that come with it. The repair administrator's task begins only when the physical inspector has completed his. Administration and configuration in the IT systems are performed by the repair administrator who is accountable for completing the components' order and necessary paperwork to send it to the contracted repair vendor.

The personnel from expedition is once again assigned to collect all the completed components and arrange their placement to the trucks that distribute them to the respective repair vendor.

The scheduling of the personnel in the outbound Logistics is very essential to be mentioned and be taken into consideration when creating the improvement scenarios. The capacity of personnel is a determinant factor for minimizing the cost of working hands while using the most effort possible. Different scheduling alternatives have been tested and selected based on meeting the turnaround time requirements and cost saving.
3. Literature Review

The review presented in this chapter provides the reader with an introduction to the literature that is relevant to the topic in question. The first section presents some literature regarding to Performance Metrics and Key Performance Indicators that will help make a clear definition of the performance measurements for the outbound process. For this purpose, the outbound Logistics have been related to job shop model. The following two sections give insight on methods and tools that have been previously used for achieving the Quality improvement and Turnaround Time reduction. An excessive review of Lean Six Sigma practices and how they can be applied in KLM Engineering & Maintenance is presented in section 3.3. Finally, the last section describes why an algorithmic approach and a simulation in terms of a calculation model is a useful tool for the purposes of this research and how it can contribute to the process improvement.

3.1 Job Shop Model

The outbound Logistics center can be considered as a job flow, in which jobs consist of a number of operations performed on different machines (Pinedo, 2005). For the case of the Logistics center a special type of job flow is recognized: the flexible flow show, where jobs go through a number parallel work centers, which consists of identical machines in parallel (Pinedo, 2005). More specifically in the Logistics center (outbound) the jobs are represented by the components (unserviceable), work centers are the logistical departments (expedition, physical inspection, repair administration and sidesteps) and the respective employees handling the components can be considered as the machines.

The objective of a flexible job flow scheduling problem is to organize the tasks in such a way that quality, turnaround time and cost are minimized. There are numerous versions of this problem in literature and different approaches to solve the scheduling problem. Researchers studied the components' process in batches (Shen et al., 2012), with no fixed order by the employees (Zu et al., 2006) and other optimization objectives (Xia et al., 2005).

In general the job shop scheduling problem is NP-hard (Garey et al., 1976); meaning that its computational time increases with the number of jobs. Therefore, it has been really hard to solve such a problem for the entire supply chain of KLM Engineering & Maintenance, where there is unlimited number of components in each flow. Nevertheless, optimizing methods (dynamic programming), heuristics (simulation) and hybrids (combining both) (Zhu et al., 2006). In the following section there is an explanation why simulation has been used in this project.

3.1.1 Dispatching Rules

In a job shop such as the Logistics center, dispatching rules prescribe which component should be handled by any type of employees and in which priority (Holthaus et al., 1997). Outbound Logistics uses FIFO (First In First Out) rule. Researchers have shown that FIFO’s performance is poor on flow time factors and good on maximum flow time (Philippom, 2000). FIFO has been an efficient tool for the Logistics center for minimizing the components' average flow time (Jayamohan, 2000). Customers' satisfaction is the final factor that determines the dispatching rules, based according to the due date (Philippom, 2000).

3.1.2 Workload Control
Similar to the dispatching, the workload control rules the number of components released is controlled. Basically, the workload control helps the normal flow of the process without external dynamics and uncertainties, by controlling the turnaround time (Soepenberg et al., 2012). In many case, employees in the outbound Logistics engage Order Review and Release tactics in order to meet the customer's satisfaction while failing the FIFO rules (Philipoom et al., 1999).

### 3.1.3 Manpower

Extreme focus has been given to the availability and capacity of manpower in the process. Manpower is a very significant factor determining the normal process flow in a job shop. Amin Sahraeian (Sahraeian, 2012) developed and used a mathematical optimization model for determining the resources to minimize the total competition time for production planning using linear programming.

In cases of unexpected disruptions that may occur in real life Logistics services, rescheduling is critical to minimize the impact on performance. Ketrina Katragjini (Katragjini et al., 2013) generated and used three types of disruptions in a flow shop. For the context of her research she developed rescheduling algorithms aiming to establish a standard framework and proposing rescheduling methods that seek a good trade-off between schedule, quality and stability.

Cannell (Cannell et al., 2004) in his book enhances the importance of human's management in the overall productivity, by proposing a complete set of human's strategies including human flows, policies, trainings, personnel's involvement etc.

### 3.2 Performance Metrics and Key Performance Indicators

Significant amount of attention has been given in the study of Performance Metrics and Key Performance Indicators regarding to Logistics processes. In order to gain a deeper understanding and define the KPIs corresponding to the case in question several scientific papers have been studied.

Krakovics, Leal and others (Krakovics et al. 2008), proposed that KPIs should be process oriented rather than functional oriented in order to evaluate the actual effectiveness in terms of customers’ needs. Process oriented KPIs have been identified for this research as well.

In their article Mentzer and Kornad present performance measurement practices in terms of efficiency and effectiveness (Mentzer et al. 1991). Byrne and Markaham’s article focus on quality and the conceptual treatment of performance indicators for various dimensions of logistics (Byrne et al. 1991). Customer service is also a significant aspect that should become measurable when assessing the performance of Logistics processes. La Londe, Cooper and Noordewier (La Londe et al. 1988) have conducted surveys among shippers, carrier and warehouse executives in order to come up with certain customer service metrics. The previously mentioned articles have been studied and valuable information has been used for the conceptualization of the performance metrics.

Several other articles have been studied to make the definition of performance clear and straight. Clarke (Clarke 1991) in his study determines which performance indicators are appropriate for measuring productivity whereas Yavas, Luqani and Quraeshi (Yavas et al, 1989) provide information on efficiency measurements.
Finally findings from literature have been used in order to come up with methods of measuring the performance in Logistics centers. Read and Miller (Read et al, 1990) studied quality in logistics assessing samples from firms on consultant's mailing list. The end result of the study was a gap between the attention that is given to the Logistics’ quality and the metrics that are actually used. Quality metrics such as on time delivery, zero defects, employee awareness of quality importance, employee education etc. are some of the performance metrics that have been studied and used in this research. Gassenheimer, Sterling and Robicheaux (Gassenheimer et al. 1989) approached the performance measurement by a factor analysis. Finally, Cooper’s, Browne and Peters (Cooper et al. 1992) study focused certain performance indicators resulting in significant variations in logistics efficiency depending on the respective performance indicators used.

Performance measurement is the basic step towards process improvement. Over the past few years significant developments have been made regarding to the supply chain performance measurement. A variety of approaches and techniques have been used targeting on different goals in various companies.

A balance scorecard is introduced by Bhagwat and Sharma (Bhagwat et al. 2007) in small and medium sized companies. The paper proposes a quantitative approach and tools such as information systems, cost management, improvement systems and multi criteria decision support for the logistics chain. Martinsons et al, 1999 have created a framework for measuring the performance of information systems and the interface between IT implementation, Supply Chain Integration and Supply Chain Performance. Muchiri et al (Muchiri et al. 2010) suggested a conceptual framework for the alignment of the key performance indicators with the company’s objectives. A definition of performance measurement system is introduced by Neely (Neely et al. 1996) and studied structured processes for their definition.

Pinheiro (Pinheiro de Lima et al. 2009) suggested a process for the integration of operations strategy to the design of operations performance measurement systems. Xu (Xu et al. 2009) presented the factors that affect the supply chain performance evaluation by developing a model based on Rough Data Envelopment Analysis.

### 3.3 Lean Six Sigma

KLM Engineering & Maintenance has adopted Lean Six Sigma approach in the company’s philosophy. The combination of Lean Manufacturing and Six Sigma is proven a successful tool for the company’s businesses and is implemented in all different kinds of departments and processes including the Logistics. This section presents Lean Six Sigma, its principles and practices in companies the aim in process improvement within their businesses.

**Lean Manufacturing**

Lean Manufacturing includes guiding principles towards reaching the company’s goals and practical tools and techniques that can lead to these objectives (Shah et al. 2007). Shah (Shah et al. 2007) managed to make a concrete definition after an extensive literature regarding to various descriptions of Lean Manufacturing “Lean Production is an integrated socio technical system whose main objective is to eliminate the waste by concurrently reducing or minimizing supplier customer and internal variability”.

From the company’s perspective Lean Manufacturing principles strive to remove non value adding activities so as to maximize the value for the company and the end customer. Ohno
(Ohno 1988) made a list of the types of waste that Lean Manufacturing aims to remove from the company's processes. The list above is used for the purposes of the research in order to identify potential waste and bottlenecks in the outbound process in the Logistics center in KLM Engineering & Maintenance.

- Transportation: unnecessary transportation of components
- Inventory: buffers with components waiting for the next step in the process
- Motion: unnecessary movement of employees in the working space
- Waiting: unnecessary waiting of employees to start the next step in the process
- Over processing: unnecessary/ extra steps
- Over production: completing more components than the trucks capacity (often caused by speed in process resulting defects)
- Defects: damaged component, missing data, missing/incomplete paperwork

The main principles of Lean manufacturing proposed by Womack (Womack et al. 1996) include:

- Defining value
- Identifying the value stream
- Making the value adding activities flow
- Transforming processes into pull
- Pursuing perfection by continuous improvement

The aforementioned principles are adjusted in the case of KLM Engineering & Maintenance and combined with the appropriate tools compromise the main approach for the outbound process' improvement.

Quality management, pull production, preventive maintenance and human resources management are according to Cua (Cua et al., 2001) ad Shah (Shah et al., 2008) the basic blocks that Lean Manufacturing can be implemented. Just in time production, turnaround time reduction, maintenance improvement and cost reduction are certain practices that help identify and remove the waste in the processes.

The application of these practices requires the use of proper tools, methods and techniques. The Value Stream Mapping (Hopp et al., 2004) (Akbulut- Bailey et al, 2012) is one the many tools to define the adding value stream in the process and identify waste within the processes.

**Six Sigma**

Six Sigma focuses mainly on identifying the sources of variability and reducing them from the process (Linderman et al., 2003). In contrast with Lean manufacturing it concerns a method of variability reduction rather a strategy towards improvement (Hopp et al., 2004). The failure rate of the company's performance should be defined as all parts that are outside the specification limit of six standard deviations (sigma) from the mean, as the name Sig Sigma denotes, meaning that there may be 1 defect per 3.4 million parts.

Schroeder (Schroeder et al. 2008) describes Six Sigma as “an organized, parallel-meso structure to reduce variation in organizational processes by using improvement specialists, a structured method and performance metrics with the aim of achieving strategic objectives”.


Six Sigma applications require the support of a parallel-meso structure team of specialists that operate outside of the company's normal business. The Blackbelts comprise the full time improvement specialists, which are trained in the Six Sigma approach focusing on continuous improvement.

The Six Sigma method includes five steps known as Define, Measure, Analyze, Improve, Control (DMAIC), aiming at identifying the root cause of problems in the company's operation using quality tools and statistical process control. Several performance metrics that can be either customer or financial oriented.

**Lean Six Sigma in KLM Engineering & Maintenance Logistics process**

KLM Engineering & Maintenance employed teams of Blackbelts that operate in the core business searching ways to reduce variability and create stability in quality and turnaround time while removing the defects and waste in the overall process. As Lean Six Sigma proposes the performance measurement is based on the P95 measure which means the 95%-percentile, the value below which 95% of all observations fall. The company attempts to define the extreme values, solve the root causes and thus reduce the span, creating stability and reliability in the process.

The main objective of Lean Six Sigma is to maximize the customer value, by measuring the quality performance and turnaround time. The same principle applies to the case in question. In order to achieve that for the outbound Logistics process waste removal should be performed and variability in the quality should be eliminated.

### 3.4 Algorithmic Approach for Personnel Scheduling

Santoso and others (Santonso et al., 2003), produce a formal problem statement of the supply chain's strategic planning and develop algorithms for its solution. Strategic planning includes configurations regarding number, location, capacity etc. For the process' improvement strategic planning is a very critical factor. The scheduling problem in job shops can be approached by heuristics for the process optimization in terms of turnaround time and cost minimization (Jagabandhu et al, 1996). In their paper regarding the algorithmic approach for scheduling in flow shops, Jagabandu and others propose a genetic algorithm that is compared with a multi criterion heuristic, where alterations are made to initialize subpopulations for scheduling. The outbound Logistics process can be considered as a n Job, m machine process flow, where "job" is the task that needs to be completed, is described by the type of employee and "machine" is the number of employees per task (Campbell et al., 1970). Campbell and others describe in their paper a simple algorithm that solves the n job, m machine problem. The problem refers to finding the best solution in tasks’ scheduling in flow shops. In their work Ho and others (Ho et al., 1991) present an improved heuristic for solving the same flow shop scheduling problem. Basic thinking and algorithmic theories have been used from the literature mentioned above to create and develop the algorithm that is developed in the context of this report.

### 3.5 Simulation

Analytical evaluation is a very complex task to perform in real world systems (Law et al. 2000). This is also the case for the future state of the outbound Logistics process, as its implementation and normal flow requires a lot of time. Input requirements, inspection and the employees’ motivation and training to the new standards are too complex to give reliable results. This is the reason why it is decided to study the outbound Logistics process by means of simulation (Law et al., 2000). In the paper of Shannon (Shannon, 1975), he introduced a process of designing a model of a system and conducting experiments with this model for the
purpose either of understanding the behavior of the system, measuring its performance or evaluating strategies in terms of predefined criteria and objectives.

In several cases Lean Six Sigma can employ a simulation tool to approach process improvement (Fowler et al., 2004). Simulation can be used in several ways for the benefit of Lean strategy, such as problem identification, evaluation of improvement strategies, and their impact prediction (Adams et al., 1999). Some of the benefits of using simulation are its ability of combining measurements of financial, operational and customer satisfaction indicators for the same analysis (Ferrin et al., 2005). The reasons of employing simulation software for enhancing the Lean process are according to Standridge and Marvel (Standridge, 2006) the following:

- Structural and random variation must be addressed
- Reliable collection of data must be analyzed to understand the random nature of the system
- Interaction between systems must be assessed
- Validation of the Future state is very essential
- Alternatives and improvement suggestions in the future state can be considered

For the purposes of the research it has been introduced a framework for combining the Lean Six Sigma approach with the application of simulation tool in order to measure the process' performance, identify defects and propose improvement alternatives. First the respective algorithm that simulates the process and solves the personnel's capacity problem, based on resources' minimization (turnaround time, cost) is created. Afterwards, historical data and measurements and alternative scenarios are used as input for the algorithms implementation in excel. The formulas created give the completion time and the number of components in buffers, combined with cost calculation. The figures mentioned are the determinant factors for the best alternative’s selection.

3.6 Conclusion

To conclude, this Chapter presented the literature and important knowledge obtained from previous researches. In order to come up with a certain approach towards process' improvement the outbound Logistics has been correlated to a job shop model. Priority rules, workload control and manpower described in literature have been related to the project. Methodologies for performance metrics’ definition have been found in literature which helped identify and calculate the required Key Performance Indicators. Lean and Six Sigma theories have been studied and important techniques of their application have been used for the research's development. Finally, several projects and case studies in which algorithmic approaches had been developed for the personnel's scheduling have been found. The research concerning the algorithms' development and application of simulation for process' improvement justifies the uses of a similar method for the project in question. The following table (Table 1) summarizes the useful literature and theories studied and applied for the project's execution.

<table>
<thead>
<tr>
<th>Category</th>
<th>Title</th>
<th>Author</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Job Shop Model: Theory</td>
<td>Planning and Scheduling in Manufacturing and Services</td>
<td>Pinedo, M. L.</td>
<td>2005</td>
</tr>
<tr>
<td>Scheduling Problem: Optimization Objectives</td>
<td>An effective hybrid optimization approach for multi-objective flexible job-shop scheduling</td>
<td>Xia, W. &amp; Wu, Z.</td>
<td>2005</td>
</tr>
<tr>
<td>Topic</td>
<td>Summary</td>
<td>Authors</td>
<td>Year</td>
</tr>
<tr>
<td>-------</td>
<td>---------</td>
<td>---------</td>
<td>------</td>
</tr>
<tr>
<td><strong>Priority Rules: Customer Satisfaction</strong></td>
<td>The choice of dispatching rules in a shop using internally set due-dates with quoted lead time and tardiness costs</td>
<td>Philippou, P.R</td>
<td>2000</td>
</tr>
<tr>
<td><strong>Lean Manufacturing theory</strong></td>
<td>Defining and developing measures of lean production</td>
<td>Shah, R. &amp; Ward, P.T.</td>
<td>2007</td>
</tr>
<tr>
<td><strong>Lean: Waste Definition</strong></td>
<td>Toyota Production System: Beyond Large Scale Production</td>
<td>Ohno, T.</td>
<td>1988</td>
</tr>
<tr>
<td><strong>Algorithmic Approach: j job-m Machines Problem</strong></td>
<td>A Heuristic Algorithm for the n Job, m Machine Sequence Problem</td>
<td>Campbell, G.H., Dudek, A.R., &amp; Smith, L.M.</td>
<td>1970</td>
</tr>
<tr>
<td><strong>Simulation: Performance Measurement and Evaluation</strong></td>
<td>How to Conduct a Successful Simulation Study</td>
<td>Law, A.M.</td>
<td>2000</td>
</tr>
<tr>
<td><strong>Simulation: Benefits of its Application</strong></td>
<td>Systems Simulation: the Art and Science</td>
<td>Shannon, R.E.</td>
<td>1975</td>
</tr>
</tbody>
</table>
3. Literature Review
4. Data Analysis of the Current Outbound Logistics Process

This chapter describes the results taken from the data analysis, which have been necessary for measuring the performance of the outbound Logistics and for gathering the data needed for the calculation model. The first section 4.1 discusses the most critical KPIs that have been identified during the research together with the company’s supervisors and the methodology that has been used in order to collect reliable and consistent data. The following section 4.2 describes the system that has been used to track the components in all the information systems. Section 4.3 presents the measurements’ results regarding the important KPIs and finally section 4.3 concludes the chapter.

4.1. Key Performance Indicators Definition and Methodology

It had been very essential for the next steps research to have a clear definition of performance metrics and the Key Performance Indicators that played an important role in the Logistics center. Some of them have been predefined by the department’s specialists. However, further research and study has been made in the contexts of the case in question, due to inadequate information regarding to performance measurements, to the process capability. This task has made the performance analysis more accurate and related to the company’s objectives.

The goal of improving the outbound Logistics process within the Logistics center of KLM Engineering & Maintenance is to come up with a process that performs better in terms of quality, turnaround time and cost. Changes in the process flow, the standard instructions and personnel scheduling would facilitate in meeting the requirements over the defined KPIs. The new process design and the instructions will not only benefit the quality of the outbound operations but also facilitate the process’ speed. Finally, roster’s rescheduling will only contribute in speeding the process and meeting the turnaround time requirements.

4.1.1 Quality Definition: Critical Buffer Level

The goal of the research had been first to improve the quality of the outbound process. That means stabilizing the quality’s performance and turnaround time. As it has been mentioned in Chapter 1, the factor defining the process’ performance in terms of quality at the end of the day indicates the number of uncompleted components that are place in Buffer 2. The Critical Buffer Level is the KPI that has been used for this research. Since the turnaround time has already been defined based on the contracts and the touch times have been measured, the personnel’s daily capability can also be calculated. The employee that determines the components’ release from buffer 2 is the repair administrator, therefore his/her capability is the one of great importance. Taken into consideration that 390 minutes is the pure working time per shift and 30 minutes per component is the touch time for a repair administrator, this means that on average 13 components can be processed per shift. Assuming that at least 2 employees are working per day, then 26 components per day is the minimum number of components that can be completed at the end of the day. Leaving more than 26 components in buffer 2 for more than 48 subsequent hours would mean that even if no other components will be added in the meantime, the Logistics center will fail to deliver the entire batch on time to the repair vendors. In contrast taken into consideration the First In Fist Out priority, the 26 or less components in buffer 2 would be the first to be handled in the next shift and be
Data Analysis of the Current Outbound Logistics Process

4. Data Analysis of the Current Outbound Logistics Process

Successfully completed within 48 hours or less. As a result, for the purposes of the research and its further steps the critical buffer level has been assumed to be 26 uncompleted components.

4.1.2. Turnaround Time Definition

Turnaround time has been defined as the most critical KPI of the outbound Logistics process. It regards to a component's time from the moment it arrives at the expedition of the Logistics center, until it is successfully handled by the repair administrators and sent for delivery to the repair vendors. According to the time that is agreed in the contracts 48 hours are given to the outbound Logistics personnel from the moment that a component is delivered to the Logistics center until the moment that this is ready for delivery to the repair vendors. This means that 48 hour should be dispersed to the different tasks performed by different type of employees. Measuring with a stopwatch the employee's handling times it has been roughly calculated that the cumulative touch time by every type of employee is around 1 hour (60 minutes) (Figure 17). As a result there is still a margin of 47 hours that could be added in the buffers in between. The buffers do not necessarily mean waste in the process, as long as they do not exceed a certain critical level, they have a logical existence in the Logistics center and facilitate the tasks' division. In other words, the waiting time in a buffer can vary from 1 minute to 47 hours but their aggregated time can never exceed the later number, otherwise there will be delay in the component's delivery to the repair station.

![Figure 17: Rough Touch Times' Estimation](image)

To be able to measure the overall performance of the outbound in terms of turnaround time, the process has been decomposed in four different but successive sections, which represent the different jobs in the supply chain, where different employees handle the component. In every job and after the required task is completed by the employee, a confirmation is placed in the information systems of the Logistics center. A confirmation includes data concerning the date and the time of the task, links the component's PO and individual numbers and the employee's data (either personal company's id or scanner's id). According to the date and time of each component's confirmation, the turnaround time in every job has been determined and a better insight of the overall turnaround time performance has been obtained.
4.1.4 Data Collection Methodology

The data collection included the action of certain measurements in the process. Some measurements have been performed in the real work floor by means of following the components' flow for 30 days. For this task, extra personnel had been hired so that the collection of the data could be reliable, consistent and would not intervening with the normal process. They have been working in a daily basis in shifts as the existing personnel does. One extra personnel per station within the Logistics center (Expedition, Physical Inspection, Repair Administration Pool, FE and CLA) has been accompanying the employees. The external observers, have completed checklists and performed scanning in the right points and the right time. The checklists are cited in the Appendix D Data Measurements (Table 24 and Table 25). The role of the researcher has been to supervise the task and participate when needed, collect the forms including the required data and inserting them in an excel file at the end of the day. At the end of the measurement period, reports have been created and presented to the management and the employees, demonstrating graphs through the results' statistical analysis of approximately 353 unserviceable components.

In order to make the entire outbound process measurable, it has been divided into four main areas described by the different type of employees that handle the component in the respective station and the buffers in between, where the components are left before proceeding to the next employee. The following chart (Figure 18) represents the stations where the measurements have taken place and the respective data collection method have been used. The scope of this research was narrowed to the second till fifth station; however, the measurements have been performed for the overall process. The checklists have been created in order to measure the quality of the components that are delivered in the Logistics center. The results from the quality measurements have been compared to the tracking data so as to see the impact of the components' quality to the overall handling time and turnaround time. The checklists and their description can be found in the Appendix D Data Measurements. During the period of one month several components have been measured in person (467), however only a part of them could be traced in the tracking system and give reliable results, because of the inconsistent scanning actions. The percentages in Figure 19 are the representative sample of the overall components that have been measured. However,
the plots shown in Figures 2-23 calculate the measured components' timings that have been found in the Tracking system.

4.2 Tracing by IT Systems
Several information systems like SAP, Tracking and Scarlos have been used in order to follow the components in the supply chain of KLM E&M. For the needs of the research the tracking system has been mainly used in order to count the touch time of every type of employee in every task for every type of component. Information about one year's tracking data has been exported from the system and statistical analysis has been performed to present the required graphs for the process' performance.

4.3 Data Analysis Results of the Current Outbound Logistics Process
The previous section described the data collection methodology; what kind of data have been gathered, the means and sources of their collection. This section presents the measurements' results and their detailed analysis. Several graphs that derive from an analysis in Minitab using a combination of historical data and measurements are included together with cumulative tables regarding the quality and handling times.

4.3.1 Quality: Defects
Figure 19 shows in a general map of the outbound Logistics the percentages of incurred issues of the measured components in every critical process step. The issues mentioned below are defects, that means waste that influences the process' quality (failed priority rules, lack of standardization etc), shown in blue and external quality issues (missing data/ warning sticker/ reason of removal etc., wrong data/packaging etc.), shown in red. As it has been mentioned, quality KPI cannot be quantified, nevertheless the percentages scored from the measurements, shown in the figure below (Figure 19) have shown inefficient quality that can undermine the process' performance. Section 4.3.4 quality's impact on the employees' handling time is calculated, providing a quantitative description of the importance of quality in the process.
4. Data Analysis of the Current Outbound Logistics Process

4.3.2 Turnaround Time

Turnaround time is a very critical KIP for the outbound process. Data from the tracking system in combination with stopwatch provide information regarding to the employees’ handling times and the waiting times in the buffers between. As it has been mentioned, it was impossible to trace every component during that period of time. Missed scanning during especially during evening shifts, unconsciousness and other reasons have given only a part of components’ measurements from the tracking system.

Time series plots have been created in Minitab to show the waiting times and touch times of every task in the outbound Logistics process (Figures 20-23). According to Six Sigma, the time series plot is a very useful tool that can give an overview of the components’ measured timings (Lindermann et al., 2003). Several features have been defined by the representation of data in time series plot and can identify the bottlenecks within the process (George et al., 2005). These features include:

- Outliers: values that are not consistent with the rest data
- Trends: general tendencies in movement or direction
- Periodicities: recurrences at regular intervals

The following tables (Table 2 -Table 5) display the summary statistics of the turnaround times between the measurement points in the outbound Logistics. The number of components
measured is very important figure to have an overview of the data's reliability and consistency. The mean turnaround time is presented in minutes for the tasks performed and in hours for the waiting times in the buffers, the differentiation of timings in minutes and hours can enhance the excess time of components spent in the buffers. The standard deviation presents the variation or dispersion of collected data.

Table 2: Summary Statistics of Expedition

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N (#of components)</td>
<td>773</td>
</tr>
<tr>
<td>Mean turnaround Time (minutes)</td>
<td>96.93</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>153.5</td>
</tr>
<tr>
<td>Adjusted Average</td>
<td>95.910</td>
</tr>
</tbody>
</table>

Figure 20: Time Series Plot of Physical Inspector’s Waiting Time (Buffer 1)

Table 3: Summary Statistics of Buffer 1

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>N (#of components)</td>
<td>302</td>
</tr>
<tr>
<td>Mean turnaround Time (hours)</td>
<td>24.15</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>30.36</td>
</tr>
<tr>
<td>Adjusted Average</td>
<td>27.366</td>
</tr>
</tbody>
</table>

Figure 21: Time Series Plot of Physical Inspector’s Touch Time
4. Data Analysis of the Current Outbound Logistics Process

Table 4: Summary Statistics of Physical Inspector

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N (# of components)</td>
<td>312</td>
</tr>
<tr>
<td>Mean turnaround Time (minutes)</td>
<td>11.55</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>8.175</td>
</tr>
<tr>
<td>Adjusted Average</td>
<td>12.794</td>
</tr>
</tbody>
</table>

Figure 22: Time Series Plot of Repair Administrator’s Waiting Time (Buffer 2)

Table 5: Summary Statistics of Buffer 2

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N (# of components)</td>
<td>67</td>
</tr>
<tr>
<td>Mean turnaround Time (hours)</td>
<td>28.93</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>51.63</td>
</tr>
<tr>
<td>Adjusted Average</td>
<td>11.185</td>
</tr>
</tbody>
</table>

Figure 23: Time Series Plot of Repair Administrator’s Touch Time plus Buffer 3

Table 6: Summary Statistics of Repair Administrator

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>N (# of components)</td>
<td>110</td>
</tr>
<tr>
<td>Mean turnaround Time (minutes)</td>
<td>31.47</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>31.73</td>
</tr>
</tbody>
</table>
Many conclusions have resulted from the time series plots that are presented above. First of all, it is very important to note the insufficient data that have been collected. Despite the inconsistency and the huge shortage of the data for the measured stations, the outliers and trends in the graphs are obvious.

**Employees’ Touch Times**

The touch times that are presented in the graphs above (Figure 20 and Figure 23) have shown several outliers. Outliers concern to the observations that are inconsistent with the rest data set (Barnett et. al., 1991). These abnormalities can be explained by different factors such as wrong scanning actions due to human errors, IT system errors and failed configurations to the systems. Therefore, the high peaks can be removed from the data and not be taken into consideration.

The trends in the graphs are not always consistent, meaning that the touch times can never be stable. For big deviations from the average touch time or remarkably large turnaround times imply that certain types of components require extra handling due to the issues mentioned above and/or there has been a defect in the system slowing down the task completion. Smaller deviations in touch times can be justified by the difference between the employee’s productivity and motivation to work. Because of the nature of the measured element, the periodicities of the timing presented in the graph are meaningless and there is not much to be explained about them.

The touch times statistics for the physical inspectors have presented a small standard deviation (8.175), which can be explained by some of the existing outliers. The physical inspector’s measured touch times are much closed to the expected mean value (11.55 minutes). Therefore, the adjusted average (12.794 minutes), which represents the average touch time after the outliers’ removal is very closed to the mean.

In contrast, the repair administrator’s standard deviation has a higher value (31.73); this can be explained by the fact that fewer measurements (110 components) with more outliers have been derived from the data analysis. As a result, the adjusted average (22.452 minutes) of the repair administrator’s touch time deviates almost 10 minutes from the measured mean (31.47 minutes).

**Waiting Times in Buffers**

As far as the waiting times are concerned, the outliers describe a complete different situation in the Logistics center. The waiting times are basically the time a component is placed in the buffers, therefore, the outliers which show long times in the buffer can either mean excess amount of workload delivered in the outbound Logistics, or lack of personnel’s capacity to work with the existing workload, or the combination of the two. Periodicities can also be seen in the graph, however, their existences do not necessarily have a negative impact in the process. From the periodicities the workload can be determined, since more workload means more time is needed to complete it and thus more buffering time for the uncompleted workload. In other words one can see the intervals when excess workload should be expected. The main conclusion from the time series plots of the buffer is that they have presented long waiting time in the buffer that most of the times exceeds their predefined turnaround times.
In the statistical tables of the buffers (Table 3 and Table 4), different observations have been concluded. First, the standard deviation (30.36) of buffer 1 has shown that the data deviate from the mean value (24.15 hours). This has been explained by the big outliers presented in the time series plots. Relatively small deviation among mean and adjusted average value (27.366 hours) has been presented when then outliers have been removed. However, the same does not apply for the buffer 2. The very small number of data (67 components) has resulted many extreme values and big outliers and therefore huge standard deviation (51.63). Therefore, a significantly smaller adjusted average (11.185 hours) is more representative figure for the waiting time in buffer 2.

4.3.3 Quality: Critical Buffer Level

Another feature that has been calculated is the critical buffer level that provides an overview of the process' performance by indicating the number of uncompleted components in the end of the day. The critical buffer can undermine the process’ quality as its existence and overloading implies waste within the process. The following graph presents the critical buffer level. A predefined critical level of 26 uncompleted components for two subsequent days (48 hours) can identify a problematic process flow, meaning that the Logistics Center is unable to meet the turnaround time requirements and fails on time delivery. The most important conclusion from the graphical representation (Figure 24) of the critical buffer level during last year is that most of the times the number of uncompleted components exceeds the predefined KPI. It is logical that there are no standard tendencies in same directions, in contrast there are several steep changes, which explain the immediate buffer release to catch up the turnaround time.

![Figure 24: Time Series Plot of Critical Buffer Level](image)

4.3.4 Quality's Impact on Turnaround Time

The most commonly occurred issues have been categorized, listed and presenting in the following table. For every defect- issue the percentage of occurrence, its impact on the process and its impact on the average touch time per employee has been defined by the measurements. The following tables (Table 7 and Table 8) summarize the aforementioned results for the physical inspector and repair administrator.

Table 7: Defects' Impact on Physical Inspector's Touch Time
### Table 8: Defects’ Impact on Repair Administrator’s Touch Time

<table>
<thead>
<tr>
<th>Defect</th>
<th>Percentage</th>
<th>Impact</th>
<th>Impact on Average touch time</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Missing Reason of Removal/Complaint</strong></td>
<td>9%</td>
<td>Over processing</td>
<td>0:32:23- 0:22:30 = 0:09:53</td>
</tr>
<tr>
<td><strong>Warranty Conversion</strong></td>
<td>5%</td>
<td>Over processing</td>
<td>0:36:04- 0:22:30 = 0:13:34</td>
</tr>
<tr>
<td><strong>Missing Data</strong></td>
<td>2%</td>
<td>Over processing</td>
<td>0:43:00- 0:22:30 = 0:20:30</td>
</tr>
<tr>
<td><strong>Other (ICT, facilities, talent)</strong></td>
<td>15%</td>
<td>Quality Delay</td>
<td>0:46:24- 0:22:30 = 0:23:54</td>
</tr>
</tbody>
</table>

The following figure (Figure 25) shows the most common defects and their percentages based on their scored impact on the employees' mean touch time. From the chart below it can be derived that missing warning sticker has the small impact on time, whereas missing reason of removal and warranty conversion can cause longer delays in the process. This analysis has proved the importance of accepting components with the required quality in order to have a normal process flow and no delays.
4. Data Analysis of the Current Outbound Logistics Process

4.4 Conclusion

The data analysis has been the most time consuming task performed for the research. After having defined the Key Performance Indicator, the main goal of the data analysis has been to measure the performance of the outbound Logistics and identify the problematic areas that concern both quality and the turnaround time. For the turnaround time, the 48 hours defined in the contracts can be divided in the touch times of the tasks and the waiting times in the buffers between them. Another attribute has been added and relates mostly to the quality and relates to the overall turnaround time is the critical buffer level described by the number of uncompleted components still placed in buffer 2 at the end of the day. From literature the critical KPIs have been defined and calculated, thereafter a data collection plan has been developed. The plan included measurements in the actual working field by actively participating in the process and joining shifts. Reliable data has also been retrieved by the tracking system. Finally the figures that have been presented above show the process' poor performance and the bottlenecks have been finally identified. The main conclusion of the data analysis is that the outbound Logistics most of the times fails to handle the complete workload on time, and this can be justified in various ways. Excess workload, lack of personnel's capacity to complete the expected workload, low personnel's productivity, components with defects that require extra work or inefficient process steps and in general waste are some of the findings from the performance measurement and observations during its execution. The results of the data analysis and the presentation of the current process' performance have been used as milestones for developing a certain set of solutions that are presented and elaborated in the following chapter.

Figure 25: Pie Chart of the Defects' Impact on Mean Touch Time

Defects' Impact on Mean Touch Time

- Missing Warning Sticker: 11%
- Wrong Packaging: 12%
- Other (Wrong Lane): 4%
- Missing Reason of Removal/Complaint: 25%
- Warranty Conversion: 29%
- Missing Warning Sticker: 12%

2%
4. Data Analysis of the Current Outbound Logistics Process
5. Findings and Set of Solutions for the Improvement of the Outbound Logistics Process

After the literature review, action research has been performed. The Kaizen event is one action tool that according to Lean manufacturing can be used in order to improve the overall Logistics process (Akbulut-Bailey, et al. 2012). Active participation and valuable input from have been given in the decision making concerning the future state. This task has been performed to develop a completely new design of the outbound Logistics. Based on the Lean strategy (Cua, et al.2001), (Shah, et al. 2008), changes have been proposed not only in the design layout of the Logistics center, but also in the physical process flow of the component and the personnel scheduling.

5.1 Solutions Overview

The main problem, its causes and their root causes have been defined and presented in the fishbone diagram in Chapter 1 (Figure 2). The extended data analysis has shown the most critical bottlenecks that undermine the process’ performance. The most critical factors of the cause and effect analysis have identified the milestones for the project’s initiatives that need to be taken into consideration towards the improvement of the outbound Logistics. The figure below (Figure 26) proposes one or more solutions for each factor that can trigger the process’ efficiency and effectiveness. A detailed elaboration and action plans for the suggested solution as agreed together with the company’s supervisor and management teams towards improving the process in a more lean way lay in the following sections.

| Method | • Standard Way of Working  
| Material | • Future State Design  
| Performance Management | • Requirement of the Complete Component  
| Workload | • System Interface  
| Machine | • Printers  
| Man | • Scheduling  
| Environment | • Communication  
| Suppliers/Customers | • Contract Details  

Figure 26: Project’s Initiatives and Set of Solutions
The following workflow diagram presents the suggested set of solutions, the links among them and their logical priority according to the company's needs and capability (Figure 27).

The suggested solutions include a complete set of actions that need to be taken into consideration for the improvement of the outbound Logistics. Nevertheless, the benefits of these solutions are multiple and explained in the following sub sections. Priority had been given to several steps so that the output from their completion could be taken and used for further actions. As it is shown in the figure above (Figure 27), several solutions are connected to each other stating the input/output requirements for their realization. Finally, a complete independent suggestion, proposing the outsourcing of the Logistics process, is presented as well, but is left out of this research's scope. The following sections introduce the set of solutions and elaborate on their benefits and their implementation plans.

5.1.1 Requirements for the Complete Component

Process' standardizations need clear definition of the input and output requirements for completing a component's handling. Therefore, all the tasks and data that are necessary for a component "ready to outsource" have been researched and listed. Joining shifts with the employees on the floor has created a first overview of every step that is needed to complete their tasks. Valuable information has been taken by this action and helped construct a meeting with all the employees. The so called "Ready for Outsource" meeting that has been held, addressed to the employees (repair administrators), whose main question was to list every step and screen they use in the system when doing their job. Attention had been given to the input requirements necessary for the system to run the process. Finally the output of
5. Findings and Set of Solutions for the Improvement of the Outbound Logistics Process

every step taken had been clearly defined so that after examination and evaluation only added value actions should exist in the finalized standard way of working.

Putting all the required information into a formal list was very essential for continuing the process improvement and end up with standards regarding to the way of working and processing the components (section 5.2). Therefore, standard rules and guiding lines can be formally reported. The tables with all the data requirements for the components' completion can be found in the Appendix G Ready for Outsource List (Tables 28-32).

5.1.2 Standard Way of Working

Multiple Value Stream Mapping sessions have been scheduled during the project’s execution. The goal of the sessions was to come up with new process flows that would help the personnel meet the quality and turnaround time requirements in more efficient way, avoiding variations in the performance and thus making the process leaner (Hopp et al., 2004). More clear and simple tasks for the complicated work of the repair administrators have been assigned to the personnel. The information for the 'Ready for Outsource" meeting (Section 5.1.1) have been used in order to simplify the repair administrator's tasks while integrating the IT systems workplaces so as more data could be retrieved with less used screens and input.

After the IT department of KLM Engineering & Maintenance responsible for the project mentioned above, have completed the software simplification, then the manager of the Logistics center can create new working instructions and rules for the employees. The main outcome of this solution would be to gain extra minutes from the repair administrators' task and make the process run faster, because less complicated steps would be taken while more output would be easily retrieved with the least required input.

5.1.3 Contract Details

In section 5.1.1 the input and output requirements for completing a task have been defined. After processing the necessary data, a list of important requirements has been created. Therefore, it is very essential that these requirements will be integrated in the contract details with the customers, so that all the required information will always be available and ready to be used in order to facilitate the employees work. A standard format should be introduced for every customer and a single delivery process should be implemented, so that no other deviations could possibly occur. Thus, no component’s delivery can be completed without giving every information and data. An example of the Aeroxchange format is presented above (Figure 28) and should be adopted by every customer of KLM Engineering & Maintenance.

Client Interface department of KLM Engineering & Maintenance would be accountable for the immediate communication with the customers. Although new agreements and contract with the customers is a time and effort consuming task, the benefits that could results from this action are very essential for the overall process. Given the proposed standardized delivery format and the software capabilities, the process would become automated and the percentages regarding to the bad quality performance will be reduced resulting to faster turnaround time.
5.1.4 Communication

Communication is very essential to the improvement of the employees’ performance. For the case in question, the communication has a double meaning. First, it refers to the bottom up and up bottom communication of employees with the managers and supervisors. The frequent physical presence of high managers in the workplace gives a very good example and caring emotion for the business. Moreover, short daily meetings among supervisors and employees create solidarity and a good atmosphere where people can share their problems, thoughts and concerns. Thus, the communication between the employees is facilitated and therefore, both employees and supervisors can have a mutual understanding and a feeling that their voices are being heard. Research has shown that the good communication in all levels of hierarchy can have a significant impact on the employees’ productivity and thus the process’ effectiveness (Darling et al., 2010).

5.1.5 Workload

The workload’s definition is very essential for the forecast of the incoming components’ deliveries, so as to assure that there is enough capacity in the Outbound Logistics every day and in every shift to complete and handle the components within the time constraints. The process Analysts of the Logistics Center, who have complete access to the systems, are accountable for creating reports regarding to incoming goods flow. Detailed reports should be issued frequently and used in multiple ways to predict the workload that is expected in the Logistics center. The graphs have been created from tracking system's data of the previous year (Figures 29-31). The workload has been divided and presented for number of components per month, day and hour for every stream of the Outbound Logistics (Pool, FE, CLA). The trends presented in the graphs are valuable input for forecasting the busiest periods where incoming workload could block the normal process flow.
5. Findings and Set of Solutions for the Improvement of the Outbound Logistics Process

The entire data set from the tracking system in combination with the quality measurements in chapter 4.3 have been taken as input for the implementation of the process' simulation in the following chapter.

**Figure 29: Monthly Deliveries in the Outbound Logistics**

The graph above (Figure 29) presents that the monthly workload. As it can be seen, the monthly workloads of Pool and FE components are relatively stable during the year. However, for CLA components, the data show that the busiest months are mostly January, April, May, June and December. This can be explained by the fact that these months are also the busiest months in operating flight due to holidays, therefore, more aircrafts require maintenance and tests and consequently more unserviceable components are detected and sent to KLM Engineering & Maintenance.

**Figure 30: Weekly Deliveries in the Outbound Logistics**

Similar analysis has been performed for the daily workload as well. The three components' streams present similar trends. The most obvious outcome from the graph above (Figure 30) is that weekdays are the busiest days during weeks, while less components should be expected in the outbound Logistics. Due to the fact that most of the aircrafts' maintenance is scheduled during weekdays and more personnel is working, the more unserviceable
components are delivered in the Logistics center during these days. Based on this outcome several scheduling scenarios have been created and tested in chapter 6.

![Figure 31: Hourly Deliveries in the Outbound Logistics](image)

The final analysis of the workload is presented in graph 31. This includes the hourly workload of unserviceable components. Useful information from this graph has also been used for the scenarios creation and evaluation of whether evening shifts are necessary. The most significant outcome from the analysis is that the peak of unserviceable components’ deliveries in the Logistics center is between 13:00 and 17:00 for FE, 15:00 and 17:00 for CLA components, while continuous flow of Pool unserviceable components from 6:00- 22:00 exists in the Logistics center. Only a few or no components are delivered over night.

5.1.6 Scheduling

After having introduced a new process flowchart for the outbound Logistics and a completely new design of the infrastructure layout in the Logistics center, an improved employees' roster should be suggested. Experimenting with the personnel schedules could benefit the company in many ways. During the Value Stream Mapping sessions, there has been identified lower personality's productivity in certain shifts and positions, more specifically during weekends and hours during the day where there are no track arrivals in the expedition. Moreover, higher salaries are given to the employees working on weekends and night shifts and there is not a constant occupation of the employees during the day. By rescheduling the employees’ roster within the outbound Logistics, significant amounts of cost can be saved and a full occupation of employees can be achieved.

For the purposes of the research an algorithm has been developed in chapter 6. The algorithm aims to solve the problem of limited capacity in the Outbound Logistics, by providing the best scenario, over the number of employees needed per day and shift, while minimizing the cost of their salaries. The best scenarios are selected based on their cost minimization and the higher score on the critical buffer level. Multiple scenarios have been created and simulated in excel to test their performance.
5. Findings and Set of Solutions for the Improvement of the Outbound Logistics Process

5.1.7 Future State Design

When talking about Lean, the need of a new design process lay-out should also be taken into consideration. The following process steps (Figure 32) have been used as guide map for reorganizing the infrastructure within the Logistics center, while facilitating the physical flow of the component in the outbound and assisting the personnel’s operations. The figure below (Figure 33) represents the proposal of the Engineering Design lay-out according to the Lean principles. The proposed design is not very different from the current state of the Outbound Logistics. As mentioned in the process' description three different flows can be distinguished. Therefore, there a clear separation between the three lanes has been created and special employees have been assigned for every flow. The new design proposed the combination of the "Pool's", "FE's" and "CLA's) tasks by one employee type. In other words the task of the physical inspector and repair administrator has been combined into a single one. The added value of the new lay-out of the outbound Logistics within the Logistics center concerns to a process with less waste due to less movement during the components' handling. Moreover, less time would be spent in making critical decisions since experts from each stream would be assigned to handle each type. Finally, the complete removal of the buffer between the physical inspection and repair administrator (buffer 2), would save remarkable time as each component could be completed within approximately 30 minutes once it is picked from the initial buffer.

After integrating the previously mentioned plans for every solution, a new process flow has been designed and should be taken into consideration for the process improvement. The new state should be simulated, tested and compared with the existing process for every scenario in order to select the best alternative, in terms of cost and critical buffer, for the improved Outbound Logistics. The figure below represents the general future state process steps (Figure 32). It is logical that radical changes cannot be implemented in the process, since it is only described by the critical tasks that need to be completed in the Outbound Logistics. However, it was considered more efficient to introduce a more incremental differentiation, by combining the two most critical activities, which are the physical inspection and the repair administration. In that way, the buffer 2, that is causing very big delay in the turnaround time of the process, will be automatically removed. The same employee will be assigned to complete both of the tasks subsequently for the same component, contributing to its faster competition.

![Figure 32: Future Process Steps](image-url)
5. Findings and Set of Solutions for the Improvement of the Outbound Logistics Process

5.1.8 Performance Management

Performance management solutions have been investigated and attempted to be connected to the Logistics center’s operations. The most critical element that can become quantified and measured regularly in the Outbound Logistics is the turnaround time. It has been confirmed that the most reliable way of taking information about the turnaround time automatically is the tracking system. Therefore, consistency in scanning is required in every station by every employee in the Logistics center. Above, there is a design layout of the Outbound Logistics with the proposed scanning points and rules that need to be followed strictly in order to retrieve realistic data any time wanted. Deviations from the desired KPIs can indicate the bottlenecks in the process and correctly actions can be performed immediately.

In Appendix G Scanning Points (Table 24) there is a description of the future state scanning points that are shown in figure 32.

Another method that is still in an experimental phase regards the Radio Frequency Identification (RFID). RFID uses wirelessly electromagnetic fields to automatically identify, and track a component. When a component enters the Logistics center a unique RFID tag will be issued, the component's documentation will be scanned and stored electronically to the tag’s data base. In contrast to the Tracking system's barcode, the tag does not necessarily need to be within line of sight of the reader and may be embedded in the tracked component. Valuable information and data of the component can automatically be retrieved and used any time needed. The proposed method has been recently introduced in the Logistics center. Its function can save time and effort that Tracking system requires while minimizing the risk of inconsistent and unreliable data. Further research and investigation should be performed for its correct installation and implementation and the recognition of its full potentials and benefits.

Performance Management is a big project that needs to attention and constant supervision. Initiators of the project in question can assign tasks to employees for the execution of Performance Management. The project can acquire a scientific character by addressing to students with technical and managerial background to assist in its realization. The proposed project is of very big importance as it can contribute to the continuous improvement of the outbound Logistics.

5.1.9 Outsourcing the Logistics Process
5. Findings and Set of Solutions for the Improvement of the Outbound Logistics Process

Another solution that is completely separate and independent from the ones mentioned above proposes the outsourcing of the Logistics process of KLM Engineering & Maintenance to external company. In few words, the company could benefit from outsourcing the Logistics process in terms of space saving, personnel reduction, infrastructure and facilities occupation and perhaps more reliable and efficient process. Outsourcing one of the company's businesses requires more research and an extended cost benefit analysis to show the real savings that might come out of this action. Moreover, the selection of the appropriate Logistics Company would regard to a completely new project.

5.3 Project's Scope and Limitations
The scope of the report has been narrowed down out of the nine set of solutions presented in the previous section. Several limitations have led to focus and elaborate more on the personnel's scheduling.

First of all the identification of the process and orientation within the process turned out to be a time consuming task. A great amount of time was also dedicated in data collection and measurements performed within the Logistics center. The benefit out of these steps, have been to define the process in a clear and as consistent way as possible. Moreover, the acquisition of reliable and correct data has been very important for the project's development and results.

The implementation of some of the previously mentioned solutions requires the permission and approval of higher managers. For other topics discussed the collaboration of different shareholder in and outside of the Logistics center is needed. Moreover, most of the solutions propose application over time, long term results and time consuming implementation. That is the reason why most of the previously mentioned topics are placed in this chapter in terms of recommendation for further projects, while most of them are already in an execution process.

From the data analysis (Chapter 4) the main bottlenecks have been identified. The results concluded that one of the reasons of long turnaround times and excess critical buffer is the insufficient personnel's capacity to handle the incoming workload. One of the solutions mentioned in the previous subsections suggested the organization of the outbound Logistics in terms of manpower. The scope of the project has been narrowed down to one solution that fits to a thesis time frames and its outcomes could have a scientific contribution, whilst the model developed for this purpose can be used for future or similar projects. For this reason, a new scheduling plan that would be able to minimize the turnaround times, reduce or even remove the critical buffer and of course provide one more cost efficient solution have been developed. The following Chapter 6 presents a scientific method to attack the problem of inadequate personnel in the Logistics center and propose scheduling scenarios that provide good performance and cost efficiency.

5.4 Conclusion
After the data analysis the bottlenecks and problematic areas within the process have been identified. Chapter 5 presented a complete solution action plan that covers all the predefined root causes of the waste within the process. Nine set of solutions have been proposed in this research. Their description and people in charge of their implementation are stated in the subsection. However, the implementation of most of them could not be included in this report, due to certain limitations that have been explained above. The work scope has been shifted to a specific solution that leads to the outbound Logistics process' improvement in terms of quality, turnaround time and cost.
5. Findings and Set of Solutions for the Improvement of the Outbound Logistics Process
6. Algorithm's Development for the Improvement of the Outbound Logistics

6.1 Algorithm's Development

This chapter introduces the algorithm that has been developed for the purposes of the research. It mainly regards a tool that has been creating in order to solve one of the main problems regarding the capacity of employees with respect to the daily workload. In the first section there is a brief introduction to the main function of the algorithm. This Section provides a detailed description of the algorithm, the main variables being used and the functions that calculate the important elements and the diagram flow of the calculation model that is used for the algorithm's application in excel. Further details and its formal statement can be found in the appendix. The simulation of the outbound Logistics process has been performed in terms of the calculation model and is cited in section 6.2. The data and scenarios creation have explained in the subsection 6.2.1 and 6.2.2. The simulations results and the algorithms' verification and validation have been presented next. Finally, Chapter 6 concludes the approach that is followed to solve the scheduling problem and proposes the best scenarios according to the simulation's results.

6.1.1 Introduction to the Algorithm

As it has already been mentioned in the methodology followed for the research in chapter 1, the workload regards the unserviceable components' flow. It can be considered as a parameter that cannot be influenced nor ignored, only forecasted by historical data and an analysis of the existing customers. Therefore, the system of the outbound Logistics is a push system, in other words every component that enters the Logistics center must be process and completed as soon as possible and no later than the time requirements indicated in the contract with the costumers. As a result the personnel's capacity can be used as a variable that when it is stimulated according to the workload, the process flow can run successfully, while minimizing the operating cost of the Logistics center and assuring that the time requirements are always met.

The algorithm being developed in this report tests the multiple scenarios for the employees scheduling. Two different versions of the algorithm have been examined in order to calculate the two states of the process that are being proposed in the solution. The two versions of the algorithm are based in the same philosophy; the only differentiation is that the first one represents the process as it is, while the second combines the two main tasks of the outbound Logistics using one type of employee.

The algorithm includes mainly a repeat loop that represents the shifts in the Outbound Logistics. For every repetition or shift the number of components that are delivered in the Logistics Center, the number of employees per task (physical inspector and repair administrator) and their capacity in handling any type of component, are given. Moreover, a maximization function is calculating the maximum number of components that can be processed by each employee. For every loop the algorithm calculates the number of each type of components and their handling time by every employee. Finally, based on the
handling time calculated, the algorithm gives the number of completed components and the number of uncompleted components. If the number of uncompleted components of the end task (repair administrator), is bigger than the KPI that has been defined, then the algorithm should give the order to hire more staff in the shift. The repeat loop continues until giving the minimum number of employees that are needed in order to complete the required number of components on time that means not exceeding the predefined KPI.

6.1.2 Description of the Algorithm

For understanding better the orders and the function of the developed algorithm, its formal statement has been presented in a pseudo code in the appendix (Appendix I Formal Statement of the Algorithm) and in a flow diagram in the next section. The algorithm is described by constants, independent and dependent variables and their constraints. Below, there is a brief definition of the algorithm's function.

The first step that needs to be done for the calculation model has been to define the independent variables. A complete set of constants and variables that have been measured within the existing process have been taken as input for the model developed.

In the context of this simulation two different types of employees have been taken (1. physical inspector, 2. repair administrator and two in between buffers and one critical buffer that represents the number of uncompleted components in the end of the shift.

The number of unserviceable component delivered in the Logistics center, can be categorized in 8 different types. Each of these types of components has difference percentage of occurrence in the process and different touch times are attached for every of the employees. A random value between minimum and maximum measured time has been selected each time during the simulation's execution.

Another constant that should be taken into consideration is the maximum process capability for every employee based on the number of components delivered in the Logistics center and their required touch times. In other words, the maximum number of components that can be handled by the employees during one shift is calculated by a maximization function. The employees' process capability per shift is a very useful figure, as it will define the number of completed component in later phases.

In the next steps the model performs a set of variables' calculations to be used for the final output. The number of components existing in buffer 1 can be calculated by the number of components delivered in every shift plus the number of unprocessed in buffer 1 from the previous shift. Moreover the buffer is divided in different type of component based on the known percentages. The number of components per type and their touch time have been used to calculate the overall handling time of the physical inspector. The calculated handling time includes the time that the physical inspectors, working in the shift, need to complete the entire buffer 1. This handling time divided by the number of physical inspectors gives the turnaround time for one physical inspector. A conditional function calculates that if the handling time is longer than the shift's time (390) then it means that the physical inspector can only provide his/her maximum capability, leaving the rest uncompleted components in buffer 1 for the next shift. Otherwise, if the handling time is less or equal to 390 minutes, it basically means that the physical inspectors are capable to complete all the components in buffer 1. Finally, the number of completed components from this task is added to buffer 2, where the unprocessed components from the repair administrators are placed.
The same calculations are performed for the second type of employees, the repair administrator. Different touch times and therefore process capability are attached to the repair administrators' data. Further, it is logical that for the normal process flow more repair administrators are needed per shift.

Finally, the number of uncompleted components by the repair administrators has been added to the critical buffer, which defines the end process capability and implies the components' on time delivery to the repair vendors. Based on the Logistics center's rules and turnaround time's requirements, a critical buffer that exceed the predefined KPI (26 components) for four subsequent shifts or more, means that the buffer is significantly overloaded, has touched the limit and the components cannot be completed within the contracted requirements and thus more employees are needed to handle the workload. More than 26 components in buffer (maximum number of components that can be handled per shift) mean that the component's turnaround time will exceed 48 hours that are agreed in the contract with the customer.

*Best Scenario Selection*

The output of the algorithm included information regarding to weekly cost of personnel’s employment. Every scenario created compromises by different number of employees per shift and day and multiple combinations have been created. Based on the calculation model regarding to their handling times and number of incoming components, the critical buffer level in the end of the shift can be calculated. The best scenario for the outbound Logistics should include a proposal of the minimum cost combined with the highest critical level accomplishment.

*6.1.3 Flow Diagram of the Algorithm*

The flow diagram presented below shows a schematic representation of the algorithms' calculation model (Figure 34). The exact steps that are followed and calculations performed to deliver the requested results can be found in this flow diagram. The algorithm is not only formally stated in a pseudo code but also designed in a flowchart to emphasize the its logical calculation steps rather than the syntax of a specific programming language. Thus, the flow diagram can be converted to several major programming languages.
6. Algorithm's Development for the Improvement of the Outbound Logistics

Figure 34: Algorithm's Flowchart

Start

\[ \text{in} = 1 \text{ to } 730 \]

Input Components

Calculate nr of Components in Buffer 1

Calculate nr of Components per type

Calculate Physical Inspector's handling time of the Components in Buffer 1

If handling time = shift

Completed Components equal to Physical Inspector's maximum capability

No

Number of completed Components equal to number of Components in Buffer 1

Calculate nr of uncompleted Components

No

Completed Components, PhysicalInspector's handling time of Components in Buffer 1

Calculate nr of Components in Buffer 2

Calculate nr of Components per type

Calculate Repair Administrator's handling time of the Components in Buffer 1

If handling time = shift

Completed Components, Repair Administrator's maximum capability

No

Number of completed Components equal to number of Components in Buffer 1

Calculate nr of uncompleted Components

No

Calculate Critical Buffer Level

If Critical Buffer Level <= 26 for four subsequent shifts

Add On Time Delivery

Output On Time

Yes

Go to the next Shift
6.2 Algorithm's Implementation

The simulation model and all the steps for its design are described in this chapter. The reason of using simulation for the research is to test the future state of the outbound process and measure its performance on multiple scenarios. The simulation regards basically to the implementation of the algorithm developed in the previous chapter, adjusted in the requirements of the process in case. Several scenarios have been created and tested in excel, providing results for the process' performance.

6.2.1 Data Creation

The data used for the simulation have been created by different means and therefore represents a reliable sample for testing the realistic process in the outbound Logistics.

Personal measurements and joining shifts with the employees have helped define eight types of components, described according to their condition (complete, missing data etc.), see Appendix J Data Creation (Table 32). The method for the collection of the required data has been elaborated in Chapter 4, where the data analysis has taken place. As it is mentioned, extra personnel was hired to act as an external observer and monitor the components' flow, while completing several forms, for 30 days. The forms included aspects regarding to components' quality, when arriving in the Logistics center and the actual handling time of the components by the employees. Finally, summarized tables have been created including information of 353 unserviceable components. The percentages of their occurrences have been summed up and attached in every type of component. Different touch times per type of component and employees have also defined by the counting with stopwatch during the measurements in combination with the tracking system (Table 33 and Table 34). For every type of component a function estimates a random value between the minimum and maximum estimated touch times. The random function provides a more realistic figure for the used touch times. Finally the maximum capacity per shift had to be taken into consideration. A maximization function calculates the maximum number of components that could be completed by every type of employee (physical inspector and repair administrator) within 390 minutes, which is the estimated actual productive time per shift.

The number of components delivered in the Logistics center per month, day and shift has been taken by last year's tracking data. The tracking system has been used to retrieve information for the touch times of every type of component by every employee. Information regarding the number of physical inspectors and repair administrators per shift (scheduling), together with the cost of every employee per day and shift have been retrieved from the company's network folders.

6.2.2 Scenarios Creation

The scenarios that have been tested are based on the previously mentioned information and have been approved by the company's supervisors. There are two versions of the process that have been tested in order to define the best process design. The first version is similar to the existing process, defined by two different tasks which must be completed by two employees, the physical inspector and the repair administrator. Following the components' physical flow the repair administrator could start processing the component only when the physical inspector had completed it. The second version presents a significant adjustment to the process; according to this version, the tasks in the outbound Logistics have been combined and executed by the same employee, in other words there is only one task by one employee type. As expected, the data have been adjusted to the needs of the new process.
Therefore, the touch time has been changed and the number of employees (scheduling) and their cost has altered. For the scenarios creation it has been taken into consideration that the company is a 24/7/365 business.

Since KLM Engineering & Maintenance operation is dependent to its customers (airlines and KLM), full time employment is required in order to satisfy its customers and always meet the time requirements. Therefore, the entire supply chain never stops running. The same applies for the Logistics center as well. Never ending process flow demands sufficient manpower to cope with the daily workload. Full time shifts are suggested by the first scenarios of two versions.

From the workload analysis performed in sub section 5.1.5 the daily average workload can vary depending the month of the year and the hour of the day. A rough estimation of the forecasted workload requires from 1-4 employees per day to handle the components and deliver them on time to the repair vendors. Since the repair administrator's task is more time consuming than the physical inspector's, the latter's capacity is bigger than the repair administrators, thus, for every scenario fewer physical inspectors are required per shift in comparison to the repair administrators.

In many cases, however, it would be possible to skip certain shifts. Analyzing the previous year's workload it has been concluded that most incoming goods are delivered to the Logistics center in the morning shifts and during week days. As a result, evening and weekend shifts can be removed from the weekly schedule. In the calculation model the scenarios have tested the suggested alternations in the schedule. Two of the scenarios per each version propose either shift only during weekdays or only day shifts, since evening and weekend shifts pay higher wages to the employees.

As it has been mentioned the need of full physical inspector's capacity is not always necessary. As long as the repair administrators cannot process the entire workload, the physical inspector’s full time employment does not add any value to the process, besides that buffer 2 overloading that can be considered waste. Therefore, certain scenarios of version 1 test the process performance when no physical inspectors work either during evening or weekend shifts, which are the most expensive shifts.

**Version 1 Scenarios**

Table 9 summarizes all the suggested scenarios that have been created and tested for the first version and their descriptions are presented above.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Weekday/Weekend</th>
<th>Day/Evening</th>
<th>Physical Inspector</th>
<th>Repair Administrator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Weekday</td>
<td>Day</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1.2</td>
<td>Weekend</td>
<td>Day</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1.3</td>
<td>Weekday</td>
<td>Day</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>Day</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
6. Algorithm’s Development for the Improvement of the Outbound Logistics

1.1 Full Time Shifts

The first scenario represents an alternative that is very close to the current state in the outbound Logistics center that means that there during weekdays there are 3 physical inspectors in day shifts and 1 in the evening. During weekends there is only one physical inspector for the morning and one for the evening shifts. The schedule of the repair administrators is the same for the entire week, 4 in the morning and 2 in the evening (Table 10).

<table>
<thead>
<tr>
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<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>Day</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1.2: Day Shifts

Scenario 1.2 testes the process’ performance with no evening shifts, as higher wages are paid during these shifts. 3 and 1 physical inspectors during weekdays and weekends respectively and 4 for every day shift of the week are proposed in this scenario (Table 11).

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Weekday/Weekend</th>
<th>Day/Evening</th>
<th>Physical Inspector</th>
<th>Repair Administrator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>Weekday</td>
<td>Day</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>Day</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1.3: Weekday Shifts

In contrast with the previous scenario 1.2, this scenario suggests no weekend shifts. The number of physical inspectors in day and evening shift would be 3 and 1, while the repair administrators 4 and 2 (Table 12). The reason why no weekend shifts are included in this scenario lies to the fact that maximum wage is paid for the employees working during weekends.
6. Algorithm's Development for the Improvement of the Outbound Logistics

Table 12: Scenario 1.3 Weekdays Shifts

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Weekday/Weekend</th>
<th>Day/Evening</th>
<th>Physical Inspector</th>
<th>Repair Administrator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3</td>
<td>Weekday</td>
<td>Day</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>Day</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1.4: Day & Weekday Shifts

This scenario tests how would the process perform if no there would be no one working on the evenings and the entire weekend. Basically, only day week shifts are included in scenario 1.4, whereas the most expensive shifts are excluded from the weekly schedule (Table 13).

Table 13: Scenario 1.4 Day and Weekday Shifts

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Weekday/Weekend</th>
<th>Day/Evening</th>
<th>Physical Inspector</th>
<th>Repair Administrator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4</td>
<td>Weekday</td>
<td>Day</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>Day</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

1.5: Physical Inspector-Day Shifts, Repair Administrator-Full Time

As it has been mentioned the constant presence of physical inspectors does not always add value to the process' performance. Therefore, a scenario should be tested in which the physical inspector does not work during evening shifts (Table 14).

Table 14: Physical Inspector-Day Shifts, Repair Administrator-Full Time

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Weekday/Weekend</th>
<th>Day/Evening</th>
<th>Physical Inspector</th>
<th>Repair Administrator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td>Weekday</td>
<td>Day</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>Day</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

1.6: Physical Inspector-Weekday Shifts, Repair Administrator-Full Time

In respect to the previous scenario 1.5, this scenario tests the process flow when no physical inspector is working during weekends (Table 15).

Table 15: Physical Inspector-Weekday Shifts, Repair Administrator-Full Time

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Weekday/Weekend</th>
<th>Day/Evening</th>
<th>Physical Inspector</th>
<th>Repair Administrator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>Weekday</td>
<td>Day</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>Day</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>
6. Algorithm’s Development for the Improvement of the Outbound Logistics

Version 2 Scenarios

Similar scenarios have been created for the second version that is proposed for the outbound Logistics process (Table 16). The first scenario examines full time employment, while the rest test the process’ performance for only weekdays and/or only day shifts, which are the most cost efficient from the others.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Weekday/Weekend</th>
<th>Day/ Evening</th>
<th>Physical Inspectors &amp; Repair Administrators</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Weekday</td>
<td>Day</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>Day</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>2</td>
</tr>
<tr>
<td>2.2</td>
<td>Weekday</td>
<td>Day</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>Day</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
</tr>
<tr>
<td>2.3</td>
<td>Weekday</td>
<td>Day</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>Day</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
</tr>
<tr>
<td>2.4</td>
<td>Weekday</td>
<td>Day</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>Day</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
</tr>
</tbody>
</table>

2.1: Full Time Shifts

As for scenario 1.1, scenario 2.1 proposes full time shifts for the employees in the outbound Logistics. Full time operation with the adequate capacity can most of the times ensure the on time delivery (Table 17).

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Weekday/Weekend</th>
<th>Day/ Evening</th>
<th>Physical Inspectors &amp; Repair Administrators</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Weekday</td>
<td>Day</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>Day</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>2</td>
</tr>
</tbody>
</table>

2.2 Day Shifts

Same as scenario 1.2, the more expensive evening shifts should be excluded and the performance of the outbound Logistics should be tested for only day shifts (Table 18).

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Weekday/Weekend</th>
<th>Day/ Evening</th>
<th>Physical Inspectors &amp; Repair Administrators</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.2</td>
<td>Weekday</td>
<td>Day</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Evening</td>
<td>0</td>
</tr>
</tbody>
</table>
6. Algorithm’s Development for the Improvement of the Outbound Logistics

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Weekday/Weekend</th>
<th>Day/ Evening</th>
<th>Physical Inspectors &amp; Repair Administrators</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Weekday</td>
<td>Day</td>
<td>4</td>
</tr>
<tr>
<td>2.3</td>
<td>Day</td>
<td>Evening</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Weekday</td>
<td>Day</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>Evening</td>
<td>0</td>
</tr>
</tbody>
</table>

2.3: Weekdays Shifts

Same as the previous scenario, Scenario 2.3 tests the process and on time deliveries when no one is working during weekend shifts (Table 19). The most expensive shift is removed and therefore the critical buffer level should be the determinant factor.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Weekday/Weekend</th>
<th>Day/ Evening</th>
<th>Physical Inspectors &amp; Repair Administrators</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4</td>
<td>Weekday</td>
<td>Day</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>Evening</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Weekend</td>
<td>Day</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Day</td>
<td>Evening</td>
<td>0</td>
</tr>
</tbody>
</table>

2.4: Weekdays Day Shifts

One final scenario that could be tested suggests the operation of the outbound Logistics only the weekday’s day shifts (Table 20). The shift with the lower wage would be the only active during week.

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>Weekday/Weekend</th>
<th>Day/ Evening</th>
<th>Physical Inspectors &amp; Repair Administrators</th>
</tr>
</thead>
</table>
| 6.2.1     | Implementation and Results

Different scenarios have been presented in the following tables (Table 8 and Table 15). The scenarios have been adjusted to the independent variables' data sets that are the percentages of types of components that regard the quality and have had an impact on the overall touch time; and the number of employees per shift and day that represents the capacity of the outbound Logistics. The Appendix J Data Creation includes the entire data sets and constants that have been used for the process' simulation (Table 32, Table 33 and Table 34). The main elements that the scenarios have tested are the shifts and days when no employees, either physical inspectors or repair administrators or both, are working in the outbound Logistics. Cutting hours from the weekly schedule has resulted less costs for the company. Therefore, the proposed calculation model should provide the best scenario in terms of cost while meeting the turnaround time requirements and minimizing the critical buffer level. A combination of different number of employees per day and shift are described in each scenario have been presented in the previous section.

The scenarios mentioned above have been simulated in excel using the algorithm developed in section 6.1. The graphs that show the results regarding to the critical buffer level and as a
6. Algorithm’s Development for the Improvement of the Outbound Logistics

conclusion the on time delivery, can be found in the Appendix K Simulation Results. The following table (Table 21) scores the scenarios’ performance in respect to the defined KPIs.

The decision making factors for selecting the best scenario are reflected to the critical buffer level that is connected to the turnaround time and the cost efficiency. The main outcome of the process' simulation is the number of uncompleted components that remain in the end of the shift, depending on the employees' scheduling. It has already been mentioned that this number should not exceed a certain number for several continuous shifts; otherwise the components will be delivered with delay, failing to meet the turnaround time (48 hours). The graphs in the Appendix K Simulation Results (Figures 41-50) represent the number of uncompleted components. Those that have not exceeded the critical level (26 components in the end of the shift) for more than four subsequent times have been counted and translated into percentages of on time delivery in Table 21. After implementing and testing the scenarios, the scores of exceeding this critical level or not have been presented.

The cost of employing the employees needs to be taken into consideration. A very critical factor in the decision making process of selecting the best scenario is to minimize the cost. For every scenario, different schedules have been proposed. As the cost of every employee per shift is already known, from internal sources, the calculation of their weekly cost has been presented in the table below (Table 21).

Table 21: Simulation’s Results

<table>
<thead>
<tr>
<th>Scenarios</th>
<th>On time delivery</th>
<th>Cost (Euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Version 1</td>
<td>Version 2</td>
</tr>
<tr>
<td>1</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>2</td>
<td>88%</td>
<td>0%</td>
</tr>
<tr>
<td>3</td>
<td>99.99%</td>
<td>50%</td>
</tr>
<tr>
<td>4</td>
<td>0%</td>
<td>1%</td>
</tr>
<tr>
<td>5</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>99.99%</td>
<td></td>
</tr>
</tbody>
</table>

6.2.4 Verification and Validation

The verification and validation are two concepts closely related to each other and are very important to justify the reliability of the calculation model's results and ensure its correct execution. After verification and validation of the calculation model valuable analysis and conclusions can be presented. Verification regards to the determination of whether the models assumptions, variables and data have been correctly translated into the used computer software. Whereas, the validation is concerned the accurate representation of the process is the simulation model (Law et al., 2000). This section presents the efforts that have been made to verify and validate the model.

First, the model has been constructed gradually; meaning that its creation has started with a low in details calculation model and then gradually its complexity has been increased by adding more elements. After each step, output data is requested so as to verify that the model has been built correctly.

Another useful technique that has been used was to step through the calculation model. Several input parameters have been changed during the execution to see whether the model would respond in the expected way. For example, there has been tested the critical buffer levels if the employees' touch times would significantly change.
Finally, there has been checked whether the complex sources of the variability have been modeled correctly though results validation. This has been realized by comparing the calculation model's results with the results derived from the data analysis. For example, the time series plot of the critical buffer level in the end of the simulation for some cases and more specifically for the selected scenarios has presented similar trends and outliers with the real existing state in the outbound Logistics. Since the plots that have been created by the simulation's results resemble to the one from the data analysis, it has been concluded that the calculation model is valid. Therefore, the use of data input and the resulted outputs have been correctly modeled and correspond to the realistic case.

6.2.5 Best Scenarios

Based on the decision making factors mentioned in the previous section the best scenario has been selected. The best alternative should combine the highest score of on time delivery and the employees' employment cost minimization. First, there has been an evaluation of the scenarios of the different versions tested and afterwards there a comparison between those two for the final proposal has been performing leading to a final proposal.

For the first version of the Outbound Logistics process the scenarios 1.1, 1.5 have scored 100% on time components' delivery and cost €21645 and €19305 per week respectively. In contrast scenario 1.4 showed the minimum score of on time delivery to the repair vendors, whilst costing the least amount for the company (€9750/week). Benefits from the cost reduction cannot equilibrate the loss of uncompleted components in the end of the shift, therefore scenario 1.4 can be considered as the worst scenario. The second worst scenario of version 1.1 is scenario 1.2, followed by scenario 1.6, where delayed delivery occurred only 0.01% whereas cost is relatively advanced. Nevertheless, scenario 1.3 should be taken into serious consideration as it presents a relatively small cost for the company (€14820/week) while at the same time the critical level is merely exceeded (1). The analysis above results to the conclusion that the best scenario for version 11. of the outbound Logistics is Scenario 1.3, according to which weekend shifts, that are less busy but more expensive for employees' occupation, have been removed from the weekly schedule. Based on the simulation the process can flow normally as all the components could be completed within 48 hours, meeting thus the time requirements on time.

The same decision making process has been made for the second version that represents the future state's proposal in this research. It is obvious that Scenario 2.1 is the best alternative for version 2.2. The results of the scenarios 2.2 and 2.4 scored the minimum cost (€9360 and €5850 per week) but had been proven to always delay (100%) deliver the components to the repair vendor. Scenario's 2.3 cost is also minor compared to Scenario 2.1 and same as Scenario 2.2 (€9360/week), however components' on time completion and delivery is only 50% guaranteed. While Scenario 2.1 is the most expensive compared to the rest scenarios of version 2.2 (€14625/week), the 100% level of on time delivery scored in the simulation justifies its selection for the best scenario. Version's 2 Scenario 2.1 proposes a 24/7/365 schedule for the employees working in the Logistics center, taken into account that the tasks of the physical inspector and repair administrator are combined and performed by the same employee.

6.3 Conclusion

This chapter presented the results of the process simulation. For the purposes of the simulation data and scenarios have been created. A validation and verification of the algorithm assures the used framework provides reliable and valid results.
To finalize the improvement process of the Outbound Logistics, two different versions of the process together with the best scheduling scenario have been suggested. In the simulation Version 1 Scenario 1.3 and Version 2 Scenario 2.1 have presented similar performance in the critical level regarding to the components on time completion and cost almost the same amount of money per week for the company. The best alternatives (Table 22) have been proposed for a specific time frame. For short term results and instant implementation of scenario 1.3 is the most efficient in terms of cost and time requirements. The scenario suggests the operation of the outbound Logistics only during weekdays; the most expensive shifts (weekend shifts) are remove, while there is still enough capacity to catch up the lost hours from the weekend shifts and meet the final time requirements. Its implementation is easy to be realized as no reorganization in the infrastructure is needed. Incremental changes demand the employees perform the same tasks as before with changes only on their daily schedule. For long term implementation and better results for the future, 2.1 has been suggested. According to this alternative radical changes have been proposed. The combination of Physical Inspector's and Repair Administrator's activities requires the employees' additional training and execution of more complicated tasks. Moreover, adjustments in the infrastructure in the Logistics center should be made so that space for the physical inspection is available to every employee. The extra in between buffer has been removed, therefore its space should be used for the purpose mentioned above. Nevertheless, this scenario requires full time occupation, including day, evening, weekday and weekend shifts. However, no additional employees need to be hired so as the time requirements will be met.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Schedule</th>
<th>On time Delivery</th>
<th>Cost in Euros per week</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3</td>
<td>Separate tasks Weekday Shifts</td>
<td>100%</td>
<td>14820</td>
</tr>
<tr>
<td>2.1</td>
<td>Combined tasks Full Time (24/7/365 shifts)</td>
<td>99.99%</td>
<td>14625</td>
</tr>
</tbody>
</table>
6. Algorithm's Development for the Improvement of the Outbound Logistics
7. Conclusions and Recommendations

This is the final chapter of the report that concludes the research performed in the Logistics Center of KLM Engineering & Maintenance. The main research questions, the methodology followed to answer them and the results summarize this report. The reflection is included in this chapter and later advice for further research and final remarks is presented.

7.1 Conclusion

It is very significant for businesses to work continuously on improving the performance of their processes. As a result, decisions, actions and coordination towards continuous improvement are some of the main core practices in the working field. Specialized teams of experts are assigned to work on the projects and deliver improved, effective and efficient processes. Lean Six Sigma Blackbelts are trained employees that apply the Lean Six Sigma principles and philosophies, combined with supporting systems and tools in the working field so as to improve the process.

This research has been conducted in the context of a Lean Six Sigma project within the Logistics Center of KLM Engineering & Maintenance. The main objective of this project has been to "How improve the Outbound Logistics process within the Logistics Center at KLM Engineering & Maintenance in terms of Quality, Turnaround Time and Cost?".

To accomplish this objective several research questions have been made and presented below to conclude the report.

RQ1: What is the current outbound Logistics process within the Logistics Center at KLM Engineering & Maintenance?

The Logistics center of KLM Engineering & Maintenance is a part of the supply chain of the company's core business. The Logistics center is the physical place where every aircraft component goes through for import/export formalities, administrator, storage and delivery to the repair vendors and/or customers (internal KLM, external airlines). The Logistics center consists of two divisions: the Inbound and the Outbound. More specifically, the outbound Logistics process include the tasks performed when an unserviceable aircraft component requires to be tested, repaired or overhauled. Those tasks are completed by different type of employees working in the Logistics center.

The aircraft components are received in the Expedition where a tracking sticker with a unique barcode is attached to them and a first confirmation in the system is being performed. The employees separate the components based on their condition (serviceable or unserviceable) and place them in the respective lane at the Logistics Center. Thereafter, the physical inspection takes place during which the employees check the physical condition of the component, its paperwork including the information and identification numbers and cross check if both of them correspond to each other. The result of this task is a completed form that includes all the component's characteristics to be used by the next employees in sequence. The component is placed in a buffer until, according to FIFO priority, it will be picked by the repair administrator who is accountable for the component's right administration in the system. This type of employee completes the paperwork, invoice and...
configuration in the system so that the component is sent to its respective repair vendor, on time and with the required data, description etc. The component is then moved to another side of the Expedition where the employees make sure that an entire batch of components are placed to the right tracks and transported to the repair vendors.

The inbound Logistics, the other division of the Logistics center, concerns the reverse process. The inbound Logistics includes the activities of receiving serviceable components, storing them to the warehouse and/or sending them directly to the customer airline which has requested it.

**RQ2: What can we learn from literature regarding to the improvement of Logistics processes?**

Valuable information has been used from literature and academic papers regarding to the Lean Six Sigma theory. Lean Six Sigma has been the most useful tool for making a process flow more efficient in terms of Quality, Turnaround Time and Cost in KLM Engineering & Maintenance. A combination of the theory mentioned together with the Engineering Design has been applied in this research. A proposed technique for minimizing the waste within process includes the capacity planning and scheduling. After that, an extended research in algorithmic approaches and simulation to attack similar problems in industries has been performed.

**RQ3: What are the selected KPIs and data to measure the performance of the outbound Logistics process?**

The definition of the critical KPIs has been a very critical task in order to create a data collection plan, gather the correct and reliable data to measure the performance of the outbound Logistics and use them in for further research. The most important identified KPIs describe quality by means of uncompleted components, missing data wrong packaging etc and turnaround time which is further decomposed to the actual employees’ touch time and waiting times in the in-between buffers. Measurements and joining shifts with the employees on floor has been proven to be the most reliable, but time and effort consuming method for obtaining the needed data. Important information from historical data has also been retrieved from the tracking system.

**RQ4: What is the performance of Outbound Logistics process?**

The data analysis has followed after the data collection. Statistical analysis and cumulative reports represent the current performance of the outbound Logistics. The results from the analysis have led to the conclusion that the poor quality of the received components, in combination with complicated process tasks, delay the entire process and the components’ delivery to their end destination (repair vendor). Moreover, inefficient process steps and task have created huge buffers, characterized by long waiting times.

**RQ5: What are the suggested solution areas for the future Outbound Logistics process within the Logistic Center at KLM Engineering & Maintenance?**

From the analysis performed to answer the previous research questions, the bottlenecks and problematic areas have been identified. Having reviewed the literature and participated in brainstorming meetings several solutions have been proposed. The solutions have been interdependent and their simultaneous implementation has been suggested for better results that completely remove the waste from the process. The solutions areas include actions to be
taken for the specific data for revising the contracts. Communication among the employees, supervisors and managers has been an essential area of interest, which would contribute to the overall performance of the process. Defining and forecasting the daily workload has been also a very significant part of the research, so as to have the process and capacity well organized in advance. A new design of the outbound Logistics would indicate more standardized process steps and rules. Finally, performance management has been the main focus for a further research proposal. Another different solution area suggested after the data analysis and performance analysis, has been the investigation of outsourcing the Logistics of KLM Engineering & Maintenance.

**RQ6: How can the outbound Logistics process within the Logistics center at KLM Engineering & Maintenance be simulated and tested in respect with its manpower performance?**

An algorithm has been developed for the purposes of the research. A general form of the algorithm can be used in order to simulate the entire process of KLM's supply chain. Input has been taken from the data collection, used as dependent and independent variables. More specifically, measurements regarding to the components' missing data, info etc., their handling times and the daily workload definition has been used as a forecast for future incoming deliveries have been reliable input for the process' calculation. Moreover several scenarios have been created, based on the company's needs and potentials for scheduling changes, which would contribute to the process quality and cost saving, and tested through this simulation.

**RQ7: How can improvement strategies can be implemented?**

A set of solutions has been the result after the data analysis regarding to the process' performance. The bottlenecks and ineffective areas have been identified. Literature review together with brainstorming sessions have resulted to certain solutions to improve the process.

A list of data requirements for a component ready for delivery, based on which the standard way of working can be defined. In order to complete the list of the data required extended research and evaluation of the work performed in the outbound Logistics has been conducted. Understanding the steps taken and their added value in every task of the outbound Logistics process, by joining shifts and questioning the employees, helped create the desired list of data.

Based on the list created for this purpose, the customers’ contract can be rewritten in a way that only components with required data will be accepted in the Logistics center. Revising and spreading an update version of contracts to the customers is a time consuming and difficult task, but it will be fruitful for both sides. Based on the new contracts components can only be sent to the Logistics center only if every required information is included and is available for usage. In this way, less issues regarding to components' deliveries and handling will be encountered resulting to a faster process.

Good communication among people is very essential for the employees’ involvement and motivation for work. Regular meetings and trainings would help the employees take more responsibilities and initiatives on their assignment. Managers and supervisors should be empowered with communication skills since they are the ones accountable for the good rapport among the employees participating in the Logistics process.
A detailed analysis of the workload needs to be defined and updated regularly, so that a forecast on incoming goods will be available and therefore the personnel's capacity could be adjusted according to the needs. Information regarding to the workload can be retrieved primarily from the tracking system, out of which aggregated reports can be created. The number of unserviceable components can be counted in a monthly, daily and hourly basis. The reason of such a deep analysis lies in the fact that the supply of incoming goods differs, but several trends and periodicities can be recorded.

Finally, a new outbound Logistics process can be designed, introducing more efficient steps. After consultation and confirmation by people in charge, the idea of the new process design has included the combination of the two main tasks performed in the outbound Logistics. In other words, the one employees would perform the physical inspection and repair administration in sequence, removing thus, the buffer between them.

Performance management has been proposed as new project that could ensure the process' performance control. Additional research on performance management tools and techniques should be the next step for the outbound process. This task would help measure the performance in regular intervals, identify bottlenecks and control the process by intervening any time needed. Finally, continuous improvement can be achieved by successfully implementing a performance management plan.

The final result of the research's scoping is recommendations that derive from the simulation and the set of solution that have been described above. Short term and incremental changes in the process include the removal of weekend shifts, whereas long term and more radical changes propose a complete redesign of the outbound Logistics center while combining the physical inspector's and repair administrator's activities into one.

Outsourcing the complete Logistics process is implied to have long term benefits for the company. However, the research behind this action is left for a different future project.

7.2 Thesis Reflections

In order to analyze and evaluate the applicability of an algorithmic approach in a combination of Lean Six Sigma and Engineering Design approach towards the process' improvement, the case study of the outbound Logistics process within the Logistics center of KLM Engineering & Maintenance has been studied. Several research questions have been formed so that the main objective and topic of the project can be clear and consistent. Process improvement is a very complex topic and there is a great amount of information regarding to the topic. Therefore, a detailed approach was necessary. There has been a great challenge in orientation and finding the appropriate work scope that can provide a scientific contribution. However, following the Lean theory have helped go deeper in the analysis and identifying the correct scope.

The presented framework, combining Lean Six Sigma and Engineering Design is generic and allows flexibility. Flexibility is very essential due to the fact that the process' needs can vary to meet consumer demands and process as much as the incoming workload. Moreover the proposed approach develops techniques for rational decision making and attributes a sustainable character.

Basically, the output of the research has been a set of solutions and actions that are needed in order to achieve better performance in the process. Finally, extreme focus was given in the development of an algorithm that can simulate the process within the Logistics Center, run
7. Conclusions and Recommendations

and test scheduling scenarios, in a way that the process can flow without waste and minimizing the cost of employing excess personnel.

As it has been concluded, there have been several limitations within the suggested solutions. For some cases the time constraints have prevented from realizing in depth research and implementation of the entire set of solutions. Moreover, the lack of authorization and license have left several topics untouched for the context of the project in question. Nevertheless, concrete proposals have been suggested and assigned to the people in charge. Their outcomes have been excluded from the report as their implementation is currently running. The nature of the existing process in the Logistics center have presented a notable shortage of data. Furthermore, the reliability of available data had been inconsistent and therefore it was preferred to use only a small amount of reliable and consistent data. This resulted in coming to hard conclusions and only a scope where the data could have been well used.

To conclude, the set of solutions and the algorithm developed for the purposes of the project compromise a complete action plan derived from the combination of literature related to Lean Six Sigma and Engineering Design and real field guidance and implementation.

The research has been conducted in the context of a Lean Six Sigma project launched in the Logistics Center of KLM Engineering & Maintenance. Having completed courses in the Supply Chain Management specialization helped gain the theoretical knowledge behind it. Moreover, having been supervised by the Logistics center's Blackbelt and having worked with a Greenbelt and other experts of Lean Six Sigma principles helped apply the university's knowledge in real field and guided the project's execution according to the scientific theories.

Besides the theories and academic knowledge, very essential has been the interaction with the employees and following the process flow several times so as to have a better understanding of the factors that could undermine the process performance. Being a part of the process has helped recognize the employees difficulties and therefore come up with solutions that would satisfy their needs. Communication skills in a manly and multicultural environment have been very useful for the connection of employees and their motivation to be espoused with the project. The employees' contribution in the research has been the most powerful input for the successful development of the process' improvement.

Despite the difficulties and limitations of the project, it was a very interesting experience that increased my capabilities and helped develop new skills, while implementing my theoretical background and knowledge to an actual working field. Having completed the master of Management of Technology and conducted a project in real field had made me realize the importance of combining technical and managerial skills for a successful business operation.

7.3 Recommendation for Further Research Projects

This research is limited to only propose several sets of generic solutions for the process' improvement and check several scheduling scenarios for the outbound Logistics process. Nevertheless, the methodology and most importantly the algorithm that is developed for the purposes of this problem can be extended and implemented for the other division of the Logistics center (Inbound process) and further for the entire supply chain of KLM Engineering & Maintenance (Figure 1). Moreover, the suggested algorithm can be used as a general model that can be applied in other programming languages and be executed to test the process in a dynamic way and therefore make use of its full potentials.
Nevertheless, the methodology and the algorithmic approach developed and used for the project can easily be applied for other products and processes in other industries as well. The integration of Lean, Six Sigma and Engineering Design approach can be applicable to every project that requires a process improvement. As for the algorithm, it can be used in its general form to any job flow process model, as long as the required data are in place for the reliable calculation model. The results from the calculation model will depend on the data representing the real process, therefore attention should be given on the data collection.

The improvement of the supply chain requires an extended research of the processes and sub processes, which compromise it. Such a project would be a rather complex and time consuming task to perform. Therefore, it should be decomposed into several sub projects for every department of the company. Integrating the forces of the company's divisions would result to the overall improvement of the its core business.

To conclude, as it already mention in Section 5.9 the outsourcing of the entire Logistics business is one task that requires further research. The benefits for outsourcing and removing the Logistics center operation might give better results in a long term period of time, might save extreme cost for the company and could even guarantee better services from a reliable company specialized in Logistics. Nevertheless, extended research should be assign to a specialized project group that would be compromised by KLM employees of different departments.


Appendix

Appendix A List of Customers
The customers of KLM Engineering & Maintenance are listed in the table above (Table 23). Customers are contracted with KLM Engineering & Maintenance. The send their unserviceable aircraft components from all over the world to the Logistics center of KLM Engineering & Maintenance. Based on the contracts and agreements, the Logistics center employees perform the correct administration and deliver the components internally to KLM shops or to external repair vendors. The contracted repair vendors vary and origin form all over the world. The aircraft components are sent back to the Logistics center of KLM Engineering & Maintenance after the repair process, where administration is performed once again to deliver the components back to the customers or store them to the warehouse within the Logistics center for later usage.

Table 23: List of KLM Engineering & Maintenance Customers

<table>
<thead>
<tr>
<th>Customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeroinstruments</td>
</tr>
<tr>
<td>Aerospace</td>
</tr>
<tr>
<td>Aerotech Aircraft Maintenance</td>
</tr>
<tr>
<td>AirFrance</td>
</tr>
<tr>
<td>Air Madagascar</td>
</tr>
<tr>
<td>Air New Zealand</td>
</tr>
<tr>
<td>Atlas Air</td>
</tr>
<tr>
<td>Atlantic Airways</td>
</tr>
<tr>
<td>Bangkok Airways</td>
</tr>
<tr>
<td>Boeing</td>
</tr>
<tr>
<td>Corendon Airlines</td>
</tr>
<tr>
<td>CSP</td>
</tr>
<tr>
<td>Epcor</td>
</tr>
<tr>
<td>Finnair</td>
</tr>
<tr>
<td>Garuda Indonesia</td>
</tr>
<tr>
<td>GMF Aeroasia</td>
</tr>
<tr>
<td>Hamilton</td>
</tr>
<tr>
<td>Hero Technology</td>
</tr>
<tr>
<td>HK Aircraft Engineering</td>
</tr>
<tr>
<td>Jetz</td>
</tr>
<tr>
<td>Jet Airways</td>
</tr>
<tr>
<td>JetLite</td>
</tr>
<tr>
<td>Kenic Electric</td>
</tr>
<tr>
<td>Kenya Airways</td>
</tr>
<tr>
<td>KLM</td>
</tr>
<tr>
<td>KLM Miami</td>
</tr>
<tr>
<td>Lan Airlines</td>
</tr>
<tr>
<td>Latam Airlines</td>
</tr>
<tr>
<td>Polskie Linie Lotnicze LOT</td>
</tr>
</tbody>
</table>
Appendix B Sidestep Processes
The following figures (Figure 35-36) visualize the process' sidesteps as they have been described in Chapter 2. The "Scoping" and "Troubleshooting" process have not been including in the work scope of the project, despite the big delay in time when the component follows the sidestep. They mainly regard to giving solutions and investigating several issues or troubles encountered in the main process. The case of missing certain type of information, which cannot be easily found in the system by the outbound Logistics employees is very common and requires the attention of other employees whose main occupation is to provide immediate solutions.
Appendix C Outbound Logistics Areas

The following photos (Figure 37-39) show the critical stations of the outbound Logistics in the Logistics center at KLM Engineering & Maintenance. In the first picture (Figure 37), components are placed in buffer 1 by expedition personnel. Each component is delivered within its appropriate package, on which a tracking sticker and a date label are attached. If needed warning sticker must be put on the box at a visible spot.
Figure 38 presents the physical inspectors working place. A clean surface, where the boxes are placed and opened compromises the main working space of the physical inspector. Important tools to complete its task are a computer, where he/she can search and/or check important information, a magnifying lens for identifying small letters and numbers on the components’ ids, cleaning solution, in case of a dirty component, the requested form and several other tools that would help the physical inspector successfully complete his/her task.

Buffer 2 (Figure 39) is the step between the physical inspection and repair administration. Components are dispatched there after physical inspection. Their important papers and the completed form from the
physical inspector are placed in the cases in front of the rack. This buffer should be just a temporary place for the components to lay on. The data analysis has shown that the components are placed in that buffer longer time than expected, influencing thus, the outbound Logistics overall turnaround time.

Figure 39: Components at Buffer 2

**Appendix D Interviews, Observations and Internal Sessions**

For the purposes of the project several interviews have been completed and internal brainstorming sessions had taken place. Informal interviews have been done in terms of discussion about the process. In the beginning a tour and orientation in the Logistics center had been provided by the supervisor (B. Kroes). Questions and observations regarding the exact process steps have been asked to the supervisors of the Logistics center. Going deeper into the process and its tasks, joining shifts and being a part of the working team in the outbound Logistics center, helped asking more precise and elaborative questions to the employees. The intension of the actions mentioned above targeted to provide a good insight over the outbound Logistics and explain it better in paper. Moreover, the inefficiencies that are presented within the process have been clearly defined after continuous observations and internal sessions.

There have been scheduled multiple sessions, both before and after the measurements and data analysis. Firstly, value stream mapping meetings had been held with the presence of supervisors and high management teams, others with the employees that take part in the process and other with the combination of the previously mentioned people. The added value of these meetings for the project was to create the existing value stream map of the process, define the data requirement in every step and finally to identify the bottlenecks and defects in the process. After the data analysis, its results have been presented to the people of interest and additional meeting took place with the same group of people in order to brainstorm and come up with solutions towards the process’ improvement. Significant input, knowledge and information have been provided by the literature review and similar cases within KLM Engineering & Maintenance.

To conclude, the interviews despite their informal and unstructured nature, in combination with personal observations and meetings added a great contribution to the improvement of the outbound Logistics process.
Appendix E Scanning Points

The following tables elaborate more on the way that the tracking system is organized in the outbound Logistics. In more details, the list includes the number of scanning point corresponding to number visualized in Figure 16 and Figure 33. The scanning points names are defined by their creator and indicate their physical location in the Logistics center. The action that should be performed in the respective scanning point and the employee who is responsible for the action are also listed in the tables. Finally, the last column describes when after a certain action is completed the scanning should be done. For the future scanning points, similar names have been used, nevertheless, as the process has become simpler the scanning actions have been more clear and precise.

Table 24: Existing Scanning Points

<table>
<thead>
<tr>
<th>Number</th>
<th>Scan name</th>
<th>Action</th>
<th>Employee</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>44001</td>
<td>Drop</td>
<td>Expedition</td>
<td>Component’s details are updated in Crocos/ Component is put in the cart</td>
</tr>
<tr>
<td>2.1</td>
<td>SPLVC</td>
<td>Drop</td>
<td>Expedition</td>
<td>Component is dispatched to Shop VC</td>
</tr>
<tr>
<td>8.1</td>
<td>SPLUSVSB</td>
<td>Drop</td>
<td>Physical Inspector</td>
<td>In case of issue, component is dispatched to the scoping buffer</td>
</tr>
<tr>
<td>9.1</td>
<td>SPLUSTSO</td>
<td>Drop</td>
<td>Repair Administrator</td>
<td>In case of trouble, component is dispatched to the troubleshoot buffer</td>
</tr>
<tr>
<td>4.1</td>
<td>OUT02/ SPLUSEXC/ JETUITGAAND</td>
<td>Drop</td>
<td>Repair Administrator</td>
<td>Component is dispatch to the drop point for the export</td>
</tr>
<tr>
<td>4.2</td>
<td>OUT02/ SPLUSEXC/ JETUITGAAND</td>
<td>Pick</td>
<td>Expedition</td>
<td>Components is picked from the drop point for the export</td>
</tr>
<tr>
<td>5.1</td>
<td>SPL350</td>
<td>Drop</td>
<td>Expedition</td>
<td>Component is dispatched to the export area</td>
</tr>
<tr>
<td>5.2</td>
<td>SPL350</td>
<td>Pick</td>
<td>Export</td>
<td>Component is picked for export formalities</td>
</tr>
</tbody>
</table>

The following figure (Figure 40) is an example of a scanning point within the outbound Logistics center. Similar scanning stickers are located in different places within the Logistics center. Employees should scan the barcode existing in the tracking sticker on the component and connect it with the tracking sticker, denoting where and when the component has passed from that location. Missing scanning actions can cause a problem in following the component’s actual flow and therefore have an unreliable performance measurement, regarding to turnaround time.
The table below (Table 25) lists the proposed scanning points and their description. The combination of existing scanning points with some alterations and new scanning points would provide a very good tool for the performance management in the Logistics center. The employees are requested to perform the correct scanning action at the correct time in order to have a complete overview in the tracking system, retrieve reliable information and therefore create representative performance reports.

### Table 25: Future State Scanning Points

<table>
<thead>
<tr>
<th>Number</th>
<th>Scan</th>
<th>Drop/Pick</th>
<th>Employee</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>44001</td>
<td>Drop</td>
<td>Expedition</td>
<td>Component arrives to Expedition</td>
</tr>
<tr>
<td>1.2</td>
<td>44001</td>
<td>Pick</td>
<td>Expedition</td>
<td>Component’s details are updated in Crocos/Component is put in the cart</td>
</tr>
<tr>
<td>2.1</td>
<td>SPLVC</td>
<td>Drop</td>
<td>Expedition</td>
<td>Component is dispatch to Shop VC/different lanes of KLM/external/forward exchange</td>
</tr>
<tr>
<td>2.2</td>
<td>SPLVC</td>
<td>Pick</td>
<td>Physical Inspector &amp; Repair Administrator</td>
<td>Component is picked for visual inspection and repair administration</td>
</tr>
<tr>
<td>7.1</td>
<td>SPLUSVSB</td>
<td>Drop</td>
<td>Physical Inspector &amp; Repair Administrator</td>
<td>In case of issue, component is dispatched to the scoping buffer</td>
</tr>
<tr>
<td>7.2</td>
<td>SPLUSVSB</td>
<td>Pick</td>
<td>Physical Inspector &amp; Repair Administrator</td>
<td>After scoping the repair administrator picks the component from the solved scoping buffer (always priority)</td>
</tr>
<tr>
<td>8.1</td>
<td>SPLUSTSO</td>
<td>Drop</td>
<td>Physical Inspector &amp; Repair Administrator</td>
<td>In case of trouble, component is dispatched to the troubleshoot buffer</td>
</tr>
<tr>
<td>8.2</td>
<td>SPLUSTSO</td>
<td>Pick</td>
<td>Physical Inspector &amp; Repair Administrator</td>
<td>After troubleshoot, repair administrator picks the component from the solve troubleshoot buffer (always priority)</td>
</tr>
<tr>
<td>3.1</td>
<td>OUT02</td>
<td>Drop</td>
<td>Repair Administrator</td>
<td>Component is dispatch to the drop point for the export</td>
</tr>
<tr>
<td>3.2</td>
<td>OUT02</td>
<td>Pick</td>
<td>Expedition</td>
<td>Components is picked from the drop point for the export</td>
</tr>
<tr>
<td>4.1</td>
<td>SPL350</td>
<td>Drop</td>
<td>Expedition</td>
<td>Component is dispatched to the export area</td>
</tr>
<tr>
<td>4.2</td>
<td>SPL350</td>
<td>Pick</td>
<td>Export</td>
<td>Component is picked for export formalities</td>
</tr>
</tbody>
</table>
Appendix F Data Measurements
The following tables are the measurement checklists that have been created for the data collection and measurement performed in the outbound Logistics for the purposes of the research. Multiple external employees had been hired and helped completing the lists while joining some shifts with the Logistics personnel. They had been assigned to follow the employees tasks and carefully fill in the forms regarding to the components’ data. Moreover, they have been asked to perform scanning to the correct scanning points so that information about the exact time and location of the component can be stored in the system and used further for the analysis.

Table 26: Measurements Checklist for Physical Inspectors

<table>
<thead>
<tr>
<th>Date/ Hour</th>
<th>Name</th>
<th>Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
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</tbody>
</table>

Physical Inspection Uitpakker VC

<table>
<thead>
<tr>
<th>Comp</th>
<th>Barcode</th>
<th>Issue</th>
<th>Scoping</th>
<th>Custom er</th>
<th>Codenumbe r</th>
<th>Following number</th>
<th>Other Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td></td>
<td></td>
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<td>3</td>
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<td></td>
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<td>5</td>
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</tbody>
</table>

Table 27: Measurement’s Checklist for Repair Administrators

<table>
<thead>
<tr>
<th>Date/ Hour</th>
<th>Name</th>
<th>Employees</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
</tbody>
</table>

Repair Administration

<table>
<thead>
<tr>
<th>Component</th>
<th>Barcode</th>
<th>Compl eted form</th>
<th>Iss ue</th>
<th>Customer /Origin</th>
<th>Destina tion/ Repair Station</th>
<th>Shop Order</th>
<th>Scoping/ TSO</th>
<th>New Barcode</th>
<th>Time (St art-Fini sh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
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<td></td>
<td></td>
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<tr>
<td>3</td>
<td></td>
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<td></td>
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<tr>
<td>4</td>
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<td>5</td>
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</tr>
</tbody>
</table>

Appendix G Ready for Outsource List
The following tables are the result of three value stream meetings. Several employees (repair administrators) and supervisors attended the meeting given the task to list the steps in sequence that are taken in order to make a component ready for outsource. The table’s columns are the following:

- Screen: in the system – software
- Input: the required input that is given in every screen
- Data not found: what action or alternative is taken if the required input data is not known
- Output: the data that is retrieved by every screen
- Notes: any comment related to the respective step
Due to the fact that different steps are made for the different types of components’ streams, the same list has been applied for the three main streams of the outbound Logistics (Pool VC, FE and internal and external CLA). An example of the outcome is presented in the tables below (Table 28 and Table 29).

**Table 28: Ready for Outsource Pool VC**

<table>
<thead>
<tr>
<th>Screen/ action</th>
<th>Input</th>
<th>Data is not found</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>TVI</td>
<td>Code &amp; following number</td>
<td>Cross check</td>
<td>Check STRU/ UN/</td>
</tr>
<tr>
<td>TBL</td>
<td>Code number</td>
<td>Purchasing mail SPL/TP</td>
<td>Vendor code</td>
</tr>
<tr>
<td>TKOU</td>
<td>TUURK, label kist reg</td>
<td>TSO</td>
<td>Registration hours</td>
</tr>
<tr>
<td>IW33</td>
<td>Label number</td>
<td></td>
<td>Check SAP status</td>
</tr>
<tr>
<td>Surplus check</td>
<td>Code number</td>
<td>Software Outsourcing</td>
<td>Either Software Outsourcing or MDH</td>
</tr>
<tr>
<td>TRAM</td>
<td>Code number &amp; following</td>
<td></td>
<td>Control limits</td>
</tr>
<tr>
<td>TWEG</td>
<td>Code number &amp; following</td>
<td></td>
<td>Order notes</td>
</tr>
<tr>
<td>TREF</td>
<td>Code number &amp; following number &amp; kist reg</td>
<td></td>
<td>Contract indicator</td>
</tr>
<tr>
<td>TRAL</td>
<td>Code number &amp; following</td>
<td></td>
<td>Check assy structure</td>
</tr>
<tr>
<td>TWI</td>
<td>Code number &amp; following</td>
<td></td>
<td>Data correction</td>
</tr>
<tr>
<td>TWO</td>
<td>Code number &amp; following</td>
<td></td>
<td>Within report in WPH Physical WOP</td>
</tr>
<tr>
<td>TMG</td>
<td>Code number</td>
<td></td>
<td>Check sum/ UN</td>
</tr>
<tr>
<td>TWVI</td>
<td>Code number &amp; following</td>
<td></td>
<td>Mod/ SB/ EO/ etc.</td>
</tr>
<tr>
<td>RIAC</td>
<td>Code number &amp; following number &amp; kist reg</td>
<td>Software Outsourcing with reason: US</td>
<td>Complaint/ Reason of removal</td>
</tr>
<tr>
<td>AEX</td>
<td>Search KI action</td>
<td></td>
<td>Control</td>
</tr>
<tr>
<td>TUB</td>
<td>Code number &amp; following</td>
<td></td>
<td>Requisition number</td>
</tr>
<tr>
<td>Tracking sticker creation</td>
<td>Requisition number</td>
<td></td>
<td>sticker</td>
</tr>
<tr>
<td>Sticker connection</td>
<td>Old and new sticker</td>
<td></td>
<td>Connection in Tracking</td>
</tr>
<tr>
<td>ME21N</td>
<td>Oi number</td>
<td></td>
<td>Repair order (print)</td>
</tr>
<tr>
<td>ASubCon</td>
<td>Repair order</td>
<td></td>
<td>Invoice</td>
</tr>
<tr>
<td>Mission taping incl control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TUBA</td>
<td>Label number</td>
<td></td>
<td>Final Software Outsourcing</td>
</tr>
<tr>
<td>Data storage</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 29: Ready for Outsource FE**

<table>
<thead>
<tr>
<th>Screen/ action</th>
<th>Input</th>
<th>Data is not found?</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sort in the buffer</td>
<td>Code number: 33* 43* 68*</td>
<td>FE</td>
<td></td>
</tr>
<tr>
<td>TVI</td>
<td>Part number, serial number &amp; label number</td>
<td>Info</td>
<td></td>
</tr>
<tr>
<td>IW33</td>
<td>Label number</td>
<td></td>
<td>Check SAP status</td>
</tr>
<tr>
<td>TKOU</td>
<td>TUURK, label kist reg</td>
<td>TSO</td>
<td>Registration hours</td>
</tr>
<tr>
<td>TBL</td>
<td>Code number</td>
<td>Purchasing mail SPL/TP</td>
<td>Vendor code</td>
</tr>
<tr>
<td>TRAM</td>
<td>Code &amp; following number</td>
<td></td>
<td>Control limits</td>
</tr>
<tr>
<td>TWEG</td>
<td>Code &amp; following number</td>
<td></td>
<td>Order notes</td>
</tr>
</tbody>
</table>
Appendix I Formal Statement of the Algorithm

The algorithm is presented in the terms of pseudo code in this appendix. The notations used and the variables explanation have been defined in the following text.

**Independent variables:**

- \( o \): number of different types of employees
- \( b \): number of buffers between the employees
- \( \text{components} \): number of components delivered in the logistics center (drop VC) per month, day and shift (day shift: 0-15, evening shift: 16-23)
- \( \text{employee}[n] \): number of employees 1...\( n \) per shift
- \( \text{touch\_time\_employee}[n] \): random touch time of the employees 1...\( n \) between the measured timings
- \( \text{percentages} \): percentage of each type of component’s occurrences, based on the measurements
- \( \text{max\_employee}[n] \): the maximum number of components that can be processed by employees 1...\( n \)

**Dependent variables:**

- \( \text{buffer}[b] \): Number of uncompleted components from previous shift plus the number of components delivered in the initial buffer[1]
- \( \text{type\_employee}[c] \): Number of components in the buffer[\( b \)] times the percentage of types 1...8. The percentage is retrieved from the "constant\_s" sheet and is calculated from personal measurements in the logistics center
- \( \text{handling\_time\_employee}[c] \): the function calculates the time that is needed to complete the entire number of components in the buffer[1]. The touch time is retrieved from the "constant\_s" sheet and is calculated by the tracking system and personal measurements per type of component. The handling time is divided by the number of employees in order to calculate the time needed to complete the buffer 1 using the existing capacity. The number of employees is retrieved from the "schedule" sheet and is taken randomly. Different scenarios and schedules need to be tested, examined and analyzed in order to find the best alternative.
- \( \text{completed\_employee}[c] \): if the handling time is less than the shift’s time (390 minutes) it means that the employees can complete all the components that are in buffer[\( b \)], otherwise we make the assumption that they can complete only the maximum number of components per shift that is calculated in the maximization function in "constant\_s" sheet.
- \( \text{uncompleted\_employee}[c] \): is the difference between the number of components that are in the buffer and the number of completed components
buffer[\(b+1\)]: is the number of completed components employee[\(o\)] and need to be handled by the employee[\(o+1\)]

The number of uncompleted components by the last employee (employee[\(o\)]) represents a KPI that is connected to the components’ TAT. If the final result in uncompleted components is bigger than a certain level (35 components) for four following shifts or more, then it means that the buffer has touched the limit, the components cannot be completed within the contracted requirements and thus more employees are needed to handle the workload.

more than 26 components in buffer (maximum number of components that can be handled per shift) means that the turnaround time of the component will exceed the 48 hours that are agreed in the contract with the customer.

**Notations and constraints**

\(o\): number of employees, \(o \geq 0\)

\(b\): number of buffers, \(b \geq 0\)

\(s\): number of shifts, \(s \geq 0\), \(s = 729\)

\(s\): shift, \(s[1,14], s[1,3,5,7,9,11,13]\): day shifts, \(s[2,4,6,8,10,12,14]\): evening shifts

\(t\): number of shifts, \(t \geq 0\), \(t = 8\)

KPI: level of acceptable uncompleted components at the end of the shift, KPI = 46

\(\text{percentage}[]\): percentage of types of components, \(0 \leq \text{percentage}[] \leq 1\), \(\sum \text{percentage}[] = 1\)

employee[\(o,s\)]: number of employee[\(o\)] per shift[\(s\)], employee[\(o,s\)] \(\geq 0\)

touch_time_employee[\(o,t\)]: employee[\(o\)] touch time of component type[\(m\)], touch_time_employee[\(o,t\)] \(\geq 0\), touch_time_employee[\(o,t\)] \(= \text{random between}[\text{touch_time_operator}_o \text{min}; \text{touch_time_employee}_o \text{max}]\)

max_employee[\(o,s\)]: maximum number of components that employee[\(o\)] can handle in shift[\(s\)], max_employee[\(o,s\)] \(\geq 0\), max_employee[\(o,s\)] = maximization sub function

variables:

buffer[\(b,s\)]: number of components in buffer[\(b\)] during shift[\(s\)]

type_employee[\(o,s,t\)]: number of components of type[\(t\)] for the employee[\(o\)] in shift[\(s\)]

handling_time_employee[\(o,s\)]: time to complete the component[s] by employee[\(o\)]

completed_employee[\(o,s\)]: number of components completed by employee[\(o\)] in shift[\(s\)]

uncompleted_employee[\(o,s\)]: number of uncompleted components by employee[\(o\)] in shift[\(s\)]

buffer[\(b+1,s\)]: number of components from employee[\(o\)] to be handled by employee[\(o+1\)]

if uncompleted_employee[\(o\)] \(\geq \text{KPI}\), then “more employees are needed”

**Algorithm**

\(s = 729\), \(t = 8\), \(r = 1\), \(p = 1\), \(k = 1\), \(m = 1\), \(d = 1\)

\(b = 2\), \(o = 2\), \(\text{KPI} = 40\), \(\text{time} = 390\),

\(\text{buffer}[1,0] = 20\)
uncompleted_employee[2,0] = 30

While i=a

    d=1

    While k=b, and m=0

        While d=14

            While uncompleted_employee[m, i, d] <= KPI

                buffer[k, i] ← component[i] + buffer[k, i - 1]

            While j=t

                type_employee[m, i, j] ← component[i] * percentage[j]

                handling_time_employee[m, i] ← sum(touch_time_employee[m, j]) * type_employee[m, i, j] / employee[m, d]

                j++

            END While

            If handling_time_employee[m, i] <= time or buffer[k, i] <= max_employee[m, i] then

                completed_employee[m, i] ← buffer[k, i]

                else

                completed_employee[k, i] ← max_employee[m, i]

            END If

            uncompleted_employee[m, i] ← buffer[k, i] - completed_employee[m, i]

        END While

        k++

        m++

        buffer[k, i] ← completed_employee[m1, i] + uncompleted_employee[m, i]

        If buffer[k, i] > KPI then

            "more employees are needed"

            employee[m, i, d] ← employee[m, i, d] + 1

        END if

        i++

    END While

END While
Appendix J Data Creation

The following tables represent the data which have been created and used in the context of the calculation model. First the components which are delivered in the Logistics center are categorized, based on their quality (complete, missing data etc) and attached with a percentage of occurrence. Afterwards the minimum and maximum physical inspector's and repair administrator's handling times per type of component have been listed and a random time has been calculated each time that the simulation runs. Finally, the maximum personnel's capability has been calculated based on the number of each type of components and their touch times per type of employees.

Table 30: Type of Components and Percentages of Occurrence

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Complete Component</td>
<td>0,3</td>
</tr>
<tr>
<td>Type 2</td>
<td>Missing Data</td>
<td>0,2</td>
</tr>
<tr>
<td>Type 3</td>
<td>Missing ID Plate</td>
<td>0,09</td>
</tr>
<tr>
<td>Type 4</td>
<td>Missing Reason of Removal</td>
<td>0,09</td>
</tr>
<tr>
<td>Type 5</td>
<td>Missing Warning Sticker</td>
<td>0,04</td>
</tr>
<tr>
<td>Type 6</td>
<td>Wrong Packaging</td>
<td>0,03</td>
</tr>
<tr>
<td>Type 7</td>
<td>Warranty Conversion</td>
<td>0,05</td>
</tr>
<tr>
<td>Type 8</td>
<td>Other</td>
<td>0,2</td>
</tr>
</tbody>
</table>

Table 31: Physical Inspector's Touch Times per Type of Component & Capacity

<table>
<thead>
<tr>
<th>Type</th>
<th>touch time physical Inspector min</th>
<th>touch time physical Inspector max</th>
<th>touch time physical Inspector r max</th>
<th>touch time physical Inspector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2,43</td>
<td>31,1</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>5,54</td>
<td>13</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>4,36</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>4,5</td>
<td>18,07</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td>11,13</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>6,44</td>
<td>16,19</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>7</td>
<td>2,43</td>
<td>31,1</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>8</td>
<td>1,44</td>
<td>26</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>capacity</td>
<td></td>
<td></td>
<td></td>
<td>28</td>
</tr>
</tbody>
</table>

Table 32: Repair Administrator's Touch Times per Type of Component & Capacity

<table>
<thead>
<tr>
<th>Type</th>
<th>touch time repair administrator min</th>
<th>touch time repair administrator max</th>
<th>touch time repair administrator</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>35</td>
<td>23</td>
</tr>
<tr>
<td>2</td>
<td>15</td>
<td>78</td>
<td>23</td>
</tr>
<tr>
<td>3</td>
<td>15</td>
<td>35</td>
<td>34</td>
</tr>
<tr>
<td>4</td>
<td>15</td>
<td>66</td>
<td>25</td>
</tr>
<tr>
<td>5</td>
<td>15</td>
<td>35</td>
<td>29</td>
</tr>
<tr>
<td>6</td>
<td>15</td>
<td>35</td>
<td>28</td>
</tr>
</tbody>
</table>
Appendix K Simulation Results
The graphs below visualize the number of uncompleted components in the critical buffer at the end of every shift as it has been given from the application of the calculation model. For each version and every scenario developed different graphs have been resulted. From the graphs the percentage of on time deliveries can be easily calculated and it has been listed in Table 21.

<table>
<thead>
<tr>
<th></th>
<th>Version 1</th>
<th>Scenario 1</th>
<th>Scenario 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>15</td>
<td>66</td>
<td>38</td>
</tr>
<tr>
<td>8</td>
<td>15</td>
<td>120</td>
<td>94</td>
</tr>
<tr>
<td>capacity</td>
<td></td>
<td></td>
<td>27</td>
</tr>
</tbody>
</table>

Figure 41: Critical Buffer Level Scenario 1.1

Figure 42: Critical Buffer Level Scenario 1.2
Figure 43: Critical Buffer Level Scenario 1.3

Figure 44: Critical Buffer Level Scenario 1.4
Appendix

**Figure 45:** Critical Buffer Level Scenario 1.5

**Figure 46:** Critical Buffer Level Scenario 1.6
Figure 47: Critical Buffer Level Scenario 2.1

Figure 48: Critical Buffer Level Scenario 2.2
Figure 49: Critical Buffer Level Scenario 2.3

Number of uncompleted Components
Version 2, Scenario 3

Figure 50: Critical Buffer Level Scenario 2.4

Number of uncompleted Components
Version 2, Scenario 4