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BPJ 420 - Final Year Project

An investigation into the improvement of the inventory management process, in the automotive OEM company's supply chain

Final Report

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Executive Summary

The automotive industry tends to have high volumes of accumulation of inventory. Likely reasons for this is that the automotive industry aim to have high customer service levels, which implies that they need to stock service-, crash- and maintenance parts which are prone to become Slow Moving and Obsolete (SLOB) inventory (inventory that did not sell in the last four years). Inventory can be divided into three types, namely: fast moving-, medium moving- and slow-moving inventory. Inventory management is vital to minimise the accumulation of all three types of inventory in an automotive supply chain. Previous research has mostly focussed on fast moving inventory, as its revenue generating ability is higher than SLOB inventory, however the profit impact of resource wastage on SLOB inventory is likely much higher than assumed in the industry and better management of this type of inventory can change bottom line returns to investors. Therefore, the project investigates the improvement of inventory management on all three types of inventory identified, however the project makes specific reference to SLOB inventory as it is particularly relevant in the automotive industry. To obtain the necessary data for the analysis both qualitative data collected from interviews and quantitative data were obtained from the automotive Original Equipment Manufacturer (OEM) company's Rosslyn warehouse's Warehouse Management System (WMS). To answer the research question, numerous inventory management techniques were researched. Two particular inventory management techniques stood out for this specific problem. Business Process Modelling Notation (BPMN) charts are used to map current inventory management process and a linear programming model is developed to optimise the automotive OEM company's inventory levels across the supply chain. The current inventory management process was mapped to identify "problem areas" within the process that could be solved by developing unique solutions for each "problem area". In the preliminary mapping it seems that more regular scrapping processes are clearly needed to minimise storage costs and improve the supply chain's efficiency. Furthermore, minor changes such as doing activities simultaneously instead of sequentially, can improve the inventory management process's efficiency, by drastically reducing idle time. The aim of the linear programming model is to minimise transportation- and storage costs across the automotive OEM company's supply chain. Therefore the model used various input data (as discussed in the quantitative data analysis chapter) to generate estimated optimal quantity of parts that the warehouse should order. If the automotive acOEM company implemented the suggested warehouse ordering quantities derived from the Linear Programming (LP) model, the automotive OEM company's supply chain can save an estimated R16 472 807 within two years, which is about a third of their current expenditure on medium- and fast moving parts in the supply chain. Furthermore the SLOB inventory, obtained from the sample data provided by the automotive OEM company's WMS costs the automotive supply chain about R 28 000 000 to store these parts for two years. If these parts can be reduced by implementing regular scrapping processes the inventory management process will operate more effectively and save vast amounts of money.

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List of Acronyms

SLOB Slow Moving and Obsolete

OEM Original Equipment Manufacturer

BPMN Business Process Modelling Notation

BPD Business Process Diagram

SIPOC Suppliers Input Process Output Customer

LP Linear Programming

ERP Enterprise Resource Planning

WMS Warehouse Management System

RMA Return Merchandise Authorisation

GA [GA]Genetic Algorithm

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Chapter 1

Introduction

The flow of inventory is at the heart of each company; therefore, the role of an efficient inventory management process is vital to the survival of any company (Stevenson 2006). Inventory management is the practice of controlling and overseeing three major aspects, namely (i) ordering inventory, (ii) the storage of inventory and (iii) the flow of inventory through the supply chain (Stevenson 2006). Controlling and overseeing the ordering of inventory implies that stock levels need to correspond to demand, if this is not the case, a situation of understocking or overstocking realise (McGowan 2016). Understocking has the potential that the demand of a client cannot be met and therefore clients switch their business to competing companies, whereas overstocking results in a wastage of resources. Both these scenarios have profit implications (Stevenson 2006). Controlling and overseeing the storage of inventory plays a significant role in inventory management, as optimised storage locations can lead to minimised travel times and part losses and improve cubic space usage (Stevenson 2006). Controlling and overseeing the flow of inventory in the supply chain is imperative to keep track of inventory that moves from the suppliers to the customers (Stevenson 2006). Therefore, an efficient inventory management process should be implemented pro-actively to enhance customer satisfaction.

Inventory can be divided into three types, namely: fast moving-, medium moving- and slow-moving inventory (Şen, Bhatia, and Doğan 2010). This project assumes the following: fast moving inventory is inventory that sells within a year, medium moving inventory sells after a year but before four years and slow-moving inventory sells after four years or longer. In comparison with other industries, such as industries trading with fast moving consumer goods, the automotive industry's parts move much slower. This is due to the fact that the automotive industry deals with service-, spare- and crash parts that do not sell as often as fast moving goods (Kutanoglu and Lohiya 2008). Research has mostly focussed on fast moving inventory, as its revenue generating ability is higher than SLOB inventory, however the profit impact of resource wastage on SLOB inventory is likely much higher than assumed in the automotive industry and better management of this type of inventory can change bottom line returns to investors (Napolitano 2013a).

The project investigates the improvement of inventory management on all three types of inventory identified, however the study makes specific reference to SLOB inventory.

SLOB inventory is a phenomenon that occurs across all industries, nonetheless it is exaggerated in the automotive industry, as the industry has service, crash- and maintenance parts, which are prone to become SLOB inventory (Kutanoglu and Lohiya 2008). Therefore in this study, all types of inventory (fast moving inventory, medium moving inventory and SLOB inventory) are analysed to determine the profit optimising order quantities. SLOB inventory does not enter the normal optimisation models, as it is often ordered sporadically. This is also the case in this study, though to emphasise the importance of SLOB inventory management the study reports qualitative data collected via interviews.

1.1 Company Background

For this project the automotive company chosen, in which the management of inventory will be investigated, will be referred to as "the automotive Original Equipment Manufacturer (OEM) company". It is a well-known and leading international automotive organisation, although the name of the company is classified due to confidentiality concerns.

One of the main goals pertaining to supply chain's inventory management of the automotive OEM company is to achieve high customer service levels. Outstanding client service is an intangible that sets a company apart from others. This entails providing exceptional and memorable client service in order to retain as many clients as possible, as mediocre or bad client service will drive customers away. Excellent client service levels can be obtained in a number of ways, such as going the extra mile, knowing your clients, treating the customers with respect and knowing what they want, responding as quickly as possible and being accessible (eMarkerter 2014).

The automotive OEM company's customer service level is measured using two performance indices, namely: (i) the order fill rate (which is the fraction of customer orders met with the stock at hand) and (ii) the stock-out rate (which is the fraction of customer orders lost due to stock-outs). High customer service levels are achieved if the order fill rate is high and the stock-out rate is low.

The automotive OEM company's warehouse in Rosslyn bases its inventory orders on dealer demands. This implies that if the dealership sells a part, they immediately order a "replacement" part from the warehouse and then in turn the warehouse orders the "replacement" part from the suppliers. The warehouse is able to order "extra" parts to compensate for demand uncertainty and ensure that parts are available when needed.

1.2 Research Problem

According to the automotive OEM company's Rosslyn warehouse's data, 40% of its inventory is sold within a year of the purchase date, as mentioned in the introduction section, this is seen as fast-moving inventory. 20% of the inventory within the warehouse is medium-moving inventory as it is sold after a year, but in less than four years. The rest of the inventory moves much slower with 40% sold only after four years, this can be seen as the SLOB inventory. The great percentage of SLOB inventory within the OEM automotive company's warehouse is the reason why this study includes SLOB inventory. The aim is to not only improve the understanding of fast- and medium moving inventory but also to address the dearth of knowledge on SLOB inventory in the automotive OEM company's supply chain.

As referred to in the introduction section inventory mismanagement, especially accumulation of inventory, leads to wasted resources. Examples of wasted resources include: (i) time and human resources wasted on redundant cycle counts and material handling, (ii) space wasted on SLOB and redundant inventory instead of priority inventory, (iii) working capital tied up in excess inventory, (iv) increased inventory damages or losses, (v) higher risk involved in storing unnecessary inventory, and (vi) negative correlation between the physical inventory and the inventory captured on the system. Hence the inventory management is of utmost importance to limit costs and increase efficiencies in the OEM company's supply chain.

The research question to be addressed in this project is as follows: "how can the inventory management process, in the automotive OEM company's supply chain, be improved and what will the effect of these improvements be on the supply chain?"

1.3 Research Design

The research design used in this study is a mixed method research design, thus both qualitative data and quantitative data are used in this project.

To collect the qualitative data, interviews were held with the automotive OEM company's After Sales Supply Chain Manager, the automotive OEM company's Rosslyn Warehouse Manager and the Inventory Optimisation Manager. The interviews were held to gather in-depth information on the current processes followed, to determine how decisions are taken with regard to the ordering of inventory, the storage of inventory and the flow of the inventory through the supply chain. In the project this information is used to map the sequence of events taking place in the automotive OEM company's supply chain. These events include (i) ordering parts from suppliers, (ii) selling parts to dealerships, (iii) receiving parts returned to the warehouse due to one of three reasons (explained in the qualitative data analysis chapter), (iv) resending parts to the dealerships and (v) scrapping parts.

The quantitative data were collected to develop an inventory optimisation model that determines the quantity of fast- and medium-moving inventory that needs to be ordered to minimise the total storage- and transportation costs across the automotive OEM company's supply chain. Although SLOB inventory can be included in the model, it does not supply significant results. Therefore SLOB inventory is not included in the model, as it is ordered sporadically and falls outside the normal ordering process.

1.4 Research Methodology

Effective inventory management requires the analysis of both qualitative data and quantitative data to develop optimal solutions. Qualitative data is information collected through observations and interviews, while quantitative data is collected by measuring an outcome in numerical quantities. The qualitative data is used to map the automotive OEM company's current supply chain and the quantitative data is used to formulate a linear programming model that optimises the inventory levels in the supply chain.

This section is divided into two subsections. The first subsection describes the collection of data used in further analyses and the second subsection discusses inventory management techniques.

1.4.1 Data Obtained Through Qualitative and Quantitative Methods

Qualitative data that were gathered during the interviews include: (i) the current customer service levels, (ii) the customer service levels the automotive OEM company wish to obtain and (iii) the main causes of accumulation of inventory.

This data is used to analyse the entire flow of the parts wherein the current "problem areas" are identified in the supply chain, such as accumulated inventory and redundant tasks within the process. Each of the identified "problem areas" are further investigated to fully understand the problem as well as the effects it has on the supply chain. A unique solution is developed for each of the "problem areas" (see section on BPMN charts).

Furthermore, to emphasise the importance of SLOB inventory management this study determines the six colossal causes of inventory accumulation. A few methods of dealing with each of these causes of inventory accumulation are discussed.

1.4.2 Inventory Management

According to Pay (2010) the root cause of inventory mismanagement is uncertainty in supply and demand. By reducing uncertainty in supply and demand, inventory mismanagement can be reduced (Pay 2010).

From this flows the research question to be addressed in this project; "how can the inventory management process, in the automotive OEM company's supply chain, be improved and how will these improvements effect the supply chain?"

To address this research question the project firstly discusses tactics to minimise the accumulation of inventory in the OEM automotive supply chain. Secondly the project analyses the current supply chain processes of the automotive OEM company by using the collected quantitative and qualitative data and maps the entire supply chain. Thirdly the project formulates a linear programming model that addresses the fast- and medium moving inventory.

The aim of the project is to develop these improvements in order to address the "major" problem areas identified within the current supply chain.

Mapping of supply chain process

To map the current supply chain process which includes a description of the ordering-, storing- and selling- and scrapping processes used in the automotive OEM company's supply chain, the project made use of Business Process Modelling Notation (BPMN). BPMN describes the notation and semantics required to formulate a Business Process Diagram (BPD) (Edelman et al. 2009). A BPD graphically documents the sequence of activities occurring within the ordering-, storing-, returning- and selling- and scrapping processes. The purpose of the BPD is to identify important parameters as well as the problem areas within the current supply chain processes to be addressed to improve the efficiency of the supply chain (Edelman et al. 2009). Once the problem areas are identified the project develops solutions for each of these and measured against the current process output.

Linear Programming Model

To address the fast- and medium moving inventory the project develops an inventory optimisation model. In this model the quantitative data collected from the automotive OEM company is used. The data is used to determine the optimal inventory levels that will serve as a target inventory level that can, if achieved, drastically reduce resources wastage and improve customer service levels. In order to ensure that the model is a representative of the "real-life" situation the optimal inventory levels need to take several considerations into account. These considerations include the following: (i) the requested customer service levels for inventory, (ii) customer demands for inventory, (iii) the average transport cost per part (which includes transportation insurance costs, toll-gate fees, fuel, truck repairs, tire costs, labour costs for the person driving the truck and other routine maintenance and service costs), (vi) the average set-up costs per part (which includes the labour costs involved in setting up orders), (v) the average holding costs per part (which includes item damages or losses, rent, electricity and insurance), (vi) shortage costs per part, (vii) space available at the warehouse and (viii) the current inventory level.

The automotive OEM company classified the inventory according to the throughput-rate by making use of ABC analysis (Martin 2016). Using the ABC analysis' results obtained by the automotive OEM company, it is assumed that the "A-parts" represent the fast-moving inventory, as it has the highest throughput rate, while the "B-parts" are the medium-moving inventory and the "C-parts" are the SLOB inventory within the the supply chain.

Currently there are more than 32000 types of inventory within the warehouse. As the data is classified a random sample of 900 parts is used for the project. These 900 parts were used to perform a Pareto analysis (80-20 rule) to identify which 20% of the inventory is accountable for 80% of the sales within the supply chain. The result of the Pareto analysis, which is the A- and B parts, are used within the model. Thus, 20% of inventory is used to formulate linear programming model that aims to minimise transportation- and storage costs accross the automotive OEM comany's supply chain. The model uses various input data sets to generate an estimated optimal ordering quantity of parts for the warehouse (Pay 2010).

In the literature review discusses different types of software that can be used for linear programming models. This project makes use of Evolver to formulate the mixed integer linear programming model.

1.5 Document Structure

The structure of the paper is as follows. In chapter two the literature on the inventory process is discussed. Chapter three discusses the qualitative data analysis that were done during the project as well as the results and recommendations related to these studies. Chapter four explains the quantitative data analysis that were done and the results and recommendations pertaining to these studies. In chapter five chapter the project concludes by summarising the major results, recommendations and making reference to future studies.

Chapter 2

Literature Review

This chapter firstly explains methods used to improve a business process within a supply chain and general types of inventory control systems. Secondly the chapter describes different mathematical modelling approaches to inventory optimisation. Thirdly the chapter explains general types of inventory controlling systems and reviews literature on multi-echelon systems. Fourthly the chapter reviews literature on inventory management techniques used in the automotive industry. Lastly the chapter explains the approach that is followed for this project based on findings during the literature review.

2.1 Business process improvement in supply chains

Firstly, the section explains the concepts "supply chain" and "business process". Thereafter this section explains different modelling types that can be used to map a business process. Lastly this section explains Deming's process improvement method.

Stadtler (2015) defines a supply chain as the network that includes all organisations, activities, resources and technology involved in the sale of a product. This includes the activities starting are the delivery of parts from the supplier and ending at the delivery of parts to the retailer (or in this project referred to as dealerships).

Appian (2017) defines a business process as a collection of linked activities that can lead to accomplishing an organisational goal. According to Edelman et al. (2009) the investigation and understanding of a business processes is a good starting point for identifying improvement opportunities. Understanding how the current business process (inventory management process) is performed, is an invaluable platform that can be used to improve the process.

There are the following types business processes modelling techniques:

A simple process flow chart, a swim lane flow chart, a Suppliers Input Process Output Customer (SIPOC) diagram, a value stream map and a (BPMN) (Deas 2009). Simple process flow charts are used to outline certain duties that need to be performed to complete a specific task. Complicated logic cannot be mapped using a simple process flow chart, as the chart easily becomes complex and clumsy, which lead to wasted time and money as the user needs to make sense of the chart before it can be implemented (Deas 2009). Swim lane flow charts are usually used to indicate information flows that occur in non-linear sequences. The lanes represent different functions or departments involved in the process. Although the swim lane flow chart is similar to a BPMN chart, is does not display the same amount of detail as is displayed in BPMN charts (Deas 2009). SIPOC diagrams was originally designed for manufacturing organisations, as it focus on the holistic view rather than on a individual processes within the combination of processes (Deas 2009). Value stream mapping is usually used to communicate highly linear information- and material flows (Deas 2009). As this project requires a non-linear mapping tool, BPMN is used to map the current processes followed by the automotive OEM company's supply chain.

BPMN is a universal graphical modelling language, that is based on fixed terms of usage which enables the involved parties to clearly communicate business processes. BPMN can be used to develop a Business Process Diagram (BPD), that graphically displays the sequence of activities that occur in a process (Edelman et al. 2009). This project makes use of BPMN to graphically define relations and attributes of the automotive OEM company's current inventory management process. The map is analysed to identify "problem areas" within the automotive OEM company's current supply chain that require improvement.

According to Platje and Wadman (1998) process improvements evolve as the process enters different phases of its life cycle. Deming introduced a control loop, called a "Deming wheel" that illustrates the systematic approach that needs to be followed to improve a process. The first phase, called "Plan", is where the "problem areas" are analysed and creative improvement solutions developed. The second phase, called "Do", is the phase in which the planned improvement solutions are implemented. The third phase, called "Check", is where the implemented solutions are measured against the initial process by using of performance metrics. A performance metric is a quantifiable measure that is used to track the organisation's behaviour, activities and performance. It is an integral part of an improvement process to determine what effect the improved solutions have on the supply chain processes. The last phase, called "Act", is the phase in which the process is modified according to the solutions that were confirmed to deliver improved results (Platje and Wadman 1998).

As stated these inventory management improvements are suggested to the automotive OEM company's supply chain. Although the definition of inventory management that was discussed in the introduction of this project focused only on three aspects (ordering inventory, storage of inventory and the flow of inventory through the supply chain), this project includes the information shared between the supply chain parties with regards to these three aspects. Sharing information among supply chain partners is vital for effective supply chain management. Effective supply chain management is essential to a company's success and customer satisfaction (Stevenson 2006). Therefore, by including shared information, this project ensures that it is in line with the OEM company's aim to improve customer satisfaction.

2.2 Mathematical modelling approaches for inventory optimisation

One technique often used for inventory management and optimisation, is mathematical modelling. Mathematical modelling deals with the use of advanced analytical models to assist with decision making. LP is a mathematical modelling approach that allows decision makers to find the optimal course of action for complex problems, including inventory management problems (Winston, Venkataramanan, and Goldberg 2003). This section focus on explaining different LP variations that can be used to solve distinct problems.

2.2.1 Linear Programming

LP was developed by George Dantzig in 1947 as a simplex algorithm that solved optimisation problems. LP is used by various industries, including but not limited to education, logistics, trucking and banking (Winston, Venkataramanan, and Goldberg 2003).

LP's are the most natural tool used to solve an array of problems with a moderate amount of effort. A LP problem is characterised by a linear objective function and linear constraint equalities or inequalities (Winston, Venkataramanan, and Goldberg 2003). A non-linear problem is characterised by a system of constraints and an objective function, where some of the constraints, the objective function or both consist of unknown, non-linear values (Winston, Venkataramanan, and Goldberg 2003).

Different variations of LP's have been developed to solve distinct problems (Winston, Venkataramanan, and Goldberg 2003), such as integer programming, mixed integer programming, dynamic programming, deterministic programming and stochastic programming. Integer programming solves a LP problem that contain non-negative integer variables, while mixed integer programming solves a LP problem that contain integer- and float variables (Winston, Venkataramanan, and Goldberg 2003). Dynamic programming transforms an optimisation problem into a number of problems that only have a single decision variable. The model has states which are often grouped into stages. The transitions as well as the decision process occur at each stage (Winston, Venkataramanan, and Goldberg 2003). Deterministic programming solves an LP problem that contains no stochastic elements and can be determined conclusively, while stochastic programming contains at least one random variable with a certain distribution function(Winston, Venkataramanan, and Goldberg 2003).

Optimisation problems can be divided into minimisation problems and maximisation problems. Both these types of problems can be solved by one of two types of algorithms, namely an exact algorithm or a heuristic (approximation) algorithm. The algorithm solution can either be a global optimum or a local optimum. A global optimum is the best feasible solution from all the feasible solutions to the optimisation problem, while a local optimum is a feasible solution to the optimisation problem (Schrage 2006).

An exact algorithm finds the global optimum solution to an optimising problem, provided that the problem is not exceedingly complex. The branch-and-bound method is used to solve integer linear programs exactly. This is done by means of a systematic approach that computes all possible combinations of the given variables in order to determine the global optimum solution (Schrage 2006).

Heuristic algorithms are used to solve very complex problems, by finding a local optimum solution close to the global optimum solution. Heuristic algorithms can be divided into three types of solving methods, namely: (i) local search improvement methods, (ii) constructive methods and (iii) metaheuristic methods. Metaheuristic methods are most commonly used to solve complex problems, such as ant colony optimisation and simulated annealing (Schrage 2006).

(Winston, Venkataramanan, and Goldberg 2003) states that a LP consists of the following three categories, namely: (i) a linear- or objective function that is to be maximised or minimised, (ii) a set of constraints that restrict the values that must be calculated for the decision variables and (iii) sign restrictions that specify whether the decision variables should be positive or negative.

2.3 Inventory controlling systems

An important subsection of inventory management is called inventory control. Inventory control is a method of regulating and maintaining the desired inventory level, while the desired inventory level fluctuates as a result of stochastic demand. Efficient inventory control leads to having the correct amount of inventory at the right time and place (Akrani 2012).

Inventory controlling systems can be divided into two main systems, namely: single-echelon systems and multi- echelon systems. Single-echelon inventory controlling problems focused on determining the optimum inventory level for an individual supply chain unit, while multi-echelon inventory controlling problems focused on the optimum inventory levels across the entire supply chain.

Multi-echelon models are very intricate and various types of multi-echelon models have been derived. This section discusses a few of the most important contributions (Ekanayake, Joshi, and Thekdi 2016).

Kreipl and Pinedo (2004) developed a multi-echelon model in which the stages in the supply chain did not compete with each other, but rather collaborated to minimise the total supply chain costs, by taking the inventory holding costs and transportation costs into account. Furthermore, the model distinguished between different product families, but not between the products within the product families. This model is not applicable to this study, as this study focuses on the order quantities of specific product types and not on different product families.

A second model was developed by Sherbrooke (1968) for the United Nations Air force. This model makes use of a multi-echelon model for a stochastic repair rates. The model was used to determine the optimal distribution and redistribution of stock that needs to be repaired within the supply chain (Sherbrooke 1968). Unlike the stochastic repair rates used by Sherbrooke, this project uses deterministic rates to determine the optimal warehouse ordering quantities. A deterministic approach is used, as the exact values are made available by the automotive OEM company.

In a third multi-echelon model developed by Moinzadeh (2002) consisted of a single product and supplier, but multiple retailers. The model assumes that the supplier has information about the product demand and activities at each retailer, which it uses as input to replenishment and ordering decisions. This study differs from Moinzadeh (2002) study as it will be dealing with multiple items and retailers.

A fourth model developed by El-Sayed, Afia, and El-Kharbotly (2010) investigated a three-echelon (supplier, manufacturer and retailer) closed-loop supply chain. The multi-echelon model considered both the forward- and the reverse logistics between echelons. Two critical assumptions were made, namely that the information was transparent between the echelons and that the replenishment policies remained constant throughout the supply chain. Managers who aimed at maintaining inventory levels in a multi-echelon supply chain, found this model helpful, as an equation was developed to eliminate the possibility of under-stocking or overstocking of inventory at each echelon. In a similar fashion, this project considers forward- and reverse logistics within the supply chain to improve inventory management across the entire supply chain.

2.4 Inventory management methods used in the automotive industry

This section specifically reviews inventory management methods used in the automotive industry. Two of these methods are single-echelon models and the rest are multi-echelon models.

The single-echelon methods are described by Memari, Rahim, and Ahmad (2014) and Jha (2012). Both of these models were specifically developed for the automotive industry and recommend that hybrid push and pull planning system should be used to manage the inventory levels at a facility within the supply chain. In practice systems of all types, use varying degrees of both "push" and "pull" features, based on the system's nature. In this project the focus is on managing inventory levels across multiple-echelons and therefore the single-echelon models are not applicable.

The multi-echelon systems described in this section were developed by Hirakawa, Hoshino, and Katayama (1992), Takahashi and Soshiroda (1996), Cochran and Kaylani (2008) , Salum and Araz (2009) , Khalaj, Modarres, and Tavakkoli-Moghaddam (2014) and Deng, Yuan, and Yan (2015).

Hirakawa, Hoshino, and Katayama (1992) and Takahashi and Soshiroda (1996), indicated that using hybrid control systems are more beneficial than the use of pure "push" or "pull" control systems. Both scientists developed mathematical models for multi-echelon production systems, that had to optimise the inventory level at each stage in the production system. In both studies, it was found that hybrid systems had a higher degree of effectiveness if they are properly operated, in comparison to pure "push" or "pull" systems. This is due to the fact that the hybrid system combine the benefits of both the "push-" and the "pull" system to ensure the optimal inventory level in the automotive manufacturing industry.

Cochran and Kaylani (2008) developed an optimisation model that horizontally integrated a "push-" and "pull" systems in a multi-product, sequential production line. His study also found that it is more effective to use a hybrid control system in comparison with a pure "push" or "pull" system in an automotive manufacturing environment.

Hirakawa, Takahashi and Cochran's studies emphasised the manufacturing of parts for the automotive supply chain, while this project focusses on the transportation- and storing costs in the automotive supply chain. Push control systems involve forecasting inventory needs to meet customer demand. Therefore push control systems are normally used in the manufacturing environment to produce enough products to meet the forecasted demand, to be able to push the parts to the customers (Hunt 2012). Pull control systems starts with the customer's order. This strategy focusses on storing just enough product's to fulfil the customer's orders (Hunt 2012). Therefore this project makes use of a pure pull control system at each of the echelons, as each echelon's orders are dependant on preceding echelon's orders.

Salum and Araz (2009) studied the application of a hybrid push-pull inventory management system that had to determine when and where to transport parts as well as when to process which parts, by comparing the hybrid control system with a Kanban system. He was found that the hybrid control system easily overcame the difficulties obtained by implementing and modelling a Kanban system. Although Salum's model incorporated transportation costs, his model's main focus is to determine when parts should be manufactured.

Khalaj, Modarres, and Tavakkoli-Moghaddam (2014) developed a genetic algorithm that investigated not only the location of the echelons, but also the allocation between the echelons to minimise the total cost of location and transportation. The genetic algorithm was applied to an automotive supply chain in Iran and showed the performance of the proposed model. Khalaj, Modarres, and Tavakkoli-Moghaddam (2014) focused on minimising the transport costs in the supply chain by reallocating the echelons to the optimal positions, while each of the echelons in this study has fixed locations.

Deng, Yuan, and Yan (2015) developed a multi-echelon inventory management model that investigated the management of automotive spare parts warehousing. The objective function of the model was maximising the total profit and efficiency of the supply chain, by optimising the amount of spare parts within the warehouse. This model will be used as a guideline for this project, although this project did not consider both forward- and reverse logistics between multi-echelons and maximised the total profit and efficiency, whereas this project minimises storage- and transportation costs.

2.5 Concluding remarks

This study determines how to improve inventory management across an automotive OEM company's supply chain. Therefore, the project makes use of a closed loop multi-echelon model that considers both forward- and reverse logistics between the echelons to develop an improved inventory management process.

According to Schage (2006) a mixed integer problems are difficult to solve and takes a long time to solve. Though this is the case this model will make use of mixed integer linear programming. As inventory needs to be sold and bought in integer amounts (Schrage 2006).

In order to formulate a LP, a computer program is needed. There are currently various types of programmes on the market. Some of these products are for free, such as the Solver (a Microsoft Excel add in), while other products such as Lingo and Evolver can be bought.

Evolver is a software developed by Palisade, "the maker of the world's leading risk and decision analysis software". Evolver is an advanced optimisation add-in for Microsoft Excel (Palisade 2017).

The difference between Solver and Evolver is that Solver can only determine a maximum of 200 variables, while Evolver does not have a variable limit. Furthermore, Evolver needs to be purchased if one wants to use it for more than 15 days. Evolver uses ground-breaking LP, OptQuest (Industrial edition only) and linear programming technology". Any type of problem that can be modelled in Excel can be solved by Evolver. These problems, are not limited to linear problems, but includes complex non-linear problems and integer problems (Palisade 2017).

This project makes use of Evolver as it has the highest level of computational accuracy and makes use of the LP optimisation, which enables the model to generate a global optimum solution (Palisade 2017).

Chapter 3

Qualitative Data Analysis

Qualitative data is information that cannot be measured numerically. Qualitative data was collected from the interviews with the automotive OEM company's After Sales Supply Chain Manager, the automotive OEM company's Rosslyn Warehouse Manager and the Inventory Optimisation Manager. The qualitative data is used to construct a BPMN chart as well as a "cause and effect" diagram. Both these diagrams are discussed in this chapter.

3.1 Current Process Mapping

This section discusses the process that is currently followed within the automotive OEM company's supply chain. The process is mapped using BPMN to develop Orchestration diagrams (see Figure 3.1). Orchestration diagrams define the processes internal to the automotive OEM company (including their third-party logistics providers). The diagram makes use of a pool with multiple lanes to map the activities within the automotive OEM company. The external parties within the supply chain, such as the dealerships and suppliers are mapped as "black-boxes", by only displaying the relationships between these parties and the automotive OEM company. Figure 3.1 illustrates the entire current inventory management process. In this section the process is broken down into smaller sections and snippets from the total process are discussed separately (see Figure 3.2 to 3.21).

The first "sub-process" that is discussed is called the "quotation receiving sub-process" (see Figure 3.2). Within this sub-process, the automotive OEM company's sales department receives a request for a quotation from a dealership. The sales department needs to analyse the request for a quotation in order to prepare the said quotation for the specified parts required by the dealership. After the quotation is completed, it is sent to the dealership for inspection. In the next step the sales department determines whether the specified parts required by the dealership are available, by retrieving a list from the automotive OEM company's WMS. There are only two options available, either the automotive OEM company has the correct quantity of the specified parts in stock, or not. In the first scenario, where the automotive OEM company has the required quantity of parts available, the sales department sends a list of the required parts to the warehousing department, whereas if the second scenario holds, that is the automotive OEM company does not have the required quantity of stock available, the sales department sends a list of the required parts to their third-party logistics provider.

In the first scenario, where the automotive OEM company has the required quantity of parts available, the warehousing department receives a list with the specified parts required by the dealership and their bin locations (see Figure 3.3). The outbound warehouse employees need to retrieve the specified parts from the bin locations and move it to the loading space. At the loading space, the parts need to be packaged according to the specifications. Thereafter the outbound warehouse employees send the parts to the dealership and the warehouse managers

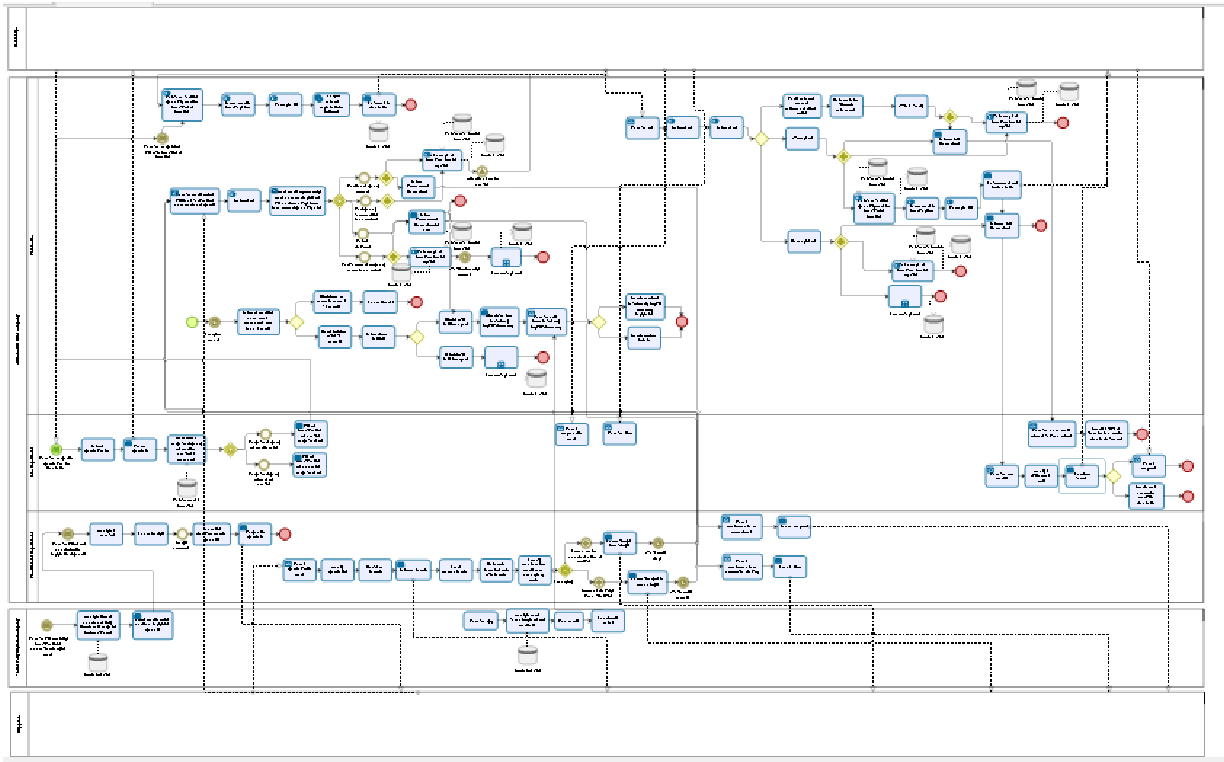

Figure 3.1: Entire Automotive OEM Company's Inventory Management Process

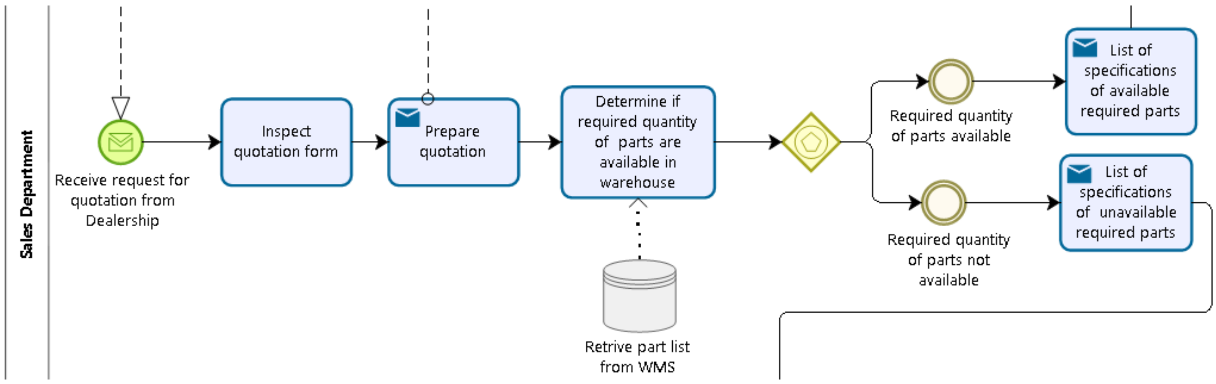

Figure 3.2: Request for quotation

update the WMS.

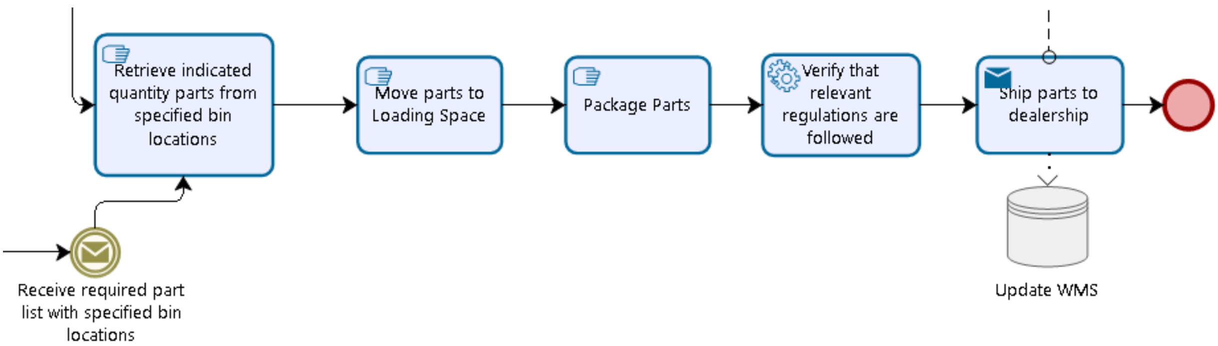

Figure 3.3: Receive parts

In case of the second scenario, in which the automotive OEM company does not have the required quantity of stock available, the third-party logistics provider receives the list of parts required by the dealership (see Figure 3.4). The third-party logistics provider needs to compare the list received from the sales department with the stock at hand according to the WMS system. Thereafter the third-party logistics provider needs to determine the optimal quantity of the specified parts needed with regards to the correct safety levels. Next the third-party logistics provider needs to send a list of the optimal quantity of the specified parts needed to the purchasing department.

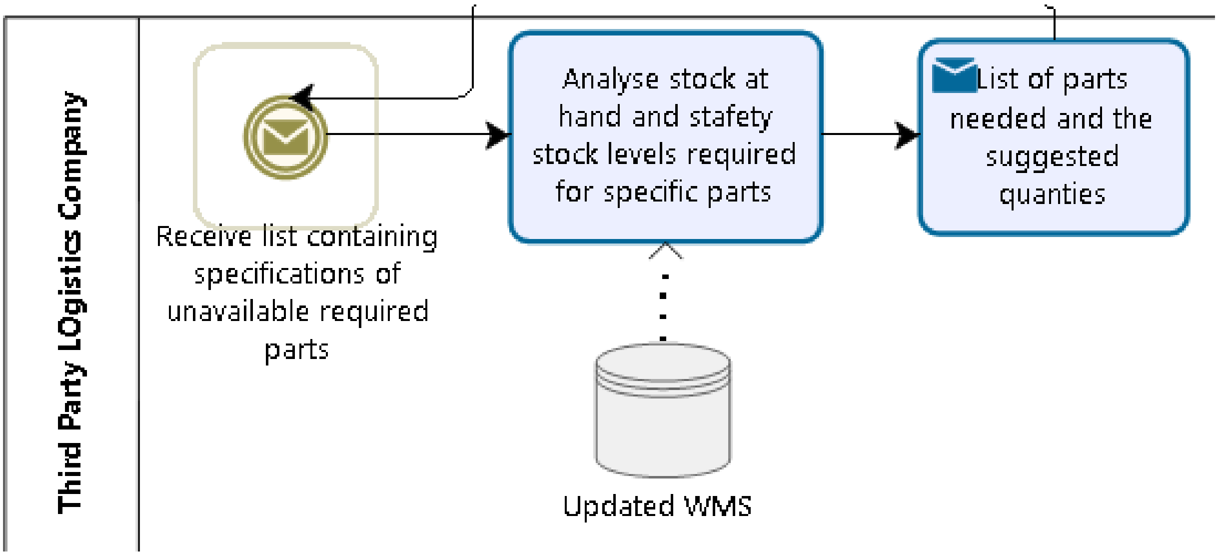

Figure 3.4: Third-party Logistics Providers

When the purchasing department receives the list of the optimal quantity of the specified parts from the third-party logistics provider (see Figure 3.5), they analyse the list. Thereafter they check if the budget is sufficient for the procurement of the quantity specified by the third-party logistics provider. Next the purchasing department makes a final decision on the quantity of parts they would like to order, before requesting quotations from the suppliers.

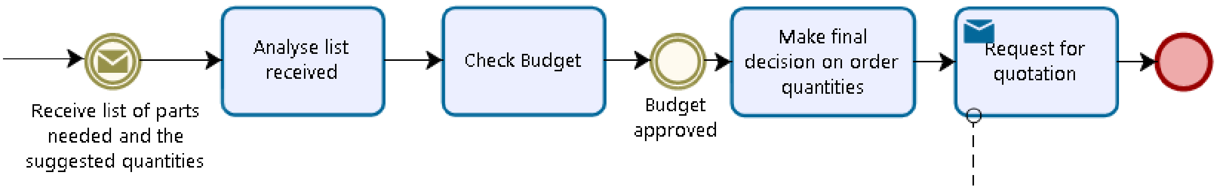

Figure 3.5: Check Budget

After receiving quotations on the parts required, the purchasing department analyses the quotations to determine from which supplier the automotive OEM company will procure the required parts (see Figure 3.6). As soon as the purchasing department determines which supplier they would procure the required parts from, they inform the supplier and create a purchase order. Thereafter the purchasing department need to determine the ordering terms with the supplier and indicate whether the procurement of the required parts was an emergency or not.

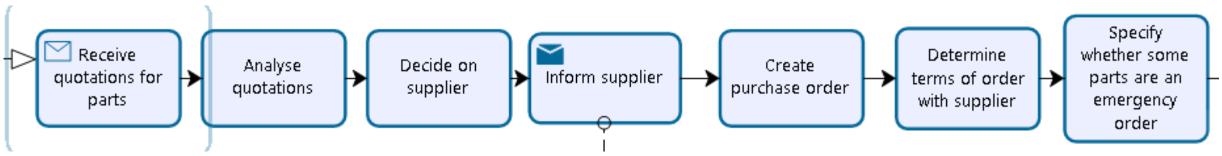

Figure 3.6: Receive quotations

If the procurement of the required parts is an emergency, the supplier has to send the parts to the automotive OEM company's warehousing department via airfreight, after which the parts will arrive at the warehousing departments within 72 hours after it was sent by the supplier (see Figure 3.7). If the procurement of the required parts is not an emergency, the supplier can send the parts to the automotive OEM company's warehousing department via ocean freight, which is a much more economical option to follow for the automotive OEM company, automotive OEM company's warehousing department will have to wait approximately 75 days for the parts to arrive.

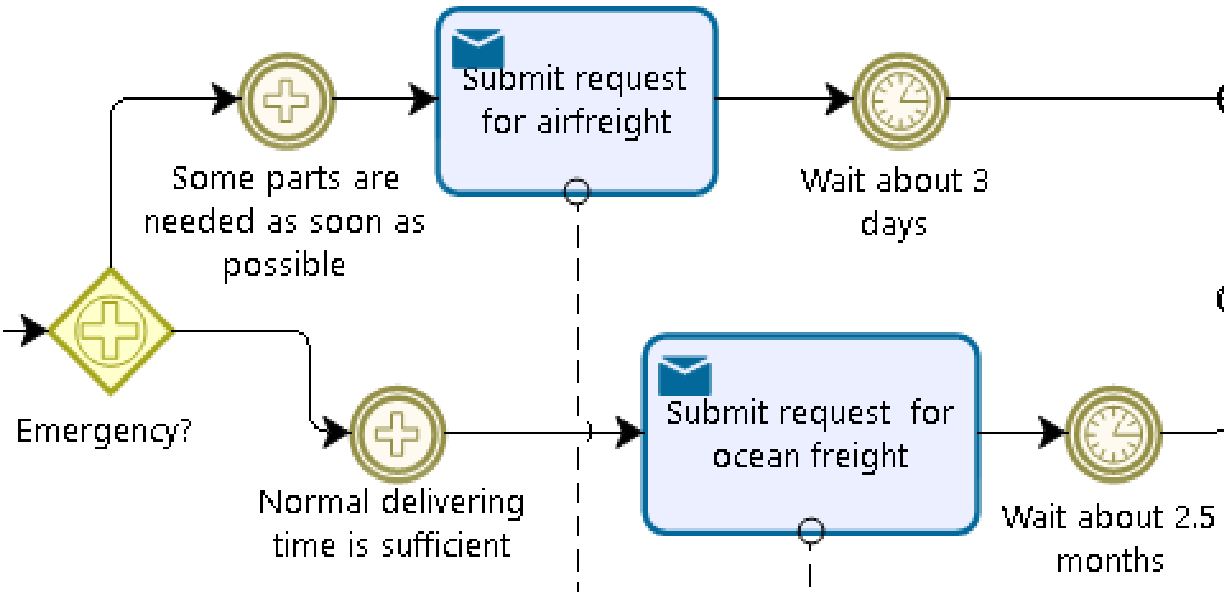

Figure 3.7: Is it an emergency?

Once the automotive OEM company's warehousing department has received the parts and the part lists, the inbound warehouse employees unload the parts before comparing the part-numbers and quantities of the parts received to the part-numbers and quantities specified on the part list (see Figure 3.8).

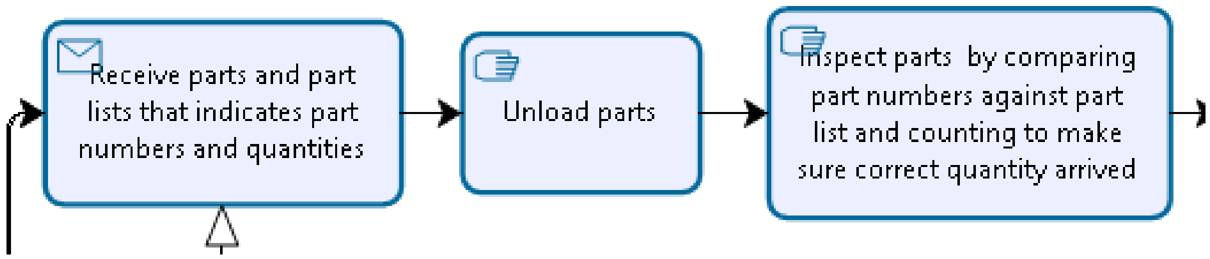

Figure 3.8: Receive part list

There are five viable outcomes after the parts were inspected (see Figure 3.9) (i) both the parts and the quantities of the parts that arrived are correct, or (ii) the quantity of the parts that arrived are less than the quantity specified on the part list, or (iii) some of the parts on the part list did not arrive, or (iv) the parts that arrived are incorrect or (v) the quantity of parts that arrived are more than the quantity on the part list. In case of the first outcome (both the parts and the quantities of the parts that arrived are correct) the inbound warehouse employees update the WMS and alert the outbound warehouse employees that the parts are available after they have put the newly arrived parts into the bins specified by the WMS.

In which case the warehouse managers inform the purchasing department that they are satisfied with the parts that have arrived. In the event of the second outcome (the quantity of the parts that arrived are less than the quantity specified on the part list), the inbound warehouse employees update the WMS and alert the outbound warehouse employees that some of the parts are available after they stored the newly arrived parts into the bins specified by the WMS, while the warehouse managers inform the purchasing department that the correct quantity of parts did not arrive. Referring to the third outcome, some of the parts on the part list did not arrive at the warehouse, the warehouse managers inform the purchasing department of this occurrence. In event of the fourth and fifth outcomes (either the parts that arrived are incorrect or the quantity of parts that arrived are more than the quantity on the part list), the warehouse managers inform the purchasing department that parts that arrived are either incorrect or that the quantity of the parts that arrived are more than the quantity specified on the parts list and the warehouse employees store the inventory in new bin locations created by the WMS and updates WMS. These parts are normally scrapped in the next cycle.

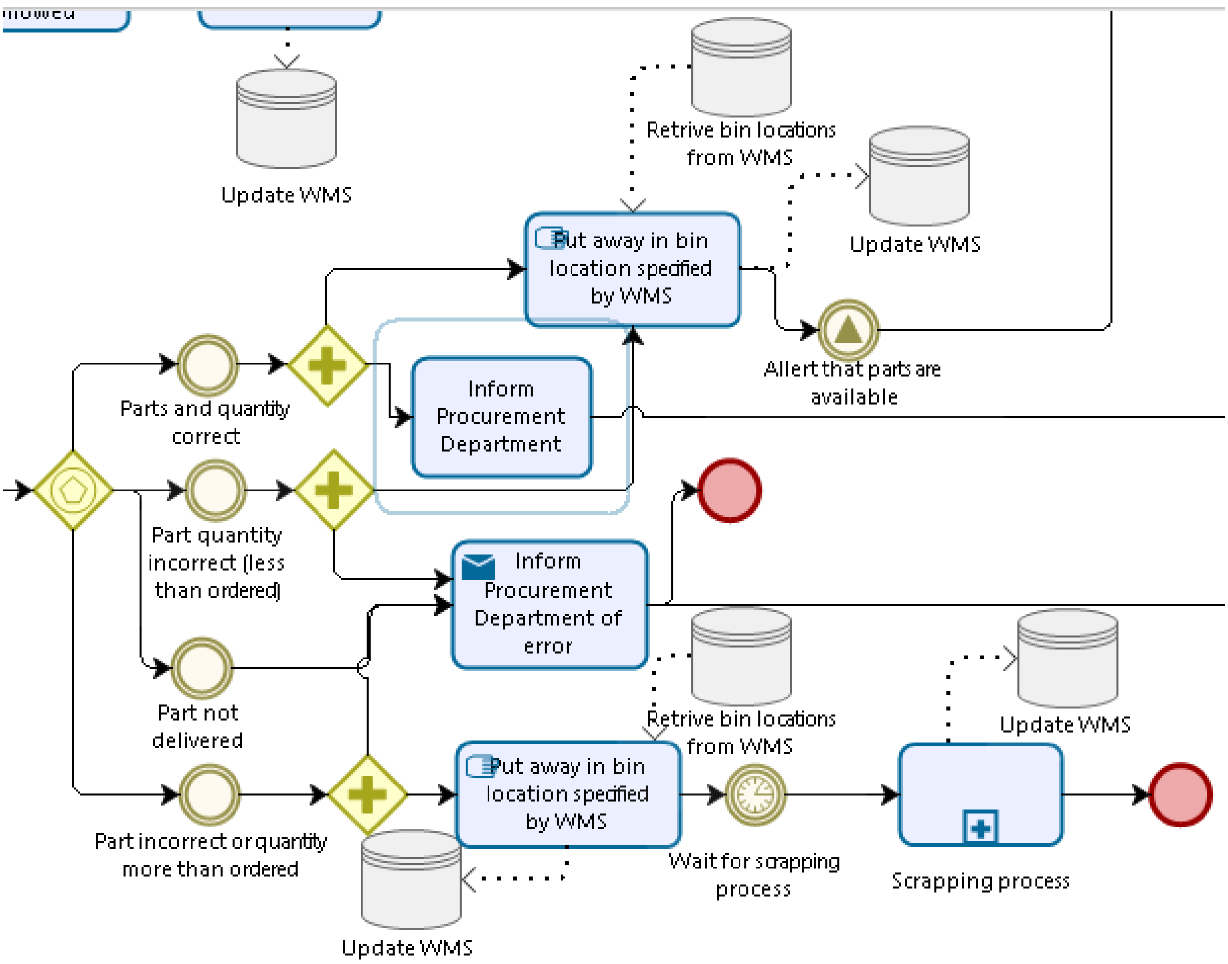

Figure 3.9: Inspect parts

If the purchasing department receives confirmation from the warehousing department that they are satisfied with the parts that arrived from the supplier, the purchasing department makes a payment to the supplier (see Figure 3.10). If the purchasing department receives confirmation from the warehousing department that there is some kind of error with the parts that arrived (such as a quantity errors, parts that did not arrive or incorrect parts that arrived at the warehouse), they make a payment for the parts that the warehousing department is satisfied with and create a Return Merchandise Authorisation (RMA), that they send to the supplier on the part arrival errors.

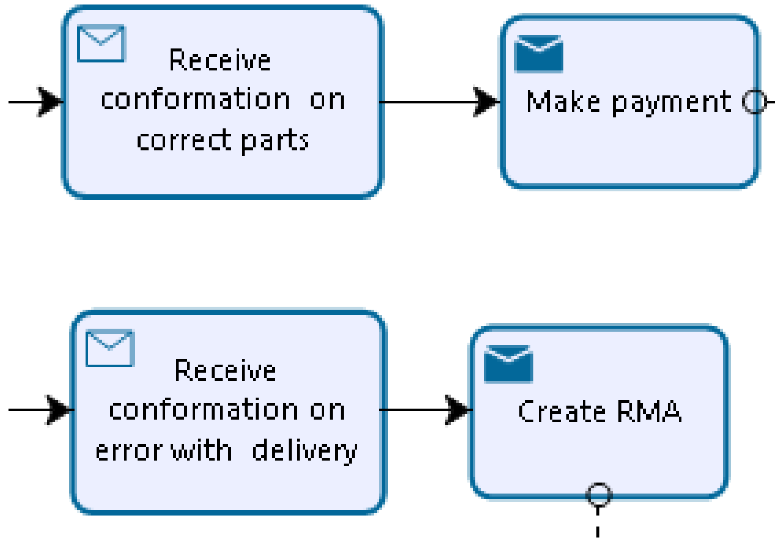

Figure 3.10: Receive confirmation

Figure 3.11 describes the dealership part returns process.

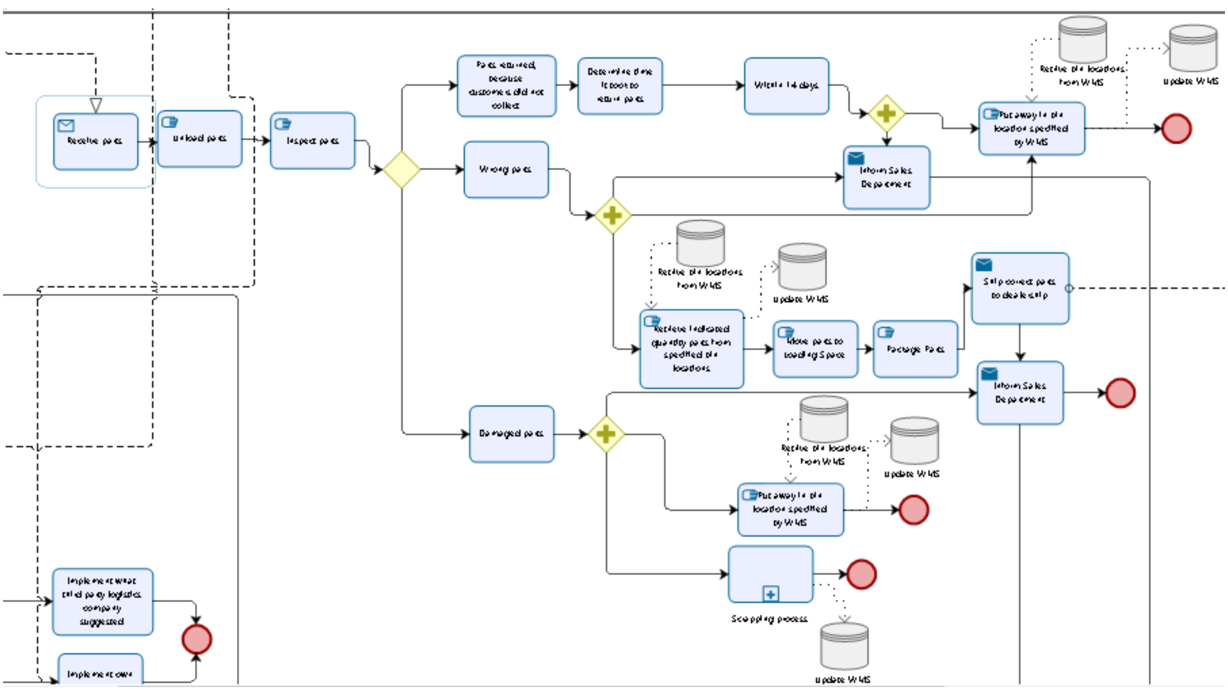

Figure 3.11: Dealership returns

The inbound warehousing employees unload the parts returned from the dealerships, to inspect it (see Figure 3.12).

The dealerships are allowed to return parts that their customers did not collect within 14 days of the date they received the parts from the automotive OEM company's warehousing department (see Figure 3.13). If the dealerships return parts within the allocated 14 days, the warehouse employees put the parts away in the bins specified by the WMS, update the WMS and inform the sales department.

If the parts were returned within 14 days of the date the dealership received the parts, the sales department receives a "new" part list and loads 70-80% of the amount received from the dealership for the procurement of the parts as credit on the dealerships account (see Figure 3.14). The 20-30% of the amount received from the dealership for the procurement of the parts that

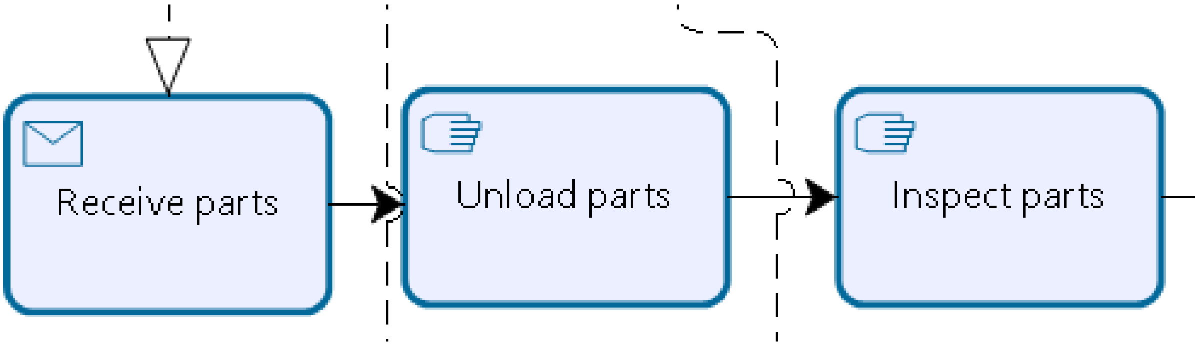

Figure 3.12: Receive returned parts

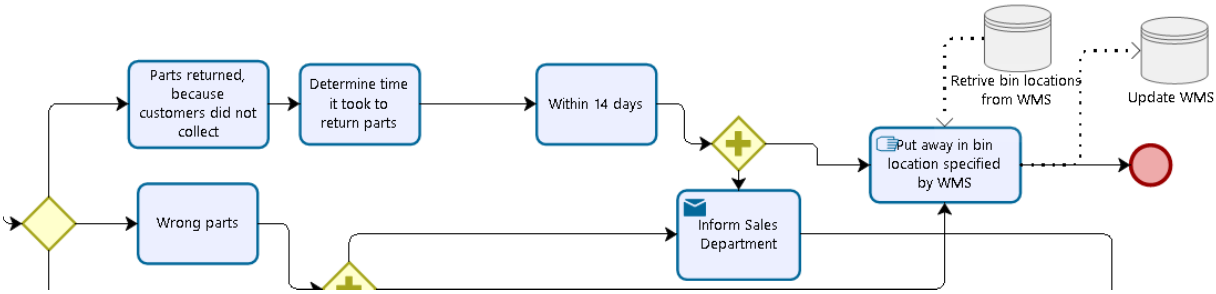

Figure 3.13: Receive parts customers did not collect

the sales department does not return to the dealership is seen as "handling and transportation fees" that the dealership forfeits.

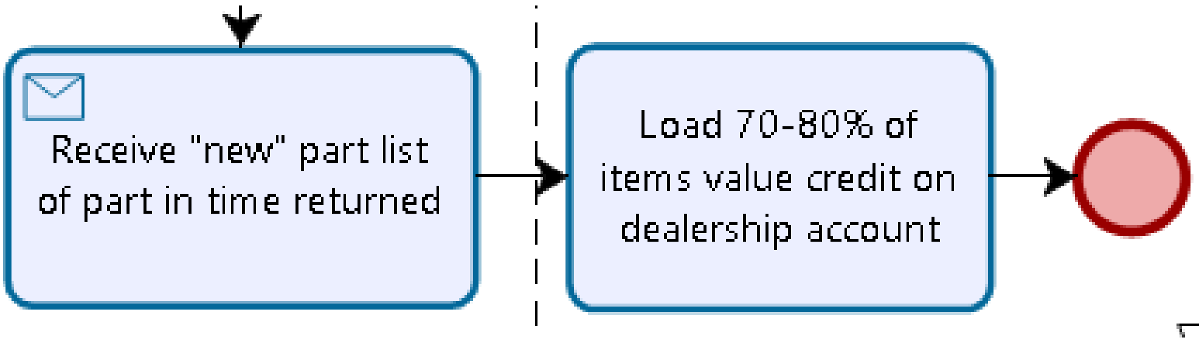

Figure 3.14: Load 70-80% credit on dealership account

If the warehouse sent the wrong parts to the dealerships and they return the parts to the automotive OEM company's warehousing department (see Figure 3.15). The warehouse managers inform the sales department, while the inbound warehouse employees put the returned parts away in the bins specified by the WMS and update the WMS. Next the outbound warehouse employees update the WMS after retrieving the required quantity of the parts specified by the dealership from the bin location stated by the WMS and moving these parts to the loading space, where the parts are packaged according to the dealerships requirements and sent to the dealership. After the correct parts are sent to the dealerships the warehouse managers inform the sales department.

If the dealership received damaged parts from the automotive OEM company's warehousing department, they are allowed to return the damaged parts to the warehouse (see Figure 3.16). Upon the arrival of damaged parts from the dealership, the warehouse managers inform the sales department, while the inbound warehouse employees put away the parts into the bins specified by the WMS and update the WMS. These parts are stored in these bins until the next warehouse scrapping process, in which it is scrapped and the WMS updated. The outbound warehouse

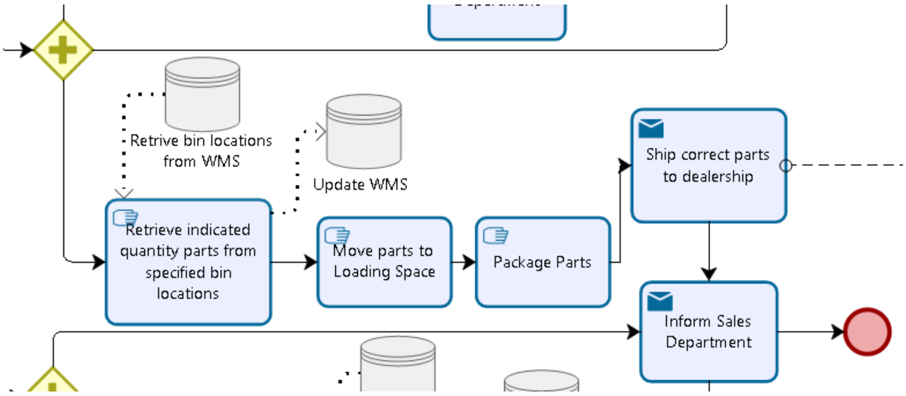

Figure 3.15: Send parts to dealership

employees update the WMS after retrieving the required quantity of the parts specified by the dealership from the bin location indicated by the WMS and moving these parts to the loading space, where the parts are packaged according to the dealerships requirements and sent to the dealership. After the correct parts have been sent to the dealerships the warehouse managers inform the sales department thereof.

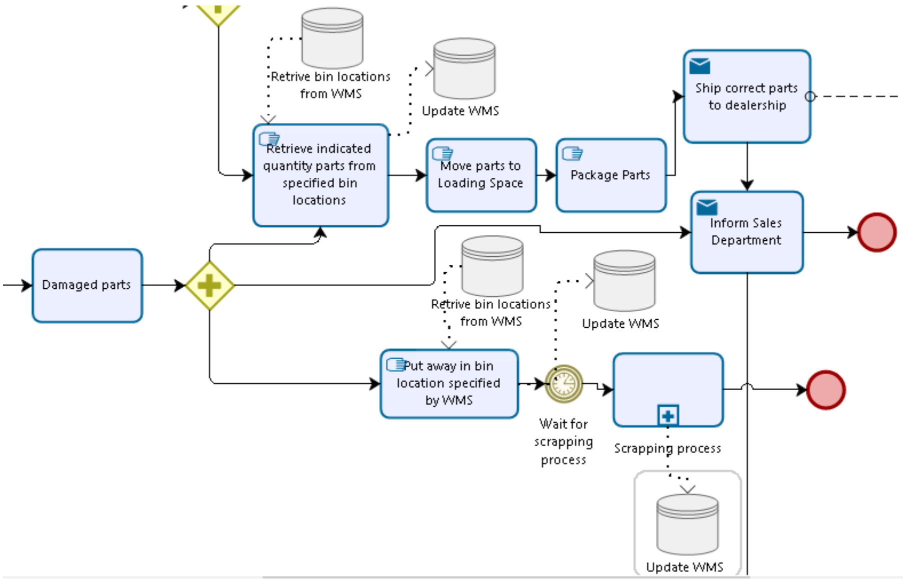

Figure 3.16: Damaged parts

The sales department receives a "new" part list from the warehousing department if the dealership returned damaged parts or incorrect parts (see Figure 3.17) and sends a new invoice to the dealership, after comparing the difference in costs, between the payment received for these parts and the actual cost of the parts the dealership required. The sales department then either has to receive a payment form the dealership, or load an excess amount of credit on the dealership's account.

In Figure 3.18 the automotive OEM company's warehouse inventory management process is illustrated.

Once every month the the automotive OEM company's warehouse managers inspect whether the parts have been sold within the last 12 months (see Figure 3.19). If the parts have been sold within the past 12 months the parts are kept "as is", while if the parts have not been sold within the previous 12 months, the warehouse managers have to inspect when last the parts have been sold.

If the parts were sold within the previous four years, then the warehouse managers should

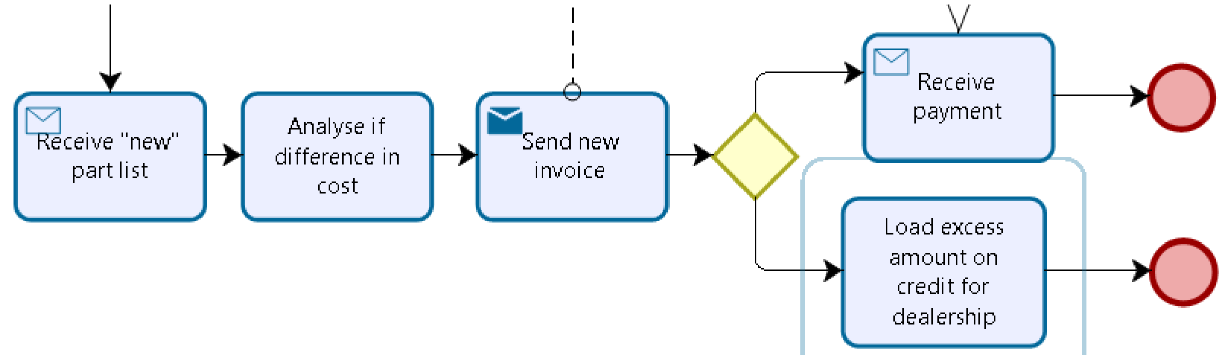

Figure 3.17: Send new invoice

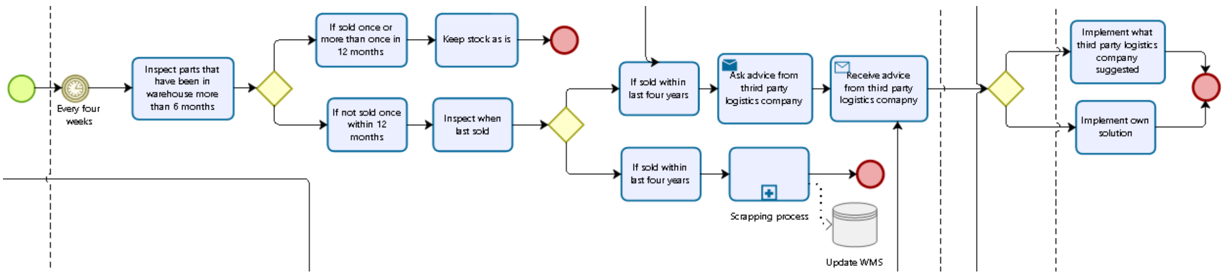

Figure 3.18: Warehouse inventory management process

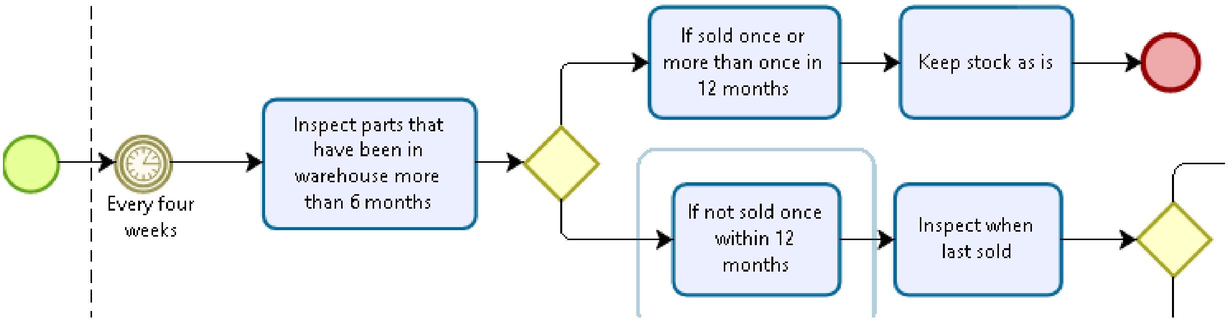

Figure 3.19: Start of inventory management process

ask advice on the management of these parts from the third-party logistics provider (see Figure 3.20). As soon as feedback from the third-party logistics provider is received, the warehouse managers can either implement the third-party logistics provider's suggestion, or they can implement their own solution (based on previous experiences). If the parts were not sold within the previous four years the parts need to be scrapped.

When the third-party logistics provider receives a query regarding the management of inventory that have not sold within the previous four years, they have to analyse the current inventory levels (received from the WMS), run the results through the inventory management model they developed for the automotive OEM company and send the results to the warehousing department as requested (see Figure 3.21).

By analysing the current process followed by the automotive OEM company's supply chain, emphasis are placed on inventory mismanagement and a few inefficiencies within the current process.

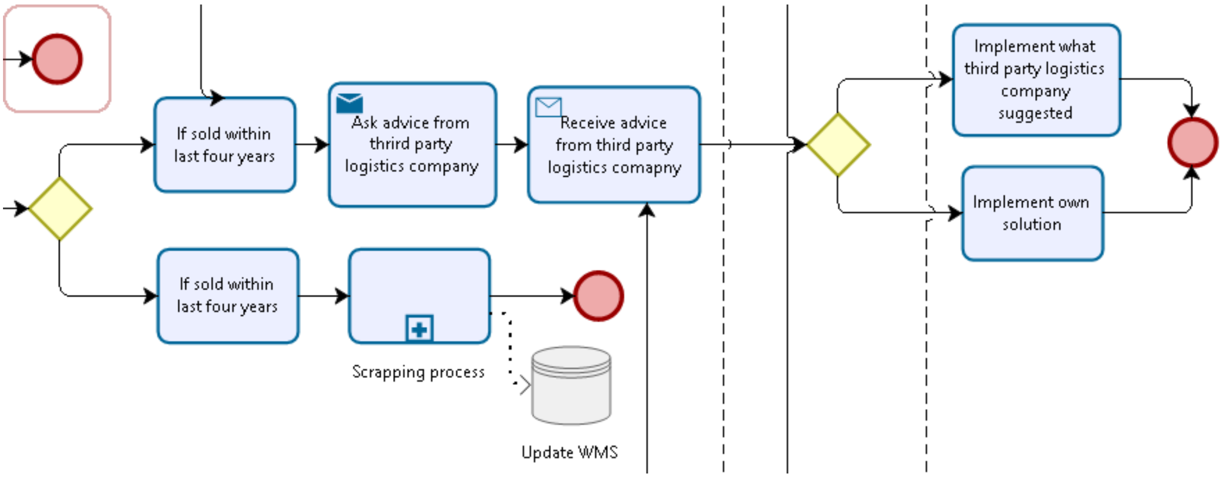

Figure 3.20: Determine when parts were last sold

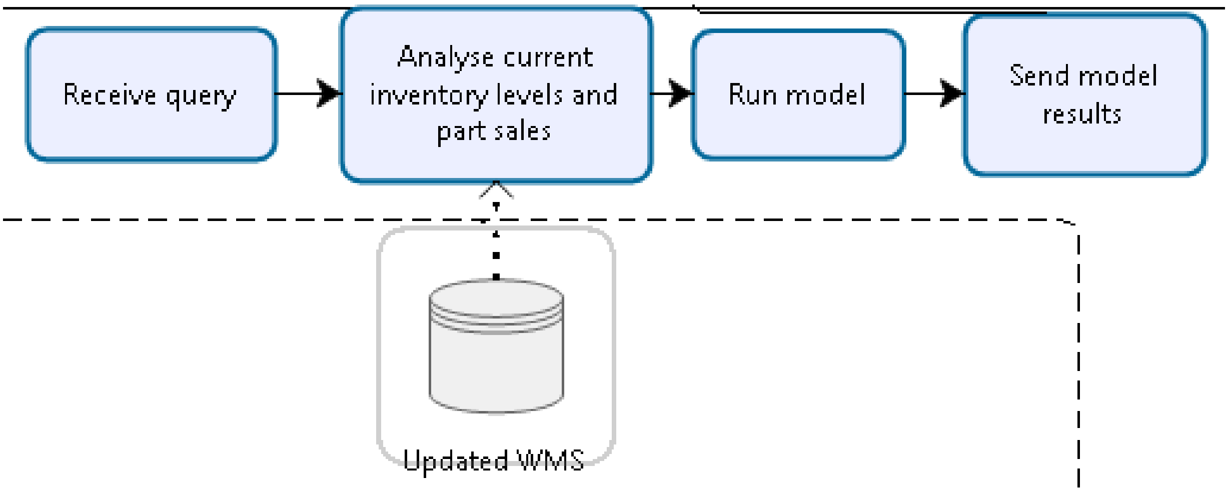

Figure 3.21: Analyse current inventory levels

3.2 "Causes and Effects" of Accumulated Inventory

A "cause and effect" diagram is constructed and discussed to explain the reasons for accumulation of inventory, which is mostly related to SLOB inventory and plausible solutions to these problems are suggested (see Figure 3.22 - the "cause and effect" diagram).

[i] The dealerships are allowed to send parts back to the warehouse, within 14 days of purchase, if customers did not purchase the part as expected, this can lead to an accumulation of parts in the warehouse, as the warehouse might have already ordered a "replacement" part from the suppliers. The dealerships do occur a cost (a handling fee) in this event of about 20-30% of the product's price.

[ii] Excess inventory occurs due to some dealerships ordering parts in large quantities to sell over a longer period of time, resulting in the accumulation of inventory throughout the supply chain. The warehouse can misinterpret these large order quantities as increased demand and overstock the parts.

[iii] High inventory levels can occur as a result of acquiring new parts where the demand did not realise as expected, due to economic factors.

[iv] A vast amount of excess inventory result due to warehouse workers or managers ordering

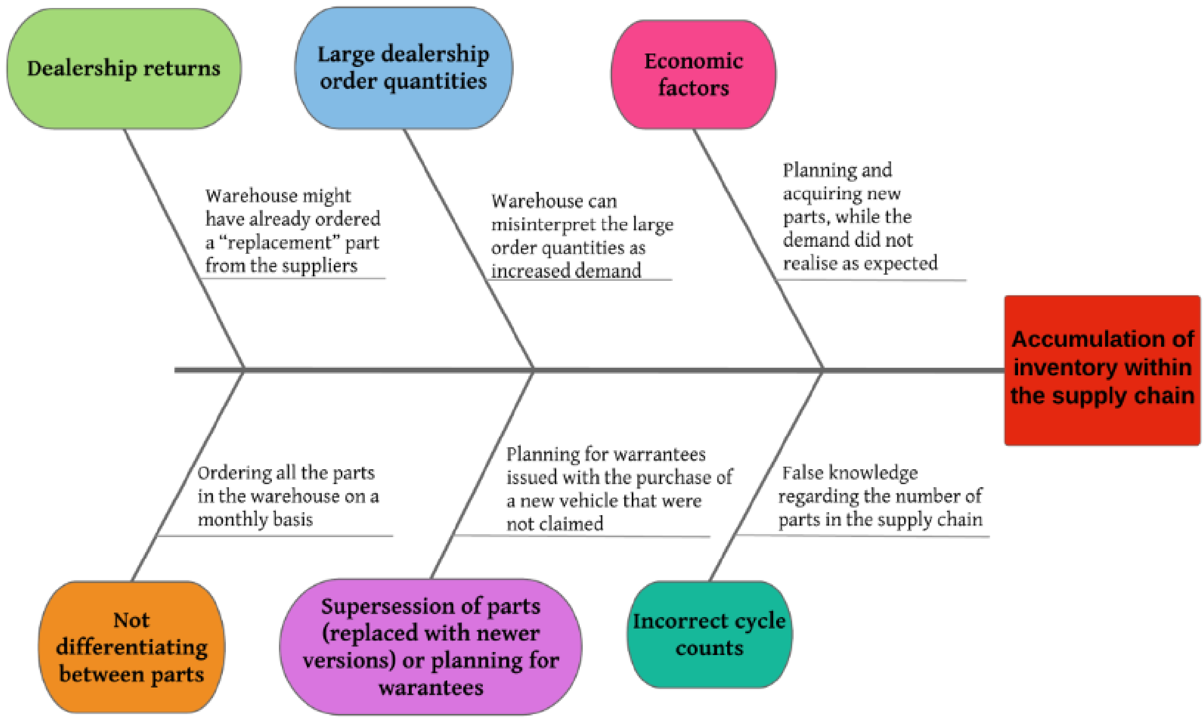

Figure 3.22: Causes of accumulation of inventory

all the parts in the warehouse on a monthly basis, without differentiating which parts were needed and which piled up in the warehouse.

[v] Parts that accumulate in the warehouse are supersession of parts (where old parts are replaced with new versions) and overstocking parts as a result of planning for warranties issued with the purchase of a new vehicle that were not claimed.

[vi] High inventory levels result from incorrect cycle counts that lead to false knowledge regarding the amount of parts in the warehouse.

3.3 Suggested Inventory Management Improvements

By knowing the six causes of the accumulation of inventory and planning to minimise the effect of these factors can drastically reduce the amount of inventory within the warehouse. This will in effect lead to reduced resource wastage such as storage and labour costs.

Possible solutions to the above mentioned are as follows:

[i] Accumulation of inventory due to dealership returns can be minimized if the warehouse waits at least 14 days before ordering a "replacement part", this will eliminate the chance of ordering a "replacement part" and receiving the same part from the dealership after the customer did not collect the part. Visibility and clear communication between the various echelons is critically important to synchronise order strategies. Synchronised order strategies reduce mismanagement of inventory as well as returns of faulty inventory made within the supply chain.

[ii] Excess inventory due to large dealership order quantities can be reduced by improving the communication between the warehouse and the dealerships, this can be done by implementing an Enterprise Resource Planning (ERP) system such as SAP or Oracle across the supply chain. The ERP system does not have to "connect" different dealerships

with each other, but should rather connect the warehouse with each of the dealerships (Stevenson 2012).

[iii] There is not much that can be done regarding South Africa's fluctuating economic factors that impact the amount of inventory within the warehouse, except to order for example 80% of the anticipated ordering amount and using air freight, as it only takes 72 hours, to import parts that exceed the 80% of anticipated orders.

[iv] Not differentiating between parts is something that should not be allowed within this industry. This can be eliminated by hiring a specific team to order parts for the warehouse when needed. This team should do their work with utmost care as the company can include a clause within their contracts that state that they could be penalised if more than a certain percentage of parts are ordered unnecessarily (Harrington 1991).

[v] Supersession of parts and planning for warranties can be done by fully understanding each part's life cycle and determining when the part reaches each of the four stages. The life cycles stages are: introduction-, growth-, maturity- and decline stage. As soon as the part reaches the maturity stage, orders must be adjusted to minimise excess inventory (Harrington 1991).

[vi] Incorrect cycle counts are something that should be avoided as much as possible. This can be done by working in pairs. For example, person one can count part B, while person two counts part A. If they are finished person two would count part A to ensure they get the same number of part A's. This would minimise incorrect cycle counts as it would be counted by two people directly after one another (Harrington 1991).

3.4 Suggested Inefficiecy Improvements

This section will discuss some improvements that can be implemented to the current inventory management process followed within the automotive OEM company's supply chain, which was mapped in the previous. Two categories of improvements will be discussed in this section, namely: (i) minor improvements and (ii) the scrapping process improvements.

3.4.1 Minor Improvements

In the section below four minor improvements that can be made to the current inventory management process, followed in the automotive OEM company's supply chain, is explained (see figure Figure 3.23 to Figure 3.26). The improvements in the inventory management process are indicated with a red circle on the diagram. Often these improvements are tasks that can be done simultaneously rather than sequentially to improve the efficiency of the process.

(i) While the company prepares and sends the quotation to the dealership, the sales department can determine whether the specified parts are available in the warehouse, as this will influence the quotation sent to the dealership as well as the time it takes to deliver the parts to the dealership (see Figure 3.23).

(ii) While the purchasing department informs the supplier from which the automotive OEM company will procure the parts from, another person in the purchase department can create the purchase order (see Figure 3.24). Preforming these tasks simultaneously rather than sequentially reduces the amount of the idle time in the current process. Therefore, simultaneous tasks lead to improved process efficiency and less wasted resources in the automotive OEM company's supply chain.

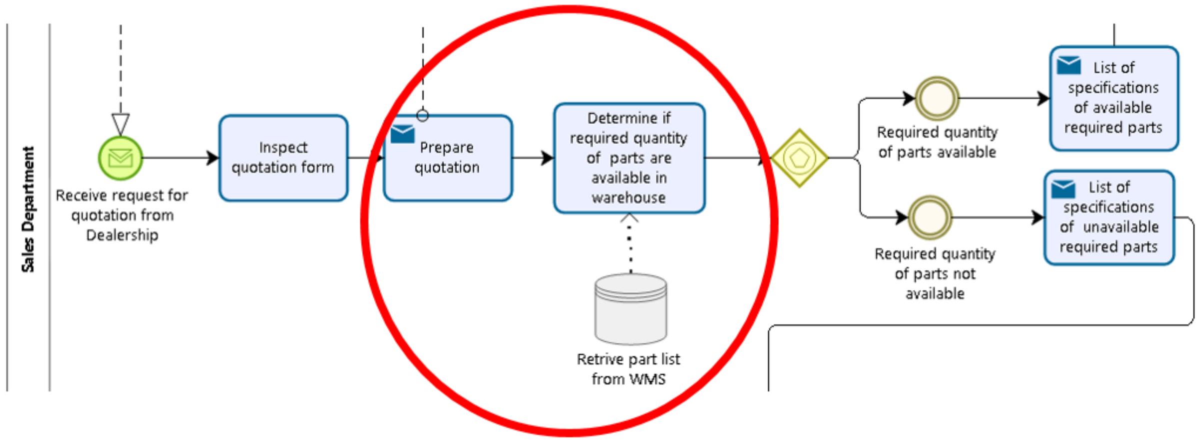

Figure 3.23: First improvement opportunity

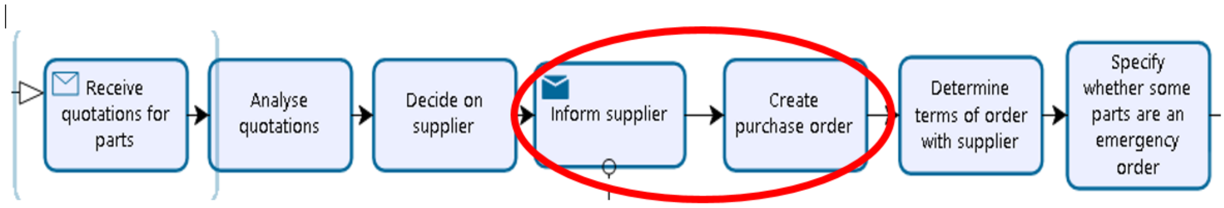

Figure 3.24: Second improvement opportunity

(iii) The warehousing department can inform the sales department on the sales transaction, while the parts are being sent to the dealership and not only when the dealership receives the parts (see Figure 3.25). Again this reduces the amount of idle time in the current process, which leads to improved process efficiency.

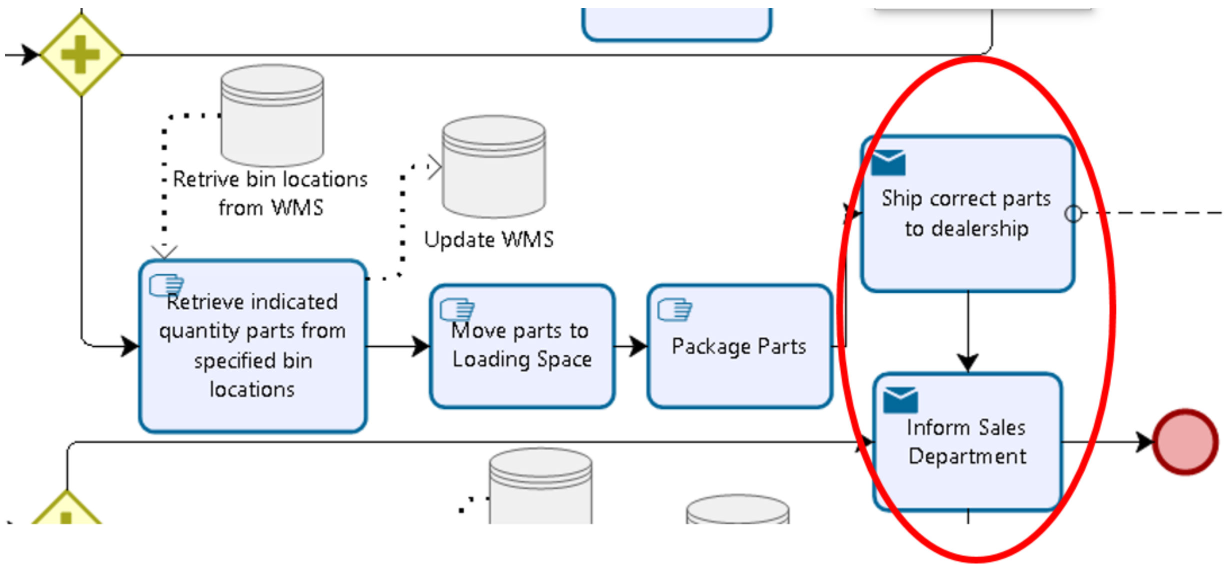

Figure 3.25: Third improvement opportunity

(iv) This is another opportunity where the warehousing department can inform the sales department on the sales transaction, while the parts are being sent to the dealership and not only when the dealership receives the parts (see Figure 3.26).

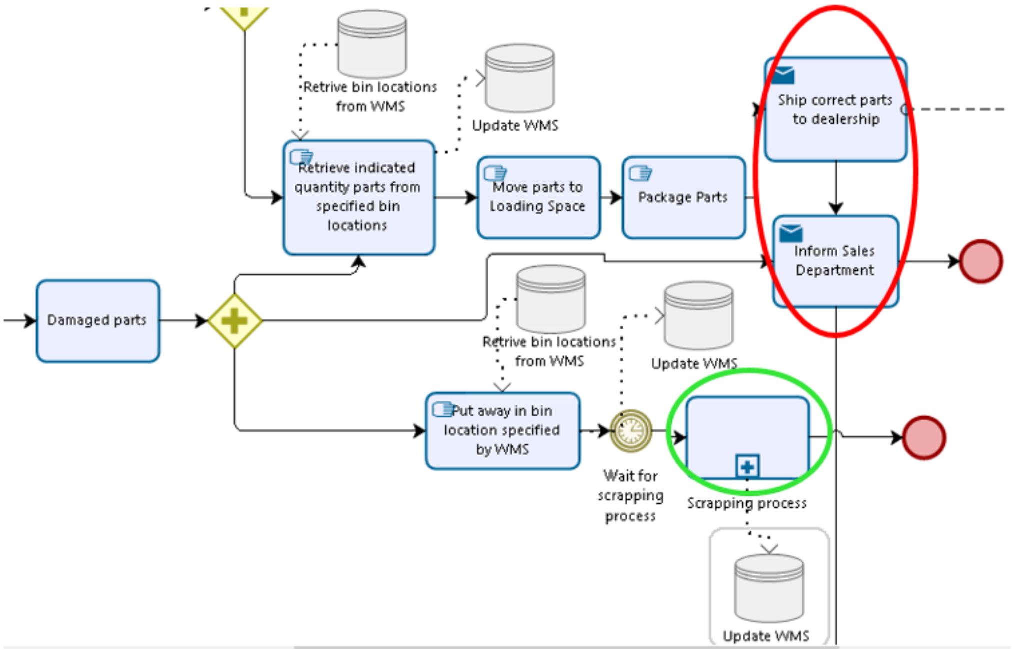

Figure 3.26: Scrapping process

3.4.2 The Scrapping Process

The current scrapping process is mapped as a sub-process in the inventory management diagram (see Figure 3.27). Sections of the process management are highlighted (see Figure 3.28 to Figure 3.29) to indicate how the scrapping process can be improved. These improvements are indicated with green ovals on the diagrams.

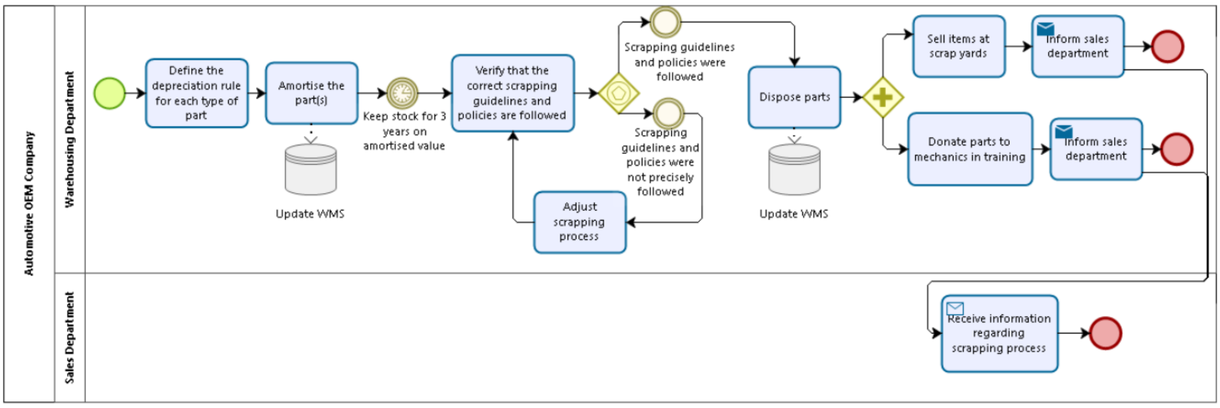

Figure 3.27: Detailed scrapping process

One of the major problems with the current inventory management process is that parts that were amortised is left within the warehouse for three years, before it is disposed of (scrapped) (see Figure 3.28). It is recommended that these parts should be scrapped. The benefit of this is that the wastage of resources allocated to obsolete parts within the supply chain is minimised.

If parts are amortised and not scrapped it can lead to large amounts of SLOB inventory within the automotive OEM company's supply chain, that increases the amount of resource wastage. This could have been avoided, by directly disposing the parts after it has been amortised.

In the scrapping process the verification that the correct scrapping guidelines and policies are followed is very important (Western Illinois University, 2008). These include the planning of disposition of scrap parts for all disposal functions, whether for a single event, or for continuous operations. If the correct scrapping guidelines and policies are not followed the process needs to be aligned with the existing guidelines and policies. Another option, not scrapping the amortised parts, are to donate the parts to mechanics in training. Nevertheless, which ever decision is taken, scrapping or donation, the sales department needs to be informed about on this decision.

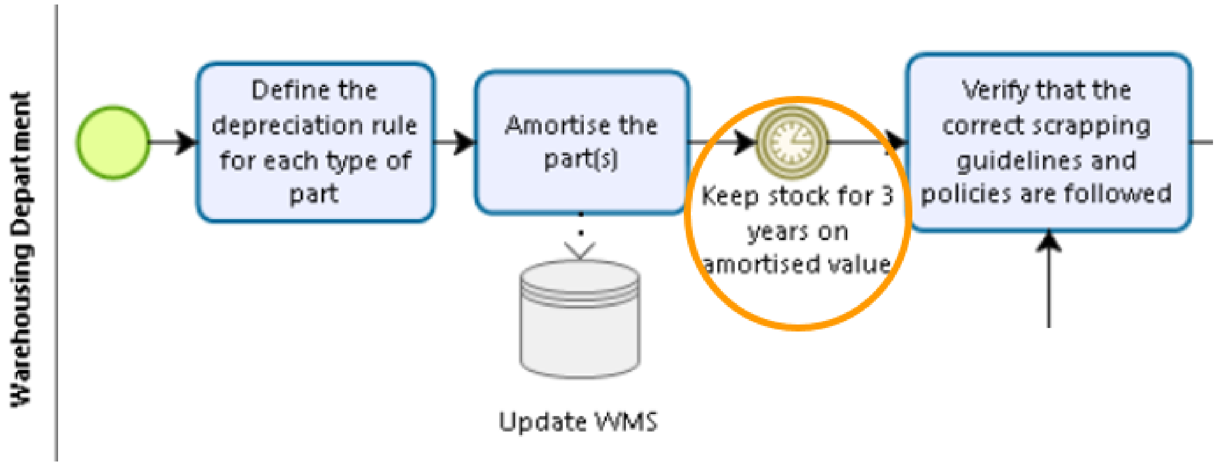

Figure 3.28: Problem with scrapping process

The same procedure discussed in the section before can be followed in scrapping amortised inventory in the sub-process (see Figure 3.29) process. Thus, the parts should be disposed of as soon as it is amortised.

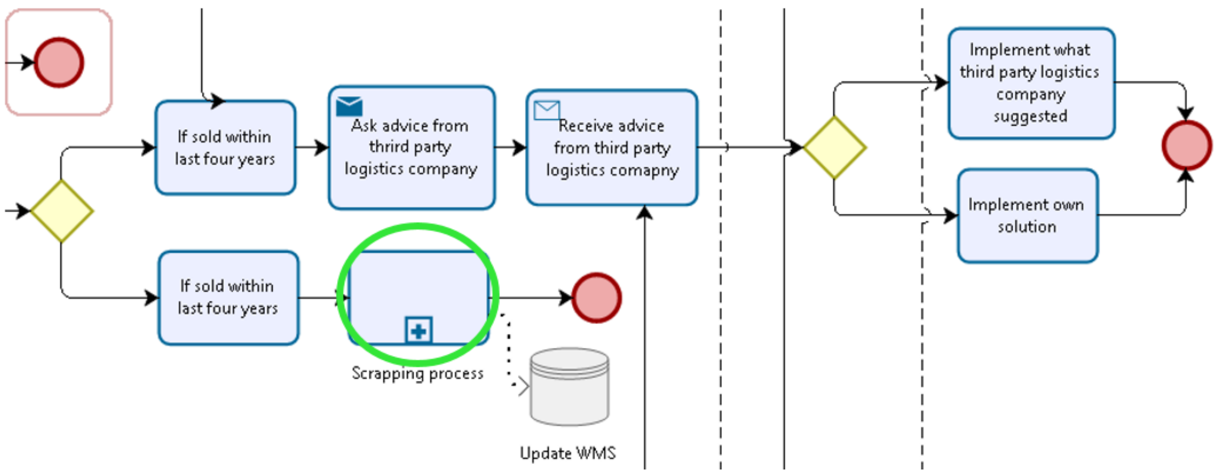

Figure 3.29: Second scrapping process

3.5 Concluding Remarks

This section analyses the qualitative data collected from the interviews to identify the areas for improvement in the current supply chain. Areas of improvement can be divided into inventory management improvements and process inefficiency improvements. The focus should be on improving the scrapping process, as the current cost of storing SLOB inventory within the automotive OEM supply chain is about R28 000 000 per two year period. This can drastically be reduced if the SLOB inventory in the supply chain can be minisised. This can be done by implementing a regular scrapping processes, improving the management of SLOB inventory and implementing the minor process improvements.

The warehouse workers mentioned that by significantly reducing the SLOB inventory levels throughout the automotive OEM company's supply chain, would drastically improve the company's inventory management. According to the warehouse workers it would save a lot of wasted time and human resources. These "wasted" time and human resources can be allocated to tasks such as emergency orders, which will improve the overall customer service experience.

The warehouse manager said that by implementing a regular scrapping process the warehouse would have to consider renting a smaller facility, which can lead to improved overhead costs. He further mentioned that it would improve the warehouse workers' productivity, as they would use the time more effectively.

Chapter 4

Quantitative Data Analysis

As mentioned in the literature review, mathematical modelling is often used for inventory management problems. Linear programming is a mathematical modelling approach that allows decision makers to find the optimal course of action for complex problems, including inventory management problems (Winston, Venkataramanan, and Goldberg 2003). This chapter focuses on developing an LP to optimise the inventory levels across the automotive OEM company's supply chain. The model incorporates medium- and fast moving inventory, as the supply chain does not need to order SLOB inventory. The chapter describes the LP model, as well as its assumptions, formulation, objective function and constraints. Furthermore the chapter explains the results obtained and methods to validate the results.

4.1 Model Introduction

In the model a closed loop network is used to model the current supply chain. A closed loop network is defined as a reverse logistics network that does not establish a coincide relationship between the market that releases used items and the market that releases new items. The main difference between a closed loop network and an open loop network is the location to which the products are returned. In a closed loop parts are returned to its original location, while parts in an open loop system are recovered by outside firms (Ene and Öztürk 2014).

4.2 Model Description

The model used in this project to address the optimisation of fast- and medium moving inventory, is a linear programming formulation for the forward- and reverse logistics network design problem. The network is a multi-period multi-echelon that consists of a warehouse and dealerships in the forward- and reverse direction, as can be seen in Figure 4.1.

Figure 4.1: Supply chain- inventory flow

The relationships between the echelons can be seen in Figure 4.2. The OEM warehouse is responsible for storing and securing the parts received either with sea freight or with air freight from the suppliers. Furthermore, the warehouse needs to supply parts to the dealerships. Dealerships are responsible for selling the correct parts to customers. Dealerships are allowed to return the following types of parts to the warehouse: (i) wrong parts, (ii) damaged parts or (iii) parts the customer did not collect within 14 days. Upon receiving parts from the dealerships, the OEM warehouse needs to resend the correct parts to the dealership and either scrap or give away damaged parts.

Figure 4.2: Supply chain- forward and reverse inventory flow

4.3 Model Assumptions

The model has the following assumptions:

- The model is a multi-echelon model (consisting of the warehouse and dealerships)
- The model is a multi-period model with four time periods
- Each time period is six months
- The model uses 180 parts, as it is the result of the Pareto analysis preformed (on the throughput rate) on the 900 sample parts
- Only an integer number of items can be bought or sold
- The warehouse does not return parts to the suppliers, as it is too expensive, but receives credit from the suppliers for wrong- or damaged parts received
- Shortage cost for the warehouse includes a loss of profit (selling price minus ordering price) and a penalty of 20% of the ordering price
- The warehouse recycles or gives-away (40%) or scraps (60%) of damaged parts received
- Recycling capacity is infinite
- The warehouse has 5440 m^3 racking space
- Dealership storage capacity is 1.5 times the warehouse capacity, thus it is 8160 m^3
- Average transportation costs between the warehouse and the dealerships are about R158,92/km.m^3
- An average distance of 49.8 km was used to define the distance between the warehouse and the dealerships, this was calculated by taking the average distance between Rosslyn and Pretoria Central and Rosslyn and Johannesburg Central
- A holding cost rate of 24% is used thoughout the project

- An average set-up cost per part is assumed to be R 11,10 per part
- An average rework cost per wrong part at the dealership is assumed to be R 4,32 per part
- An average rework cost per wrong part at the warehouse is assumed to be R 26,29 per part
- An average rework cost per damaged part at the dealership is assumed to be R 4,32 per part
- An average rework cost per damaged part at the warehouse is assumed to be R 18,86 per part
- An average rework cost per part returned due to customers not collecting the part at the dealership is assumed to be R 4,32 per part
- An average rework cost per part returned due to customers not collecting the part at the warehouse is assumed to be R 26,29 per part

Assumption Motivation:

Each of the two echelons in the model represents a location at which inventory is bought and sold. Inventory models are run over various periods, therefore this model is a multi-period model that is run over four periods with a total length of two years. The model can be run for more periods if be needed. A Pareto analysis was preformed on the sample data to identify the medium- and fast moving items on which is used within the model.

During interviews with the warehouse manager the following information were obtained: Only integer amounts of inventory can be sold or bought by the echelons. The warehouse does not return faulty items as it is too expensive, but receives credit for these items. The warehouse normally gives away about 40% of these items and scraps about 60%, as there are no recycling limit. The warehouse does receive items returned from dealerships due to various reasons. The warehouse can occur shortage costs due to unavailability of items. The shortage cost is normally equal to the profit that should have been earned and a penalty fee of 20% of the ordering cost. The warehouse currently has a racking space of 5440 m^3. It was assumed that the dealership has much more racking space, therefore a multiplier of 1.5 was used to estimate the dealership's raking space.

According to the average price Eezi Move charges to transport items, the average transportation cost is R158/km.m^3 (Move 2017). The average distance between Rosslyn and Pretoria Central as well as between Rosslyn and Johannesburg Central is used in the model. A holding cost of 24% is used throughout the project, as it is used by the automotive OEM company. The average set-up- and rework costs are calculated by measuring the time (converted to minutes) it took a warehouse worker to perform the specific tasks required for either the set-up or rework multiplied by their salary per minute.

4.4 Model Formulation

In the model formulation the project firstly defines the sets used in the linear program, secondly the variables are defined, thirdly the objective function is stated and fourthly the constraints are described.

4.4.1 Sets

The three sets which are defined for this linear programming model are as follows: The first set I, consists of 180 values which represents the type of inventory. The second set J, comprises of two values, where $j = 1$ is the dealership and $j = 2$ is the warehouse. The third set T, contains five values that represent different (six month) time periods. The first set of variables are the product variables the second set the finance variables and the third the capacity volume and distance.

Set I is described in Figure 4.3

$\bar{I} \in$

i=1	Spark Plug	i=2	Filtering Element 1	i=3	Air Filter 1
i=4	Fixed Tightener 1	i=5	Brake Pad-Set 1	i=6	Seal 1
i=7	Oil Filter	i=8	Thermostat	i=9	Stud 1
i=10	Sealing Gasket 1	i=11	Filtering Element 2	i=12	Nut
i=13	Bushing 1	i=14	Brake Disc 1	i=15	Protection 1
i=16	Cover 1	i=17	Hub 1	i=18	Battery 1
i=19	Intake Valve 1	i=20	Flowmeter	i=21	Brake Pad-Set 2
i=22	Brake Pad-Set 3	i=23	Bracket 1	i=24	Cable
i=25	Tappet Lock Cone	i=26	Brake Disc 2	i=27	Bracket 2
i=28	Cylinder Head Gasket	i=29	Alternator	i=30	Collar
i=31	Ornament 1	i=32	Seal 2	i=33	Tinted Glass 1
i=34	Driven Gear 1	i=35	Brake Disc 3	i=36	Radiator
i=37	Direct Switch	i=38	Sensor 1	i=39	Trans Belt 1
i=40	Licence Plate Lamp	i=41	Grille 1	i=42	Shock Absorber 1
i=43	Glass 1	i=44	Protection 2	i=45	Support 1
i=46	Track Rod End	i=47	Plug 1	i=48	Portfolio 1
i=49	Heater Windscreen	i=50	Brake Pad-Set 3	i=51	Sealing Gasket 2
i=52	Lockring	i=53	Retaining Block	i=54	Sealing Gasket 3
i=55	Plug 2	i=56	Gaskets for Engine	i=57	Valve Guide
i=58	Cover 2	i=59	Oil Sump 1	i=60	Track Rod
i=61	Sensor 2	i=62	Ornament 2	i=63	Coupling
i=64	Constant Velocity Join	i=65	Protection 3	i=66	Crossrail
i=67	Hood Bonnet	i=68	Glass 2	i=69	Kit Clutch
i=70	Screw 1	i=71	Moulding 1	i=72	Cap
i=73	Tank	i=74	Moulding 2	i=75	Plug 3
i=76	Front Bumper	i=77	Radiator	i=78	Moulding 3
i=79	Support	i=80	Screw 2	i=81	Type Plate 1
i=82	Protection 4	i=83	Wheel	i=84	Screw 3
i=85	Ornament 3	i=86	Tinted Glass 2	i=87	Air Filter 2
i=88	Sealing Gasket 4	i=89	Flywheel	i=90	Tank Cap
i=91	Battery 2	i=92	Spring	i=93	Piston
i=94	Frame	i=95	Panel	i=96	Brake Disc 4
i=97	Rigid Pipe	i=98	Lever 1	i=99	Moulding 4
i=100	Pin	i=101	Plate 1	i=102	Intake Valve 2
i=103	Moulding 5	i=104	Sending Unit 1	i=105	Link Rod
i=106	Adhesive Tape	i=107	Hinge	i=108	Rivet
i=109	Screw 4	i=110	Kit Brake	i=111	Bushing 2
i=112	Recondition Starter	i=113	Stud 2	i=114	Retaining Block
i=115	Protection 5	i=116	Tail Lamp 1	i=117	Reflector
i=118	Srew and Washer	i=119	Pedal	i=120	Grille 2
i=121	Moulding 5	i=122	Ornament Gasket	i=123	Probe 1
i=124	Hood Bonnet	i=125	Oil Sump 2	i=126	Flex Sleeve
i=127	Sealing Gasket 5	i=128	Hub 2	i=129	Fixed Tightener 2
i=130	Sealing Gasket 6	i=131	Handle	i=132	Trans Belt 2
i=133	Cylinder Head Gasket	i=134	Sending Unit 2	i=135	Tool Bag
i=136	Bulb	i=137	Plate 2	i=138	Screw 5
i=139	Trans Belt 3	i=140	Bearing	i=141	Brake Back Plate
i=142	Screw 6	i=143	Sealing Gasket 7	i=144	Relay
i=145	Shock Absorber 2	i=146	Air Compressor	i=147	Lever 2
i=148	Probe 2	i=149	Oil Sump 3	i=150	Lid
i=151	Swinging Arm	i=152	Tail Lamp 2	i=153	Kit
i=154	Covering	i=155	Bracket	i=156	Tail Lamp 3
i=157	Trans Belt 4	i=158	Sealing Gasket 8	i=159	Sending Unit 3
i=160	Link Rod	i=161	Crossrail	i=162	Boot
i=163	Seal 2	i=164	Tool	i=165	Bearing
i=166	Rear Mudguard Fender	i=167	Tail Lamp 4	i=168	Driven Gear 2
i=169	Type Plate 2	i=170	Handle	i=171	Pipe
i=172	Type Plate 3	i=173	Pad	i=174	Tail Lamp 5
i=175	Door Check	i=176	Probe 3	i=177	Sending Unit 4
i=178	Moulding 6	i=179	Plug 4	i=180	Sealing Gasket 9

Figure 4.3: Set **I**

Sets J and T are described below:

$$J = \begin{cases} 1 & \text{Dealership} \\ 2 & \text{Warehouse} \end{cases} \tag{4.1}$$

$$T = \begin{cases} 0 & \text{Period 0} \\ 1 & \text{Period 1} \\ 2 & \text{Period 2} \\ 3 & \text{Period 3} \\ 4 & \text{Period 4} \end{cases} \tag{4.2}$$

4.4.2 Variables

Parts:

$Y_{ijt} \triangleq$ the quantity of item $i \in \boldsymbol{I}$ at the end of period $t \in \boldsymbol{T}$ at location $j \in \boldsymbol{J}$ and an integer.

$P_{ijt} \triangleq$ the determined quantity of item $i \in \boldsymbol{I}$ purchased during period $t \in \{\mathbf{1;4}\}$ at location $j \in \boldsymbol{J}$ and an integer.

$V_{ijt} \triangleq$ the given quantity of item $i \in \boldsymbol{I}$ sold during period $t \in \{\mathbf{1;4}\}$ at location $j \in \boldsymbol{J}$ and an integer.

$G_{ijt} \triangleq$ the given quantity of item $i \in \boldsymbol{I}$ given away during period $t \in \{\mathbf{1;4}\}$ at location $j \in \{\mathbf{2}\}$ and an integer.

$S_{ijt} \triangleq$ the given quantity of item $i \in \boldsymbol{I}$ recycled or scrapped during period $t \in \{\mathbf{1;4}\}$ at location $j \in \{\mathbf{2}\}$ and an integer.

$W_{ijt} \triangleq$ the given quantity of wrong item $i \in \boldsymbol{I}$ received by location $j \in \boldsymbol{J}$ during period $t \in \{\mathbf{1;4}\}$ and an integer.

$U_{ijt} \triangleq$ the given quantity of damaged item $i \in \boldsymbol{I}$ received by location $j \in \boldsymbol{J}$ during period $t \in \{\mathbf{1;4}\}$ and an integer.

$C_{ijt} \triangleq$ the given quantity of item $i \in \boldsymbol{I}$ received by location $j \in \{\mathbf{2}\}$ during period $t \in \{\mathbf{1;4}\}$, due to customers not collecting the item within 14 days and an integer.

$R_{ijt} \triangleq$ the given quantity of item $i \in \boldsymbol{I}$ not meeting the demand at location $j \in \{\mathbf{2}\}$ during period $t \in \{\mathbf{1;4}\}$ and an integer.

Finance:

$A_{jt} \triangleq$ the given average set-up cost (in R) for an item during period $t \in \{\mathbf{1;4}\}$ at location $j \in \boldsymbol{J}$.

$H_{ijt} \triangleq$ the average given holding cost (in R$/m^2$) per item $i \in \boldsymbol{I}$ during period $t \in \{\mathbf{1;4}\}$ at location $j \in \boldsymbol{J}$.

$L_{ijt} \triangleq$ the given shortage cost (in R) of item $i \in \boldsymbol{I}$ during period $t \in \{\mathbf{1;4}\}$ at location $j \in \{\mathbf{2}\}$.

$B_{jt} \triangleq$ the average given rework cost (in R) of a wrongly received item during period $t \in \{\mathbf{1;4}\}$ at location $j \in \{\mathbf{2}\}$.

$I_{jt} \triangleq$ the average given rework cost (in R) of a damaged item received during period $t \in \{\mathbf{1;4}\}$ at location $j \in \{\mathbf{2}\}$.

$J_{jt} \triangleq$ the average given rework cost (in R) of an item received during period $t \in \{\mathbf{1;4}\}$ at location $j \in \{\mathbf{2}\}$, due to customers not collecting the item within 14 days.

$T_{ijt} \triangleq$ the average transportation cost (in R$/m^3$) for item $i \in \boldsymbol{I}$ obtained by location $j \in \boldsymbol{J}$ during period $t \in \{\mathbf{1;4}\}$.

Capacity, Volume and Distance:

$K_{jt} \triangleq$ the given storing capacity (in m^2) of location $j \in \boldsymbol{J}$ during period $t \in \{\mathbf{1;4}\}$.
$N_{it} \triangleq$ the given volume (in m^3) of item $i \in \boldsymbol{I}$ during period $t \in \{\mathbf{1;4}\}$.
$D_t \triangleq$ the given distance (in km) between the warehouse and the dealership locations during period $t \in \{\mathbf{1;4}\}$.

4.4.3 Objective Function

The objective of the model is to minimise the total transportation and storage costs in the forward- and reverse supply chain network. The total transportation and storage costs include: the holding cost per item, the set-up cost per item, the transportation cost per item and the shortage costs that can be occurred.

According to Russell (2006) holding cost is the cost of holding one item for one period of time. Holding cost in this model includes costs such as rent, salaries, utilities and financial costs such as opportunity costs incurred by tying up the capital in inventory, inventory costs related to theft, damage and obsolescences, taxes on inventory and insurance costs. The holding cost per item is expressed as a percentage of an item's value (Russell and Taylor 2005).

Set-up costs are costs associated with the labour preformed on inventory ordered. Set-up costs in this model includes labour costs for the following tasks: receiving, unloading, inspecting, put-away of items, retrieving, moving and packaging of items.

The transportation cost include the cost to transport an item in the forward- and reverse supply chain network, eg. from the warehouse to the dealerships and from the dealerships back to the OEM warehouse.

A shortage cost is incurred when dealership demands for an item is not met on time due to a shortage of inventory in the OEM company's warehouse. The OEM warehouse shortage costs include: the lost contribution margin, idle employees and the lost customer goodwill (Junior 2016).

The objective function is specified in Equation 4.3:

$$\begin{aligned} MinZ = & \sum_{i=1}^{180}\sum_{j=1}^{2}\sum_{t=1}^{4} H_{ijt}Y_{ijt} + \sum_{i=1}^{180}\sum_{t=1}^{4} T_{i2t}N_{it}W_{i2t}D_t + \sum_{i=1}^{180}\sum_{t=1}^{4} T_{i2t}N_{it}U_{i2t}D_t \\ & + \sum_{i=1}^{180}\sum_{t=1}^{4} T_{i2t}N_{it}C_{i2t}D_t + \sum_{i=1}^{180}\sum_{j=1}^{2}\sum_{t=1}^{4} T_{ijt}N_{it}P_{ijt}D_t + \sum_{i=1}^{180}\sum_{j=1}^{2}\sum_{t=1}^{4} B_{jt}W_{ijt} \\ & + \sum_{i=1}^{180}\sum_{j=1}^{2}\sum_{t=1}^{4} I_{jt}U_{ijt} + \sum_{i=1}^{180}\sum_{j=1}^{2}\sum_{t=1}^{4} J_{jt}C_{ijt} + \sum_{i=1}^{180}\sum_{j=1}^{2}\sum_{t=1}^{4} A_{jt}P_{ijt} + \sum_{i=1}^{180}\sum_{t=1}^{4} L_{i2t}R_{i2t} \end{aligned} \tag{4.3}$$

The objective function implies: The minimisation of transportation and storage costs, which include (i) holding cost spent on storing items at each of the two locations, (ii) transportation cost spent on wrong items returned to the warehouse, (iii) transportation cost spent on damaged items returned to the warehouse (iv) transportation cost spent on items returned to the warehouse due to customers not collecting items in 14 days, (v) transportation cost spent on ordering items at any of the two locations, (vi) average rework/reset-up spent cost on wrong items returned to the warehouse, (vii) average rework/re-set-up spent cost on damaged items returned to the warehouse, (viii) average rework/reset-up spent cost on items returned due to customers not collecting the item within 14 days (ix) average set-up cost spent on items ordered at any of the two locations, (x) shortage cost due to demand not fulfilled obtained by the warehouse.

4.4.4 Constraints

The constraints specified within the model are as follows:

$$Y_{i1t} = Y_{i1(t-1)} + P_{i1t} - V_{i1t} - W_{i1t} - U_{i1t} - C_{i1t}, \qquad \forall \quad i \in \mathbf{I}, t \in \{1,4\} \tag{4.4}$$

$$Y_{i2t} = Y_{i2(t-1)} + P_{i2t} - V_{i2t} - G_{i2t} - S_{i2t} + W_{i2t} + C_{i2t}, \qquad \forall \quad i \in \mathbf{I}, t \in \{1,4\} \tag{4.5}$$

$$Y_{ij0} = X_{ij0}, \qquad \forall \quad i \in \mathbf{I}, j \in \mathbf{J} \tag{4.6}$$

$$Y_{ijt}S_{ijt} = 0, \qquad \forall \quad i \in \mathbf{I}, j \in \mathbf{J}, t \in \mathbf{T} \tag{4.7}$$

$$V_{i2t} = P_{i3t}, \qquad \forall \quad i \in \mathbf{I}, t \in \{1,4\} \tag{4.8}$$

$$\sum_{i=1}^{180} N_{it}Y_{ijt}, \qquad \forall \quad j \in \mathbf{J}, t \in \{1,4\} \tag{4.9}$$

Equation 4.4 represents the conservation of inventory at the dealership, while Equation 4.5 represents the conservation of inventory at the warehouse. Equation 4.6 indicates the amount of inventory present at t the beginning of period t. Equation 4.7 ensures that there cannot be parts at the end of period t at a specific location, if shortage for that specific part occurred at the same location within period t. Equation 4.8 ensures that the dealership bought the exact number of items the warehouse sold, while Equation 4.9 represents the storing capacity of each location.

Non-negativity:

$$P_{ijt}, V_{ijt}, W_{ijt}, U_{ijt}, Y_{ijt}0, \qquad \forall \quad i \in \mathbf{I}, j \in \mathbf{J}, t \in \{1,4\} \tag{4.10}$$

$$H_{ijt}0, \qquad \forall \quad i \in \mathbf{I}, j \in \mathbf{J}, t \in \{1,4\} \tag{4.11}$$

$$G_{ijt}, S_{ijt}, C_{ijt}, R_{ijt}0, \qquad \forall \quad i \in \mathbf{I}, j \in \{2\}, t \in \{1,4\} \tag{4.12}$$

$$L_{ijt}, T_{ijt}0, \qquad \forall \quad i \in \mathbf{I}, j \in \{2\}, t \in \{1,4\} \tag{4.13}$$

$$A_{jt}, K_{jt}, 0, \qquad \forall \quad j \in \mathbf{J}, t \in \{1,4\} \tag{4.14}$$

$$B_{jt}, I_{jt}, J_{jt}0, \qquad \forall \quad j \in \{2\}, t \in \{1,4\} \tag{4.15}$$

$$N_{it}0, \qquad \forall \quad i \in \mathbf{I}, t \in \{1,4\} \tag{4.16}$$

$$D_{t}0, \qquad \forall \quad t \in \{1,4\} \tag{4.17}$$

4.5 Solving the Linear Programming Model

A linear program solver is needed to run the model. As mentioned in the literature review various software products are available on the market. Evolver was chosen as it is adaptable to Microsoft Excel and it is able to formulate this forward- and reverse logistics network design problem, furthermore it has the capacity to handle a large number of variables. In this project 360 variables are used which need to be solved simultaneously.

The model was executed for four six-month periods. The results of these four periods determine the optimal quantity of each type of inventory that needs to be ordered by the warehouse to minimise the transportation and storage costs in the automotive OEM company's supply chain.

The spread sheets, attached in Appendix 2, was developed with the sample data provided. The Roundup function is used to round all parts to integer amounts, IF statements are used to ensure that there are not be parts at the end of period t at a specific location, if shortage for that specific part occurred at the same location within period t (=IF(AP13>=0;0;-1*AP13)), sum functions are used to sum the volume of the parts at each location to ensure the parts fit into the location - to find the amount of shortage parts at each location =COUNTIF(AY4:AY184;">0").

In Figure Figure 4.4 the blue bar indicates the total cost currently spent on transport and storage within the automotive OEM supply chain and the orange bar indicates the improved or optimised transport and storage costs. The values for the four time periods, for which the model was executed, were calculated on a 24% holding cost rate, which is the holding cost rate currently used by the automotive OEM company's supply chain. According to the project's estimation a total amount of R16 472 807 can be saved during the four time periods if the optimised model is implemented throughout the automotive OEM company's supply chain.

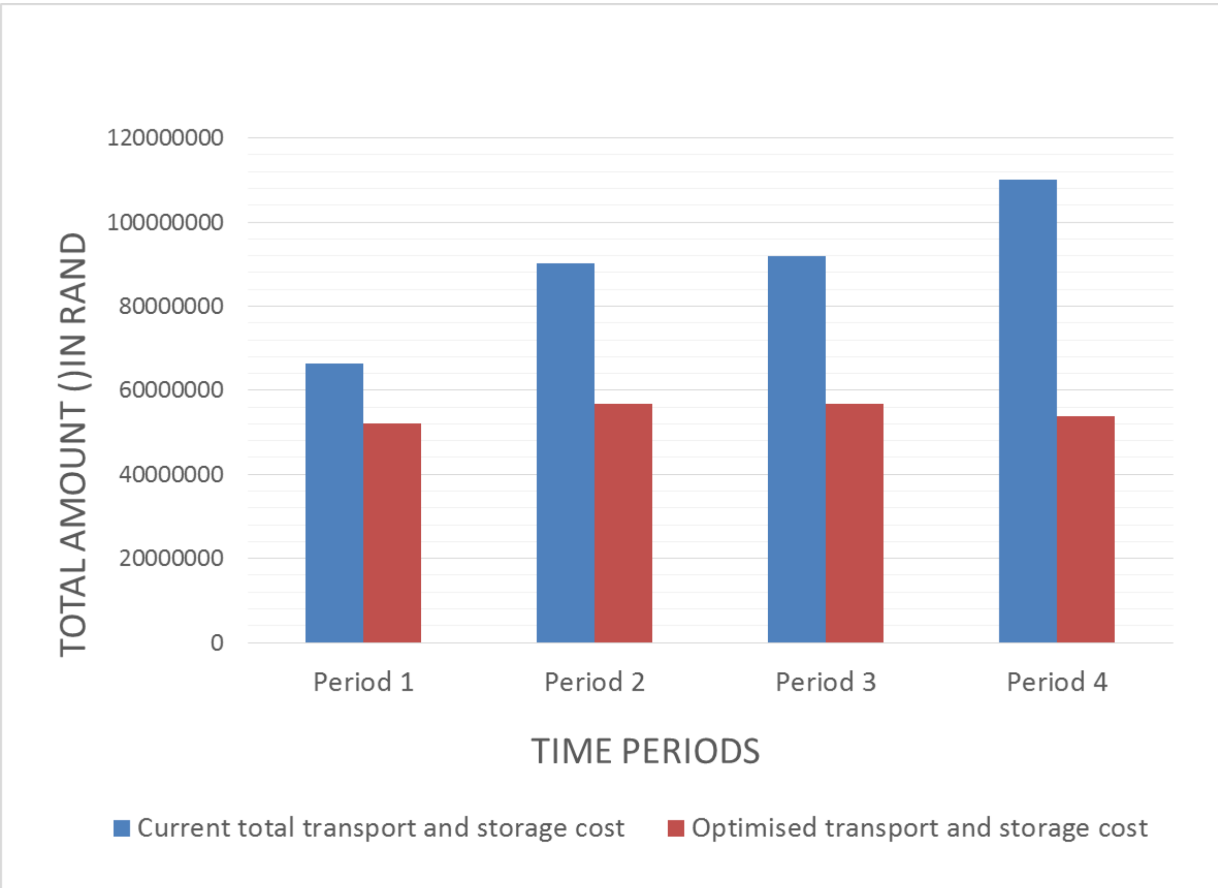

Figure 4.4: Total amount vs time periods at a 24% holding cost rate

The LP model estimates that a combination of 2624, 4299, 3112 and 5301 parts should respectively be ordered by the warehouse during the first period, the second period, the third period and the fourth period to minimise the transportation- and storage costs accross the automotive OEM company's supply chain. As the parts in the model are sorted from the highest amount of sales during the periods to the lowest amount of sales, during the LP model suggests that each of the time periods order respectively 388, 1217, 570 and 760 spark plugs. Although the LP model incorporates only medium- and fast moving items, the automotive industry does not sell items as often as various other companies, due to reasons perviously mentioned. The LP model estimated that 32%, 25%, 19% and 19% of the parts in each of the respective time periods are not ordered during these time periods. If the estimated amount of parts are ordered by the warehouse, the automotive OEM company can save about R2 000 000 during the first time period, R1 500 000 during the second time period, R 6 000 000 in the third time period and R8 000 000 in the fourth time period. The exact ordering amounts of each of the 180 parts for each of the four time periods can be viewed in Appendix 2.

4.6 Model Validation

Two tests are done to validate the results of the linear programming model. The first test validates the model against historical data and the second validation test validates the results obtained by the LP against expert opionion.

The historic warehouse ordering data, obtained from the automotive OEM company's WMS, is compared to the results obtained by the LP model. As the LP model focus on minimising the transportation- and storgae costs accross the automotive OEM company's supply chain, a decrease in ordering amounts is expected. Figure 4.5 displays the percentage difference between the historical ordering amounts and the ordering amounts estimated by the LP model. As can be seen the LP model suggests to reduce the order amounts of each of the four periods by between about 2% and 7%. These percentages are obtained by averaging the percentage difference between the historical ordering amounts and the ordering amounts estimated by the LP model for all medium- and fast moving parts used within the model. As expected the model requires the automotive OEM copany to lower the ordering amounts, but not by much.

The warehouse workers said that by ordering the optimal amount of parts, would drastically improve the productivity within the warehouse. They mentioned that the warehouse currently orders too many parts and that these parts are prone to become SLOB parts. Furthermore by ordering the optimal quantity of parts, the warehouse workers will have more time to spend on ensuring that the parts are correctly packaged and placed in the correct bins specified by the WMS.

According to the warehouse manager approves the estimated results from the LP, as he said that the warehouse are currently ordering more than needed by about 5% to 9%. The warehouse does this to qualify for quantity discounts as well as to anticipate for late deliveries. By implementing the estimated results obtained by the model, the company will save more than the quantity discounts offered. Furthermore, airfreight is an option that can be used if deliveries are late. The warehouse manager mentioned that sparkplugs are currently the most sold item in the warhouse, therefore it makes sense that it is the most ordered product according to the model's results.

4.7 Recommendations

By implementing the LP model developed for the automotive OEM company, the model estimates the optimal quantity of each type of medium- and fast moving part the warehouse should

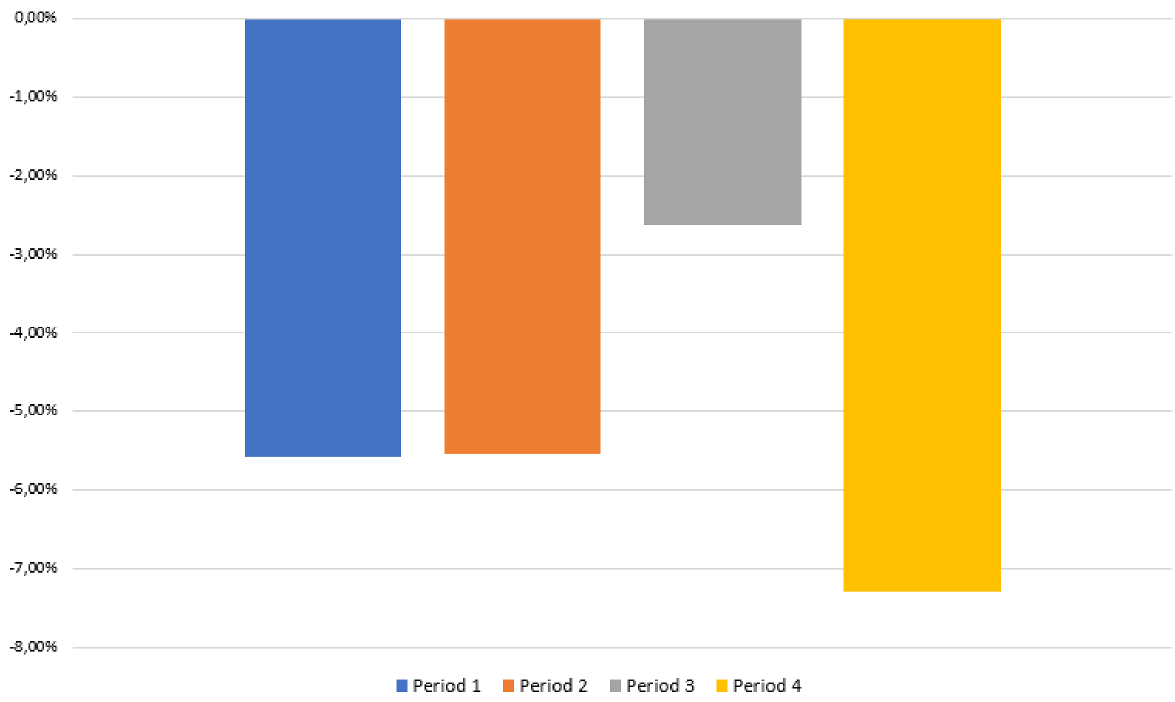

Figure 4.5: Average percentage difference in the number of parts ordered by the warehouse over four time periods

order. If the company implemented the model it would have saved about a third of the costs spent on medium- and fast moving parts. These results are obtained by comparing the optimal cost with the actual cost.

Furthermore the automotive OEM company's supply chain inventory management will improve, as time spent on redundent tasks such as unloading and storing excess items are minised when the optimal item quantities are ordered by the automotive OEM company's warehouse. By reducing excess orders the warehouse workers will have more time to spend on productive tasks, which will in effect improve the automotive OEM company's productivty. It will also improve the accuracy of the tasks performed and the data stored on the WMS.

4.8 Concluding Remarks

The model used in this project to address the optimisation of fast- and medium moving inventory, is a linear programming formulation for the forward- and reverse logistics network design problem. The model aims to minimise the transportation- and storage costs across the automotive OEM company's supply chain. The model defines three sets that respectvely represent the types of inventory, the locations in the supply chain and the time periods for which the LP model is run. Evolver are used to solve the model as it is adaptable to Microsoft Excel and it is able to formulate this forward- and reverse logistics network design problem. BY implementing the model the company can save about a third of the costs currently spent on medium- and fast moving parts.

Chapter 5

Conclusion

An efficient inventory management process is vital to the survival of any company, as it leads too enhanced customer satisfaction. Inventory can be divided into three types, namely: fast moving-, medium moving- and slow-moving inventory. Research has mostly focussed on fast moving inventory, as its revenue generating ability is higher than Slow Moving- and Obsolete (SLOB) inventory, however the profit impact of resource wastage on SLOB inventory is likely much higher than assumed in the automotive industry and better management of this type of inventory can change bottom line returns to investors.

Therefore, the aim of this project is to investigate the improvement of inventory management on all three types of inventory identified, however the project makes specific reference to SLOB inventory as it is particularly relevant in the automotive industry.

To achieve this aim, the project firstly collected qualitative data and quantitative data from the Rosslyn warehouse of the automotive OEM company's WMS. The qualitative data was collected from interviews and the quantitative data was collected on the inventory's sales, orders and costs obtained by storing and transporting parts.

To answer the research question, numerous inventory management techniques were researched. Two particular inventory management techniques stood out for this specific problem. BPMN charts are used to map current inventory management process and a linear programming model is developed to optimise the automotive OEM company's inventory levels across the supply chain. The current inventory management process was mapped to identify "problem areas" within the process that could be solved by developing unique solutions for each "problem area". Furthermore the inventory mismanagement causes and effects are identified. Suggested improvements for the inventory mismanagement problems as well as the current process inefficiencies are suggested. These include more regular scrapping processes in order to minimise storage costs and the improvement of minor process changes such as doing activities simultaneously instead of sequentially. By implementing these improvements the automotive OEM company's inventory management process's efficiency will improve, as idle time and redundent parts are reduced.

The aim of the linear programming model is to minimise transportation- and storage costs across the automotive OEM company's supply chain. Therefore the model used various input data (as discussed in the quantitative data analysis chapter) to generate estimated optimal quantity of parts that the warehouse should order. If the automotive acOEM company implemented the suggested warehouse ordering quantities derived from the LP model, the automotive OEM company's supply chain can save an estimated R16 472 807 within two years, which is about a third of their current expenditure on medium- and fast moving parts in the supply chain.

Furthermore the SLOB inventory, obtained from the sample data provided by the automotive OEM company's WMS costs the automotive supply chain about R 28 000 000 to store these parts for two years. If these parts can be reduced by implementing regular scrapping processes the inventory management process will operate more effectively and save vast amounts of money.

5.1 Future Studies

Two types of future studies are identified and discussed. Firstly the OEM company can make use of a multi-echelon stochastic linear programming model. Stochastic linear programming problems involve uncertainty. Almost all problems in the real world have some extent of uncertainty or unknown parameters. These models make use of probability distributions to estimate the uncertain data. Thus, instead of running multiple tests on a deterministic linear program, as done in the current project, a stochastic model can be used to verify this model's results.

Secondly the OEM company can formulate an alternative study that makes use of geographical linear programming. This can be done in order to optimise the supply chain management process to see whether or not the current supply chain "set-up" is the optimal set-up. The supply chain currently has only one warehouse located in Rosslyn, which supplies the dealerships. Three alternative set-ups can be tested. Firstly the OEM automotive company can relocate their warehouse to Durban, as most supplies are delivered there and it would eliminate back and forth travelling of parts that need to go to dealerships located in Durban, Cape Town, East London and Port Elizabeth. Secondly the OEM automotive company can built a warehouse in each of the cities with many dealerships, such as Durban, Cape Town, East London and Port Elizabeth. Thirdly another alternative could be to function without a warehouse, thus the suppliers can deliver parts directly to the dealerships to avoid warehouse holding costs. This study did not include this model, as there were not sufficient data available at the time this study was completed.

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Appendix A

Linear Programming Model Summary

Table A.1: LP Cost Summary

									Sum Row	**Average Row**	
Holding Cost Rate:	**18%**	**19%**	**20%**	**21%**	**22%**	**23%**	**24%**	**25%**			
Original Total Cost	7808968	7821907	7834846	7847786	8716716	8729655	8742594	8755534	66258005	8282251	
Optimised Total Cost	7137830	6536112	6614657	5702104	7961709	5317424	6806565	6136007	52212409	6526551	
Difference	671138	1285795	1220189	2145681	755007	3412231	1936029	2619527	14045597		
% improvement	8,6%	16,4%	15,6%	27,3%	8,7%	39,1%	22,1%	29,9%			
Original Total Cost	11473687	11432292	11482496	11314844	11441509	11366938	11375201	10195915	90082883	11260360	
Optimised Total Cost	4109930	9840100	4508604	4512044	4892271	10157594	10033205	8793402	56847150	7105894	
Difference	7363757	1592193	6973892	6802800	6549238	1209344	1341997	1402513	33235732		
% improvement	64,2%	13,9%	60,7%	60,1%	57,2%	10,6%	11,8%	13,8%			
Original Total Cost	11814139	11745989	10873500	10943989	11521288	11455923	11965834	11581920	91902582	11487823	
Optimised Total Cost	9737961	6672505	4712895	5606107	7366598	8873730	5890735	7808642	56669172	7083647	
Difference	2076178	5073484	6160605	5337882	4154691	2582193	6075099	3773278	35233410		
% improvement	17,6%	43,2%	56,7%	48,8%	36,1%	22,5%	50,8%	32,6%			
Original Total Cost	14374734	14443271	12580073	13211610	14225144	14690634	13256357	13367809	110149632	13768704	
Optimised Total Cost	8541904	3977919	4301347	5034947	5989787	9759835	5140674	11044018	53790432	6723804	
Difference	5832829	10465352	8278726	8176663	8235357	4930799	8115682	2323791	56359200		
% improvement	40,6%	72,5%	65,8%	61,9%	57,9%	33,6%	61,2%	17,4%			
Sum Original values in column	13867723	13343340	16472807	17125145	15539602	9552374	11393708	6345830			
Sum Optimised values in column	45471527	45443460	42770916	43318230	45904656	46243150	45339986	43901178			
Sum Difference values in column	29527625	27026635	20137504	20855203	26210364	34108582	27871179	33782070			

Appendix B

Estimated Warehouse Orders and Dealership Sales

B.1 Estimate Warehouse Orders

Table B.1: Estimated warehouse orders at a 24% holding cost rate

Part numbers	Period 1	Period 2	Period 3	Period 4
i=1	388	1217	570	760
i=2	164	334	182	256
i=3	158	229	148	183
i=4	152	170	102	112
i=5	89	91	83	85
i=6	0	0	0	0
i=7	55	103	92	58
i=8	103	100	82	92
i=9	80	137	90	127
i=10	34	70	60	56
i=11	49	85	70	89
i=12	17	13	29	49
i=13	36	26	30	60
i=14	0	12	4	6
i=15	20	35	27	33
i=16	28	51	34	23
i=17	18	46	23	35
i=18	23	23	15	14
i=19	37	60	42	34
i=20	10	18	20	24
i=21	0	0	0	0
i=22	25	39	19	25
i=23	14	11	11	16
i=24	0	0	0	0
i=25	34	37	83	13
i=26	5	12	11	14
i=27	12	30	21	28
i=28	10	12	9	10
i=29	13	22	14	17
i=30	12	13	19	20
i=31	2	32	10	29
i=32	15	19	12	13
i=33	0	0	0	0
i=34	10	8	12	14
i=35	4	4	12	9
i=36	0	1	2	13
i=37	8	19	16	23
i=38	4	5	5	5
i=39	11	12	16	6
i=40	6	7	13	12

Table B.2: Estimated warehouse orders at a 24% holding cost rate

Part numbers	Period 1	Period 2	Period 3	Period 4
i=41	4	5	5	5
i=42	11	12	16	6
i=43	6	7	13	12
i=44	5	12	13	13
i=45	8	11	11	16
i=46	8	8	7	10
i=47	22	22	5	6
i=48	6	6	3	4
i=49	28	14	8	8
i=50	0	0	0	0
i=51	0	0	0	0
i=52	0	0	0	0
i=53	29	10	3	3
i=54	9	2	23	10
i=55	14	21	9	8
i=56	0	9	7	16
i=57	0	6	6	10
i=58	7	18	8	11
i=59	0	0	0	0
i=60	4	8	7	5
i=61	9	15	11	10
i=62	4	8	16	6
i=63	4	4	1	10
i=64	5	7	4	6
i=65	8	15	9	8
i=66	0	0	0	7
i=67	3	6	5	11
i=68	0	0	5	8
i=69	2	5	3	6
i=70	3	10	6	5
i=71	0	0	0	0
i=72	6	8	3	6
i=73	1	4	3	0
i=74	4	11	4	6
i=75	9	11	6	2
i=76	8	2	6	9
i=77	0	0	0	4
i=78	5	5	6	6
i=79	0	0	0	0
i=80	10	11	11	6

Table B.3: Estimated warehouse orders at a 24% holding cost rate

Part numbers	**Period 1**	**Period 2**	**Period 3**	**Period 4**
i=81	27	4	0	0
i=82	12	17	2	5
i=83	12	17	2	5
i=84	4	3	5	6
i=85	5	6	4	8
i=86	0	12	6	3
i=87	2	3	5	5
i=88	0	1	2	6
i=89	0	5	2	2
i=90	5	5	0	6
i=91	0	0	1	1
i=92	0	7	1	6
i=93	0	0	14	4
i=94	2	1	5	4
i=95	10	7	9	6
i=96	0	0	0	0
i=97	1	4	2	5
i=98	2	6	6	2
i=99	0	9	1	14
i=100	0	0	0	0
i=101	2	4	4	5
i=102	0	0	5	22
i=103	1	0	1	4
i=104	5	1	0	5
i=105	0	0	0	0
i=106	4	3	4	4
i=107	5	5	5	5
i=108	0	1	0	0
i=109	0	4	4	0
i=110	0	6	3	2
i=111	0	11	1	2
i=112	0	0	0	3
i=113	0	0	4	6
i=114	2	9	5	0
i=115	3	6	3	5
i=116	3	7	2	2
i=117	0	6	0	6
i=118	0	5	5	3
i=119	1	3	7	4
i=120	4	2	4	2
i=121	4	3	2	3

Table B.4: Estimated warehouse orders at a 24% holding cost rate

Part numbers	**Period 1**	**Period 2**	**Period 3**	**Period 4**
i=122	2	6	5	4
i=123	5	1	1	1800
i=124	2	4	2	3
i=125	5	6	2	2
i=126	4	4	2	3
i=127	0	1	1	0
i=128	1	1	2	2
i=129	0	0	0	0
i=130	4	3	4	4
i=131	3	5	2	2
i=132	7	6	2	0
i=133	2	7	4	0
i=134	0	11	1	4
i=135	1	2	2	1
i=136	4	0	0	2
i=137	0	3	1	2
i=138	4	7	3	1
i=139	6	2	2	0
i=140	1	4	2	4
i=141	2	0	2	0
i=142	2	2	1	-1
i=143	1	3	0	0
i=144	2	4	29	3
i=145	2	2	1	4
i=146	0	1	24	4
i=147	2	3	4	1
i=148	4	6	3	1
i=149	0	0	8	7
i=150	4	0	1	3
i=151	0	0	2	2
i=152	0	8	2	0
i=153	3	5	0	0
i=154	4	6	1	2
i=155	0	0	0	6
i=156	4	2	4	4
i=157	0	1	2	7
i=158	1	0	2	0
i=159	0	0	0	0
i=160	0	0	0	0
i=161	0	3	1	2
i=162	1	0	2	3

Table B.5: Estimated warehouse orders at a 24% holding cost rate

Part numbers	**Period 1**	**Period 2**	**Period 3**	**Period 4**
i=163	0	0	0	0
i=164	1	1	2	0
i=165	2	3	2	1
i=166	1	2	1	3
i=167	2	0	4	4
i=168	4	4	0	0
i=169	0	0	1	4
i=170	0	0	1	2
i=171	3	2	1	1
i=172	1	0	2	2
i=173	0	0	4	2
i=174	0	0	1	2
i=175	0	0	0	2
i=176	1	2	0	3
i=177	2	0	0	2
i=178	0	0	0	2
i=179	0	0	1	0
i=180	159	178	206	181
i=181	374	420	425	427

Appendix C

Sponsorship Form

Project Sponsor Details:

Company:	DSV
Project Description:	Inventory optimisation with regards to a DSV warehouse.
Student Name:	Megan Talita Greyling
Student number:	14048915
Student Signature:	Greyling
Sponsor Name:	LIAAN BOSMAN
Designation:	ADVISOR, IO
E-mail:	lbosman@gozuti.com.
Tel No:	011 456 7438
Cell No:	0827098965.
Fax No:	—
Sponsor Signature:	

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Final Year Projects
Identification and Responsibility of Project Sponsors

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Key responsibilities of Project Sponsors:

A project sponsor is the key contact person within the company. This person should thus be able to provide the best guidance to the student on the project. The sponsor is also very likely to gain from the success of the project. The project sponsor has the following important responsibilities:

1. Confirm his/her role as project sponsor, duly authorised by the company. Multiple sponsors can be appointed, but this is not advised. The duly completed form will considered as acceptance of sponsor role.
2. Review and approve the Project Proposal, ensuring that it clearly defines the problem to be investigated by the student and that the project aim, scope, deliverables and approach is acceptable from the company's perspective.
3. Review the Final Project Report (delivered during the second semester), ensuring that information is accurate and that the solution addresses the problems and/or design requirements of the defined project.
4. Acknowledges the intended publication of the Project Report on UP Space.
5. Ensures that any sensitive, confidential information or intellectual property of the company is not disclosed in the Final Project Report.