MASTER

Optimal procurement of spare parts in the final phase of the life cycle in the automotive industry

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Optimal procurement of spare parts in the final phase of the life cycle in the automotive industry

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I. Abstract

This master thesis describes the problem of spare part procurement in the final phase of the spare part life cycle. By means of a cost model, the optimal spare part procurement is determined. This model is applied to determine the optimal spare part procurement strategy for MME.

II. Management summary

This report is the result of a Master thesis project at Mitsubishi Motors Europe B.V. (MME). In 2002, MME, a subsidiary of Mitsubishi Motors Company (MMC), was founded to coordinate the sales and distribution of vehicles in Europe. Furthermore, they are responsible for the sales and distribution of spare parts and accessories in Europe.

MME has difficulties with the spare part procurement after the production of an accompanying vehicle ends. When Nedcar B.V. terminates vehicle manufacturing, the demand for spare parts will decrease rapidly, because usually less spare parts are necessary for service than for the production of vehicles. As a result, the supplier will probably increase prices when production of spare parts is continued after the termination of vehicle production. Furthermore, it is possible that the supplier terminates the production of spare parts.

The problem of MME is that they do not know how much should be ordered per procurement option per time unit. Furthermore, they do not know how much spare parts are available for remanufacturing. Therefore, the main goal of the project is to develop a spare part procurement model for MME, which minimizes total relevant costs and achieves a predefined service rate. An example of such a procurement model is proposed by Inderfurth and Mukherjee (2008). However, multiple assumptions made by Inderfurth and Mukherjee are not valid for MME. Therefore, the main research assignment is the following:

Develop a spare part procurement model for spare parts in the final phase in the automotive industry that minimizes total relevant costs and achieves a predefined service rate.

In order to determine which spare parts are included in the case study a spare part analysis is conducted. The following (quantitative) variables are used to classify the most important spare parts: Item price, Inventory holding costs, Volume, Demand, Criticality, Substitutability and Obsolescence. Besides this quantitative analysis also a qualitative analysis is conducted. It can be concluded that the most interesting spare parts are parts that have complex production streets, parts where the raw material should be ordered in high quantities and parts produced by suppliers that are almost bankrupt. As a result, in these cases the spare part price will increase after the vehicle production ends.

The scope of the study is narrowed down to spare parts that are produced by Nedcar B.V. Moreover, safety parts and competitive parts are excluded from the study. For safety parts it is prohibited to sell them second hand. Competitive parts are also available at the unbranded market and therefore spare part availability is no problem.

In the proposed situation, MME has the opportunity to acquire spare parts in three different ways. The first option to acquire spare parts is to place a final order at the current supplier. For the case study this supplier is Nedcar B.V. This company ends the

production of parts when the vehicle production, where the part is used for, is ended. Thereafter MME has the option to continue production at a third party. In contrast to the final order option fixed setup costs should be paid to the supplier. As replenishment policy a (s,Q) replenishment policy is chosen, because of the simplicity to implement it, the spare part demand characteristics and the setup costs that have to be included. After the last extra production batch the purchase of remanufactured spare parts is used to reduce the uncertainty of stock outs and obsolete stock at the end of the service time horizon. This option is defined as the possibility to buy remanufactured spare parts from car dismantlers. In this case a simple order up to level as replenishment policy is chosen, because no setup costs per batch are included and the demand characteristics.

Based on the proposed situation a life cycle cost model as function of τ, defined as the expected final order period, and N, defined as the last period where extra production is allowed, is developed. The costs that are included in the life cycle cost model are purchase costs, inventory holding costs, backorder costs and disposal costs at the end of the service period.

The developed model is used to find the optimal spare part procurement strategy for the spare parts included in the case study. The optimal values of the decision variables and total costs can be found in table 1.

Confidential

Table 1, results per spare part

The model is validated extensively and a sensitivity analysis is conducted to test the robustness of the model.

The following conclusions can be drawn after this master thesis project:

- The model proposed by Inderfurth and Mukherjee (2008) cannot be used in the automotive industry, because multiple assumptions (i.e. random product returns, sufficient returns needed to cover remaining demand) are not valid.
- A new option to acquire spare parts is introduced. MME can purchase remanufactured spare parts at car dismantlers. The advantage of this option is that it can be used to reduce uncertainty at the end of the service time horizon. As a result of this option, it is no longer necessary to add a fixed percentage to the last extra production batch, which results in less obsolete stock.
- It is possible to determine the optimal spare part procurement strategy and the accompanying costs. These costs can be used by MME for budgeting the costs for the total service time horizon per part, vehicle model, etc. The spare part procurement model consists of approximations to make it useable in practice.
- The automotive market is subject to multiple changes nowadays. To determine the optimal spare part procurement strategy MME can conduct scenario analyses with the model. The consequences of different scenarios can be evaluated and the optimal spare part procurement strategy can be chosen.

- It was not possible to compare the proposed model with the strategy used in the current situation, because insufficient data was available. However, when looking to the data available (i.e. data about the buffer period) it can be concluded that when in the current situation the other decisions (i.e. related to the optimal batch quantity and order level) are optimal the proposed spare part procurement model realizes cost savings of at least 6% based on the case study.
- After the sensitivity analysis it can also be concluded that it is necessary to determine the inventory holding costs and the variable spare part cost price for extra production appropriately, because these two variables have a moderate effect on the optimal spare part procurement strategy and the accompanying costs. Furthermore, it can be concluded that the forecasted demand has a major impact on the expected costs. However, the optimal values of the decision variables are robust to changes in demand. These optimal values of the decision variables are also robust to changes in the service time horizon as result of the rolling horizon principle.
- The purchase price for remanufactured spare parts has not much effect on the optimal spare part procurement strategy and accompanying costs for the parameter deviation (i.e. from -50% until 100%) used in the sensitivity analysis.

The following recommendations can be made after this master thesis project:

- The first recommendation is to make the program ready for implementation. This means that the functionality to run multiple spare parts at the same time should be programmed. Furthermore, the user interface should be improved. Besides these modelling issues it is also important to set up a network of car dismantlers from which it is possible to purchase remanufactured spare parts.
- The most important recommendation to MME is to implement the spare part procurement model when it is ready for implementation.
- To fit a distribution for the demand during a period and to fit a distribution for the demand during the replenishment lead time a binomial distribution is used. It is recommended to set up a project in which the demand pattern for multiple spare part groups is investigated. With the result of this research the demand forecast could be improved. In the time this demand analysis is not yet completed it is recommended to use the forecast method (explained in 4.5.6), which uses a dying curve to forecast the units in operation.
- The model depends on the information available. The more reliable this information is, the more reliable the output of the spare part procurement model is. Within MME it is possible to find the appropriate values for multiple variables easily. However, there are some variables for which it is difficult to obtain the appropriate values. For these variables it is determined whether it is important to put effort in the appropriate determination of parameter values. As a result of the sensitivity analysis, it is recommended that the inventory holding costs, the variable spare part cost price for extra production and the expected demand should be determined appropriately.
- It is also recommended to update the spare part procurement strategy annually. Furthermore, it is recommended to implement the optimal procurement strategy

for the current period (i.e. a rolling horizon) only. The advantage of this method is the possibility to anticipate on changing markets. In practice this means that the order level, s_t, and the optimal batch quantity, Q_t, should be updated annually. Furthermore, the moment as from which it is possible to purchase remanufactured spare parts from car dismantlers can be adjusted to react on changes in the market.

- A recommendation for further scientific research is to compare the results of this spare part procurement model with the results of a simulation study. With this simulation study it is possible to examine whether the model reflects the environment of the automotive industry.

III. Preface

This master thesis is the result of my graduation assignment at Mitsubishi Motors Europe B.V. in Born, the Netherlands. This thesis represents the final piece of my study Industrial Engineering and Management Science at the Eindhoven University of Technology.

First of all, I would like to thank Henny van Ooijen, my primary university supervisor, for his enthusiasm and support during the project. The discussion and brainstorm sessions we had were very helpful for the progress of my project. Furthermore, I would like to thank Gudrun Kiesmüller, who is an expert in the field of spare part management, for her feedback on my reports. Furthermore, I would like to thank her for refining the models I was working on.

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Tom Zanders,
September, 2009

IV. Table of Contents

1. Company description

In this chapter first in paragraph 1.1 a company description of the case company is given. Thereafter, in paragraph 1.2, it is explained which products the company sells and what this means for service and logistics. Also some numerical figures about revenue, quantity of spare parts in inventory, capital tied in inventory, and fill rate are presented in this paragraph.

1.1. Mitsubishi Motors Company

Nearly 100 years ago Mitsubishi produced their first motor vehicle, the A Model. In 1970, Mitsubishi Motors Company (MMC) was set up as an independent company to manufacture motor vehicles. Today MMC has manufacturing facilities in 30 countries over the world. The sales and after-sales organization serves more than 170 countries. In 2007 MMC sold 1,360,000 vehicles and total revenue was €23,258 million. In 2007 they were the fifteenth largest vehicle manufacturer in the world and they produced 2% of the total world automobile production (OICA, 2008).

The corporate philosophy of MMC is formulated as follows: "*We are committed to providing the utmost driving pleasure and safety for our valued customers and our community. On these commitments we will never compromise. This is the Mitsubishi Motors way.*"

In 2002, Mitsubishi Motors Europe B.V. (MME), a subsidiary of MMC, was founded to coordinate the sales and distribution of vehicles in Europe. They are also responsible for the sales and distribution of spare parts and accessories in Europe. Headquarters of MME is based in Amsterdam, the Netherlands. Moreover they have two production facilities, in Born, the Netherlands, and Turin, Italy. Also they have two distribution centers for handling and storing spare parts and accessories. In Born, The Netherlands, the European Parts Distribution Center (PDC) is located and a small regional distribution center (RDC) is based in Madrid, Spain. The company serves 2,500 dealers in 36 countries. In 2007 MME sold 227,630 vehicles and the revenue was €5,750 million.

Moreover, the European design studio Mitsubishi Design Europe (MDE), the research and development center Mitsubishi R&D Europe (MRDE) and the Mitsubishi Motors Motor Sports (MMSP) are based in Europe.

1.2 Service and logistics

MME offers, next to vehicles, spare parts and accessories for their vehicles to dealers and distributors. The PDC is located in Born, the Netherlands, and a RDC is based in Spain. It is important to make a distinction between parts for production and parts for service. In the remaining report parts for service are defined as spare parts. These spare parts are stored in the PDC or RDC. The parts for production are stored at Nedcar B.V. In Appendix 1 the European Part Distribution Network is showed. Furthermore, in this Appendix a table can be found in which it is listed which dealers are directly supplied by

MME and which dealers are supplied by distributors. These distributors are also supplied by MME.

MME sells vehicles in the Netherlands with a standard warranty period of 3 years. The length of this warranty can be different per country. Once the warranty period expires customers are offered the possibility to extend this warranty period. In this period maintenance, except the scheduled maintenance, is free of charge. Therefore, customers are more willing to get parts, which do not influence the drivability of the vehicle, repaired. After the warranty period the willingness to repair a broken part is dependent on the criticality of the part (i.e. for the drivability of the car), age of the vehicle, and the repair cost, which includes the cost price of the spare part and the costs of the man hours needed to replace the broken spare part (Ritchie and Wilcox, 1976). Besides the warranty obligations MME has the obligation to supply spare parts for 10 years after a vehicle production stop. The company policy adds another 5 year of service obligation to please customers. This can be seen in line with the findings of Cohen et al. (2006), who stated that in the automotive industry the after sales service is correlated with the customer intends to repurchase a vehicle of the same brand.

The revenue of MME of spare parts in 2008 was €245,576,000. In Appendix 2 the revenue per year since 2004 is presented. It can be seen that the revenue has increased with 30% since 2004. In January 2009 111,967 different SKU's are stocked and the total capital investment in stock is €81,170,000. Also in Appendix 2 it can be seen that the capital invested in stock increased from €30,834,000 to €81,170,000 since January 2000. This increase is partly the result of taking over the distribution center in Germany. Furthermore, it is showed that the quantity of parts on stock increased significantly from January 2000, from 2.8 million pieces in January 2000 to 11 million pieces in January 2009. The fill rate, which is defined as the percentage of customer demand which is satisfied immediately off-the-shelf, fluctuates around the 95%, with a minimum of 93% and a maximum of 97% per month (Verkoelen, 2009). MME's current policy is to achieve at least 90% availability on all parts business, except for Direct Dealer Delivery (DDD) for which it requires 95% (Anonymous, 2003).

To offer sufficient service to dealers and distributors MME offers a wide range of service levels, ranging from 1 to 4 days for the three normal orders and significant longer lead times for special orders. The following order types can be distinguished:

- Normal Order
    - Stock Order (SO)
    - Daily Order (DO)
    - Vehicle-Off-Road Order (VOR)
- Initial Order (IO)
- Promotional Order (PO)

A stock order can be described as a normal stock replenishment order. A dealer or stockholding distributor can order once a week on a fixed day. The shipment preparation time, defined as the time between the day the order is placed and the day of departure from MME's PDC, is three days. The transportation time from the PDC to the customer is approximately one day. The next normal order, which is the daily order, is used for parts which should have been covered by the stock order, but where the stock order was already released and it is expected that the normal order does not cover demand. The shipment preparation time for these orders is one day just like the transportation time to the customer. The last normal order type is the vehicle-off-road order, which is used for parts that are urgently required. Parts are urgently required when a vehicle stands still in the workshop of the dealer. These parts are sent to the customer the same day they are ordered. The total time, which consists of shipment preparation time and transportation time, needed to deliver the spare parts to the customer is one day. Besides these normal orders there are also two special orders. An initial order is only used when a new vehicle model is launched. The problem in this case is that MME's PDC has not stocked the spare parts of the new vehicle. For internal convenience a distinction is made between stock orders and initial orders to make accurate predictions of future demand. The last order type is used for promotional purposes. Just like the initial order the promotional order is used for parts that are not stocked already. Another characteristic that these two special orders have in common is that they encounter longer lead times than the normal orders. The difference is that the promotional order is usually used for accessories, whereas the initial order is only used for spare parts which are introduced in a new vehicle model.

2. Problem definition and Research assignment

In the first paragraph the initial assignment is described, which is based on the initial contact with the case company. Thereafter, in paragraph 2.2 the environmental context is described and in paragraph 2.3 the common spare part characteristics are presented. This is done to get insight in the characteristics of the automotive industry and MME in particular. In paragraph 2.4 the current spare part procurement process is described. Subsequently, the literature is reviewed to check which models can be used to solve the problem and to evaluate the current spare part procurement policies of MME, which is presented in paragraph 2.5. As a result of paragraph 2.2 until 2.5 the definitive research assignment is presented in paragraph 2.6. In paragraph 2.7 is the research methodology presented and in the last paragraph the layout of the report is showed.

2.1 Initial assignment

The initial assignment is based on the first intake meeting with an employee and executive of the Business Logistic Development department. They stated that MME has difficulties with the spare part procurement after the production of an accompanying vehicle ends. These difficulties are caused by multiple reasons. In this after sales period the demand for spare parts decreases rapidly. Besides this decrease in demand also the demand uncertainty increases. Furthermore, it is quite normal that after the production period of vehicles the unit cost price per spare part increases significantly. MME has the possibility to order an amount, which covers the remaining demand, that is included in the last production batch for manufacturing new vehicles. To reduce the uncertainty of going out of stock an extra percentage of the expected demand is added. As a result of the aforementioned, usually much obsolete stock is left after the service obligations are achieved. The initial assignment is therefore to develop a model that optimizes the spare part procurement in the after sales period.

2.2 Environmental context automotive industry

In the automotive industry vehicles are sold to customers and these customers go to third parties for maintenance. A problem that occurs is that demand, for spare parts that are replaced when corrective maintenance is done, follows a random pattern (Zanders, 2009). For spare parts that are replaced when scheduled maintenance is carried out a more predictable demand pattern can be found (Zanders, 2009). Therefore, in the automotive industry there are two groups of spare parts: parts that have more or less a predictable demand pattern and parts that have a random pattern. Another environmental variable that can be considered is the spare part life cycle. As discussed in the literature (Fortuin, 1980) there are three phases, namely the initial, normal, and final phase. In the automotive industry the same holds. In this industry the most complex phase for spare part procurement is the final phase. However, there is another variable that influences the demand. It is the age of the vehicle that predicts the willingness of the customer to replace a certain broken part. Customers with newer vehicles are more willing to repair broken parts, which do not influence the drivability, than customers with older vehicles, which will influence demand (Fortuin, 1980). The next environmental variable is the service time horizon. In the automotive industry it is quite normal to deliver service up to fifteen years after the vehicle is taken out of production. A vehicle is produced on average six years and therefore the total service horizon becomes twenty-one years. The service time horizon is long, but the length is known in advance. In the automotive industry it is possible to remanufacture certain parts. However, only parts that can be remanufactured economically beneficially are usually remanufactured. Another reason to repair parts is to guarantee spare part availability (Zanders, 2009). With respect to this remanufacture issue it can be mentioned that car manufactures are legally obligated to take back their vehicles (Directive 2000/53EC). However, in practice the recycling of end of life vehicles is usually carried out by independent car dismantlers. These car dismantlers have random returns of end of life vehicles. One step in the car dismantling process is to reuse or remanufacture valuable spare parts. Car dismantlers sell these valuable spare parts to the market. The last environmental variable that has an influence on spare part management in the automotive industry is the possibility to reorder spare parts. Whether it is possible to reorder spare parts depends largely on the phase of the life cycle the spare part is in (Zanders, 2009). In the automotive industry also spare parts that cannot be repurchased at suppliers are supplied to customers, which are dealers and distributors.

2.3 Common spare part characteristics

MME sells vehicles and spare parts to customers in Europe. To comply with the obligations and company policy approximately 110,000 different spare parts are kept on stock. This is only 12 percent of parts that are used in vehicles that are driven by customers nowadays. The spare part characteristics vary considerably; the following characteristics can be given:

- Purchase prices for spare parts range from €0.01 to €6,000 per part.
- 3,000 out of 110,000 different spare parts are remanufactured.
- Demand ranges from 0 to more than 1500 order lines per year per type; In Appendix 3 the demand rank distribution can be found.
- Remaining service times of spare parts vary from 0 to 20 years, depending on the year a vehicle is produced and the demand distribution of a specific part.
- The total stock has a value of €81 million (January 2009).
- Regularly, due to a production stop of a specific part, the supplier forces MME to place a final order to cover the demand during the remaining service period.

When looking at the above mentioned characteristics and the market MME operates in, it is logical that problems with regard to excess inventory, which is defined as inventory that is not used when service obligations are expired, appear. Another problem that MME has to deal with is the probability of having stock outs. These problems arise especially in final order situations where large quantities should be purchased to fulfill all service obligations and demand is uncertain.

2.4 Current spare part procurement

In this paragraph the spare part procurement process in the normal and final phase at MME is elaborated. The difference between these two phases is that in the normal phase it is possible to reorder spare parts, whereas in the final phase it is usually impossible to reorder spare parts. When it is possible to reorder spare parts in the final phase of the life cycle it is at significant higher prices. In addition to the spare part procurement in these two phases also the current remanufacturing activities at MME are presented.

MME's Inventory Control department (and at the end of course MMC) is responsible for the availability of spare parts in Europe. To assure spare part availability the Inventory Control department has to cooperate with the Purchase department of Nedcar B.V. Nedcar B.V. is just like MME a subsidiary of MMC. At Nedcar B.V., which is located in Born, the Netherlands, multiple Mitsubishi models are produced. This cooperation is necessary, because the Purchase department sets up the contracts with suppliers. In Appendix 4 the organization chart of MME is presented. The Purchase department of Nedcar B.V. is not included, because it is a private company. In the following paragraphs the processes involved with spare part procurement are elaborated.

2.4.1 Spare part procurement in the normal phase

In the normal phase of the spare part life cycle, demand is more or less constant over time (Fortuin, 1980). As a result it is easier to predict demand and therefore a minimum order quantity policy can be used for example. The Inventory Control department of MME is responsible for ordering the right quantity at the right time at the right place at the right price. The Inventory Control department cooperates with the Purchase department of Nedcar B.V., which is responsible for setting up contracts with suppliers. In Appendix 5 a process map for the spare part procurement and preparation goods receipt is showed. It can be seen that the inventory control system, used by the Inventory Control department of MME, checks every day whether there are backorders. When there are backorders the supplier is contacted to get information about the reason for delay and is asked for the new delivery conditions. For the normal purchase orders the system proposes order quantities once a week on a fixed day. The employees of the Inventory Control department check the correctness of the proposed order quantities by using sales forecasts, historical sales, minimal order quantities, etc. When the proposed order quantities are sufficient the order is placed at the supplier, otherwise the order is changed or cancelled. When an order is placed the supplier confirms the order and the order data is processed.

2.4.2 Spare part procurement in the final phase

The period from the termination of vehicle manufacturing until the end of service is called the final phase. When Nedcar B.V. terminates vehicle manufacturing, the demand for parts will decrease rapidly, because usually less spare parts are necessary for service than parts for the production of vehicles. As a result, the supplier will probably increase prices when production of spare parts is continued after the termination of vehicle production. Furthermore, it is possible that the supplier terminates the production of spare parts. Then another supplier is needed. The prices of the spare parts produced at the new supplier are probably higher than the price per spare part produced during the production of vehicles. The reason is that the supplier may have an alternative product that is more profitable than the low volume production of spare parts for the after sales market. In this case it could be economically interesting for MME to place a final order that can be produced with the last batch for the production of vehicles. Therefore, the methods that are used in the normal phase of the spare part life cycle to achieve spare part availability are not suitable anymore in the final phase. However, there are parts, which have a high demand in the after sales period and can be produced very easily. These parts are defined as competitive parts and can be purchased at other companies in this period. Examples of such competitive parts are brake pads, bumpers, wiper blads, etc. For these spare parts it is usually no problem to assure spare part availability during the lifecycle.

There are two different processes that can be described to deal with spare parts in the final phase. The first one is the more general one, which investigates the consequences of the introduction of a new vehicle model or variant. In the production period, which is approximately six years, usually a model improvement, which leads to design changes, occurs. The result for after sales could be that demand of spare parts used in the old vehicle model and not in the new will decrease rapidly. To identify and deal with the consequences a phase out process is defined, which can be found in Appendix 6. The Purchase department of Nedcar B.V. checks what the consequences are for the spare parts that are included in the old vehicle model. Then information is collected about the spare parts of which the introduction of a new vehicle model has an impact on. Thereafter a meeting is organized where the managers of Purchase, Inventory Control and Product Design are present. In this meeting potential problems and potential solutions for these problems are discussed. However, there is no common procedure to determine the cost optimal solution. When for spare parts that are produced at Nedcar B.V it is decided to outsource production a buffer stock is ordered at Nedcar B.V. This buffer stock is equal to the demand during the period necessary for adjusting and transporting the machinery to the external company. For pressed parts this buffer period is at least a half year.

The second process is used when contract conditions for a specific spare part change, through which it could be interesting to make a final order proposal. This process can be found in Appendix 7. Usually, the primary reason for a final order proposal is the significant increase in unit cost price. This increase in unit cost price can have multiple reasons which are elaborated extensively in paragraph 3.3.

When it is decided by the management that a final order should be made to cover the demand in the remaining service period the Inventory Control department is responsible for calculating the quantity that is necessary. For the final order calculation MME uses information about the units in operation (sum of the vehicles on the market per model type in the countries they are responsible for), historical sales of spare parts, and the length of the remaining service period. With this information it is possible to calculate the usage rates per year per spare part up to now. The most appropriate usage rate is chosen for forecasting the remaining demand. For some parts also a trend correction factor is added, which is calculated by comparing the usage rate of two or more sequential years.

The choice of the most appropriate usage rate and the trend correction factor is made based on experience of the employee of the Inventory Control department. To calculate the demand per year the usage rate is multiplied with the units in operation and optionally with a trend correction factor. The demands per year are summed up and the result is the demand necessary to cover the remaining service period. To deal with demand uncertainty an extra percentage, ranging from 0 to 50 percent, is added to the total final order. The choice of this percentage is based on experience and risk aversion of the individual employee.

When evaluating the current situation a few comments should be made. The first comment is about the units in operation. The information about the units in operation, which is provided per vehicle model, is supplied by an external company. However, each vehicle model has many variants (e.g. an engine variant, an interior variant, etc.), which causes a problem; since several spare parts are not used in every vehicle of the specific model.

When looking at the usage rate it can be concluded that the usage rate used for the forecasts is chosen based on experience. A more accurate forecast probably could be made when applying a usage curve that is based on the spare part type. In the literature Moore (1971) describes that the demand of spare parts in the automotive industry can be characterized, in 85% of the cases, by three functions. In paragraph 2.5 a detailed explanation of the findings of Moore (1971) can be found. When comparing these proposed functions with the demand forecasts found by the Inventory Control department it can be concluded that with these average usage rates the demand is slightly overestimated. As a result, there is a potential for obsolete stock, because more is ordered than probably is demanded. For a graphical representation of this comparison see Appendix 8. However, an extensive study on spare part demand is necessary to draw conclusions about the correctness of the used demand forecast technique.

Another comment that should be made is about the customer loyalty with respect to maintenance at a Mitsubishi dealer. According to Cohen et al. (2000) customer loyalty is dependent on the age of the vehicle and the level of repair required. It seems that customer loyalty decreases for light repairs and scheduled maintenance when vehicles become older. Therefore, the demand for the remaining service period could be lower than forecasted.

2.4.3 Remanufacturing activities

In October 2006 Mitsubishi has started with remanufacturing activities. Since October 2006 they sold 16,239 remanufactured spare parts, which resulted in a cumulative revenue of €6,039,073. The dealers and distributors send back broken cores that can be remanufactured profitable. MME checks whether these returned cores are correctly documented and afterwards the returned cores are sent to the remanufacturer. The remanufacturer stores the broken cores until MME orders remanufactured spare parts, therefore this can be seen as a Pull control policy (Van der Laan, 1997). When the order is ready the remanufacturer sends the spare parts to MME where they are stored. The remanufactured spare parts get a part number code that differs from the one that new spare parts of the same type get. These remanufactured spare parts are offered to the market as a distinct product with a lower price, which is approximately 70-80 percent of the price of a new spare part of the same type. When dealers or distributors order a spare part that is included in the remanufacturing program they are forced to send the broken spare part back to Mitsubishi. This can be seen as the deposit-based relationship described by Ostlin et al. (2008). When a dealer or distributor sends a broken part, which is included in the remanufacturing program, back they get a reward. However, when they don't send back the broken part within 13 weeks a penalty cost has to be paid.

2.5 Literature review

In this paragraph a review of the literature that is available in the field of spare part management is presented to get insight in the different models that can be used for spare part management. An extensive review can be found in Zanders (2009). This paragraph starts with the key questions of logistic control. Thereafter models that can be used to determine the optimal spare part procurement in the final phase are discussed.

2.5.1 Spare part management in the final phase

First the key questions of logistic control are presented. Fortuin and Martin (1999) state that four important questions for controlling spare parts should be answered:

- Which items are needed as spare parts?
- Which spare parts have to be stocked?
- When do we need to (re)order?
- How much do we need to (re)order?

The answers on these questions depend on the environmental context, which is described in section 2.2. In Zanders (2009) an extensive review is presented on the environmental variables that affect spare part management and thus the answers of these questions. In this thesis only the spare part procurement in the final phase is discussed, because other phases are out of scope. An extensive review for spare part management in the normal phase can be found in Zanders (2009). The final phase of a spare part starts when the production of part ends. This final phase is usually the larger part of the service horizon and it is also called the end of life period (EOL) (Teunter and Fortuin, 1999). Typical characteristics of the final phase are declining demand rates and the difficulty of estimating the remaining demand.

According to the literature review (Zanders, 2009) suppliers often force manufacturers to place a final order in the final phase of a spare part. According to Cattani and Souza (2003) there are benefits for the manufacturer when delaying a final order decision. They state that a longer delay is always as good as or better than a shorter delay under the same circumstances (Cattani and Souza, 2003). Furthermore, it is mentioned that these benefits are obtained early. Whether this finding is useful in practice is doubtful, because in the final phase of the spare part life cycle usually multiple cost parameters (for example the unit cost price, fixed setup costs, etc) change.

However, when the manufacturer produces parts in-house benefits can be obtained when placing a final order. Some of the benefits for the manufacturer are for example (Moore, 1971):

- Reduced file maintenance as engineering drawings and manufacturing instructions.
- Scrap payments and tax write-offs for discarded production tools.
- Reduced purchased components inventory costs.
- Reduced required floor space.

These benefits can be obtained when demand is accurately forecasted. For the automotive industry Moore (1971) found that when historical sales data are transformed from an arithmetic scale to a logarithmic scale and the years of sales were indexed, demand patterns that describe 85% of the parts considered can be found. The data that he uses is quarterly, seasonally adjusted sales information. The three demand patterns that can be used for 85% of the parts are the eclipse, parabola, and the straight line. He found that the elliptical decay function can be used for the demand pattern of major engine and transmission parts, body panels, axles, springs and windshields. The parabolic function can be used for moderately priced essentials and several cosmetic items for higher priced vehicles, for example lamp assemblies, valves, connecting rods, speedometers, fuel and water pumps and chrome body trim. The last function is the linear decay function, with exponential decay when the logarithmic axis is used, which can be used for a wide range of general maintenance parts such as shock absorbers, brake cylinders, pads, valve lifters, gaskets, brackets and small fittings. With these patterns it is possible to predict the all time requirement for specific parts.

Predicting the demand per year, up to 15 years in the future, for a specific spare part is very complex. According to Fortuin (1980) this is because there are many factors that influence demand in the final phase. Some examples of these factors are:

- The customer's preference to buy a new product instead of having the broken product repaired.
- The customer's decision not to repair a broken part, this can be the case when a part is non functional or the customer does not need the part.
- Improved quality of spare parts. New spare parts, with improved quality, are introduced on the market, which can be used as substitution of the old spare parts.

Others, like Ritchie and Wilcox (1976), state that the less critical a spare part is for the functioning of a machine, the quicker the demand of such a spare part decreases. The model to calculate the final order, which is proposed by Ritchie and Wilcox (1976), also takes into account the criticality of the machine functionality, the number of machines sold, and the failure rate per machine hour. The problem of this model is the computational effort that is necessary to calculate the different parameter values.

Models that require less computational effort are presented by for example Fortuin (1980). From historical data analysis he concludes that the demand per year can be estimated with a non-stationary and uncorrelated Gaussian process and the mean of this process decreases exponentially during the years in the final phase. An important assumption that he made is that the expected demand during the EOL phase is exponentially decreasing with rate 0.7, which means that the demand in a specific year is 70% of the demand of the previous year (Fortuin, 1980 and Teunter and Fortuin, 1999). Moreover, in the article (Fortuin, 1980) multiple formulas are derived which present the relationship between the degree of availability, safety stock, length of the final phase, shortage risk and obsolescence risk on the one hand, and the statistical properties of the demand process of spare parts on the other hand.

With the findings of Moore (1971) and Fortuin (1980), Teunter and Fortuin (1999) tried to determine two cost optimal models. The first model places a final order at the beginning of the EOL phase and removes all remaining stock at the end of the service period. The other model adds the possibility to remove stock at each time interval. In both models it is not possible to reorder spare parts. When comparing the two models it can be seen that there is a small difference in expected costs. This difference is however quite small, therefore the simple model is sufficient (Teunter and Fortuin, 1999). Furthermore, they assume that demand and supply of slow moving spare parts are driven by a Poisson process. In Teunter and Fortuin (1998) the model that is proposed in Teunter and Fortuin (1999), is tested in practice at Philips. For calculating the final order they use the EOL demand and the price of a spare part. The penalty costs are defined as the costs of a new product. However, these costs are not necessary in case the failed product can be repaired using a different spare part or when the broken spare part is non-functional (Teunter and Fortuin, 1998). It is concluded that the model proposed in Teunter and Fortuin (1999) is far from optimal. Therefore, they introduce some improvements to optimize the accurateness of the solution for the final order problem.

Until now models are described where it is only possible to place a final order. With these models it is not possible to check which influence the possibility of ordering spare parts after the final order, against a higher unit cost price, has. Teunter and Haneveld (2002) use the above described models as basis and add the possibility of ordering spare parts after the final order. The price per spare part of parts ordered after the final order is higher than the price per spare part of parts ordered in the final order. Two important assumptions that are made are that the service time horizon is known in advance and that demand is stationary and follows a Poisson process. Furthermore, it is not possible to dispose parts before the end of the planning horizon.

In Teunter (1998) multiple different models to calculate final order quantities are proposed. The first model considers an environment in which it is possible to reorder spare parts at a higher price than in the final order and where there is one central warehouse. The next model considers the same context as in model one, however it restricts the range of spare parts to spare parts with low demand and a short lead time. The third model can be used when the price of a spare part of parts ordered after the final order is higher than the price of a spare part in the final order. Furthermore, it considers the availability of repair kits and the presence of one central warehouse. The last model can be used when it is possible to reorder spare parts after the final order and when service is offered to multiple customers. The assumption made in all models is a fixed service horizon period. Assumptions that are made in multiple models are stationary demand, which is modelled as a Poisson process, discounted costs, presence of ordering costs, and the possibility of remanufacturing and negligible lead time (Teunter, 1998).

The most recent model found in literature is that of Inderfurth and Mukherjee (2008), who extend the model of Teunter and Haneveld (2002) with the possibility to acquire spare parts from remanufacturing. They consider a company that produces parts for production and for service. When production of vehicles ends it could be that it is not economically interesting to continue production only for service. They conclude that such a company has three possibilities to acquire sufficient spare parts:

- Final order
- Extra production
- Remanufacturing

The first option is to place a final order when the company decides to stop production. The final order is added to the last lot of production. After this lot production is stopped and the tooling is sold or scrapped. In this case the cost price per product is low, because this lot is combined with the last production lot. Therefore, no extra setup costs are included and batch quantities are large. A disadvantage of the final order is the large uncertainty in demand. This uncertainty is caused by two reasons; the first reason is the lack of knowledge about the demand distribution and the second reason is the long period that should be forecasted. Another disadvantage is that products are kept in stock for a long period, which will result in a large investment in inventory and storage capacity.

Another option to acquire spare parts is to outsource production. A disadvantage of this option is that the unit cost price is much higher than the unit cost price in the final order. The reason for this unit costs price increase is that the production company produces in small lots and fixed costs for ordering are added. The advantage is less uncertainty in demand than in the case of a final order; this is due to a relatively small forecast period. When outsourcing is an option, it nevertheless can be interesting to place a final order. This is especially the case when fixed costs are high. The costs of inventory holding and obsolescence or stock outs should be weighted with the fixed costs and higher product prices when ordering at a third party.

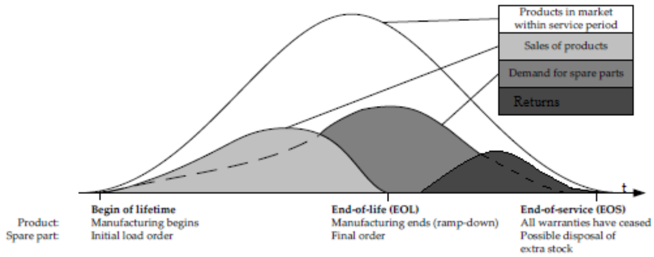

Figure 1, Demand for new products, spare parts, and products returns adapted from Inderfurth and Mukherjee (2008)

The last option for acquiring spare parts is remanufacturing. This option is considered as a supplement to the final lot. A characteristic of remanufacturing is the moderate costs of production through remanufacturing. The cost of a remanufactured item is usually less than the costs of extra production and somewhat more than the cost of an item in the final lot. A disadvantage of this option is that there is uncertainty in the quantity, timing, and quality of returns. Inderfurth and Mukherjee (2008) assume that product returns occur randomly. In figure 1 the underlying dynamics of demand for spare parts and supply of returned used products is showed.

2.6 Research assignment

Especially in the automotive industry the final phase of the spare part life cycle is the most complex one. As mentioned in the literature review (Zanders, 2009) it is in this phase usually not possible to reorder. When it is nevertheless possible to reorder spare parts after the final order the price is usually higher than in the normal phase. According to the literature it can be concluded that there are three options to acquire spare parts in the final phase of the spare part life cycle; placing a final order, extra production (with a higher variable unit cost price than in the final order), and remanufacturing. In this final phase there are large risks of having stock outs or having excess inventory in the final phase.

As a result of the environmental context and the spare part characteristics of the automotive industry on average 50% of the customers are facing unnecessary delays in getting vehicles repaired, because the right spare parts are not at hand. Furthermore, it is estimated that in the automotive industry each year 23% of the parts become obsolete (Cohen et al., 2006). Another important point to mention is that there is a direct relation between stock prices and the after sales performance of companies. In the automotive industry the after sales performance is correlated with the customer intend to repurchase a vehicle (Cohen et al., 2006). Another reason for the growing importance of spare part management in companies is the decreasing product life cycle and the increasing competition between companies. The result of these two trends is an increase in demand variability (Käki, 2007).

The problem of MME is that they do not know how much should be ordered per procurement option per time unit. Furthermore, they do not know how much spare parts are available for remanufacturing. Therefore, the main goal of the project is to develop a spare part procurement model for MME, which minimizes total relevant costs and achieves a predefined service rate. In paragraph 2.5 the findings of Inderfurth and Mukherjee (2008) are presented, which can be used to solve this problem.

However, it is doubtful whether the heuristic proposed by Inderfurth and Mukherjee is useful, because they used only one example to validate their heuristic. This is insufficient to draw conclusions on the appropriateness of the heuristic. Also the assumption that there should be sufficient product returns to cover demand after the final order is doubtful. When for example product returns are relatively low, compared with demand, a large final order should be placed. However, it could be cheaper, especially for spare parts with a high inventory holding cost percentage, to decrease the final order quantity and manufacture extra spare parts after the final order decision. Furthermore, Inderfurth and Mukherjee (2008) assume random product returns. In paragraph 2.2 it is explained that car dismantlers have random product returns. However, when MME buys these spare parts at car dismantlers MME has no random product returns. Therefore, the assumption of random product returns is not valid for MME. The same holds for most of the other car manufacturers.

Therefore, the main research assignment is the following:

Develop a spare part procurement model for spare parts in the final phase in the automotive industry that minimizes total relevant costs and achieves a predefined service rate.

This assignment will be put into effect by an empirical research at MME. Another goal of this case study is to determine the optimal spare procurement policy for specific defined spare parts at MME. The questions that will be dealt with throughout the thesis are:

- *What are the characteristics and assumptions of the spare part procurement model proposed by Inderfurth and Mukherjee?*
- *Which spare parts should be investigated?*
- *What are the characteristics of the investigated spare parts?*
- *Are there, besides the options to place a final order and extra production, alternative sources to acquire spare parts?*
- *Can the model, proposed by Inderfurth and Mukherjee (2008), be used in the automotive industry? If necessary adapt the model in such a way that it can be used in the automotive industry.*
- *What is for MME the optimal spare part procurement strategy for the investigated spare parts?*

2.7 Methodology

The research methodology that is used for this project is that of Van Aken et al. (2007), which is specifically designed for Industrial Engineering and Management Science MSc. projects. They divide such a research project into a diagnostic and redesign phase. The diagnoses phase is almost completely described in the previous chapters. Therefore, in this paragraph only the methodology for the redesign phase is presented. According to the authors the aim of this methodology is to confront theoretical knowledge with the practical situation found at the company where the business problem solving project is conducted.

After the diagnostic phase the redesign phase starts. A research model is built, which is presented in figure 2. At the right hand side the primary process is presented, which is the spare part procurement process in the final phase. At the left hand side demand theory, final order theory, expert opinions from university supervisors and planners and managers from MME are listed. Furthermore, change theory is used to develop organizational support for implementation. The main goal of this phase is to deliver a valid redesign and an implementation plan.

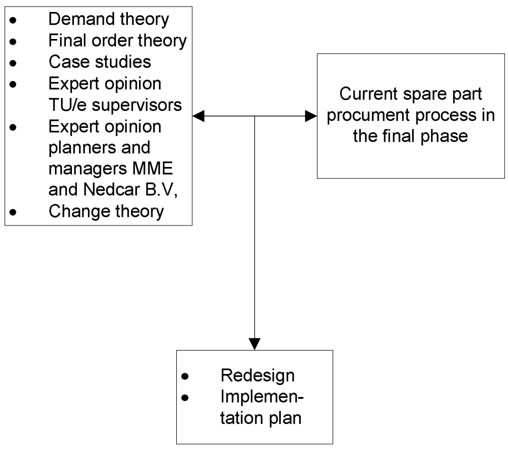

Figure 2, research model for redesign phase

2.8 Report layout

This chapter has provided an insight into the problem background, the current situation at MME, the problem and the research assignment. Based on this research assignment this report is structured as follows:

Chapter 3 provides an analysis of the spare parts that are stocked at the PDC. Furthermore, the causes of obsolete stock are presented in this chapter. As a result of the analysis and the causes of obsolete stock, the scope of the project and the spare parts included in the case study are elaborated. Chapter 4 provides a new model to determine the optimal spare part procurement strategy. In this chapter also the input parameters are described and determined for MME. Chapter 5 provides the results of the case study and the sensitivity analysis. Chapter 6 provides the issues of implementing the model into the current business process. Chapter 7 provides conclusions and recommendations.

3. Analysis

This chapter provides the reader with an analysis of the spare parts that are stocked at the PDC to become familiar with the spare part characteristics. In paragraph 3.1 it is explained which data is analyzed and why some spare parts are not included in the analysis. Thereafter, in paragraph 3.2 the data that is left is analyzed based on quantitative variables found in the literature. Besides these common variables there are also qualitative variables which are more industry specific. These qualitative variables, which have an impact on the spare procurement policy for MME, are discussed in paragraph 3.3. In paragraph 3.4 subsequently the causes of obsolete stock are discussed. Then in paragraph 3.5 the scope of the project is defined. The scope of the project is based on the analysis presented in paragraph 3.2, 3.3 and 3.4.

3.1 Parts investigated

In paragraph 2.3 common spare part characteristics are presented for the spare parts that are stocked in Born. However, for this analysis only spare parts that are supplied by Nedcar B.V. or are outsourced by Nedcar B.V. are included. This is because MME is fully responsible for spare part availability of vehicles made at Nedcar B.V. Furthermore, MME has the power to determine whether the tooling, for making these spare parts, should be kept or scrapped. Usually when the production of a vehicle model is stopped the production of spare parts also stops at Nedcar B.V. This is because in the after sales period much lower quantities of parts are required. MME can decide to make a final order or to outsource production to a local supplier. When the production is outsourced usually a fixed cost should be paid annually for storing the tooling. When production of a spare part is required also fixed costs per order and a unit cost price per part has to be paid, which is higher than the unit cost price at Nedcar B.V., because of the lower batch quantities. When filtering the part database to spare parts produced at Nedcar B.V. or outsourced by Nedcar B.V. 22,000 spare parts are left, the total number of SKU's on stock is 110,000.

As mentioned in the literature review (Zanders, 2009) MME can obtain benefits when delaying the final order decision. Therefore, MME will not propose to place a final order when supply conditions do not change. In the current situation, of which a detailed description can be found in chapter 2.4, the Inventory Control department makes the final order decision on request of the Purchase department or suppliers. As mentioned before it is quite normal that spare part prices increase after the production of vehicles. When the last production batch is produced, MME has to decide how much spare parts should be ordered with the last batch for production and whether spare production should be outsourced. Therefore, only spare parts for which in the past a final order decision is made or for which production is outsourced, when the production of vehicles is ended, are included. Data is only available from the last 5 years. In this database approximately 1,900 spare parts are included. For the other 20,100 spare parts insufficient information is available.

Furthermore, safety parts are excluded from the database. In the automotive industry safety is an important aspect. To ensure safety some safety related spare parts are defined as safety part, which means that they cannot be sold second-hand and that they are extensively tested. Furthermore, these parts should include detailed information, so that in case of imperfection other parts that are produced in the same batch could be traced.

The database that is left after filtering contains some missing values. For these cases it is individually checked whether these should be deleted or not based on the available information. The result of the filtering is that 1,692 spare parts are left for investigation. In the next paragraph it is explained which variables are used to determine which spare parts are included for research on the optimal spare part procurement policy.

3.2 Result quantitative analysis

In the previous paragraph it is described which spare parts are included in the analysis. In this paragraph the variables that are used to determine which parts should be included in the case study, are explained. Käki (2007) mentions the following variables to classify the most important spare parts: Item price, Inventory holding cost, Volume, Demand, Criticality, Substitutability and Obsolescence.

In table 2 the descriptive statistics of multiple variables included in the analysis are presented. Whether a variable is included in the analysis depends on the information available at MME. In the upcoming subparagraphs the variables and results are explained separately.

	mean	min	max	std. deviation
Unit cost price (in Euros)	29	0.01	3,468	117
Demand in 2008 (in Parts)	13.8	0	3740	125
Capital investment (in Euros)	2,434	0	287,400	14,245
Volume (in dm^3)	40	0	990	112
Inventory cost holding percentage (in %)	35	9	3,052	108
Final order period (in years)	10.8	2.5	19	3.0

Table 2, result descriptive statistics

3.2.1 Unit cost price

The first variable is the unit cost price. In figure 3 the distribution of the cost price per unit is showed in a histogram. It can be seen that most of the spare parts are very cheap and that there are a few expensive parts. This is also supported by the descriptive statistics in table 2. It can be seen that the mean in proportion to the range, which is defined as the maximum minus the minimum, is very low. These expensive spare parts could be interesting to investigate, because an inaccurate forecast has higher financial impact for expensive parts than for cheap parts.

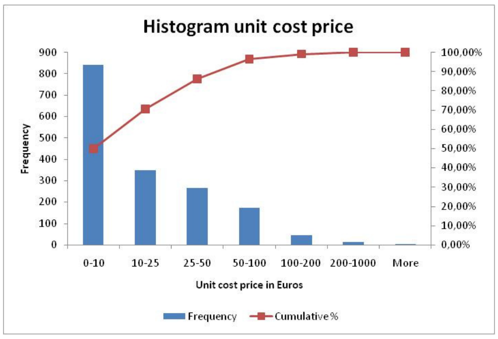

Figure 3, histogram unit cost price

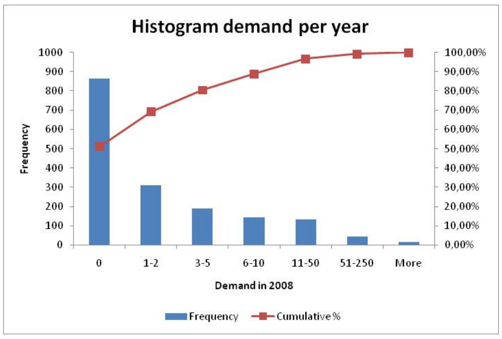

Figure 4, histogram demand per year

3.2.2 Demand per year

Another important variable is the demand per spare part, this variable is defined as the number of spare parts sold in 2008. In table 2 the descriptive statistics of the demand can be found. As can be seen in figure 4 the demand per spare part is for most spare parts very low, 80% of the spare parts is sold maximally five times per year. The "fast" movers, which are in this thesis defined as parts with a demand of fifty or more parts per year, count for 3.3% of the spare parts.

3.2.3 Capital investment final order

The next variable that is investigated is the capital investment in the final order. This variable is calculated by multiplying the final order quantity with the unit cost price. In table 2 the descriptive statistics of the capital investment in the final order can be found. When looking at the histogram (see figure 5) it can be seen that most of the final order decisions involve little capital investment. However, there are some outliers that could be interesting to investigate. As described in paragraph 2.4, the Inventory Control department tries to forecast demand. Due to uncertainty a percentage between 0% and 50% is added to the forecasted final order quantity. With a new spare part procurement policy this extra percentage probably could be reduced or even deleted, which saves money. This new spare part procurement policy is most interesting for capital intensive spare parts, because more money can be saved.

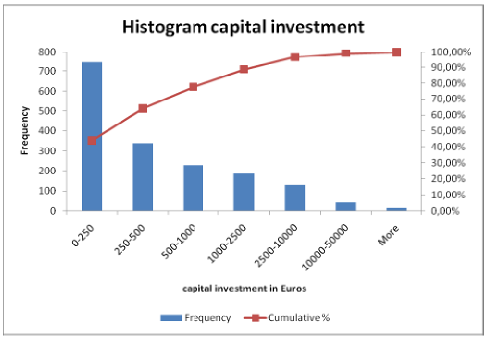

Figure 5, histogram capital investment final order

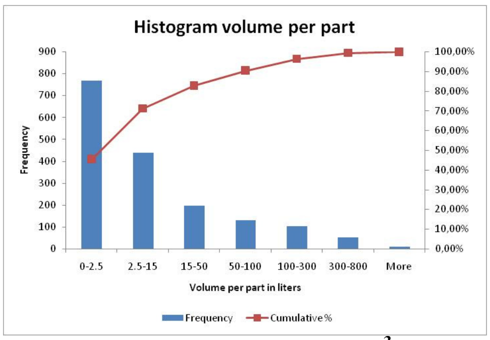

Figure 6, histogram volume (in dm^3)

3.2.4 Spare part volume

Another variable that is analyzed is the volume of the spare part. In table 2 the descriptive statistics are showed. It can be seen that the range is large and that the mean in proportion to the range is low. This is also showed in figure 6 where a histogram of the volume per spare part is presented. Also there it can be seen that most of the spare parts have a low volume. However, there are some spare parts that account for large volumes, 9.5% of the spare parts have a volume larger than hundred liters. This variable is interesting, because products that have a large volume per spare part encounter high inventory holding costs.

3.2.5 Inventory holding costs

Usually in companies a fixed percentage of the unit cost price is used to determine inventory holding costs (Silver et al., 1998). However, spare parts with the same unit cost price but with a different volume have a different inventory holding cost percentage. As a result the method that uses a fixed inventory holding cost percentage is not appropriate. Therefore, a variable alpha (α) is created that adds the unit cost price and volume, which will result in the correct inventory holding cost percentage. The following formula is used to calculate α (Hegelsom, 2002):

$$\alpha = 0.09 + 0.11039 \bullet (l \,/\, p)$$

Where:

α Inventory holding cost percentage
l Volume (in dm^3)
p Unit cost price (in €)

As can be seen this formula includes an independent part, which is 0.09, which is composed of an interest rate of 6% and additional stock holding costs of 3%. The other part is the spare part dependent part and includes the space and storage equipment used for the particular part. The value 0.11039 is based on an empirical study (Hegelsom, 2002). The distribution of this variable (α) is presented in figure 7. In this figure it can be seen that most of the spare parts have an inventory holding cost percentage that is below 20%. However, 7.5% of the spare parts have an inventory holding cost percentage higher than 100%, which means that the inventory holding costs per year are equal to or higher than the unit cost price.

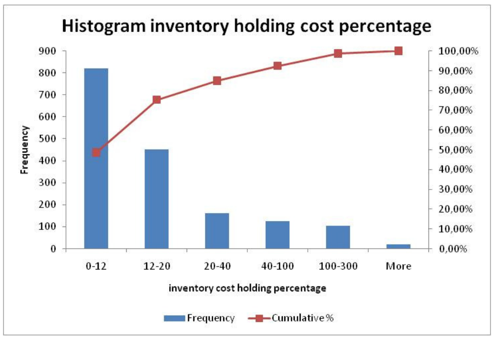

Figure 7, histogram holding cost percentage

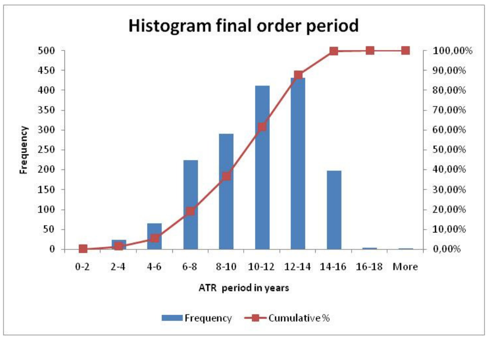

Figure 8, histogram final order period

3.2.6 Final order period length

Another variable is the final order period length, which is defined as the period between the final order decision and the point in time where all service obligations are ceased. The final order quantity should cover the demand during this period, because no other options to purchase spare parts are available. In the literature review (Zanders, 2009) it is mentioned that this period is deterministic. However, this period is not equal for all spare parts. In table 2 (for a graphical representation see figure 8) it can be seen that the final order period ranges from 2.5 to 19 years. This final order period length is determined by looking at the difference between the date the final order decision is taken and the date where all service obligations for the accompanying vehicle are ceased. When the final order period is higher than 15 years, the final order decision is made before the phase out date of the vehicle in which the part is used (remind that after the phase out date 15 years of service should be delivered). Spare parts with a high final order period are the most interesting ones, because of the higher uncertainty.

3.3 Result qualitative analysis

Besides the variables mentioned by Käki (2007) there are other important spare part aspects that have an impact on the final order decision. This information is based on interviews with purchase employees of Nedcar B.V., planners of MME's Inventory Control department, and employees of MME's Business Logistic Development department.

When the vehicle manufacturing is ended, the demand for parts will decrease rapidly as already described. This is because usually less parts are needed for service than parts for the production of vehicles. As a result of this, the supplier will probably increase the price per spare part when production of spare parts is continued after the manufacturing of vehicles is ended. According to the Purchase department of Nedcar B.V. and the Inventory Control department of MME this price increase is usually the result of three aspects:

- Potential price increase
    - Complex production streets
    - Raw material
    - Supplier bankruptcy

The first aspect that can result in a significant price increase after the production of vehicles is the complexity of the tooling used to produce the spare parts. A good example is the production of sheet metal parts, which are produced in the press shop of Nedcar B.V. In this press shop around 250 different pressed parts are produced, which are for example floor, side, and roof panels. The press shop covers approximately 26,000 square meters and consists of 10 high quality press lines that form, cut, and square sheet metal. For the production of a specific part dies are used. These dies should be stored when not used, which will result in an inventory holding costs per die. Besides these inventory holding costs also setup costs occur. Through the process improvement programs it is nowadays possible to change the dies in a production line on average in 15 minutes.

When the demand for a specific sheet metal spare part is low this will result in lower batch quantities. This implies that the setup costs should be distributed over less products, which results in a higher unit cost price. Furthermore, these fixed inventory holding costs for dies are distributed over less spare parts, which also leads to a higher unit cost.

The second aspect that will result in a higher unit cost price is the minimum order quantity of raw materials. For the press shop this means that raw material, in this example sheet metal, is ordered in fixed large quantities due to economies of scale. Another example is the production of car seats. After the production of vehicles is ended, the demand for car seats decreases rapidly. As a result the optimal order quantity based on the new demand per year is much lower than in the production period. However, the supplier of raw materials uses minimum order quantities which are many times larger than the quantity needed. As a result of this too much raw material is purchased, which results in extra costs per spare part.

The third aspect is the risk that a supplier goes bankrupt. This is the only aspect that is not known in advance. However, according to a purchase employee it is the task of a purchase employee to build a good relationship with the supplier so that the supplier will inform the purchase employee in time when the supplier goes bankrupt. When the supplier is bankrupt and there is still demand for the spare parts produced at this supplier the Purchase department of Nedcar B.V. should search a new supplier. This new supplier will only produce the spare parts when profit can be made. For the after sales period this implies that unit cost prices usually increase. In the contract with the old supplier agreements were made about the unit cost price in the production and after sales period. This supplier made most of the profit in the production period. As a result of this the spare parts produced in the after sales period were relatively cheap.

3.4 Analysis obsolescence and final order

In the previous paragraphs it is explained which quantitative and qualitative variables have an impact on the final order decision. Besides these variables also reasons for obsolete stock should be analyzed. When analyzing the database with the 1,692 spare parts it could be seen that 535 parts had no demand in the past three years. These 535 parts account for approximately €330,000 of inventory value and this is (potential) obsolete stock. The inventory value of the 1,692 spare parts is €2,900,000. These large values of potential obsolete stock are the result of suboptimal spare part procurement. Therefore, in this paragraph aspects that have the largest impact on the obsolete or excess inventory are discussed. First some general reasons for obsolete stock are given (Stout and Hanson, 1989; Van Kooten, 2006):

- Lack of demand: This occurs when demand is less than forecasted resulting in slow moving inventory. This effect is stronger in industries where short life cycles are common.
- Lot sizing: To maximize efficiency it could be that larger quantities, based on for example the EOQ or MOQ formula, are ordered than needed, which is risky at the end of the sales period.

- Product change: Driven by competition a company may decide to make a redesign of the considered spare part, for example to improve spare part quality. As a result spare parts used before the upgrade become obsolete, because demand decreases rapidly.

An analysis of the current final order decision for spare parts at MME results in a number of reasons for obsolete stock. These reasons are divided in three categories and are based on interviews with employees of MME and Nedcar B.V.:

Replenishing

- Too large final order: Final orders are calculated by the Inventory Control department in cooperation with the Purchase department of Nedcar B.V. In the automotive industry the manufacturer has obligations to deliver spare parts up to ten years after a vehicle production stop and MMC adds another 5 year, because of their company policy. So the final order should cover demand up to 15 years. Therefore, the risk of obsolete stock is high.
- Excess ordering upon occurrence of few demands: An increase in requests for a spare part, which had no demand in the previous periods, can trigger orders. This is usually caused by the lumpy demand of spare parts. MME delivers spare parts to dealers and distributors. Such a distributor can order a large quantity to cover a certain large period, which will trigger orders. This is risky when the spare part is in the end of life phase, because demand decreases rapidly.
- Too large initial order: Upon the launch of a new vehicle model MME's Inventory Control department determines the initial order quantity. In practice it turns out that in some cases expected failures do not occur, which can result in obsolete stock.

Quality issues

- Redesign: Redesigns of spare parts, for example to increase quality, may cause orders for spare parts that were originally not included in the bill of material of a vehicle. The demand for the original spare parts will decrease and the result could be obsolete stock.

Systems

- Difficulties to estimate installed base of spare parts: Identifying exactly which spare parts are installed in which vehicles is difficult. Nowadays, there are multiple vehicle models and multiple different model variants. With the current systems it is not possible to trace down which spare parts are installed in which vehicles for reasonable costs. Furthermore, some parts are sold as add-ons or extensions to existing vehicles.
- Units in operation: The units in operation are estimated and forecasted by an external company. The reliability of these estimations and forecasts is quite doubtful. These units in operation are only given per vehicle model.

3.5 Scope

In this paragraph the scope of the study is described. It is based on several aspects, which are each presented in different subsections.

3.5.1 Geographical

MME serves customers through Europe with a Mitsubishi vehicle. However, in this study only spare parts used in vehicles produced by Nedcar B.V. are included, because MME has the responsibility for spare parts which are locally sourced. This means that MME has the power to decide what should be done with the tooling in the final phase.

3.5.2 Alternative sources

As described in the literature review MME has three options to acquire spare parts. In this study only existing sources are used. This means that in this study the option to set up a new network for remanufacturing is not an option. To set up a new remanufacturing network, large investments should be made. The market conditions at the moment are such that large investments are postponed or abandoned.

3.5.3 Safety parts

In the automotive industry safety is an important aspect. To ensure safety some spare parts are defined as safety part, which means that they cannot be sold second-hand and that they are extensively tested. As these safety parts cannot be sold second-hand they are excluded in this study, because remanufacturing is included as spare part procurement option.

3.5.4 Competitive parts

In this study also competitive parts are excluded. These competitive spare parts can also be bought at unbranded firms. Furthermore, the demand for these products is usually high so that it is not necessary to place a final order.

3.5.5 Summary

After the quantitative and qualitative analyses conducted in the previous paragraphs of this chapter, it is possible to determine which spare parts are the most interesting ones for a case study. The spare parts that are included in the case study have the following characteristics; high unit cost price, low value density per square meter, large ATR period and high capital investment. In Appendix 9 the accompanying spare part number codes are presented. Besides these quantitative characteristics the spare parts have the following qualitative characteristics; minimal order quantity for raw materials and complex production streets. These spare parts are the most interesting ones, because they have the largest potential for cost reductions.

4. Development of solutions

In this chapter a procurement model for spare parts in the final phase is developed for the automotive industry. In paragraph 4.1 the proposed new situation is explained. Subsequently in paragraph 4.2 a common cost model, which describes the costs and logic of the detailed cost model of the new situation is presented. Thereafter in paragraph 4.3 the decision variables are described. Then in paragraph 4.4 first the detailed cost model is explained per procurement option and for each cost type. Next the total detailed cost model is presented with the notation used. Furthermore, the input parameters, the input parameters as result of the heuristics and the decision variables are presented. In paragraph 4.5 the input parameters are described and the method used to fit a demand distribution is presented. The heuristics that are used are explained in paragraph 4.6. Finally, the model that is used is validated and verificated.

4.1 Proposed new situation

In this paragraph a description of the situation that is modelled is given. An important model decision is that the total service time horizon is modelled as a periodic model with equal periods of one year. This is concluded based on multiple interviews with employees of MME who have expertise in the area of inventory holding, the after sales market where MME is operating in. They concluded that there is only yearly demand information available. In the new situation, MME has the opportunity to acquire spare parts in three different ways.

The first option to acquire spare parts is to place a final order at the current supplier. For the case study this supplier is Nedcar B.V. This company ends the production of parts when the vehicle production, where the part is used for, is ended. However, Nedcar B.V. gives MME the possibility to order a last batch where the purchase price per part is as used for vehicle car cost calculation, which is a low price compared to the variable spare part cost price of extra production.

Secondly, MME has the option to continue production at a third party. Orders can be placed at the supplier according to supplier contracts. In contrast to the final order option fixed setup costs have to be included. A (s,Q) replenishment policy is chosen, because of the simplicity to implement it, the spare part demand characteristics, the setup costs that have to be included and the appropriateness of the results (Silver et al, 1998). Another important reason to use this replenishment policy is the fact that it is already used at MME in the normal phase of the spare part life cycle.

After the last extra production batch the purchase of remanufactured spare parts is used to reduce the uncertainty of stock outs and obsolete stock at the end of the service time horizon. This option is defined as the possibility to buy remanufactured spare parts from car dismantlers. This option is only used at the end of the service time horizon, because it is assumed that customers with new cars would like to buy new spare parts instead of remanufactured spare parts. However, when a car matures, customers are more willing to buy cheap alternatives to repair broken parts. As a result it is assumed that remanufactured spare parts can be used after the last extra production batch to deal with the demand uncertainty in the last periods of the service horizon. In this case a simple order up to level as replenishment policy is chosen, because no setup costs per batch are included, the demand characteristics and the appropriateness of the results (Silver et al, 1998; Kiesmüller and Minner, 2003).

4.2 Common cost model

In this paragraph a basic cost model is described to explain the logic of the detailed cost model described in paragraph 4.4. First the model assumptions that are necessary to define the common cost model are presented.

It is chosen to calculate the average inventory per period. When it is assumed that demand is equally spread over the period the average inventory can be calculated by taking the average of the start and end inventory of a specific period. Another important assumption is that setup costs are excluded in the final order, because these costs are paid by Nedcar B.V. This is because the largest part (i.e. approximately 95%) of the production batch is for the production of vehicles, which are produced at Nedcar B.V. However, for extra manufacturing fixed setup costs are included each time a production batch is ordered. It is important to mention that the inventory holding costs for dies at the external company are not included in this model. For purchasing remanufactured spare parts no fixed setup costs are included.

Moreover, there is another important assumption that should be made. It should be kept in mind that remaining demand is smaller than or equal to inventory plus the available capacity of remanufactured spare parts from the moment that remanufactured spare parts are used to satisfy demand. To deal with this requirement it is assumed that in the last periods of the spare part life cycle there is sufficient capacity of remanufactured spare parts. This is an appropriate assumption, because it is possible to extent the number of countries where remanufactured spare parts are purchased until the capacity is higher than the demand. In figure 1, presented in paragraph 2.5.1 it can be seen that at the end of the service time horizon the return of products is higher than the demand, which also shows the appropriateness of the assumption that capacity of remanufactured spare parts at the end of the spare part life cycle is sufficient.

The costs in the new situation, based on the assumptions above, can be divided in purchase costs, inventory holding costs, backorder costs and disposal costs at the end of the service period. This results in the following common cost model:

$$c_f \bullet y + \sum_{t=\tau}^{N} \left(c_E \bullet \mathrm{E}(P_t) + F_E \bullet \mathrm{E}(X_t) \right) + \sum_{t=N+1}^{T} \left(c_R \bullet \mathrm{E}(R_t) \right) +$$
$$\sum_{t=1}^{T} \left(h \bullet \mathrm{E}(I_t) + p \bullet \mathrm{E}(B_t) \right) + d \bullet \mathrm{E}(I_T^{'}) \qquad (4.1)$$

Where

c_f Unit variable cost price final order

c_E	Unit variable cost price extra production
c_R	Unit variable cost price remanufactured product
F_E	Fixed costs per batch for extra production
y	Final order quantity
τ	Expected time that final order covers demand
N	Last period that extra production is allowed
T	Total service time horizon
h	Inventory holding costs per product per period
p	Backorder costs per product per period
d	Disposal costs
$E(P_t)$	Expected spare parts produced by extra production in period t
$E(X_t)$	Expected number of extra production batches in period t
$E(R_t)$	Expected purchase of remanufactured spare parts in period t
$E(I_t)$	Expected average inventory in period t
$E(B_t)$	Expected number of backorders in period t
$E(I_T^{'})$	Stock on hand at the end of the service horizon

4.3 Decision variables

In the previous paragraph the common cost structure of the model is described. In this paragraph the decision variables are described. The first decision variable is the expected time that the final order covers demand, τ. This variable has a relationship with the final order quantity, which is defined as y. Therefore, it is determined to express y as function of τ. Another decision variable is the last period where it is allowed to use extra production as procurement option, defined as N. After period N it is only allowed to purchase remanufactured products from car dismantlers. This N is restricted, because it is expected that customers are only willing to purchase remanufactured spare parts at the end of the service horizon.

Besides the decision variables described there are also decision variables as result of the replenishment policies chosen. First it should be mentioned that the demand rate is not constant during the total service time horizon, but it is assumed that the demand rate is constant within a period. As mentioned before for extra production a (s_t, Q_t) replenishment policy is chosen. For each period t, with $t = \tau + 1,..,N$, a new s_t and Q_t value should be determined, because it is assumed that the demand rate is only constant within one period. The same holds for the option of purchasing remanufactured spare parts, where it is chosen to use an order up to level, defined as S_t, as replenishment policy. Again for each period t, with $t = N + 1,..,T$, a new S_t value should be determined.

It is obvious that this number of decision variables will result in high complexity and dependencies between decision variables. An example of a dependency is the relation between the final order quantity and the expected time that the final order quantity covers demand. When the period that the final order should cover demand increases (assuming that in this extra time demand is larger than zero) the final order quantity should also increase to achieve the same service level and vice versa. To reduce complexity it is chosen to use heuristics to determine the decision variables for the replenishment policies. Thus, the s_t, Q_t and S_t values are determined using heuristics that are well tested and accepted in literature. The used heuristics can be found in paragraph 4.6. As a result of this reduction in decision variables only two decision variables are left, which are τ and N.

4.4 Detailed cost model

To find a solution to the problem of MME it is important to know whether it is possible to calculate the costs over the total service time horizon as function of τ and N. Only then it is possible to compare different solutions and to conclude which strategy is optimal. First the costs and assumptions associated with the final order are presented. Thereafter the same is done for extra production and the purchase of remanufactured parts. This can be found in paragraph 4.4.1 until paragraph 4.4.3. Then in paragraph 4.4.4 it is explained how the optimal spare part procurement solution can be found.

4.4.1 Costs and assumptions final order

In this paragraph the cost structure for the final order is explained. For each cost type (i.e. purchase, inventory holding and backorder costs) the assumptions that are made are presented and thereafter the accompanying cost function is presented.

First the purchase costs are defined. Without loss of generality it is assumed that the net inventory at the moment of the decision (at the start of the first period) is zero. When this is not the case, it is possible to subtract the net inventory from the final order when the net inventory is smaller than the calculated final order quantity. As a result, it should also be assumed that the net inventory at the start of the first period is smaller than the final order quantity. The final order quantity can be calculated with the heuristic presented in paragraph 4.6.1. The purchase costs for the final order can be defined as follows:

$$c_f \bullet y \tag{4.2}$$

Where

c_f	Unit variable cost price final order
y	Final order quantity

In this part it is explained how the inventory holding costs can be calculated. In paragraph 4.2 it is decided to use the average inventory per period to calculate the inventory holding costs per period. This average inventory is approximated by the net inventory at the end of period $t-1$ minus a half of the demand in period t. This expected demand in period t is calculated with the chosen demand distribution (in formula 4.3 a discrete demand distribution is used, because demand is discrete). This average inventory is an approximation, because demand is not precisely equally spread. To calculate net inventory in period t it is assumed that stock outs only occur at the end of the period in which the final order should cover demand or more specifically in the last period of τ. When this assumption is correct the expected demand in the period or periods preceding period τ can be used for the calculation of the net inventory of period τ. In the same way the net inventory of the first $\tau - i$, with $i = 1,...,\tau$, periods is calculated. Whether it is correct to assume that backorders only occur at the end of the final order period is explained below. First the function to calculate the inventory holding costs during the final order period is presented:

$$\sum_{t=1}^{\tau-1}\left(y-\sum_{j=1}^{t-1}\mathrm{E}\left(D_j\right)-\frac{1}{2}\bullet\mathrm{E}\left(D_t\right)\right)\bullet h+$$
$$\frac{1}{2}\left(y-\sum_{j=1}^{\tau-1}\mathrm{E}\left(D_j\right)+\sum_{k=0}^{y-\sum_{j=1}^{\tau-1}\mathrm{E}\left(D_j\right)}\left(\mathrm{P}\left(D_\tau = k\right)\bullet\left(y-\sum_{j=1}^{\tau-1}\mathrm{E}\left(D_j\right)-k\right)\right)\right)\bullet h \qquad (4.3)$$

Where

y	Final order quantity
τ	Expected time that final order covers demand
h	Inventory holding costs per product per period
t	Period t, which starts at time $t-1$ and ends at time t
j	Period j, which starts at time $j-1$ and ends at time j
$\mathrm{E}\left(D_t\right)$	Expected demand in period t
$\mathrm{P}(D_\tau = k)$	Probability that demand is equal to k in period τ

After calculating the inventory holding costs the backorder costs during the final order period are calculated. Also for calculating the backorder costs it is needed to calculate the net inventory. The same net inventory is used as used for calculating the inventory holding costs. However, it should be kept in mind that it is assumed that backorders only occur at the end of the final order period. So the appropriateness of this assumption should be checked. First it can be argued that when the coefficient of variation is low the assumption is appropriate. This is because in that case the probability that the demand of the first $\tau - 1$ periods is higher than the expected demand of the first τ periods is very low. Furthermore, this assumption could be checked numerically by calculating the backorder costs. When the backorder costs of period $\tau - 1$ are zero the assumption is appropriate. When the backorder costs of period $\tau - 1$ are zero also the backorder costs of the preceding periods are zero, because net inventory of a previous period is always equal to or higher than net inventory in the current period. This results in the following formula to calculate the backorder costs:

$$\sum_{k=y-\sum_{j=1}^{\tau-1}\mathrm{E}(D_j)+1}^{\infty}\left(\left(k-\left(y-\sum_{j=1}^{\tau-1}\mathrm{E}(D_j)\right)\right)\bullet\mathrm{P}(D_\tau=k)\right)\bullet p \tag{4.4}$$

Where

y	Final order quantity
τ	Expected time that final order covers demand
p	Backorder costs per product per period
j	Period j, which starts at time $j-1$ and ends at time j
$\mathrm{E}(D_j)$	Expected demand in period j
$\mathrm{P}(D_\tau = k)$	Probability that demand is equal to k in period τ

4.4.2 Costs and assumptions extra production

In this paragraph the cost structure for extra production is explained. For each cost type (i.e. purchase, inventory holding and backorder costs) the assumptions that are made are presented and thereafter the accompanying cost function is presented.

First the purchase costs are defined. The first point to mention about extra production is about the purchase costs. These costs consist of variable costs per product and fixed costs based on the number of setups. However, it could be that the number of spare parts purchased in the first extra production period (i.e. period $\tau+1$) is not equal to the expected demand during this period. When the final order quantity is equal to the expected demand during the final order period it is expected that no spare parts are on stock and that there are zero backorders at the start of the first period where extra production is used. When the final order is not equal to the expected demand during the final order period a correction should be made on the purchase costs of extra production. When the final order is larger than the expected demand during the final order period it is expected that spare parts are on stock at the beginning of the first period where extra production is used. As a result, less spare parts should be produced to meet demand, which will result in less batches that should be produced. The following formula is used to make this correction on the purchase costs:

$$-\left(c_E\bullet\left(y-\sum_{t=1}^{\tau}\left(\mathrm{E}(D_t)\right)\right)+\frac{y-\sum_{t=1}^{\tau}\left(\mathrm{E}(D_t)\right)}{Q_{\tau+1}}\bullet F_E\right) \tag{4.5}$$

Where

y	Final order quantity
τ	Expected time that final order covers demand
t	Period t, which starts at time $t-1$ and ends at time t

$\mathrm{E}(D_t)$	Expected demand in period t
Q_t	Fixed order quantity in period t, with $t=\tau,\ldots,N$
c_E	Unit variable cost price extra production
F_E	Fixed costs per batch for extra production

The purchase costs for extra production per period are defined as the costs for production, which is divided in variable and fixed setup costs. This results in the following formula:

$$\sum_{t=\tau+1}^{N}\left(c_E \bullet \mathrm{E}(D_t)+\frac{\mathrm{E}(D_t)}{Q_t} \bullet F_E\right) \tag{4.6}$$

Where

τ	Expected time that final order covers demand
N	Period in which last extra production batch is produced
t	Period t, which starts at time $t-1$ and ends at time t
$\mathrm{E}(D_t)$	Expected demand in period t
Q_t	Fixed order quantity in period t, with $t=\tau,\ldots,N$
c_E	Unit variable cost price extra production
F_E	Fixed costs per batch for extra production

Next the inventory holding costs should be calculated. Therefore, it is needed to know how inventory is replenished. As mentioned in paragraph 4.1, in which the proposed situation is described, a simple (s,Q) replenishment policy within a period is used for extra production (from period $\tau+1$ until period N). This is only possible when it is assumed that demand is stationary within one period. For each period a new order level and optimal batch quantity should be defined, because in the after sales market demand declines over time, which influences the optimal decision. In the literature much information is available to determine the s and Q levels (Silver et al. 1998; Zipkin, 2000). The method to calculate appropriate s and Q levels is presented in paragraph 4.6.2. For the inventory holding costs and backorder costs formulas, both based on De Kok (2005), it is assumed that there are multiple replenishment cycles per period, because otherwise the formulas used are not valid anymore. The average net inventory of extra production is calculated by adding half a batch quantity to the safety stock. When period N is approaching it is possible that the assumption of multiple replenishments per period is violated, because demand is declining over time and it could therefore be too low for multiple replenishments per period when N is approaching. As a result, the formulas of De Kok (2005) are not appropriate anymore to calculate the inventory holding costs and backorder costs. However, it is expected that the effect of violating this assumption at the end of the extra production period, which is defined as the period between τ and N, has little impact on the total life cycle costs and therefore on the optimal spare part procurement strategy. This assumption can be made, because demand and accompanying costs are rapidly decreasing at the end of the extra production period.

As a result of this low demand little costs are incurred with holding inventory and the number of stock outs is also expected to be low. To check whether this expectation is correct a simulation study should be conducted.

In the inventory holding and backorder costs formula a discrete demand distribution is used to model demand. This results in the following formula for the inventory holding costs:

$$\sum_{t=\tau+1}^{N}\left(\frac{Q_t}{2}+\sum_{k=0}^{s_t}\left(\mathrm{P}\left(D_{t,L}=k\right)\bullet\left(s_t-k\right)\right)\right)\bullet h \tag{4.7}$$

Where

τ	Expected time that final order covers demand
N	Period in which last extra production batch is produced
t	Period t, which starts at time $t-1$ and ends at time t
Q_t	Fixed order quantity in period t, with $t=\tau,\ldots,N$
s_t	Fixed order level in period t, with $t=\tau,\ldots,N$
h	Inventory holding costs per product per period
$\mathrm{P}(D_{t,L}=k)$	Probability that demand during the lead time is equal to k in period t

The backorder costs can be calculated with the following formula:

$$\sum_{t=\tau+1}^{N}\left(\frac{\mathrm{E}\left(D_t\right)}{Q_t}\bullet\sum_{k=s_t+1}^{\infty}\left(\mathrm{P}\left(D_{t,L}=k\right)\bullet\left(k-s_t\right)\right)\right)\bullet p \tag{4.8}$$

Where

τ	Expected time that final order covers demand
N	Period in which last extra production batch is produced
t	Period t, which starts at time $t-1$ and ends at time t
$\mathrm{E}(D_t)$	Expected demand in period t
Q_t	Fixed order quantity in period t, with $t=\tau,\ldots,N$
s_t	Fixed order level in period t, with $t=\tau,\ldots,N$
p	Backorder costs per product per period
$\mathrm{P}(D_{t,L}=k)$	Probability that demand during the lead time is equal to k in period t

4.4.3 Costs and assumptions purchase of remanufactured spare parts

In this paragraph the cost structure for the purchase of remanufactured spare parts is explained. For each cost type (i.e. purchase, inventory holding, backorder costs and disposal costs) the assumptions that are made are presented and thereafter the accompanying cost function is presented.

For this option a (R,S) replenishment policy is used as mentioned in paragraph 4.1. The review period for this policy is equal to the period length of one year defined before. This is because expected demand per period is very low in the last years of the service time horizon. Again sufficient information is available in literature to determine the order up to levels (Silver et al., 1998; Kiesmüller and Minner, 2003). For each period an order up to level is defined. This order up to level should be updated every year (or period), because of non stationary demand. At the beginning of period $N+1$ it is possible to purchase remanufactured products. The quantity that should be ordered is depended on the S_{N+1} level and the inventory on hand at the end of period N. In period N a (s_N, Q_N) replenishment policy is used. It is therefore impossible to determine how many spare parts are in inventory at the beginning of period $N+1$. Therefore, it is assumed that the inventory at the end of period N is equal to the average inventory in period N. Furthermore, it is assumed that this average inventory in period N is lower than the order up to level S_{N+1}. This results in the following formula for the purchase costs in period $N+1$ (based on a discrete demand distribution):

$$c_R \bullet \left(S_{N+1} - \left(\frac{Q_N}{2} + \sum_{k=1}^{s_N} \left(\mathrm{P}\left(D_t = k\right) \bullet \left(s_N - k\right)\right)\right)\right) \tag{4.9}$$

Where

N	Period in which last extra production batch is produced
Q_N	Fixed order quantity in period N
s_N	Fixed order level in period N
S_{N+1}	Order up to level in period $N+1$
c_R	Unit variable cost price remanufactured product
$\mathrm{P}(D_t = k)$	Probability that demand is equal to k in period t

For the periods $N+2$ until T the purchase costs can be calculated with the following formula:

$$c_R \bullet \left(\sum_{t=N+2}^{T} \left(\mathrm{E}\left(D_t\right) - \left(S_{t-1} - S_t\right)\right)\right) \tag{4.10}$$

Where

N	Period in which last extra production batch is produced
S_t	Order up to level in period t
c_R	Unit variable cost price remanufactured product
T	Total service time horizon
$\mathrm{E}(D_t)$	Expected demand in period t
t	Period t, which starts at time $t-1$ and ends at time t

The inventory holding costs are calculated by using the average net inventory. This average net inventory can be found using the start inventory, which is equal to the order up to level, and the demand, which is modelled by a demand distribution. It is assumed that the lead time is zero. This results in the following formula:

$$\sum_{t=N+1}^{T}\left(\frac{1}{2}\bullet\left(S_t+\sum_{k=0}^{S_t}\left(\mathrm{P}\left(D_t=k\right)\bullet\left(S_t-k\right)\right)\right)\right)\bullet h \qquad (4.11)$$

Where

N	Period in which last extra production batch is produced
S_t	Order up to level in period t
T	Total service time horizon
t	Period t, which starts at time $t-1$ and ends at time t
$\mathrm{P}(D_t=k)$	Probability that demand is equal to k in period t
h	Inventory holding costs per product per period

The backorder costs can be calculated in a similar way. Again the start inventory and the demand are used to calculate the backorder costs. It is assumed that there are no backorders at the beginning of a period.

$$\sum_{t=N+1}^{T}\sum_{k=S_t+1}^{\infty}\left(\mathrm{P}\left(D_t=k\right)\bullet\left(k-S_t\right)\right)\bullet p \qquad (4.12)$$

Where

N	Period in which last extra production batch is produced
S_t	Order up to level in period t
T	Total service time horizon
t	Period t, which starts at time $t-1$ and ends at time t
$\mathrm{P}(D_t=k)$	Probability that demand is equal to k in period t
p	Backorder costs per product per period

The last cost type that should be calculated are the disposal costs. The spare parts that are in inventory at the end of the service period T become obsolete. At the end of the service time horizon obsolete spare parts are disposed of. The costs that are incurred with deposal can be calculated with the following formula:

$$\sum_{k=0}^{S_T}\left(\mathrm{P}(D_T=k)\bullet\left(S_T-k\right)\right)\bullet d \qquad (4.13)$$

Where

S_T Order up to level in period T

d	Disposal costs at the end of the service time horizon per spare part
$P(D_T = k)$	Probability that demand is equal to k in period T

4.4.4 Total detailed cost model

In this paragraph the total cost model is presented with the notation used. Furthermore, it is explained how the optimal spare part procurement strategy can be found as a function of τ and N. The optimal value of τ and N can be found by enumeration. For all the possible combinations of τ and N the total costs are calculated. The combination of τ and N for which the costs are minimal is the optimal combination and results in the optimal spare part procurement strategy. As a result of the heuristics that are used to determine s_t, Q_t and S_t the predefined service rate is achieved (see paragraph 4.6 for the used heuristics). In the total cost function the costs are sorted based on cost type (purchase costs, and inventory holding, backorder costs and disposal costs). The total cost function is presented in the following formula:

$$
\begin{aligned}
& c_f \bullet y - \left(c_E \bullet \left(y - \sum_{t=1}^{\tau} \left(\mathrm{E}(D_t) \right) \right) + \frac{y - \sum_{t=1}^{\tau} \left(\mathrm{E}(D_t) \right)}{Q_{\tau+1}} \bullet F_E \right) + \\
& \sum_{t=\tau+1}^{N} \left(c_E \bullet \mathrm{E}(D_t) + \frac{\mathrm{E}(D_t)}{Q_t} \bullet F_E \right) + c_R \bullet \left(S_{N+1} - \left(\frac{Q_N}{2} + \sum_{k=1}^{s_N} \left(\mathrm{P}(D_t = k) \bullet (s_N - k) \right) \right) \right) + \\
& c_R \bullet \left(\sum_{t=N+2}^{T} \left(\mathrm{E}(D_t) - (S_{t-1} - S_t) \right) \right) + \sum_{t=1}^{\tau-1} \left(y - \sum_{j=1}^{t-1} \mathrm{E}(D_j) - \frac{1}{2} \bullet \mathrm{E}(D_t) \right) \bullet h + \\
& \frac{1}{2} \left(y - \sum_{j=1}^{\tau-1} \mathrm{E}(D_j) + \sum_{k=0}^{y - \sum_{j=1}^{\tau-1} \mathrm{E}(D_j)} \left(\mathrm{P}(D_\tau = k) \bullet \left(y - \sum_{j=1}^{\tau-1} \mathrm{E}(D_j) - k \right) \right) \right) \bullet h + \\
& \sum_{k = y - \sum_{j=1}^{\tau-1} \mathrm{E}(D_j) + 1}^{\infty} \left(\left(k - \left(y - \sum_{j=1}^{\tau-1} \mathrm{E}(D_j) \right) \right) \bullet \mathrm{P}(D_\tau = k) \right) \bullet p + \\
& \sum_{t=\tau+1}^{N} \left(\frac{Q_t}{2} + \sum_{k=1}^{s_t} \left(\mathrm{P}(D_{t,L} = k) \bullet (s_t - k) \right) \right) \bullet h + \\
& \sum_{t=\tau+1}^{N} \left(\frac{\mathrm{E}(D_t)}{Q_t} \bullet \sum_{k=s_t+1}^{\infty} \left(\mathrm{P}(D_{t,L} = k) \bullet (k - s_t) \right) \right) \bullet p + \\
& \sum_{t=N+1}^{T} \left(\frac{1}{2} \bullet \left(S_t + \sum_{k=0}^{S_t} \left(\mathrm{P}(D_t = k) \bullet (S_t - k) \right) \right) \right) \bullet h + \sum_{t=N+1}^{T} \sum_{k=S_t+1}^{\infty} \left(\mathrm{P}(D_T = k) \bullet (k - S_t) \right) \bullet p + \\
& \sum_{k=0}^{S_T} \left(\mathrm{P}(D_t = k) \bullet (S_T - k) \right) \bullet d
\end{aligned}
\qquad (4.14)
$$

Input parameters

c_f	Unit variable cost price final order
c_E	Unit variable cost price extra production
c_R	Unit variable cost price remanufactured product
F_E	Fixed costs per batch for extra production
h	Inventory holding costs per product per period
p	Backorder costs per product per period
d	Disposal costs at the end of the service time horizon per spare part
T	Total service time horizon
$N^{'}$	After this period it is allowed to purchase remanufactured spare parts
$\mathrm{P}(D_t = k)$	Probability that demand is equal to k in period t
$\mathrm{P}(D_{t,L} = k)$	Probability that demand during the lead time is equal to k in period t
t	Period t, which starts at time $t-1$ and ends at time t
j	Period j, which starts at time $j-1$ and ends at time j

Input parameters as result of heuristics

y	Final order quantity
s_t	Fixed order level in period t, with $t = \tau, \ldots, N$
Q_t	Fixed order quantity in period t, with $t = \tau, \ldots, N$
S_t	Order up to level in period t, with $t = N+1, \ldots, T$

Decision variables

τ	Expected time that final order covers demand
N	Period in which last extra production batch is produced

Constraint

$N \geq N^{'}$

4.5 Input spare part cost model

In this paragraph the input that is needed for the spare part cost model and for the heuristics is described. As input multiple cost parameters are needed, which are presented in paragraph 4.5.1 until 4.5.5, and a method to fit a demand distribution, which is presented in paragraph 4.5.6. For each cost parameter it is explained which costs are included. Furthermore, it is explained where the information can be gathered for the case study.

4.5.1 Variable spare part price (c_f, c_E, c_R)

The variable spare part price is defined as the sum of the costs of the manufactured parts per assembly, the purchase parts per assembly, the variable assembly costs, and other costs. For sheet metal parts these other costs consist of for example painting and packing costs. These variable costs per unit produced within the final order could be different from the variable costs of units produced with extra production. An explanation for this could be that the production process at the outsourced supplier is less efficient than the production process of Nedcar B.V. The information about the unit variable cost price for units produced within the final order and for units produced with extra production could be found at the Purchase department of Nedcar B.V. The unit variable spare part price for remanufactured parts, which are purchased from car dismantlers, is not known in advance. However, this information is available at car dismantlers. Furthermore, manufacturers of vehicles have the right to buy these parts back where the price is approximately 20% of the retail price.

4.5.2 Backorder costs (p)

Backorder costs are the costs incurred when demand occurs and no spare parts are on stock. It is quite difficult to determine these costs, because also intangible aspects as customer goodwill should be included. The company policy is to achieve a 95% service level. The backorder costs are therefore determined based on this service level and the inventory costs.

4.5.3 Disposal costs (d)

When holding inventory it is possible that parts become obsolete, which means that demand for these spare parts is ceased. These parts should be scrapped, because holding inventory is expensive. Disposal costs are therefore defined as the costs that are associated with scrapping obsolete parts. These costs can consist of for example transportation costs from the distribution center to the junkyard, treatment of environmental unfriendly spare parts, etc. However, it could be that these disposal costs are negative (i.e. that revenue is obtained). This is for example the case when sheet metal parts are scrapped. The raw material of sheet metal spare parts can be recycled. These materials can be bought by for example ironmongers. The information about the disposal costs is provided by the safety and facilities department of MME.

4.5.4 Setup costs (F_E)

The setup costs are defined as the fixed costs of extra production. In this case the setup costs consist of the costs associated with the setup time of the machines needed to produce a specific part. Furthermore, costs that occur while the machine is fine-tuned, thus when the machine produces at a lower quality or at a lower speed, are included in the setup costs (Silver et al., 1998). The last costs that are included in the setup costs are the replenishment costs. The replenishment costs are defined as the costs for MME to order a batch. These replenishment costs can be determined by looking at the costs of the Inventory Control department per year and the number of orders placed per year. As a result the costs per order can be found. This information is available at the financial department in combination with the Inventory Control department of MME. The information about the remaining setup costs for extra production is provided by the Purchase department of Nedcar B.V.

4.5.5 Inventory holding costs (h)

According Silver et al. (1998) inventory holding costs consist of the opportunity cost of the invested money, the expenses incurred in running a warehouse, handling and counting costs, the costs of special storage requirements, deterioration of stock, damage, theft, obsolescence, insurance, and taxes. Besides these holding cost aspects Timme and Williams-Timme (2003) also mention administration costs. Furthermore, there are other aspects of inventory holding costs that are used in practice like storage space, equipment and overhead (Anonymous, 2005). The most extensive list is proposed by La Londe and Lambert (1975 and 1977) who propose the aspects mentioned by Silver et al., Anonymous and Timme and Williams-Timme.

To minimize the costs of spare part procurement it is important to accurately determine the inventory holding costs per part. However, in the literature surprisingly little effort is spent on methods to determine the cost parameters used for Inventory Control accurately (Berling, 2008; Timme and Williams-Timme, 2003). Furthermore, Raturi and Singhal (1990) argue that many firms misestimate the inventory holding costs per spare part. The most common way to calculate the inventory holding costs in practice is to multiply the unit variable cost with a fixed percentage, because traditionally it was assumed that the capital cost are the main costs of the inventory holding costs. However, this method does not make a distinction between products with a high value density per square meter and products with a low value density per square meter.

To define the inventory holding cost parameter for MME multiple interviews are conducted with employees of different departments within MME and with an employee of the Purchase department of Nedcar B.V. From these interviews it is concluded that the aspects presented in table 3 should be included in the inventory holding cost parameter. Furthermore, in this table the accompanying inventory holding costs as a percentage of the spare part cost price is presented. These percentages are based on the information acquired from the financial department of MME.

Aspect	Percentage of cost price spare part (in %)
Cost of capital	6
Insurance	0.15
Security	0.34
Maintenance	0.43
Deterioration	0.08
Obsolescence	2
Total	**9**

Table 3, inventory holding cost percentage per aspect

Besides the inventory holding aspects mentioned in table 3 also space costs should be included. In contrast to these aspects it is not possible to define a fixed inventory holding cost percentage for the space costs. This is because the space costs depend on the dimension of the spare part and the storage equipment used. To determine this inventory holding cost percentage an intern investigation is done at MME. The result is an excel sheet in which only the dimension of the spare part and the storage equipment should be inserted. This results in the inventory holding costs and the inventory holding costs as percentage of the spare part cost price (both including the before mentioned 9%) per spare part per storage equipment type.

4.5.6 Demand model ($D_t, D_{t,L}$)

MME forecasts the demand per year until all demand obligations are ceased. To calculate the costs over the total service time horizon it is important to fit a demand distribution per period and a demand distribution during the lead time. Currently this information is not available at MME and therefore in this paragraph a method to fit a demand distribution is described. Van Kooten (2006) developed a method, based on the findings of Ritchie and Wilcox (1976) and Kelle and Silver (1989), to deal with this problem.

Van Kooten (2006) divides the remaining service period (RSP) into k intervals $(k \in RSP)$ with length t. He formulates probability $p_{i,k}$ as the probability that a given spare part i $(i \in I)$ fails in interval k. In the automotive industry, however, not every part that has failed is replaced as mentioned in paragraph 2.5.1. Therefore, the probability $p_{i,k}$ is defined as the probability that a given spare part i $(i \in I)$ is requested in interval k. The failure probability over time, used by Van Kooten (2006), can then be described as the demand probability and can be calculated by dividing the demands of spare part i in period k, which is defined as $d_{i,k}$, by the units in operation of spare part i in period k, which is defined as $N_{i,k}$. This results in the following formula:

$$p_{i,k} = \frac{\text{demand of spare part } i \text{ in period } k}{\text{average units in operation featuring spare part } i \text{ in period } k} = \frac{d_{i,k}}{N_{i,k}}$$

The aforementioned can also be seen as a Bernoulli experiment with probability $p_{i,k}$ of a failing part that will result in demand and $1 - p_{i,k}$ as no demand of the specific part in period k and $N_{i,k}$ as the number of trials, defined as the units in operation (Van Kooten, 2006; Montgommery and Runger, 1999). The random variable $D_{i,k}$ that equals the number of trials that result in demand has a binomial distribution with parameters $p_{i,k}$ and $N_{i,k}$. The accompanying probability mass function of $D_{i,k}$ is (Montgommery and Runger, 1999):

$$f_{i,k}(x) = \binom{N_{i,k}}{x} p_{i,k}{}^{x} \left(1 - p_{i,k}\right)^{N_{i,k} - x}, \quad \text{with x = 0, 1,..., } N_{i,k}$$

The random variable $D_{i,k}$ with parameters $p_{i,k}$ and $N_{i,k}$ has the following mean and variance (Montgommery and Runger, 1999):

$$\mu_{i,k} = N_{i,k} p_{i,k}$$

$$\sigma_{i,k}^2 = N_{i,k} p_{i,k} \left(1 - p_{i,k}\right)$$

When $D_{i,k}$ is a binomial random variable the normal distribution can be used as good approximation when (Montgommery and Runger, 1999):

$N_{i,k} p_{i,k} > 5$ and $N_{i,k} (1 - p_{i,k}) > 5$

For the case company $N_{i,k}$ can be calculated based on the vehicle production volumes per year and the dying curve of vehicles that is defined (Manders, 2001). In table 4 the dying curve that is used to forecast $N_{i,k}$ is presented. In this table it is stated that after one year 0.98 of the units is left, after two years 0.96 of the units is left, etc.

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Table 4, Dying curve units in operation

To find $p_{i,k}$ it is possible to look at the sales history and the units in operation. Notice that $p_{i,k}$ can only be calculated for periods in the past, because only for these periods sales information is available. Then the average is taken of these $p_{i,k}$ values. The average $p_{i,k}$ could be used to forecast future demand. However, this method could give problems when the failure probability that results in demand increases over time, for example for spare parts that are subject to mechanical wear. It could also be that the failure probability that results in demand decreases overtime. Reasons for declining demand are already presented in paragraph 2.5.1. Only an employee who is familiar with the part can determine whether it is justified to use the average probability or that an adjusted failure probability should be used. The method used for MME is that a constant $p_{i,k}$ is used or when there are reasons to assume that the failure probability is not constant, $p_{i,k}$ is adjusted.

Besides fitting a distribution for the demand per period it is also necessary to fit a distribution for the demand during the lead time. The method used to fit a distribution for the demand during the lead time is about the same as the method used to fit a distribution for the demand during a period. The only difference is the failure probability used. When it assumed that a period (i.e. a year) has 52 weeks the failure rate probability during the lead time can be calculated by:

$$p_{L,i,k} = \frac{p_{i,k}}{52} \bullet L$$

Where

$p_{L,i,k}$	Failure rate probability during lead time for spare part i in period k
$p_{i,k}$	Failure rate probability per period for spare part i in period k
L	Lead time in weeks

4.6 Heuristics

In this paragraph the heuristics, which are used to determine the input parameters, are explained.

4.6.1 Final order quantity (y)

The first heuristic that is explained is used to calculate the final order quantity. This heuristic is based on the findings of Inderfurth and Mukherjee (2008), which are extensively described in Appendix 10.

The newsvendor formula is applied to determine the fraction of the demand that has to be covered over the first τ periods. The binomial demand distribution function for the first τ periods is defined as $\Omega_{1,\tau}^{D}$. The underage of a single unit will result in a shortage cost per period. It is assumed that this shortage occurs only in the last period as explained in paragraph 4.4.1. A one unit overage will result in an extra period serviceable inventory costs during τ periods. It is important to mention that only y is unknown in the formula, because τ is fixed for each enumeration option. As a result the final order quantity (y) can be calculated with the following formula:

$$\Omega_{1,\tau}^{D}(y) = \frac{p}{p + h \bullet \tau}$$

Where

y	Final order quantity
h	Inventory holding costs per product per period
p	Backorder costs per product per period
τ	Expected final order period

The right hand side of this formula is used to calculate the service level that should be used. However, when the service level is already defined by for example company policy it is possible to change the right hand side of the formula in the required service level.

4.6.2 Extra production (s_t , Q_t)

The second heuristic is the determination of the optimal batch quantity for each period. The most common method used to calculate the optimal batch quantity is the economic order quantity (EOQ) formula (Silver et al., 1998):

$$Q_{opt} = \sqrt{\frac{2AD}{vr}}$$

Where

Q_{opt}	Economic order quantity
A	Fixed setup costs
D	Demand rate of the item
v	Unit variable cost price of the item
r	Inventory holding cost percentage

This simple EOQ calculation can be extended by including quantity discounts, inflation, capacity restrictions and other factors. For MME it is decided to use the method used by the Purchase department of Nedcar B.V. as a basis. This method is slightly adjusted to make it useful for MME. The method is an extension of the simple EOQ formula, because it includes some extra cost factors.

An important assumption of a simple EOQ formula is that demand should be more or less constant over time and deterministic. However, in practice both assumptions are not valid. The demand of spare parts in the final phase of the life cycle is usually declining. To deal with this declining demand it is assumed that the demand rate in a year (defined as one period) is constant. As a result, the economic order quantity should be recalculated every year (or period). This results in a time dependent optimal order quantity, defined as Q_t in the cost model.

Another assumption of the EOQ formula that does not hold for MME is that the replenishment lead time is of zero duration. However, this can be solved by introducing a reorder level, which takes into account both the demand and demand uncertainty during the lead time, which is necessary because demand is not deterministic. Therefore, p_2 is defined as the long-run fraction of total demand, which is being delivered from stock on hand (also known as fill-rate).

De Kok (2005) describes a method, based on the EOQ formula, to calculate the reorder level. In the cost model a binomial demand distribution is used to calculate average net inventory and average number of stock outs, whereas De Kok (2005) uses a normal distribution. As already described in paragraph 4.5.6, it is possible to approximate the binomial distribution with a normal distribution when some conditions are met, these conditions are met for the case company. The most important reason to use the normal distribution instead of the binomial distribution is the computer time needed to run the cost model with the binomial distribution. It is checked whether the chosen distribution will have an impact on the results of the cost model. From this test it can be concluded that the difference between the model where a binomial distribution is used and the model where a normal distribution is used is negligible. Therefore, the formulas of De Kok (2005) are used in this paragraph:

$$G(k_\beta) = \frac{(1-\beta)\bullet Q}{\sigma\sqrt{L}}$$

Where

$G(k_\beta)$	$\int_k^\infty (u_0 - k) f_u(u_0)\, du_0$ (Silver et al., 1998)
$f_u(u_0)$	Probability density function normalized normal distribution
β	Required p_2 service level
Q	Optimal batch quantity
$\sigma\sqrt{L}$	Standard deviation of demand during the lead time

Now it is possible to calculate k_β. An example of an approximation formula is presented by Silver et al. (1998). An approximation is used so that it can be implemented within a software program.

$$k_\beta = \frac{a_0 + a_1\bullet z + a_2\bullet z^2 + a_3\bullet z^3}{b_0 + b_1\bullet z + b_2\bullet z^2 + b_3\bullet z^3 + b_4\bullet z^4}$$

Where

$z = \sqrt{\ln(25/(G_u(k_\beta))^2)}$	$b_0 = 1$
$a_0 = -5.3925569$	$b_1 = -7.2496485\bullet 10^{-1}$
$a_1 = 5.6211054$	$b_2 = 5.07326622\bullet 10^{-1}$
$a_2 = -3.8836830$	$b_3 = 6.69136868\bullet 10^{-2}$
$a_3 = 1.0897299$	$b_4 = -3.2912914\bullet 10^{-3}$

Then it is possible to calculate the reorder level, s, with the following formula:

$$s = \mu L + k_\beta \bullet \sigma\sqrt{L}$$

Where

s	Reorder level
μL	Expected demand during the lead time
$\sigma\sqrt{L}$	Standard deviation of the demand during the lead time
k_β	Factor required for p_2 service level β

Just like the economical order quantity the reorder level should be recalculated each period (i.e. year).

4.6.3 Purchase of remanufactured spare parts (S_t)

The last heuristic is used to determine the order up to levels per year. To calculate the order up to levels Inderfurth and Mukherjee (2008) developed a method that is based on the newsvendor formula. However, as described in the paragraph 4.1 MME wants to purchase remanufactured spares instead of remanufacturing them within MME. Therefore, the formula of Mukherjee and Inderfurth (2008), which can be found in Appendix 10, should be slightly adjusted, which results in the following formula:

$$\Omega_t^D\left(S_t\right)=\frac{p}{p+h}$$

Where

S_t	Order up to level in period t
p	Backorder costs per product per period
h	Inventory holding costs per product per period

4.7 Model validation and verification

The above mentioned cost model is implemented using VBA in Microsoft Access such that the optimal spare part procurement strategy with accompanying costs is given. Due to an internal reorganization there are not sufficient resources available to make the program ready for implementation, because a user friendly interface should still be programmed. However, the program can be used, because the functionality to determine the optimal spare part procurement is programmed.

To check whether the proposed model is correct a validation, whether it is the right model for the intended application environment, and verification, whether the model is build right, are conducted. A complete overview of the validation and verification is given in Appendix 12. From this analysis it can be concluded that the model is valid and appropriate results are given. The program can be used as a standalone executable file.

5. Results

In the first paragraph of this chapter the optimal values of the decision variables and accompanying costs are presented for the spare parts included in the case study. There are only five spare parts included in the case study, because of the available information. Furthermore, it is expected that with these spare parts it is possible to test the appropriateness of the model. Thereafter, in paragraph 5.2, a sensitivity analysis is conducted to investigate the effect of the input parameters on the total costs and the optimal procurement policy.

5.1 Results case study

In table 5 the total costs during the service horizon are presented. Besides the total costs also the optimal values for the two decision variables are presented. The two decision variables are the expected final order period, defined as τ, and the first period in which remanufactured parts are purchased, defined as N. In Appendix 13 the input that is used for this case study is presented.

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Table 5, results per spare part

It can be seen that the optimal final order period is higher than 1 for four out of the five parts. This implies that the policy used in the present situation, where a final order period of a half a year is used, is not cost optimal according to the model proposed in chapter 4 and accompanying results in table 5. When comparing the total costs when a final order period of 1 year is used with the total costs when the optimal final order period, which can be found in table 5, is used it can be concluded that using the optimal final order will result in a 6% decrease in total costs. It can also be remarked that in the proposed model each period the optimal batch quantity is updated, whereas this does not happen in the current situation. However, it is not possible to calculate the cost advantage of the proposed model, because too little information is available about the periods after the final order period in the current situation. It can also be concluded that the optimal N is always the first period from which it is allowed to use remanufacturing. This is caused by the fact that the purchase price of remanufactured parts is cheaper than the variable cost price of extra production.

5.2 Sensitivity analysis

In the previous paragraph the results for the case study are presented. In this paragraph the effect of the input parameters on the total costs and optimal spare part procurement strategy is investigated.

The model described in chapter 4 is dependent on the information available. The more reliable this information the more reliable the output of the spare part procurement model is. Within MME it is possible to find the appropriate values for multiple variables easily. However, there are some variables for which it is difficult to obtain the appropriate values. For these variables it is investigated what the effect on the total costs and the optimal procurement strategy is. It is chosen to check the input parameters inventory holding costs, the variable cost price extra production, the purchase price of remanufactured spare parts, the expected demand and the service time horizon. These input parameters are chosen, because it is expected that they have the largest impact on the outcome of the model. Furthermore, it is difficult for these input parameters to determine the appropriate value at the moment that the optimal spare part procurement strategy should be determined. Depending on the outcome of the sensitivity analysis it could be concluded for which input parameters it is important to determine the right values and for which input parameters it is less important.

5.2.1 Inventory holding costs (h)

In figure 9 the result of the sensitivity analysis for the inventory holding cost parameter is given. It can be seen that when the inventory holding costs increase (decrease) also the total costs increase (decrease) as well. However, the total costs show a small increase (decrease) compared to the increase (decrease) in parameter value. As a result of the change in the parameter value the optimal strategy will also change. Therefore, figure 9 also depicts the average deviation in the optimal value of the decision variable τ given. It can be seen that when the inventory holding costs increase (decrease) the optimal value of τ will decrease (increase). This sounds logical, because when inventory holding costs increase (decrease) it is less (more) interesting to keep stock. It can be concluded from this analysis that it is important to determine the inventory holding cost parameter rather accurate.

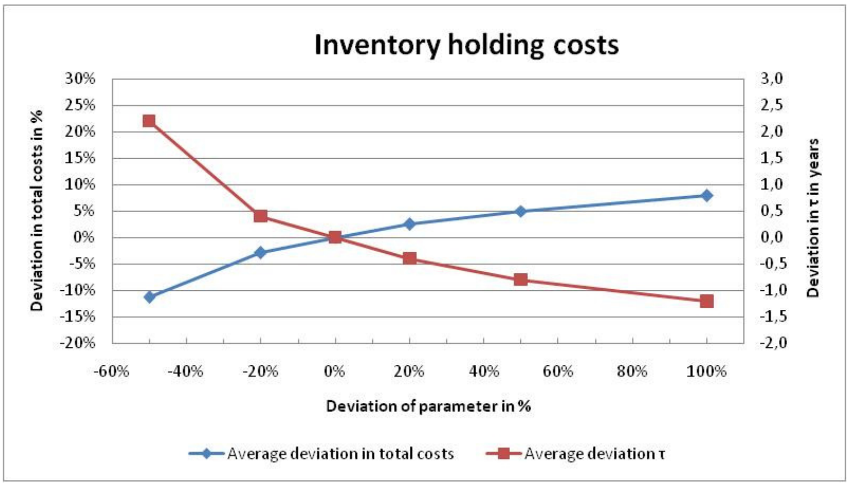

Figure 9, result sensitivity analysis inventory holding costs

5.2.2 Variable spare part cost price for extra production (c_E)

In figure 10 the result of the sensitivity analysis for the variable spare part cost price for extra production is given. It can be seen that when the input parameter is increased (decreased) the total costs also increase (decrease). Besides the change in the total costs also the optimal spare part procurement strategy changes. In figure 10 it can also be seen that when the parameter value for the variable spare part cost price for extra production increases (decreases), the optimal decision variable τ will also increase (decrease). This sounds logical, because when the variable spare part cost price for extra production will increase it is interesting to produce more parts within the final order. It can be concluded from this analysis that it is important to determine the variable cost price for extra production parameter appropriate. It can also be concluded that it is more important to determine the variable spare cost price for extra production appropriate than the inventory holding costs, because a change in the variable spare part cost price will have a larger effect than a change in the inventory holding costs.

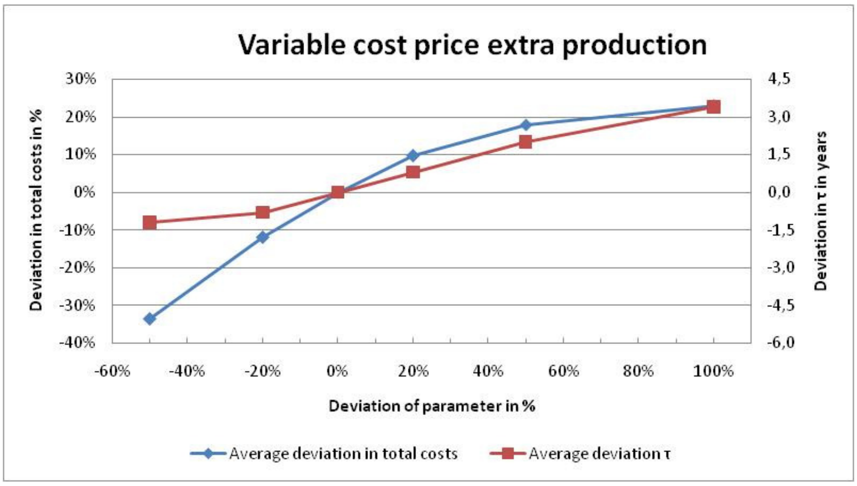

Figure 10, result sensitivity analysis variable spare part cost price for extra production

5.2.3 Purchase price remanufactured spare parts (c_R)

In figure 11 the result of the sensitivity analysis for the purchase price is given. It can be seen that an increase in the purchase price will not have much effect on both the total costs and the optimal spare part procurement strategy. This could be explained by the fact that it is assumed that the purchase of remanufactured spare parts is only allowed at the end of the life cycle. In this period demand is very low and accompanying costs are also very low. From this analysis it can be concluded that it is not necessary to spend much time on determining the optimal value of the purchase price, because it has almost no effect on the total costs and the optimal spare part procurement strategy.

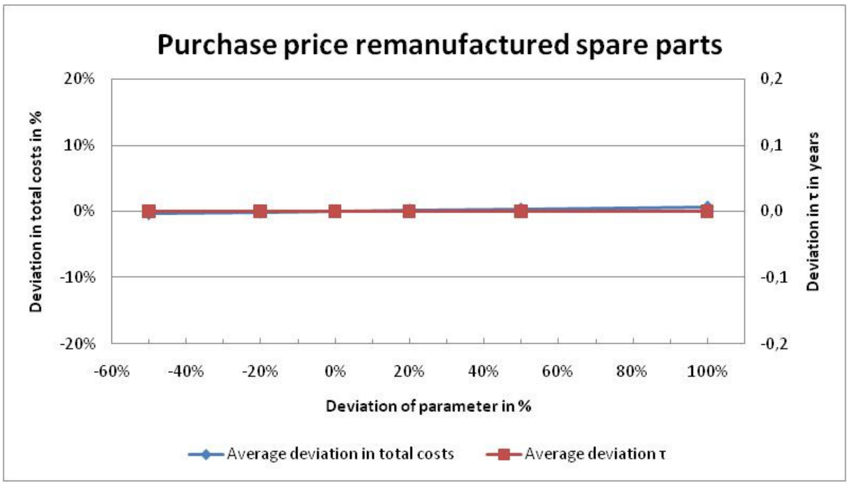

Figure 11, result sensitivity analysis purchase price remanufactured spare parts

5.2.4 Expected demand ($p_t \cdot N_t$)

In figure 12 the result of the sensitivity analysis for the expected demand is given. It can be seen that when the input parameter is increased (decreased) the total costs also increase (decrease). This can be explained by the fact that more (less) parts should be purchased. Moreover, the inventory holding costs with respect to the final order also increase (decrease). When the optimal spare part procurement strategy is analyzed it can be concluded that the optimal strategy (i.e. τ and N) is robust when the expected demand changes.

However, the results of the heuristics are influenced by the change in demand. The rolling horizon principle can be used to reduce the consequences of a misconceived forecast when it is assumed that uncertainty in demand increases the further the forecast time is projected into the future. As a result of using a rolling horizon, it is only necessary to determine the demand for the next year appropriately, because optimal order quantities, order levels and order up to levels are recalculated each year. However, when the final order period is higher than one, demand should be forecasted more than one year into the future. When the optimal final order period (i.e. τ) increases, the uncertainty in demand also increases. As a result of this sensitivity analysis, it can be concluded that it is important to make an appropriate demand forecast. Furthermore, when the rolling horizon principle is implemented, it can be concluded that a misconceived demand forecast has the most effect on the final order quantity. In paragraph 6.3 it is explained how the effect of a misconceived forecast with respect to the final order can be reduced.

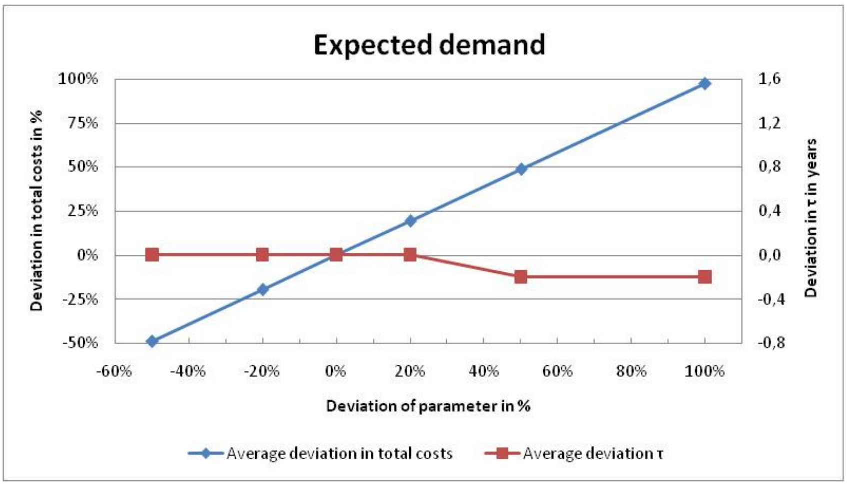

Figure 12, result sensitivity analysis expected demand

5.2.5 Service time horizon (T)

As a result of a rolling horizon the service time horizon decreases each year the model is used. Therefore, in this paragraph the impact on optimal value of the decision variables is investigated. The first decision variable, the expected final order period, is not influenced by using a rolling horizon, because this option can be used only the first time the model is used. Thereafter, it is not possible to make a new final order. Therefore, this analysis will only include the other decision variable, which is the first period in which it is allowed to purchase remanufactured parts. For this variable it can be concluded that every year the model will give the same result when the purchase price for remanufactured spare parts is lower than the variable spare parts price for extra production. In this case the first period in which remanufactured spare parts are purchased is always equal to the input parameter (e.d. first period from which it is allowed to purchase remanufactured spare parts), which is set manually. When the price for remanufactured parts is not lower than the variable spare part price for extra production, it can be argued that when demand in consecutive years is equal or declining always the same solution, with respect to the first period where the purchase of remanufactured products, should be used. This can be explained by the fact that with declining demand fixed setups costs have to be distributed over less parts, which results in a price increase for spare parts produced with extra production in consecutive years. In case demand is not declining and variable spare part prices for extra production are lower than the purchase price of remanufactured products it is best to fix the period from which it is allowed to purchase remanufactured products. As a result, the solution will not be optimal, but very close to the optimum because costs at the end of the life cycle are very low. Furthermore, it is very common that at the end of the service horizon demand is declining in consecutive years.

6. Implementation

This chapter describes the issues related to the implementation of the proposed model. In the first paragraph some common issues are explained. Thereafter in paragraph 6.2 it is explained which activities should be done before the program is ready for implementation. In the last paragraph it is explained how the program should be maintained.

6.1 Willingness to implement

An issue when implementing a new spare part procurement strategy is support from multiple stakeholders. Therefore, in Appendix 13 the issues that are related to the implementation of the model are investigated. In this paragraph the conclusion of this analysis is presented.

Due to the difference between the current and proposed method to determine the optimal spare part procurement, it is important that resources are made available for the implementation of the proposed design. An intervention strategy is to inform direct stakeholders about the problem, why it is a problem, how to solve it and why the solution solves the problem. Furthermore, it is important to create support at the management of MME, because they have the resources and power to create support. Also employees of the Inventory Control department should have the idea that the new design does not conflict with their own interests. Therefore, it is advised to involve stakeholders early in the project. Furthermore, it is recommended to give a presentation to the employees of the Inventory Control department in which the program is explained, because these employees should work in the future with the new program. This presentation can also be given to the management, because they have to decide whether it is a better program than the program currently used. It is also possible to give a demonstration in which the functionalities of the program are showed. Furthermore, it is important to write a clear hand out, which can be used as reference work.

6.2. Before implementation

In this paragraph it is explained which activities should be conducted to start the implementation.

The first point to mention is that the program is not ready for implementation, as mentioned in paragraph 4.7. In the original case the program was built to run the program with a single spare part. To make the program ready for implementation, the functionality to run the program with multiple spare parts at the same time should be programmed first. As a result of this change, the program can be used more efficiently. Furthermore, the user interface should be programmed to make it easy usable for the employees of the Inventory Control department.

Besides the functionality of the program also a network of car dismantlers should be built from which it is possible to purchase remanufactured spare parts. In the current situation it is not possible to purchase remanufactured spare parts from car dismantlers. With these car dismantlers contracts should be set up in which prices of remanufactured spare parts, lead times, transportation options and accompanying costs are determined.

6.3. Maintaining the tool

At the Inventory Control department one employee is responsible for life cycle management. This employee has the responsibility to make a final order at the supplier. In case production is continued the responsibility for spare part procurement can be given to other employees of the department. Therefore, the employee who is responsible for making a final order should insert the input parameters the first time. The input parameters that are necessary to run the model can be found in Appendix 13. When after the final order decision another employee becomes responsible he or she should only update input parameters when the values change. It is recommended to update input parameters at the beginning of a calendar year, to prevent mistakes.

As a result of the sensitivity analysis, it can be concluded that when the demand deviates from the forecasted demand problems arise, especially when the demand is significant higher than the forecasted demand. To reduce the probability of going out of stock in the final order period and to increase flexibility to react on changing markets, it is advised to determine an order level for the final order period. When the inventory level is equal or lower than the proposed order level extra production should be started. This order level should be determined based on the lead time during the final order period (e.g. for example time necessary to transport and install machinery, production, etc), which is usually larger than the lead time defined for the extra production period.

7. Conclusion and recommendations

In this final chapter the conclusions and recommendations resulting from the master thesis project are presented.

7.1 Conclusions

The goal of this master thesis was to develop a procurement model for spare parts in the final phase in the automotive industry that minimizes total relevant costs and achieves a predefined service rate.

In the current situation there was no structured model to deal with final orders. In the literature some models were presented to deal with final orders. However, after an analysis of the problem it could be concluded that these models proposed in literature cannot be used for the problem of MME. Therefore, a new model is proposed in chapter 4 with which it is possible to find the optimal spare part procurement strategy.

The following conclusions can be drawn after this master thesis project:

- The model proposed by Inderfurth and Mukherjee (2008) cannot be used in the automotive industry, because multiple assumptions (i.e. random product returns, sufficient returns needed to cover remaining demand) are not valid.
- A new option to acquire spare parts is introduced. MME can purchase remanufactured spare parts at car dismantlers. The advantage of this option is that it can be used to reduce uncertainty at the end of the service time horizon. As a result of this option, it is no longer necessary to add a fixed percentage to the last extra production batch, which results in less obsolete stock.
- It is possible to determine the optimal spare part procurement strategy and the accompanying costs. These costs can be used by MME for budgeting the costs for the total service time horizon per part, vehicle model, etc. The spare part procurement model consists of approximations to make it useable in practice.
- The automotive market is subject to multiple changes nowadays. To determine the optimal spare part procurement strategy MME can conduct scenario analyses with the model. The consequences of different scenarios can be evaluated and the optimal spare part procurement strategy can be chosen.
- It was not possible to compare the proposed model with the strategy used in the current situation, because insufficient data was available. However, when looking to the data available (i.e. data about the buffer period) it can be concluded that when in the current situation the other decisions (i.e. related to the optimal batch quantity and order level) are optimal the proposed spare part procurement model realizes cost savings of at least 6% based on the case study.
- After the sensitivity analysis it can also be concluded that it is necessary to determine the inventory holding costs and the variable spare part cost price for extra production appropriately, because these two variables have a moderate effect on the optimal spare part procurement strategy and the accompanying costs. Furthermore, it can be concluded that the forecasted demand has a major impact on the expected costs. However, the optimal values of the decision variables are robust to changes in demand. These optimal values of the decision variables are

also robust to changes in the service time horizon as result of the rolling horizon principle.

- The purchase price for remanufactured spare parts has not much effect on the optimal spare part procurement strategy and accompanying costs for the parameter deviation (i.e. from -50% until 100%) used in the sensitivity analysis.

7.2 Recommendations

After the conclusions it is possible to present some recommendations. Therefore, in this paragraph the recommendations for MME and for further scientific research are presented.

The following recommendations can be made after this master thesis project:

- The first recommendation is to make the program ready for implementation. This means that the functionality to run multiple spare parts at the same time should be programmed. Furthermore, the user interface should be improved. Besides these modelling issues it is also important to set up a network of car dismantlers from which it is possible to purchase remanufactured spare parts.
- The most important recommendation to MME is to implement the spare part procurement model when it is ready for implementation.
- To fit a distribution for the demand during a period and to fit a distribution for the demand during the replenishment lead time a binomial distribution is used. It is recommended to set up a project in which the demand pattern for multiple spare part groups is investigated. With the result of this research the demand forecast could be improved. In the time this demand analysis is not yet completed it is recommended to use the forecast method (explained in 4.5.6), which uses a dying curve to forecast the units in operation.
- The model depends on the information available. The more reliable this information is, the more reliable the output of the spare part procurement model is. Within MME it is possible to find the appropriate values for multiple variables easily. However, there are some variables for which it is difficult to obtain the appropriate values. For these variables it is determined whether it is important to put effort in the appropriate determination of parameter values. As a result of the sensitivity analysis, it is recommended that the inventory holding costs, the variable spare part cost price for extra production and the expected demand should be determined appropriately.
- It is also recommended to update the spare part procurement strategy annually. Furthermore, it is recommended to implement the optimal procurement strategy for the current period (i.e. a rolling horizon) only. The advantage of this method is the possibility to anticipate on changing markets. In practice this means that the order level, s_t, and the optimal batch quantity, Q_t, should be updated annually. Furthermore, the moment as from which it is possible to purchase remanufactured spare parts from car dismantlers can be adjusted to react on changes in the market.
- A recommendation for further scientific research is to compare the results of this spare part procurement model with the results of a simulation study. With this

simulation study it is possible to examine whether the model reflects the environment of the automotive industry.

Glossary of terms

MMC	Mitsubishi Motors Company
MME	Mitsubishi Motors Europe
EOL	End Of Life period
EOS	End Of Service period
PDC	European Parts Distribution Center
RDC	Regional Distribution Center
SKU	Stock Keeping Unit
RSP	Remaining Service Period

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Appendix 1 – European Parts Distribution Network

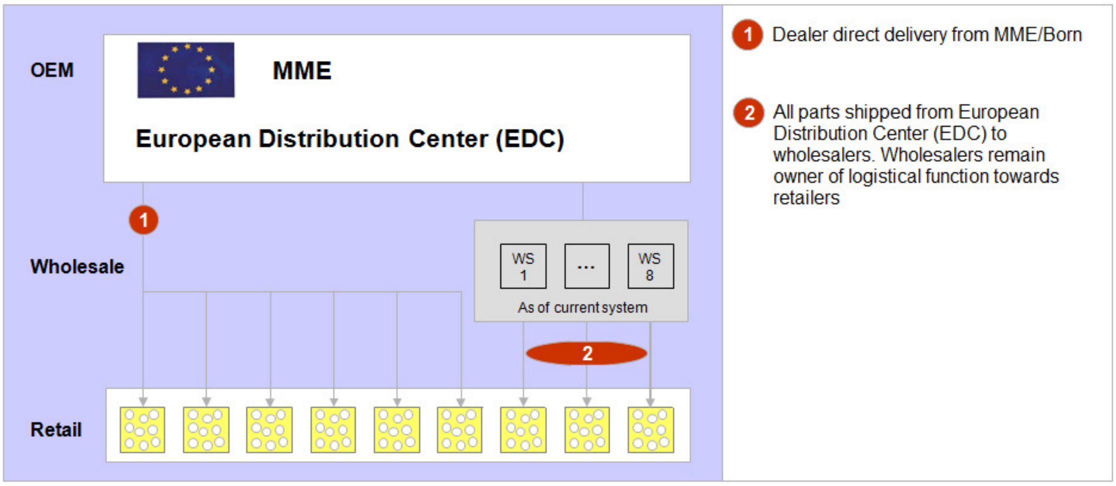


Figure 13, representation of the European Parts Distribution Network

In Europe Mitsubishi Motors Europe (MME) is responsible for vehicle and spare part sales. MME supplies in multiple countries direct to the dealer, which is called Direct Dealer Delivery (DDD). In other countries there is a distributor who takes care of the dealer demand of his own region. In the table below can be seen per country whether it is a dealer direct delivery concept or that the distributor supplies the dealers in his region. Furthermore, it should be mentioned that the RDC in Spain delivers spare parts according to the DDD protocol to Spain and Portugal.

DDD	Distributor	Distributor	Distributor
France	Cyprus	Israel	Ukraine
Switzerland	Slovenia	Greece	Austria
Belgium	Romania	United Kingdom	Finland
Germany	Lithuania	Hungary	Iceland
Denmark	Estonia	Czech Republic	Bulgaria
The Netherlands	Latvia	Slovakia	Croatia
Spain	Ireland	Norway	Bosnia
Portugal	Sweden	Poland	Serbia
	Russia	Turkey	

Table 6, summary DDD and Distributor countries

Appendix 2 – Revenue and stock quantity and investment

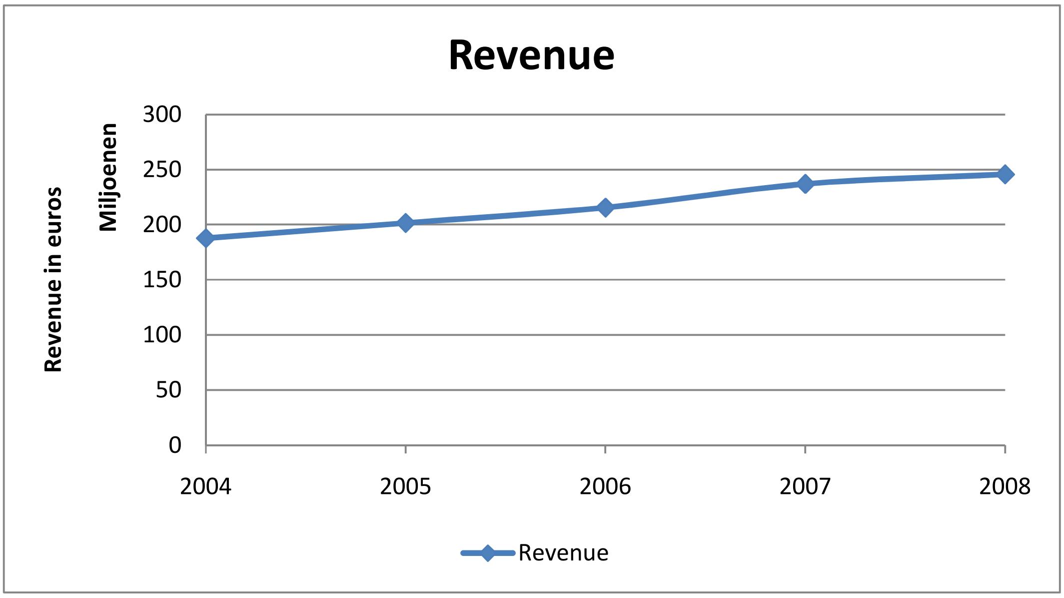


Figure 14, representation of the revenue

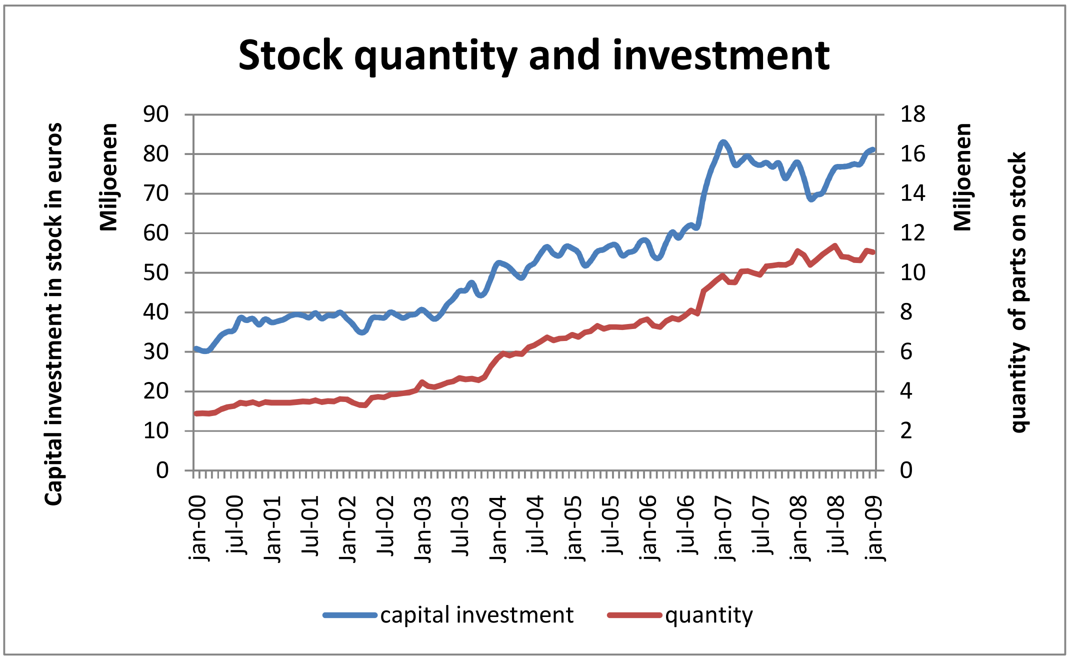


Figure 15, representation of the stock quantity and investment

Appendix 3 – Demand rank distribution

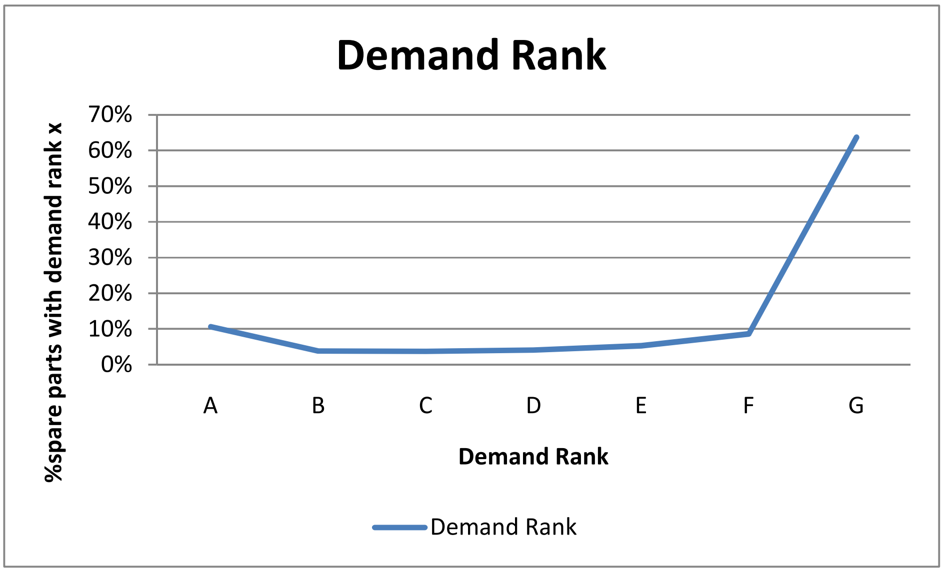


Figure 16, percentage of spare parts with a specific demand rank

In which demand rank a spare part is classified is depended on the number of order lines in the past 6 months per month. When in every month of the 6 months minimal 1 order line is placed the spare part is classified as a part with demand rank A. When in 5 out of the 6 months minimal 1 order line is placed the spare part is classified as a part with demand rank B. When in the last six months no order lines are placed for a specific spare part it is classified as a part with demand rank G. As can be seen in the graph, most spare parts (63%) are classified as a part with demand rank G.

Appendix 4 – Organization chart MME

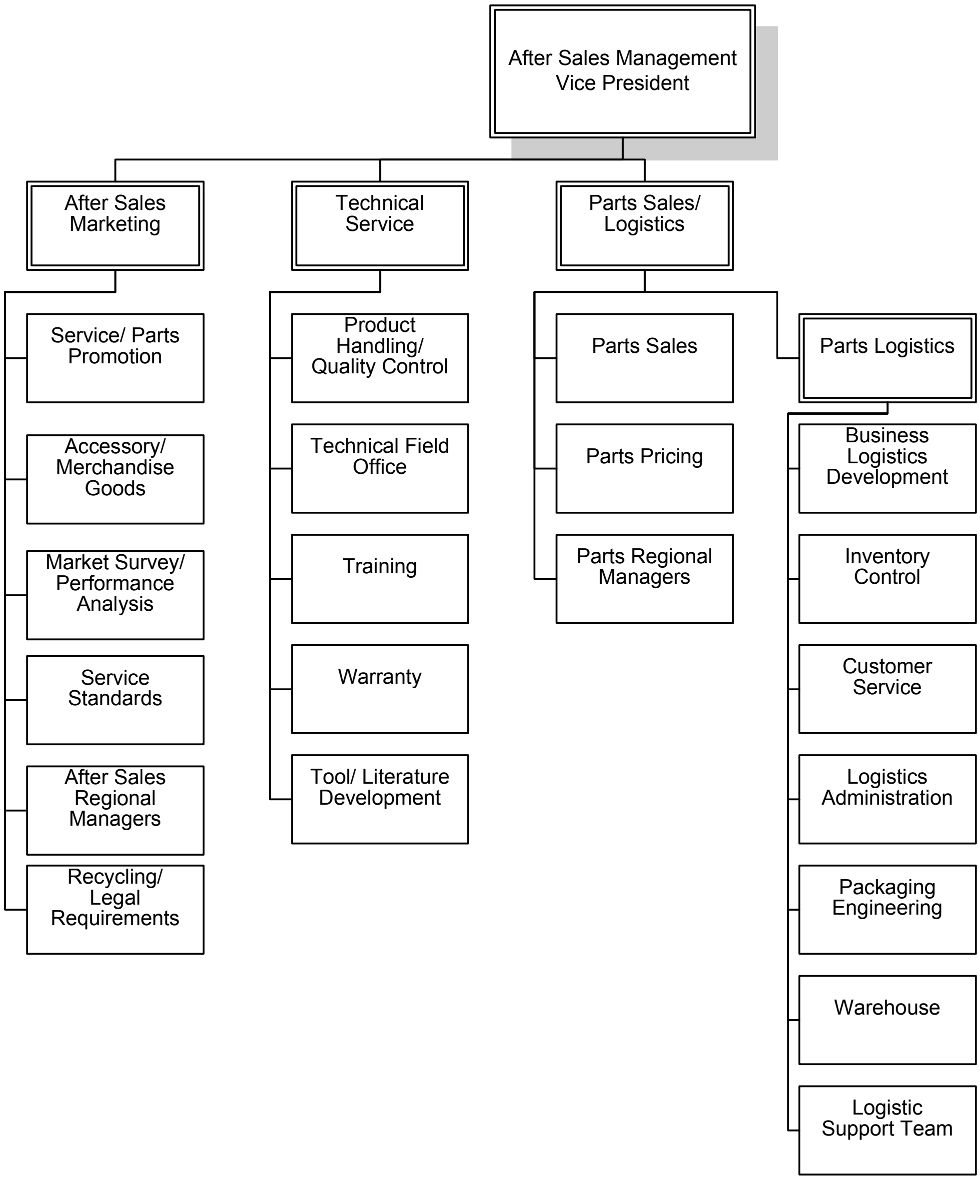


Figure 17, overview organization chart

Appendix 5 – Procurement and preparation goods receipt

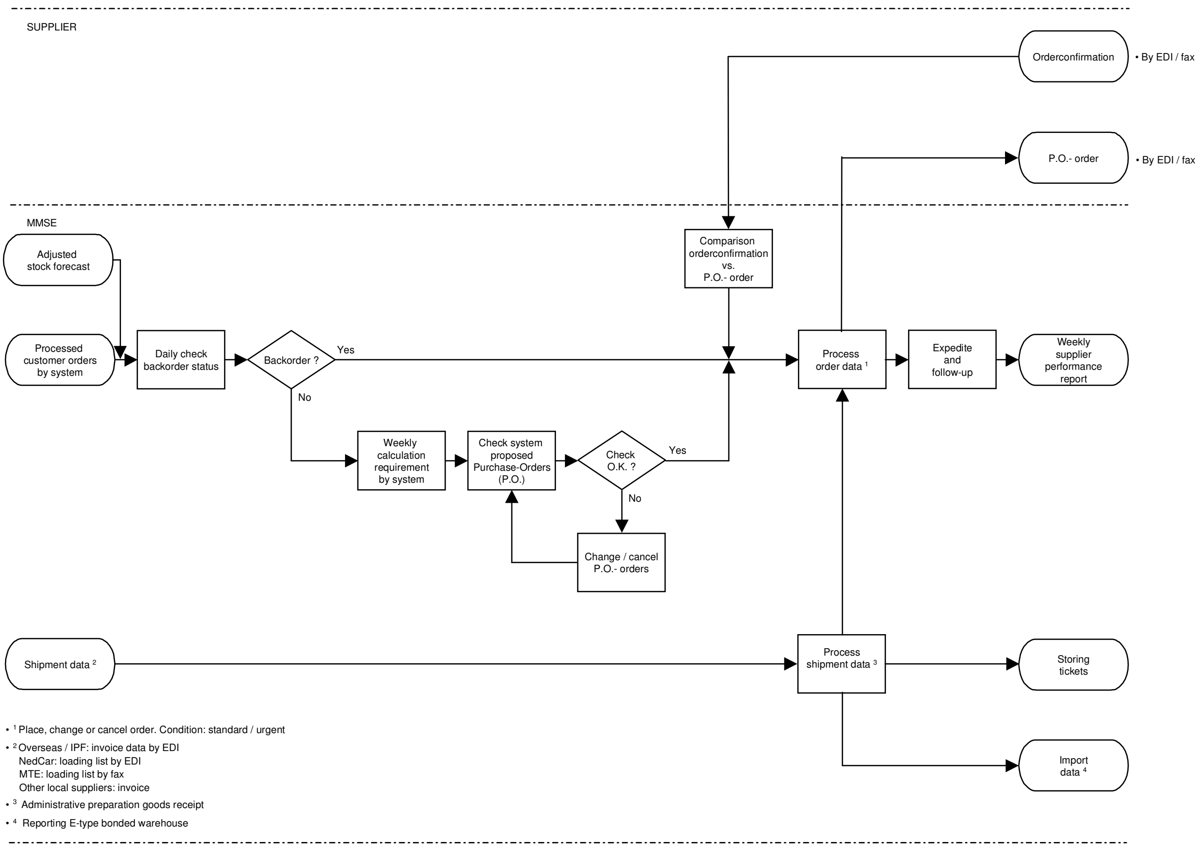
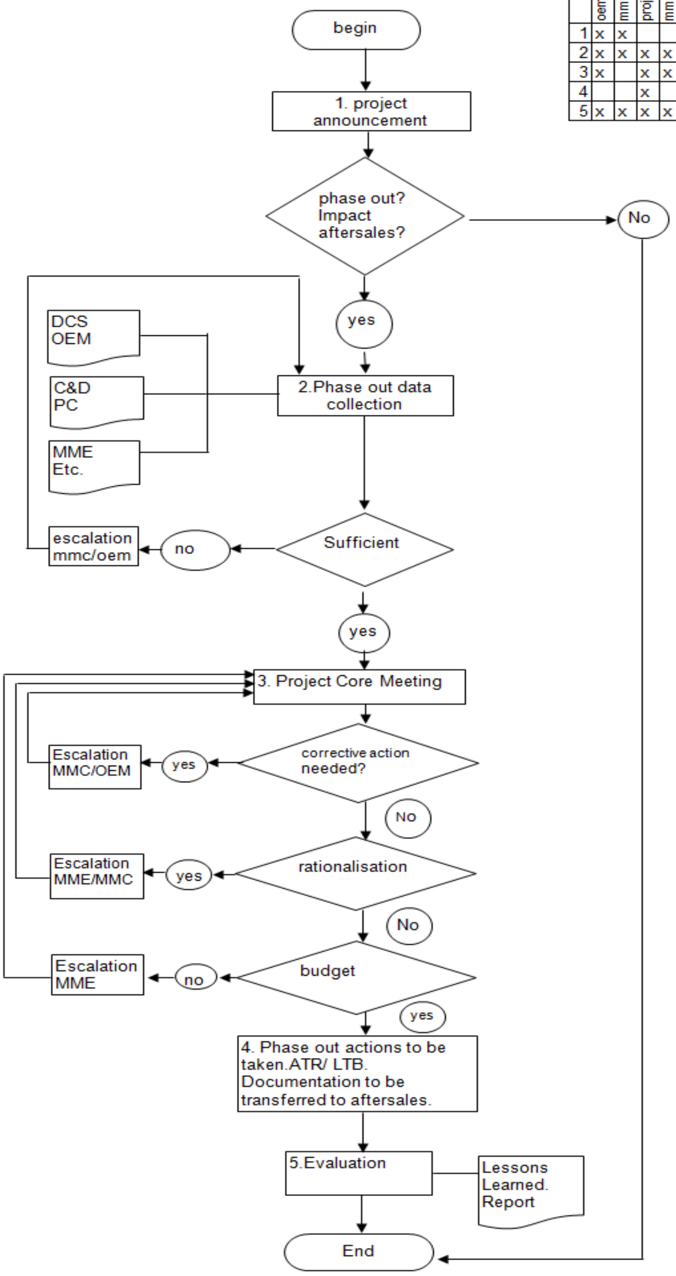


Figure 18, overview process procurement and preparation goods receipt

Appendix 6 – Phase out process

	oem	mmc	proj. man. oes	mme prod. dev.	mme inv. contr.
1	x	x			
2	x	x	x	x	
3	x		x	x	x
4			x		x
5	x	x	x	x	x



1. - decision on new car project.
2. - oes projectmanagement will collect information in close co-operation with oem/mme
3. - decide on critical items. Meetings on regular basis. Consolidate all info.
   - collect possible problems(running process). Budget. Reporting status.
4. - Ordering critical items before phase-out at serial prices. Decide on LTB's and ATR's
   - Documentation on cancelled suppliers OEM to be transferred to OES.
5. - Receive/collect feedback from all project members. Meeting to evaluate.

Figure 19, phase out process

Appendix 7 – Phase out process individual parts

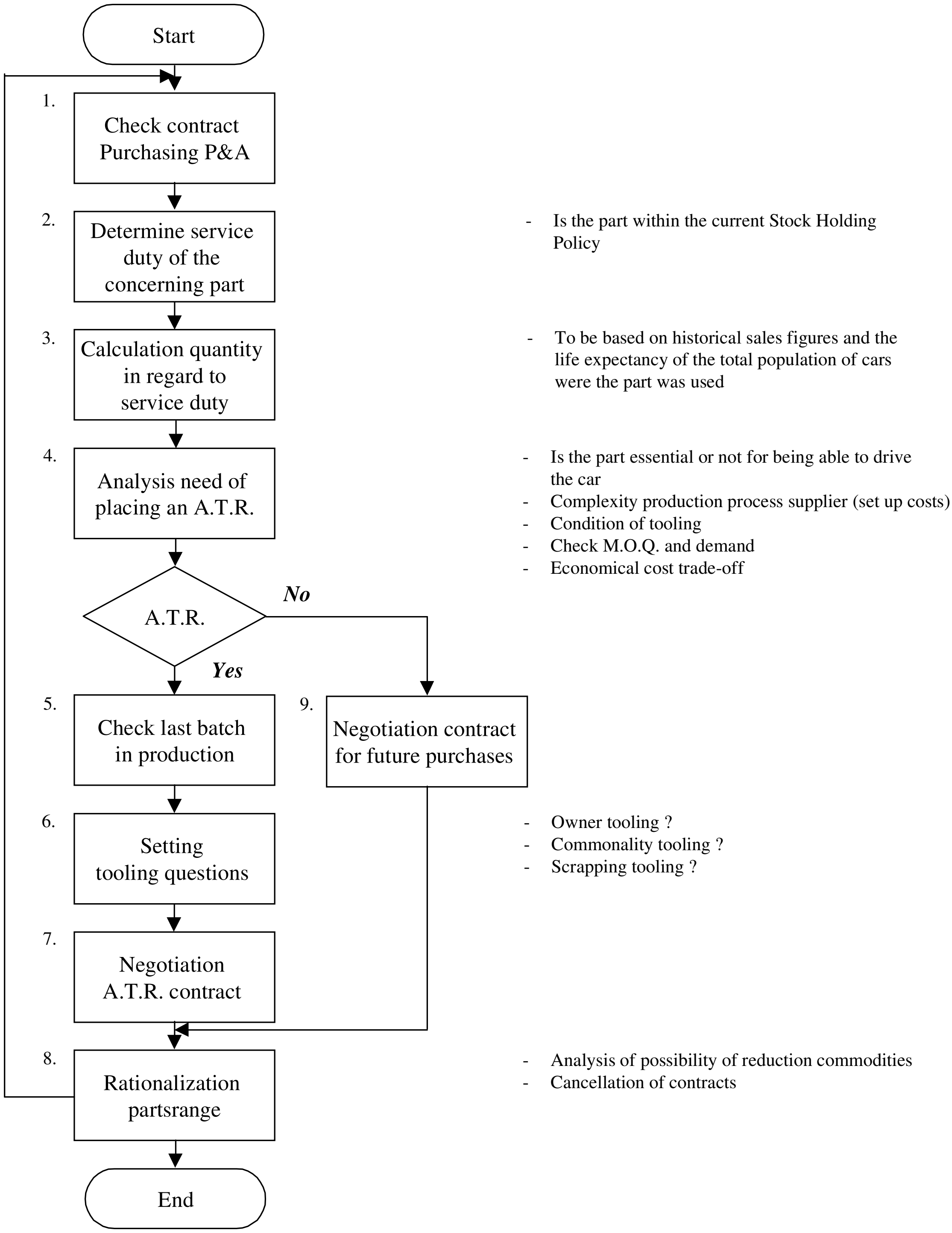


Figure 20, phase out process parts

Appendix 8 – Demand forecast analysis

In this Appendix the method to forecast demand, used at MME's inventory control department, is evaluated based on the findings of Moore (1971). To compare the results of the demand forecast of the Inventory Control department with the results found in literature first the sales data should be adapted. This means that the year where sales peaks should be indexed as year one. When this is done the sales data and year should be transformed from an arithmetic scale to a logarithmic scale. For investigating whether the proposed demand patterns are also applicable at MME approximately 50 spare parts are investigated. The group of spare parts that is investigated consists of spare parts such that the demand patterns proposed in literature are presented. In the figures 21 through 28 a graphical representation of the three demand patterns proposed in literature and the actual forecasted demand is given. In figure 21, 22 and 23 it can be seen that the actual forecasted demand follows an elliptical decay function. In figure 24, 25 and 26 it can be seen that the actual forecasted demand follows a parabolic decay function. In the last two figures, which are figure 27 and 28, it can be seen that the actual forecasted demand follows a linear decay function. As explained in the literature review (Zanders, 2009) it is possible to divide spare parts in groups with different demand patterns. According to Moore the elliptical decay function can be used for the demand pattern of major engine and transmission parts, body panels, axles, springs and windshields. The parabolic function can be used for moderately priced essentials and several cosmetic items for higher priced vehicles, for example lamp assemblies, valves, connecting rods, speedometers, fuel and water pumps and chrome body trim. The last function is the linear decay function, with exponential decay when the logarithmic axis is used, which can be used for a wide range of general maintenance parts such as shock absorbers, brake cylinders, pads, valve lifters, gaskets, brackets and small fittings.

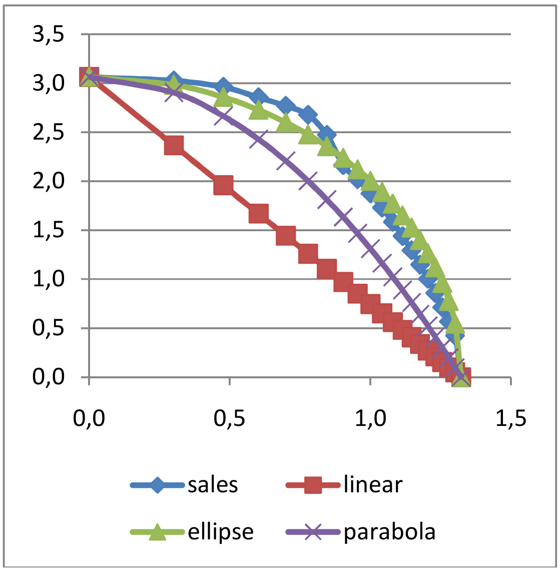


Figure 21, spare part MR288252

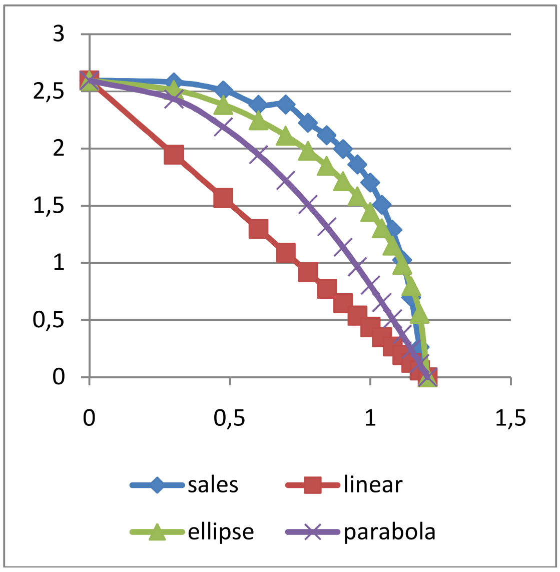


Figure 22, spare part MR287535

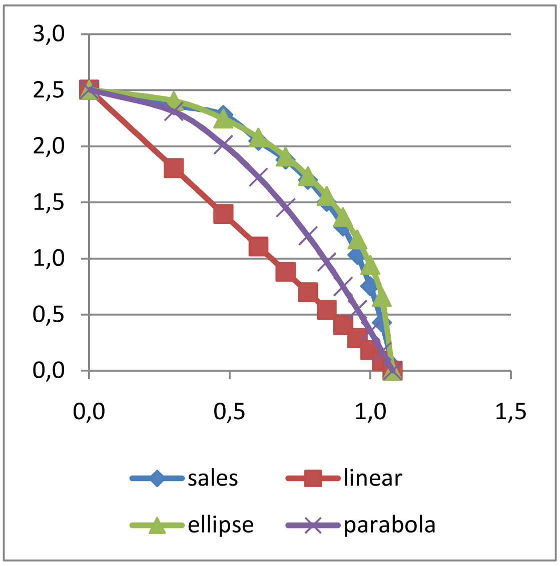


Figure 23, spare part MR287536

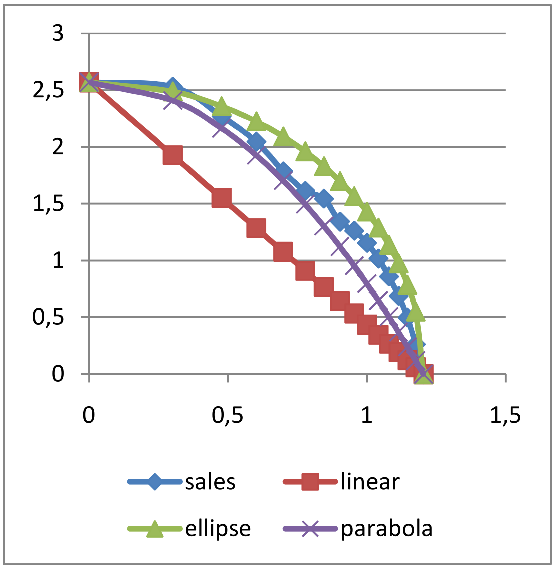


Figure 24, spare part MR793069

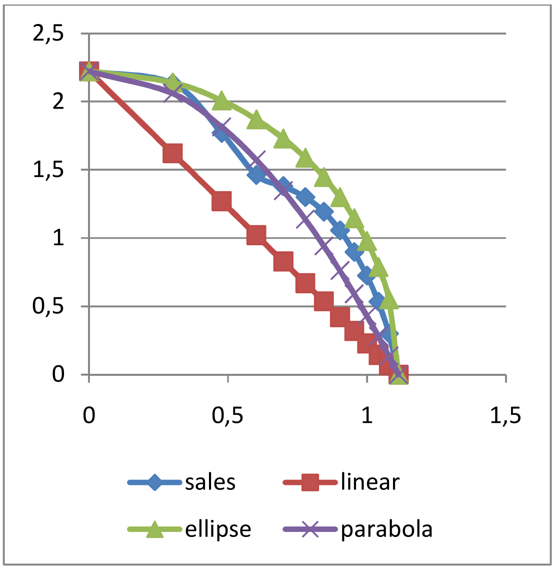


Figure 25, spare part MR913018

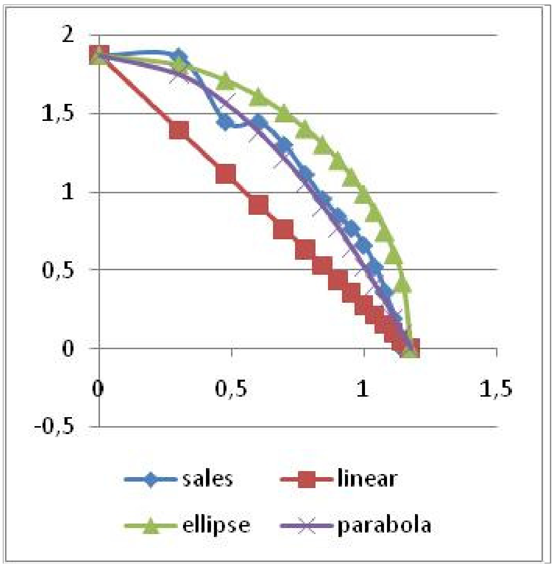


Figure 26, spare part M342698

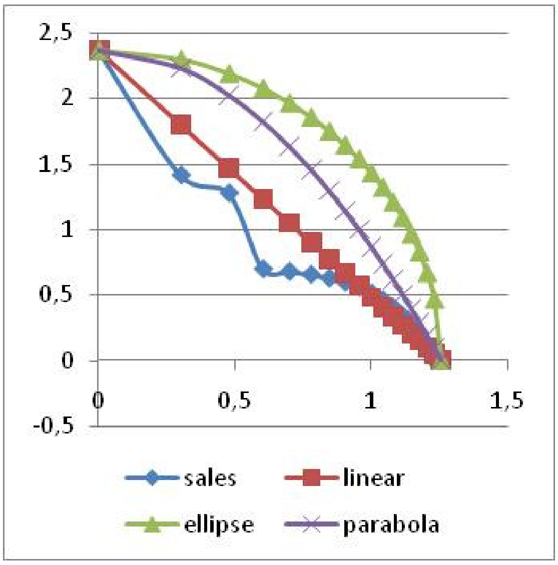


Figure 27, spare part M865787

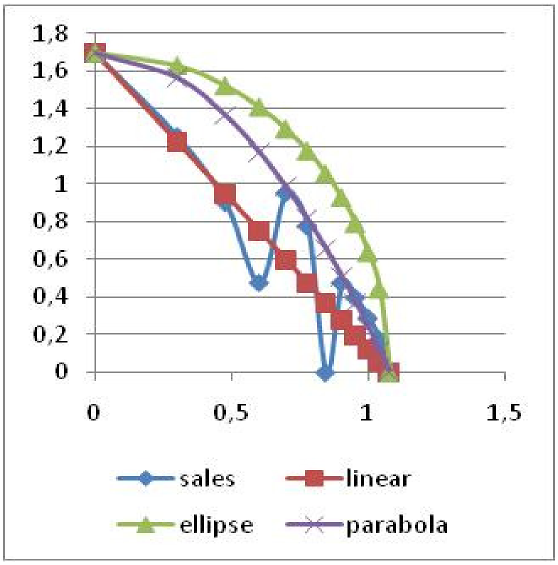


Figure 28, spare part M617273

Appendix 9 – Included spare parts case study

Confidential

Appendix 10 – The model proposed by Inderfurth and Mukherjee

In this Appendix the model proposed by Inderfurth and Mukherjee (2008) is presented. They introduce a decision tree approach to determine the optimal procurement strategy. However, when the number of periods increases the decision tree's size increases almost exponentially, which will result in computational problems. To cover this problem they opt for stochastic programming, which needs still some computational effort. However, they also present a heuristic approach which will result in a 4.6% cost increase compared to the minimum cost found with stochastic programming for the example they used. So it seems that the heuristic works fairly well for the example of Inderfurth and Mukherjee (2008).

The heuristic that is proposed can be characterized as a three-parameter (s_t, S_t, M_t) policy when fixed costs are non-negligible and is based on the newsvendor formula (the used notion can be found in Appendix 11). The order up to level L is a fractile of the cumulative demand distribution F :

$$F(L) = \frac{c_u}{c_u + c_o}$$

They also introduce a method to deal with non-negligible fixed costs. This method can be described as setting up a production lot once in a longer production cycle. As a result, only one adjusted parameter, an adjusted produce-up-to level S_t^τ , is necessary for control, which reduces the computational effort needed for parameter determination.

Final order quantity

The first parameter that should be determined is the final order quantity. This quantity is primarily influenced by the unit costs in the final order, the unit cost price of the best alternative, which is usually remanufacturing, and the inventory holding cost. The result is a critical time span for which the final order should cover demand. Furthermore, the stochasticity factor plays an important role. The critical time span can be calculated with the following formula:

$$\tau_{RO} = \frac{c_R - c_F}{h_S}$$

However, after this period sufficient spare parts have to be available to be remanufactured in order to achieve all required service obligations. For meeting this demand the following should hold:

$$I_1^R + \sum_{t=1}^{T} \bar{R}_t \geq \sum_{t=\tau_{RO}+1}^{T} \bar{D}_t$$

In case $\tau_{RO} \geq T$, the run out time is of course equal to the complete horizon of T periods. When $\tau_{RO} \geq T$ it is assumed that returned spare parts are immediately disposed of so that they do not add to any future holding costs. The final order should be determined with taking demand risk into account. The newsvendor formula is used to determine the fraction that should be covered over these periods. The demand distribution function is defined as $\Phi^{D}_{1,\bar{\tau}}$, which is the same as the fractile formula used in the newsvendor formula:

$$F = \Phi^{D}_{1,\bar{\tau}}$$

The underage of a single unit will result in a shortage cost per period assuming that sufficient recoverables or cores (which are used for remanufacturing) are available for compensating the shortage one period later. A one unit overage will result in an extra period serviceable inventory costs. As a result the final order quantity can be given with the following relationship:

$$\Phi^{D}_{1,\bar{\tau}} = \frac{v_S}{v_S + h_s \bullet \bar{\tau}}$$

Remanufacturing
In this subsection the method to determine remanufacturing levels is explained. First it is assumed that only returns of prior periods can be remanufactured. In case of remanufacturing, the underage of a unit will result in backorder costs per period plus inventory holding costs of a returned product. The overage of a unit will result in extra inventory holding costs for a serviceable spare part, but less inventory holding costs for returned products. This will result in the following remanufacture-up-to level M_t:

$$\Phi^{D}_{t}(M_t) = \frac{v_S + h_R}{v_S + h_S}$$

Extra production
In this subsection the decision parameters for extra production are determined. The Economic Order Interval is well known in literature. With this approach it is possible to calculate the macro period τ, which is dependent on the setup costs, unit price, and inventory holding costs. Within this macro period the inventory level can only be increased by remanufacturing. First the cumulative net demand (demand minus returns) over τ periods is determined:

$$F = \Phi^{(D-R)}_{t,\tau} = \sum_{i=0}^{\tau-1} D_{t+i} - \sum_{i=0}^{\tau-2} R_{t+i}$$

A one unit underage cost in case of extra production results in a shortage cost v_s during (t+ τ-1) micro periods. Furthermore, underproduction saves $c_E - c_R$, which is the cost saving by remanufacturing instead of extra production. This effect is will only be valid when cumulative demand in the remaining periods from t to T does not exceed the cumulative returns. The probability that returns are higher than demand is expressed by the following formula:

$$\pi_t^{D \le R} = \mathrm{P}\left(\sum_{i=t}^{T} D_i \le \sum_{i=t-1}^{T-1} R_i \right)$$

As a result underage costs can be defined as:

$$c_u = v_S - (c_E - c_R) \bullet \pi_t^{D \le R}$$

For the overage cost it is assumed that holding costs, h_s, will occur during all τ micro periods following period t and will remain so in case of excess returns in the period $t+\tau$ and possibly in subsequent periods until the end of the planning horizon. Besides these costs a one-unit overage will also result in an extra stock holding cost of h_R. The expected number of additional periods with such forced stock-holding can be calculated with the following formula:

$$\Theta_{t+\tau}^{D \le R} = (T - t - \tau + 1) \bullet \pi_{t+\tau}^{D \le R}$$

Now it is possible to calculate the produce-up-to level:

$$\Phi_{t,\tau}^{D-R}(S_t^{\tau}) = \frac{v_S - (c_E - c_R) \bullet \pi_t^{D \le R}}{v_S + h_S \bullet \tau + (h_S + h_R) \bullet \Theta_{t+\tau}^{D \le R}}$$

Appendix 11 – Overview of used notation

In this Appendix an overview of the used notation in the model of Inderfurth and Mukherjee, which is described in Appendix 10 is given.

S_t	Order up to level
s_t	Reorder point
M_t	Remanufacture up to level
c_u	Underage cost (in €)
c_o	Overage cost (in €)
L	Order up to level

Decision variables

Period 1:

y	Final production order (released in period 1)

Period ≥2:

x_t	Extra production/procurement order (released in period t)
r_t	Remanufacturing order in period t

Parameters and data

c_F	Unit variable cost of production with final lot
c_R	Unit cost of remanufacturing per unit return
F_E	Fixed setup cost for extra production or transaction cost for extra procurement
c_E	Unit variable cost of extra production/procurement
h_S	Inventory holding cost of serviceables spare parts per unit time period
h_R	Inventory holding cost of returned or used spare parts per unit per time period
v_S	Shortage cost of serviceables spare parts per unit per time period

Inventory variables

Period 1:

I_1^S	Stock of serviceables parts at the end of product life cycle or beginning of the planning horizon, i.e. first period
I_1^R	Stock of remanufacturable returns available at the end of product life cycle or beginning of the planning horizon, i.e. first period

Period ≥2:

I_t^S	Net serviceables inventory at the beginning of period t
I_t^R	Recoverables inventory at the beginning of period t

Random variables

D_t	Stochastic demand in period t, with t=1,…,T
R_t	Stochastic returns in period t, with t=1,…,T

Restrictions

$r_t \le I_t^R$ For $t = 1,\ldots,T$

$I_{t+1}^R = I_t^R + R_t - r_t$ For $t = 1,\ldots,T$

$I_2^S = I_1^S + y - D_1$

$I_{t+1}^S = I_t^S + r_t + x_t - D_t$ For $t = 2,\ldots,T$

Appendix 12 – Validation and verification

To check whether the proposed solution is correct, it should be tested whether it is the right model for the environment of the case company and whether the model is built right.

Verification

The model is programmed with VBA in Access. According to Gass (1983) verification can be split in two parts: experiments to debug the logic of the computer program, and checks to demonstrate the correctness of the numerical and data procedures as carried out by the computer program. The code is tested and debugged while programming the independent sub programs. Also the numerical and data procedures are tested per sub module. Thereafter the first spare part of the case study is used as test case to run the complete program. It was checked whether the output seems reasonable. Then extreme parameter settings were used to check the effect on the output of the model. Furthermore, a sensitivity analysis, which can be found in paragraph 5.2, is conducted to check the effect of a change in input parameters on the total costs.

Validation

Besides the verification of the model it is also important to validate the model, because MME need know whether this model can be used within the company. Gass (1983) mentions multiple aspects of validation, which are explained below.

Model validation

Model validation is defined as the correspondence of the model to the real world and is concerned with identifying all stated and implied assumptions, identification and inclusion of all decision variables, and hypothesized relationships between variables (Gass, 1983). This is carried out in cooperation with professionals of MME and Nedcar B.V.

Data validity

According to Gass (1983) data validity deals with raw and structured data. Structured data are raw data upon which some manipulation has been performed. With professionals of MME and Nedcar B.V. it is check whether the raw material used is measured correctly. The structured data is already checked in the verification where the calculations per sub module and for the complete model are checked.

Logical validity

Logical validity is concerned with translating the model form into a numerical, computer process that produces solutions (Gass, 1983). This validity is checked by evaluating the mathematical and numerical formulas used in the model. Furthermore, it is checked whether intermediate results are correct and whether all relationships that do exist are included. Also a comparison is made between model outcomes and expected results. This analysis is conducted with professionals of MME.

Operational validity

Operational validity is concerned with whether the model can produce unacceptable answers for proper ranges of parameter values (Gass, 1983). Therefore, for different variable values, which are within proper ranges, the model output is checked on robustness.

Appendix 13 – Input case study

Confidential

Appendix 14 – Implementation

In this Appendix the issues that are related to the implementation of the model are described based on Van Aken et al (2007). First the differences between the old and the new spare part procurement strategy are briefly explained. Thereafter the stakeholders are presented. Then sources of resistance to change are described. Furthermore, for each stakeholder (group) sources of resistance are given. Subsequently the invention strategy, which consists of actions to avoid and overcome the resistance to change, is described. This Appendix ends with a conclusion.

Delta analysis

According to Van Aken et al. (2007) a delta analysis identifies the differences between the present situation and the designed one. The problem in this case is that there is no clear procedure to determine the (optimal) spare part procurement in the present situation. In paragraph 2.4.2 it is only mentioned that a final order (i.e. buffer stock) is ordered that covers the demand during the period that the machinery is transported to the external company and adjusted. This period is equal to a half year. The only difference that could be investigated is the difference between the final order period and quantity in the present and in the proposed situation.

Stakeholders

In this paragraph direct and indirect stakeholders are identified. Direct stakeholders are defined as individuals or groups of which the work processes and/or organization roles will change (Van Aken et al., 2007). Indirect stakeholders are people who have to cooperate with the direct stakeholders and therefore need to know about the problem and about the changes in roles and processes of the direct stakeholders (Van Aken et al., 2007). For this project the following stakeholders can be identified:

- Management (Parts Logistic) MME: This direct stakeholder has the authority to approve or reject the design.
- Business Logistic Development department MME: This department gives an advice to the management (Part Logistic) of MME about the feasibility of the design.
- Inventory Control department MME: This department orders the spare parts at suppliers. The employees of this department should understand and work with the new method to order spare parts at suppliers.
- Warehouse department MME: This department is an indirect stakeholder, because they only notice the results of the new spare part procurement method. It could be that batch quantities of incoming purchased spare parts changes, which could have an effect on the efficiency or work planning of employees. Furthermore, this department also notices changes with respect to the floor area needed to store the purchased spare parts. When batch quantities change this will have an effect on the floor area needed.
- Nedcar B.V.: This department is responsible for setting up contracts with suppliers. To optimize the negotiation results the new spare procurement tool can be used.

- Suppliers: As a result of the new spare part procurement method, (batch) quantities that should be ordered at suppliers can differ from the old quantities that are ordered. Furthermore, the final order quantity, which is produced in-house, can be higher which will result in less sales for the suppliers.
- Customers: The customers are indirect stakeholders, because they will notice the performance of the new spare part procurement method.

Types of resistance to change

In this paragraph first the different types of resistance to change are presented. Thereafter for each stakeholder (group) it is explained which types of resistance to change are expected. The following types of resistance can be found (Van Aken et al, 2007):

- Lack of understanding: It is possible that people may not understand that there is a problem. It could also be that they do not understand the new system or they may misunderstand the consequences of the change for their own work.
- Differences in opinion: People may understand the problem, but disagree with the solution for technical, economical or personal reasons.
- Lack of trust: It could be that the employees do not trust the change organization, because of intentions or competences.
- Low willingness to change: This type of resistance can occur when employees fear the unknown or fear that they will perform well in the new situation.
- Conflicts of interest: The stakeholders could have different interests, which could give problems to implement the new design.

Now the definition of the different types of resistance to change are clear it is possible to describe the types of resistance per stakeholder (group):

Management (Parts Logistic) MME

Three types of resistance to change for the management are identified. First, it is possible that management does not understand that there is a problem, which is a lack of understanding. A reason could be that the service level and associated costs are according to (higher) management targets. When management understands the problem there could be also a lack of understanding due to the fact that the method is new and not well-known in literature and practice. Furthermore, it could be that there is a difference in opinion. Management understands the problem, but does not agree with the proposed solution, because until now no remanufactured spare parts are purchased at car dismantlers. Management can doubt the influence on customer goodwill. The last type of resistance could be lack of trust, because they can doubt the competences of the change team. When a student, without experience in the automotive market, is used to conduct the project this could be the case.

Business Logistic Development department MME

Within this department it is possible to identify multiple types of resistance to change. The first one is lack of understanding, because the proposed method is new and not yet described in literature. It is therefore difficult for this department to advice the parts logistic management of MME. Furthermore, differences in opinion could happen which is the result of a lack of trust in the competences of the change team. When this department questions the competences of the change team it could be that there are differences in opinion.

Inventory Control department MME
Within this department it is also possible to identify multiple types of resistance to change. The first one is a lack of understanding due to the fact that the employees do not understand that there is a problem. This is because the performance is currently in line with management targets. When the number of backorders is acceptable the employees do not understand why a new spare part procurement method is needed. Furthermore, they do not understand the new system, because it is new in practice and literature. Another important type of resistance to change is lack of trust, because the change team has no experience in the automotive market. It also could be that there is low willingness to change, because the employees fear the unknown. The last and maybe most important type is conflict of interests. The employees could think that this change will result in lay-offs or transfers to other departments.

Warehouse department MME
The resistance to change for the employees of the warehouse department is expected to be low, because it is expected that the new system will have a minor influence on the warehouse operations.

Nedcar B.V.
For Nedcar B.V. the following types of resistance to change are identified. First it is possible that there is a lack of understanding. This is because the employees do not understand the new system. Furthermore, there can be differences in opinion, because these employees have a sales view, whereas the change team has an operational view. In this operational view, costs and the availability of parts is included. Another important type of resistance to change could be conflict of interests. This is because Nedcar B.V. produces vehicles whereas MME services the after sales market. For setting up contracts it is important to keep the characteristics of the particular market in mind. However, the market for the production of vehicles and the market for servicing vehicles are quite different with respect to the demand characteristics.

Suppliers
The first type of resistance to change that can be expected from this stakeholder is the lack of understanding, because the method is new in practice and in literature. The most important type of resistance to change is the conflict of interests. As a result of the new procurement method it is possible that less parts are ordered at suppliers, because more parts are produced in-house. On the other hand it could be that more parts are ordered at suppliers and less parts are produced in-house. It is not possible to draw conclusions in advance, because the decision to order at a supplier or produce in-house depends on the market and product characteristics.

Customers

It is expected that the resistance to change of customers is low, because the only concern of the customers is the price of the service and the quality of the service (e.g. the right spare parts at the right price at the right place at the right time). When the use of the new method will result in lower costs and the same service level customers can profit. So no types of resistance to change are expected.

Intervention strategy

The intervention strategy is built on Tychy's TPC-model (Van Aken et al., 2007). According to Itchy, one should manage organizational change processes simultaneously in three intertwined aspect systems: the technical system, the political system and the cultural system.

Technical system

According to Van Aken et al. (2007) the technical system is the domain of technical and economic issues. In this case it is important to inform the direct stakeholders (which are the Business Logistic Development department, the management of MME, the Inventory Control department and the Purchase department of Nedcar B.V.) about the business problem, why it is important to do something about the business problem, what solution has been designed, and why that solution will solve the problem. This can be done in the form of a report or representation or both. For the Inventory Control department, which is the department that should use the new method, also training and a manual should be facilitated to create support and understanding.

Political system

The political system is the domain of material and immaterial interests and of the formal and informal power individuals and groups may use to protect these interests (Van Aken et al., 2007). In this case it is important to convince the management of MME, because they have the power to give a go or no-go. Furthermore, this stakeholder can create support within the company, because when the management will support the project, department managers will follow. Moreover they have the power to dismiss or transfer employees who are opposing the change. However, this is the last option, because of the impact of such a decision.

Cultural system

Van Aken et al. (2007) define the cultural system as the domain of corporate and departmental culture, of corporate, group and individual identity, and of the emotions connected with the close and repetitive interactions with other people within the organization. In this case cultural intervention is used during the whole project. Stakeholders are involved in the problem definition, analysis and solution.

Conclusion

Due to the difference between the current and proposed method to determine the optimal spare part procurement, resources are needed to implement the proposed design. An intervention strategy is to inform direct stakeholders about the problem, why it is a problem, how to solve it and why the solution solves the problem. Furthermore, it is important to create support at the management of MME, because they have the resources and power to create support. Last but not least it is important that employees have the idea that the new design does not conflict with their own interests. Therefore, stakeholders should be involved early in the project.