Using reverse logistics for failed spare parts

A new opportunity for Vanderlande Industries

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Master Thesis

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MANAGEMENT SUMMARY

This thesis is the result of a six months research at Vanderlande Industries in Veghel, the Netherlands. Vanderlande develops, manufactures and maintains automated material handling systems for customers all over the world.

Vanderlande faces an increasing amount of last time buy situations. Last time buys occur when a supplier stops producing a part. At that point Vanderlande is offered a last option to purchase enough parts to cover demand until the moment their systems are not used anymore. Due to the possibly long period and different influencing factors, last time buys are associated with high risks. In order to mitigate these risks, parts can be reused by giving them a second life after they fail. This way a different source of supply is created. Currently Vanderlande does not reuse parts, but they are interested in the benefits which this option can realize. Therefore this thesis focuses on the reverse logistic process which needs to be set up in order to realize the reuse option and on the economic feasibility of reusing failed parts. However, since reuse can lead to larger improvements during the steady state compared to the last time buy, the reverse logistic process and economic feasibility are determined under the assumption that the part is still available at the supplier. Therefore the following problem statement has been made:

Currently it is unclear how Vanderlande can benefit from repairing broken spare parts. There is no well defined process to accommodate the returning parts and neither a way to determine for which parts reverse logistics is feasible.

The first part of the research focused on how the reverse logistic process has to be organized. The most important recommendations towards the organization of the reverse logistic process are:

Three strategies are proposed to decide when and how many failed parts should be repaired and new parts be purchased

The choice for a strategy can be made on part level depending on the resulting profit and which lead time is acceptable towards the customers.

- The re-process to order (RTO) model waits with making a decision on re-processing or purchasing until demand occurs. At that point an order is placed which can cover the demand. This results in long lead times, but low risks and inventory costs.
- The push model immediately re-processes failed parts when they are returned. However, it waits with purchasing additional new parts until the inventory level reaches the reorder point. In order to determine the reorder point formulas have been developed for Poisson and compound Poisson distributed demand. The order quantity is determined along an order up to level, which can be calculated with an EOQ type formula.
- The pull model postpones both re-processing and purchasing until the inventory position reaches the reorder point. At that time the inventory position is raised to the order up to level, in the first place by re-processing the available failed parts. Additionally new parts are purchased when the re-processed parts are not enough to bring the inventory position to the specified level. For the pull model similar formulas are used for the reorder point and the order up to level as for the push model.

The delivery of serviceable parts and pickup of failed parts should be combined

In order to save transportation costs and reduce the efforts from the employees of the customer as well as Vanderlande, it is recommended to combine the delivery of serviceable part (new or repaired) with the pickup of the failed parts. This requires good communication between the transportation company, the customer and Vanderlande, but it will lead to a more efficient process.

New branches should be created in the ERP system to accommodate reverse logistics

In order to keep the parts in different condition separated from each other, the ERP system should facilitate the differentiation between states (failed, repaired, new). This issue was resolved by creating branches for failed and re-processed parts. At these branches the inventory of the different parts in that condition can be registered. This does not only allow the inventory of different parts to be separated, it also provides a good overview of the inventory, the same item number can be used for all states and different prices can be used for the different states. This allows optimal handling in the IT system.

The prices for re-processed and failed parts should be a percentage of the sales price of new parts

In order to determine for which price re-processed parts should be sold, two factors have to be considered; the quality of the repaired part and the attitude of the customer towards using repaired parts. The price of a failed part, or the compensation fee, which is offered to the customers for returning their failed parts, is influenced by three factors; the required effort of the customer for returning the part, the value the failed part represents to them, and their attitude towards sustainability. The compensation fee can best be disbursed as a credit, which is settled the next time they purchase a spare part.

The second part of the research is concerned with the economic feasibility. The calculations of the economic feasibility were done on a part level. Hereby the profits that are realized in the current situation, without reverse logistics, are compared to the profits which could be realized when reverse logistics would be applied. The reverse logistic process is economically feasible if it leads to an increased profit. This can be written as:

$$profit_{rev} - profit_{cur} > 0$$

The method defines six different cost components:

Cost component	Cost included
Transportation	The cost for picking up failed parts, transportation between the service central warehouse and the supplier and delivering the serviceable parts to the customers
Inventory	The cost for keeping money locked up in inventory
Warehousing	The costs for the shelf/pallet place and the handling costs which are charged by the organization which operates the service central warehouse
Re-processing/ purchasing	The costs for re-processing and purchasing parts, also including the inspection costs for failed parts and fixed order costs
Coordination	The costs for the time of Vanderlande's staff that is spend on coordinating the reverse logistic process
Compensation fee	The costs for purchasing the failed parts from the customers

The method has been successfully validated and verified with an expert form Vanderlande. Subsequently the method has been applied to a real life case study in order to illustrate the method and indicate the potential of reverse logistics. The case study showed an increase in the profit of 54 percent. This is a very large improvement and therefore shows that big benefits can be realized through reverse logistics. Further employment of the method on other parts can show whether this is a representative number.

Based on the outcomes of the case study a sensitivity analysis has been performed. The most influential factor is the price for which the repaired parts are sold. For the case study, the maximum discount which could be offered while keeping an increased profit is 14,2 percent. Luckily this value is fixed by Vanderlande and does not randomly fluctuate. The second biggest influence comes from the repair yield. However, the repair yield can be as low as 0,58 and still lead to an increased profit. This is a large difference compared to the estimated 0,8. Therefore the success of reverse logistics is not threatened by uncertain factors.

The two main conclusions that can be drawn from this research are:

The proposed reverse logistics process can be easily implemented and will only require minimal adjustments to the current business processes

The proposed method for determining the economic feasibility is a quick and reliable way to determine for which parts reuse will result in additional profit

PREFACE

"In the sweat of your face you shall eat bread till you return to the ground. For out of it you were taken; for dust you are, and to dust you shall return." Genesis 3:19

This famous quote points out, that where one life ends, another starts. This is the essence of this thesis. When a spare part reaches the end of its useful life and fails, it should not be simply disposed of, but it should be repaired, remanufactured, refurbished, re-used, cannibalized or recycled. By doing so, a company can make a difference in a matter which I find personally very important: Sustainability.

In February of this year I was presented with the great opportunity to write my master thesis at Vanderlande Industries. Here I was asked to research the benefits which could be realized by applying reverse logistics to the spare parts. I have gladly accepted the challenge and before you lay the result of my work at Vanderlande over the past half a year. Working at Vanderlande was a great experience and I am therefore very thankful to Vanderlande Industries. In particular I would like to thank Katja for her input, support and dedication to my work. Furthermore I would like to thank everyone who has freed up their time for answering my questions during the interviews and the great people at the Supply Chain Management Services department for making my time at Vanderlande a very funny, friendly and happy experience.

Finally I want to use this opportunity to thank Matthieu and Ahmad for their great guidance throughout the process of writing this thesis. They have always been available for questions, have pointed me in the right direction and gave me very valuable input for this thesis.

LIST OF ABBREVIATIONS

CC	Customer Center
CSR	Corporate Social Responsibility
EOS	End Of Supply
EOSe	End Of Service
DPP	Distribution Parcel and Postal
FFF	Form Fit Function
LTB	Last Time Buy
RMA	Return Material Authorization
RTT	Required Transition Time
SCMS	Supply Chain Management Services
SCW	Service Central Warehouse
SLA	Service Level Agreement
SOP	Steering committee Operational Products
VI	Vanderlande Industries

Contents

1 INTRODUCTION OF THE COMPANY

In this chapter the company will be introduced. First some general information will be given, then the four markets in which Vanderlande is active will be addressed. Subsequently the department where the research is conducted will be further introduced. The chapter is concluded by a discussion on end-of-supply (EOS) and last time buy (LTB) situations.

1.1 GENERAL

“Vanderlande Industries provides automated material handling systems and accompanying services. It focuses on improving its customers’ business processes and strengthening their competitive position” (www.vanderlande.com, February 2012). The company was founded in 1949 by Eddie van der Lande and grew from a small family business to a mature company with almost 2000 employees worldwide. The year 2011 resulted in a turnover of 566 million euro and a net result after tax of 22,5 million euro. At the end of the year, the company’s balance sheet had a value of almost 250 million euro (Year report Vanderlande, 2011).

Vanderlande Industries is headquartered in Veghel, The Netherlands. All production is performed there, as well as R&D and other business support functions. From the headquarters the different customer service centers are supported. These customer centers are located in Belgium, Germany, France, Great Britain, Spain, Canada, PR China, South Africa and the USA. These Customer Centers operate fairly autonomous; they handle all key business functions and maintain direct contacts with customers (www.vanderlande.com, February 2012).

1.2 MARKETS

Vanderlande serves customers in different markets, based on these markets there are four different organizational groups.

- *Baggage Handling*. Develop solutions for airports, which take care of the transportation of passengers’ suitcases from the check in point until inside the planes. Vanderlande has implemented over 600 of their systems in airports over the whole world. The airports differ in size between major hub airports like Schiphol and Heathrow to regional airports like Eindhoven and Bremen.
- *Distribution*. Supplies their customers with integrated logistics systems for the automation of warehouses and distribution centers. The solutions that are used focus on the entire goods flow from goods receiving, storage, order picking up to shipping and the related information flow. The customers are in a wide range of business, from food, to fashion, to automotive and many other areas.
- *Parcel and Postal.* Supplies fully automated systems for parcel and postal sorting centers. They offer systems that support the processes from the arrival of the packages at the distribution center through data acquisition and sorting to the shipment. Over 350 systems are installed at customers that range between worldwide express companies to national postal companies.
- *Services.* Vanderlande provides all required services throughout the operational lifetime of the supplied systems. The services are maintenance, spare parts, IT & control, process management, site based services, life cycle services and training.
  Over time the importance of services increased at Vanderlande. Figure 1 represents this increasing importance (www.vanderlande.com, February 2012)

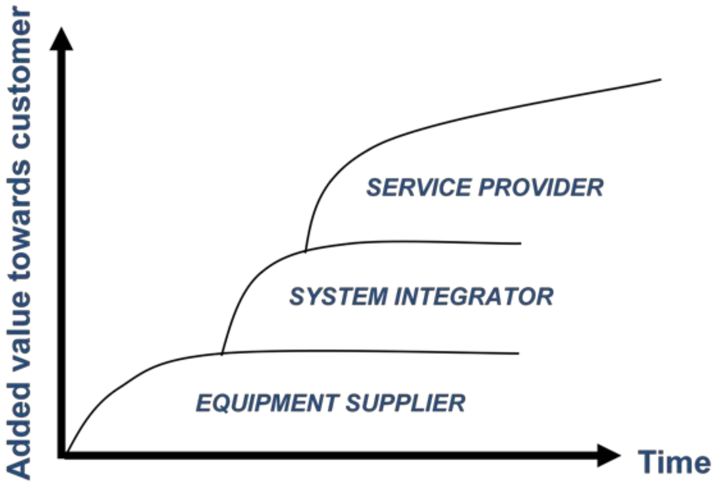

Figure 1 – The development of Vanderlande's added value over time

1.3 SUPPLY CHAIN MANAGEMENT SERVICES

This research is conducted at the Supply Chain Management Services (SCMS) department. They are part of the business group Services, one of the four business groups at Vanderlande. The SCMS department is concerned with the supply of spare parts to the customers. The supply of spare parts starts after the development and implementation of a new system. Before that point in time, parts are purchased by the purchasing department.

The supply of spare parts is a responsibility for the different customer centers. They take care of the spare parts that are requested by customers in their region. They can order these spare parts directly from the suppliers, but they can also order the spare parts through the SCMS department in Veghel. The customer centers can choose freely between these two alternatives. One part of the SCMS department, the ordering and dispatching team, is responsible for the spare part sales placed by the customer centers. Besides this team the department consists of the spare part coordinators of customer centers International and DPP (Distribution, Parcel & Postal). These spare parts coordinators take care of spare part orders and customers that fall outside of the regions of the other customer centers.

SCMS is responsible for supplying the spare parts and they control the supply process from the moment the customer places the order until the delivery at the customers' site. The supply process for spare parts is done in different ways. With a new system, a customer can either order an initial spare part package, or they request consignment stock. When the customer uses consignment stock, spare parts are kept at the customer's site or in a warehouse close by. When demand for spare parts occurs, it can be directly fulfilled from the consignment stock. When a customer does not use consignment stock, spare parts are ordered through replenishment orders (department presentation, 2011) Replenishment orders are delivered from stock or, when there is no stock available, the order first has to be placed with the supplier before it can be shipped.

Before January 2007 SCMS physically stored their inventory together with that of the projects. This became an undesirable situation and therefore it was decided to outsource the service warehouse. Currently the inventory is managed by DHL at the service central warehouse (SCW) in Veghel. Here there are around 650 different items on stock. This is free inventory, which is available for any customer that needs them. The items which are stored here are parts with a long lead time and/or a relatively high demand.

Occasionally there are also return flows, where customers send broken parts back to Vanderlande for repair. This is done on the customer's initiative, by filling in a return material authorization (RMA) form. Currently SCMS takes care of the RMAs.

1.4 SERVICE AND SPARE PART CONTRACTS

In order to ensure the service to the customer, Vanderlande has service contracts with their customers. In these contracts it is determined whether maintenance is done by Vanderlande or by the customer themselves. In case Vanderlande performs maintenance, agreements are made regarding the frequency of preventive maintenance and the response time for corrective maintenance. The service contracts with large customers sometimes contain a service level agreement (SLA). This specifies a minimum uptime and/or a maximum downtime. For part of the customers the way spare parts are supplied is also fixed in the service contract, although in other cases a spare part contract is drawn up for this purpose. The length of service and spare part contracts differs among customers. The length is normally between three and five years. However, Vanderlande is obligated by law to supply spare parts for a period of ten years after a system has been installed.

1.5 END-OF-SUPPLY AND LAST TIME BUY

During the service period, which is determined in the service contract, Vanderlande is obligated to provide the spare parts that are necessary to keep the system running. For most of the spare parts this does not lead to problems; When parts are needed, they can order them from suppliers. However, sometimes Vanderlande faces an end-of-supply (EOS). This means that they cannot buy the corresponding part anymore. This situation can be initiated by the supplier, if they stop producing it, as well as by Vanderlande self, when it is not desirable anymore to use the part.

In case of an EOS, it becomes more difficult for Vanderlande to ensure the supply of the part, since they cannot order it anymore at the moment they need it. Therefore they have two alternatives to fulfill the demand for the part. At the moment an EOS is announced, Vanderlande can place a last time buy (LTB) order that covers the remaining service period, or they can find another part which can replace the original one. In order to replace the original part without any complications, the new part should comply with the form, fit, function (FFF). This is not always possible and therefore time is needed to find a qualifying part, or to adapt technical specifications or drawings. The time between the moment a part is EOS and the moment the replacing part is available at Vanderlande, is called the required transition time (RTT). The transition time is subjected to uncertainty, since it is not known beforehand how long it will take to have a replacing part available. This also greatly depends on the availability of the R&D department. When a replacing part is used, the required transition time (RTT) is at least half year and can be as long as one and a half year. In case it turns out to be too undesirable to use a replacing part, the RTT is equal to the remaining service time.

During the RTT, the original part should cover the demand. Two sources for the parts can be distinguished, as is shown in Figure 2. In the one hand returning parts could be re-paired and afterwards re-used and the other option is to keep sufficient stock, from the moment the part is EOS. Currently Vanderlande does not use the first option and therefore they cover all demand during RTT from stock. A sufficient stock level should be achieved through the last time buy (LTB) order. The size of this order is important, since a too large order leads to extra costs for buying, stocking and disposing of unnecessary parts. When the LTB order is too small, a shortage occurs and customers' orders are not satisfied. There are usually no penalties specified in case a shortage occurs, but service is very important to Vanderlande. Therefore, this situation is very undesirable and sufficient safety margins have to be used. This excess inventory makes LTB situations expensive. In order to control these costs, a research was conducted at Vanderlande to determine the optimal LTB order size. In this research a tool was developed that is based on a total cost approach and takes into account, the substitution of items, an uncertain transition time, and a service level (Bakx, 2010).

During the last years, Vanderlande has faced increasingly more last time buy decisions. Since high costs and uncertainties are involved with these decisions there was a big interest in the cost reduction of LTBs. A possible solution to mitigate the risk involved in the LTBs is to re-use returning parts. In this way the dependence on the last time buy decreases, since there will be an alternative source to supply the spare parts.

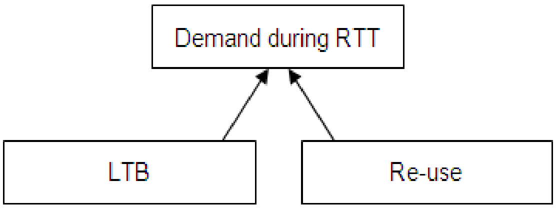

Figure 2 – Sources of supply in case of EOS

2 RESEARCH DESIGN

In this chapter the research will be introduced. First, the motivation for the research (2.1) and the problem definition (2.2) will be given. Then the goal of the research (2.3) is stated to clarify the intended research outcomes. In paragraph 2.4 the scope of the research will be defined. Finally the research questions (2.5) and the research approach (2.6) are discussed.

2.1 MOTIVATION FOR THE RESEARCH

The main motivation for this research is the rising costs of LTB orders. These are between the 25.000 and 75.000 euro per LTB order, depending on the part. In total the LTB orders cost Vanderlande 100.000 to 200.000 euros on a yearly base. Currently these costs are minimized by using a tool to provide the optimal order size. However, this tool assumes that the parts are non-repairable. By introducing the option of repair, the costs from LTB orders might be further decreased.
Besides the costs of LTB orders there are two other reasons to repair parts. The first reason is that it will have a positive effect on the environment. This is due to the reuse of materials and parts, instead of disposing them. This kind of “green” initiative fits well to Vanderlande, since they already do a lot on corporate social responsibility (CSR). One of the areas of their CSR efforts is the environment. Vanderlande has green initiatives, like energy saving projects and they design their products such that they use a minimum of scarce materials. Because of the value Vanderlande places on CSR, repairing broken parts is important to Vanderlande.
The second reason is to increase the profitability of the SCMS department. When the margin on a repaired part is higher than on a new part, the profits on selling spare parts will turn out to be higher. This does not only count for EOS situations, but also on parts that can still be ordered a higher margin can be achieved through repair.

2.2 PROBLEM DEFINITION

Due to the increasing costs from last time buy situations, action has to be undertaken to control it. Management sees repairing broken parts as a solution to the increasing costs without risking stock outs and wants to investigate this possibility. This research therefore aims to find out if, and how benefits from repairs can be realized. In the first place, it should determine how the processes concerning returning parts should be organized to enable the repairs. Currently there are some return flows, but they are not well organized. It is therefore important that a model is made for the organization of reverse logistics. This model should provide both a formal design of the process and also a practical organization of this process. This also includes a method to indentify parts for which it is economically beneficial to be repaired.

Furthermore the impact of repairing broken parts on the LTB decision has to be determined. Only then the benefits in connection to LTB orders can be realized.

Thereby the following problem definition can be stated:
Currently it is unclear how Vanderlande can benefit from repairing broken spare parts. There is no well defined process to accommodate the returning parts and neither a way to determine for which parts reverse logistics is feasible.

2.3 RESEARCH GOAL

Solving the problem that was stated above should provide two concrete results:

- In the first place the research has to identify an efficient organization to accommodate the returning parts. All possible flows will be taken into account and a process has to be defined that offers an integral approach for the total reverse logistics. This should result in flowcharts that graphically show the process, a textual explanation of how the process should be managed and a method to determine for which parts repair is economically beneficial.
- Secondly, it should be possible to measure and evaluate the impact of reverse logistics on the LTB order size. This has to be realized by creating a model that can forecast the amount of returning parts that are available for reuse.

2.4 SCOPE OF THE PROBLEM

This research serves as a master thesis; therefore the workload should be approximately six months. In order to limit the workload to fit this period, not all aspects that are connected to the problem definition can be treated. The following aspects will be excluded from the research:

- Returned systems
  Systems that are replaced could also be returned, disassembled and used for spare parts. This will not be considered, although the model should be easily adaptable to also include returning systems.
- Parts handled in Veghel
  The research focuses on the parts which pass through the service central warehouse in Veghel. Other orders are outside of the scope.
- Determining the feasibility of repairs
  In order to determine whether it is feasible to repair a part, there are both the technical and the economic aspect. In this thesis the focus will be on the economical feasibility, since the detailed technical knowledge is not available.

2.5 RESEARCH QUESTIONS

In order to reach the goal of the research, six research questions have been formulated. They are in a logical order in the process towards achieving the research goal.

1) What is the current situation at Vanderlande?
   The current practices related to the research have to be made insightful. This information has to provide a starting point as well as a reference point, since knowing the current practices will provide knowledge on which actions have to be included and a new solution can be compared to the current one to prevent over complication for stake holders.
   a) Analyze the spare parts (amount, repairability, prices, types)
   b) How does SCMS organize the supply of spare parts
   c) Which parts are currently returned and for which reasons
   d) How are parts currently returned and repaired
   e) What is the process in case of an EOS announcement
   f) How are LTB order sizes currently determined

2) Which issues have to be considered in defining a reverse logistics approach
   It has to be clear which issues have to be tackled, before it can be determined how Vanderlande can organize the reverse logistic process for their spare parts. The issues will be retrieved from literature and organized in the logical order in which they have to be tackled.
   a) What is considered to be reverse logistics
   b) Which issues are faced in determining a reverse logistics approach
   c) How are the issues addressed in the literature

3) How can the reverse logistics best be organized
   Based on the outcomes from research question 2, internal demands from Vanderlande and experiences from other companies an appropriate process has to be defined. In this plan also practical details have to be taken into account.
   a) How should the different issues be addressed by Vanderlande
   b) Who are the stake holders and who should be responsible
   c) How can this process be depicted in order to be easily understandable

4) How can the economic feasibility of reverse logistics be determined for a part
   It has to be made insightful when it is economically feasible to use reverse logistics. Therefore a method needs to be developed which can be easily applied on the different spare parts.
   a) Which costs components determine the total costs for supplying a spare part
   b) How can the cost per component be calculated
   c) How can this method be validated
   d) To what extent is the method dependent on uncertain variables

5) How can the findings best be implemented
   An implementation plan for introducing the repairs of broken parts and the improved model should be formulated, since it can be assumed that it incurs significant changes for Vanderlande as well as its customers, suppliers and third party service providers (e.g. parcel transportation)
   a) Which elements have to be included in the implementation plan
   b) How should the reverse logistics be implemented at Vanderlande
   c) How should the improved model be implemented at Vanderlande

2.6 RESEARCH APPROACH

In order to answer the research questions, different sources of information are used. For most questions interviews are used, either to get information about the current way of working, or for feedback on possible solutions. For these purposes also some other sources will be used, like the presentation about the SCMS department, the corporate website, intranet, the yearly report of 2011 and the master thesis of Lonneke Bakx. Furthermore, literature and company visits will be used to find state of the art solutions to the research questions. Hereby the experience from other companies and academics can be used.

2.7 OUTLINE OF THE RESEARCH

The rest of the research will be built up along the research questions. This means that in chapter 3 the current situation concerning the spare parts and their delivery, the return flows and LTB decision will be addressed. In chapter 4 a framework is defined which deals with important issues concerning the process of reverse logistics. Chapter 5 subsequently customizes the framework to the situation of Vanderlande. Chapter 6 focuses on determining the feasibility of reverse logistics, on a part level. A method should be developed to determine whether it is beneficial to take back a certain spare part from the field after it failed. Finally, chapter 7 will define an implementation plan and finish with some possible extensions of the reverse logistic process, which can be made in the future.

3 CURRENT SITUATION

In this chapter the current situation at Vanderlande is discussed. First the process of supplying parts to customers is studied. Subsequently the return flows that occasionally occur are described. Finally attention is paid to the process that is used to cope with an LTB announcement and the way the order size of an LTB is determined.

3.1 SPARE PARTS

Vanderlande develops large and complex systems. These consist of many different parts. In total over 800.0000 parts are stored in the ERP system. However, not all of these parts have to be available as spare. Most of the parts either do not to fail, or they are obsolete and only kept as historical data. Besides that there is a lot of data pollution of “fake” items that were created to test, or try something in the ERP system.

For this research data was used from 2010 and 2011, on the parts which are passing through the service central warehouse in Veghel. Currently 43.283 parts are in use as spare part. These parts range from simple bolts and nuts to complete engines and scanners. All spare parts are subdivided into categories along their condition at the end of their useful life. The categorization should be done before the completion of a project. The R&D department can indicate a spare part to be a consumable, which is consumed throughout its life, a durable, which is supposed to lasts the whole lifetime of the system, a repairable, which can be repaired upon failure, a wearable, which is assumed to wear out too much to be repaired and therefore becomes useless after its use, or a tool. It is remarkable that there are also parts which are indicated not be a spare, but are still sold as spare part. It concerns 2 percent of the spare parts in use. Another remarkable finding is that 24 percent of the spare parts are not categorized. This group represents 23 percent of the total cost price of the revenue.

In Table 1 the different spare part categories are shown. In the second column a short description of the category is given. The third column provides some examples of parts that fall in that group. The last three columns respectively indicate the total amount of spare parts in the category, the average value of a part in the category and the percentage of the (cost price of) revenue created by the parts in the group.

Group	Description	Examples	# Items	Ave. value (€)	% Tot. revenue
Repairable	Parts which can be repaired after they fail	e.g. (drum/gear) motor, electronic equipment (frequency regulators, LMS), rolls, different assemblies	5.511	416,70	11
Durable	Parts which are assumed not to fail	e.g. (linear) motors, metal frame components, covers	6.566	408,22	19
Consumable	Parts which are consumed throughout their lifetime	e.g. oil, greasing	175	12,78	1
Wearable	Parts which wear out too much to be repaired	e.g. rolls, motors, axles	19.400	104,15	43
Tools	Tools that are sold as spare part	e.g. jig, cutting tools, welding tools, tensioning tools	42	259,20	0
No spare	Are indicated as non spare, but still sold as spare	e.g. screws, spray cans, aluminum frames	1.282	243,35	2
Blank	Not categorized	-	10.307	176,81	23
Total	-	-	**43.283**	**211,28**	**100**

Table 1- Grouping of the parts in line with Vanderlande

With reference to the research topic, the categorization of the parts was discussed with the lead engineers. They explained that during the development of a system, in the first place they have to indicate whether a part should be marked as a spare part. This is the most important differentiation and a procedure has been developed for this. In case a part qualifies as spare part, the above categorization is made. This is no priority for R&D and is therefore merely based on their gut feeling, or copied from a comparable part. They indicate that there will be more parts technically repairable than currently categorized as "repairable". However, since they do not know when a part is repairable and what would be the consequence regarding the quality of the part after repair, they cannot give a further indication at this point.
Another important side note for the repairable parts is that some of them are already being repaired on-site. Most customers have a maintenance team that takes care of the system, either from Vanderlande, or their own. When a part fails they will repair it when possible. Parts that are repaired on site are mainly assemblies. The maintenance team replaces the whole assembly online and subsequently disassembles it off line. Then they replace the part in the assembly which actually failed and put it back together. Besides assemblies also the conveyor belts are repaired at some sites. The belts can be welded together if a special welding tool is available.

At this point, an upper and lower bound of the potential for reverse logistics can be derived. The lower bound assumes that only for parts which are currently indicated as repairable, reverse logistic is technically feasible. This leads to a lower bound, since the categorization is done very conservative and there are most likely more parts technically repairable than currently indicated. From the repairable parts, the lower bound assumes that only parts which have a value of 500 Euro or more are repairable against a profit. The value of 500 Euro is a rather arbitrary estimation from one of Vanderlande's managers with whom the feasibility was discussed. He indicates that for parts with a value exceeding 500 Euro, reverse logistics should result in a profit.
For the upper bound all parts are assumed to be technically repairable. For parts with a value below 100 Euro it is assumed that it will not result in a profit and therefore these parts are excluded. The value of 100 Euro is based on a discussion with a manager from Vanderlande. He assumes that a minimum of 50 Euro is spent on the repair and 20 euro on logistical handling. These numbers are based on his previous experience and conversations with suppliers. In that case only 30 Euro is left on a part of 100 Euro. From this €30 a discount has to be offered to the customer, since a repaired item is generally worth less than new one and an additional margin for Vanderlande has to be included for coordinating the whole process. This will not be feasible for part under 100 Euro.
Taking into account the unreliability of the categorization and the price at which reverse logistics is profitable, an upper bound and lower bound are established. Reverse logistics will be applicable on a minimum of 1323 parts and a maximum of 15.914 parts. This represents respectively 4 and 55 percent of the revenue that has been generated from the sales of spare parts in the fiscal years 2010 and 2011.

The difference between the upper and lower bound is large. In order to provide more clarity on the applicability of reverse logistics at Vanderlande, Chapter 6 discusses the feasibility of reverse logistics. Here both the economic feasibility and the technical feasibility will receive further attention.

3.2 SUPPLYING SPARE PARTS TO CUSTOMERS

The customers are provided with spare parts in different ways. With a new system they can chose between consignment stock and an initial spare part package. Consignment stock can be kept against a fee, either on site or in a warehouse close by the customer, but the parts will remain property of Vanderlande until they are taken into use. An initial spare part package is property of the customer and is bought together with the new system. For both options Vanderlande determines which spare parts are included.

When a customer uses parts from their stock position, they can place a replenishment order at Vanderlande. Replenishment orders are in some cases delivered from stock in the service central warehouse (SCW) in Veghel. When a part is not available from stock, Vanderlande first has to place the order with a supplier before they can be shipped to the customer. In most cases the suppliers send the orders to the SCW. Only in case of emergency a supplier can deliver straight to a customer. These different ways of supplying spare parts to the customers are depicted in Figure 3.

When a customer places a replenishment order, different actions have to be undertaken before the order is fulfilled. Figure 4 shows the process which is followed when a customer places replenishment order which cannot be fulfilled from stock. The different steps in the process will be shortly addressed in order to explain the activities.

Quotation – After a customer has contacted Vanderlande with a request for spare parts, they prepare a quotation and send it to the customer. The quotation is automatically generated by the ERP system (JD Edwards) and is composed of the lead time and the sales price for the order. In this price a mark-up for Vanderlande is included. All spare parts are stored in the system in 13 categories. For each category a mark-up is specified as a percentage of the purchasing price. These mark ups vary between low percentages for parts that are widely available to higher percentages for more unique parts. Parts from the Vanderlande brand have the highest mark up.

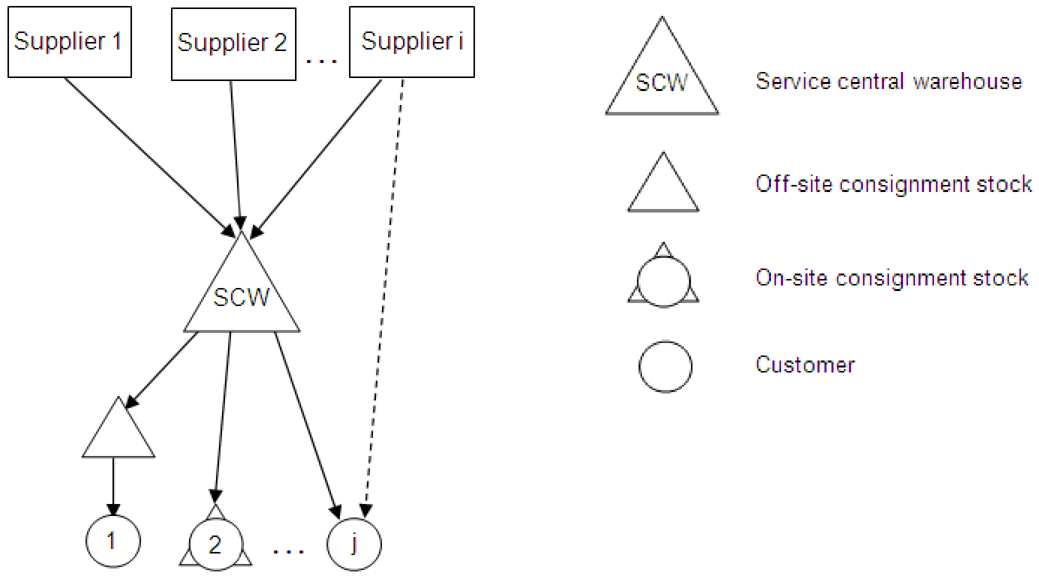

Figure 3 – The supply system of Vanderlande

The transportation costs are normally billed to the customer after the part has been sent and are therefore not included in the quotation. In the ERP system also the standard lead times are stored, so this can be communicated to the customer.

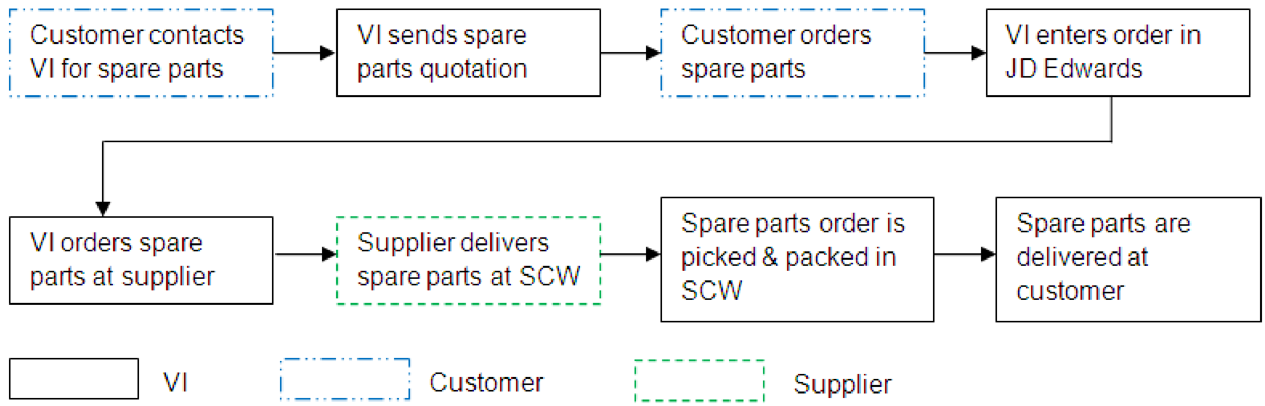

Figure 4 – The process of a replenishment order which is not available from stock

Enter order – When the customer has placed the order, VI enters the order in the ERP system by setting the status to “ordered”. Subsequently an order confirmation is automatically sent to the customer and the order is included in the planning.

Order spare parts – After the order is entered in the system and it is not available from stock, the spare parts are ordered from the supplier. Normally the required part(s) are ordered per email. In case the customer needs the parts faster than the quoted lead time, VI will contact the supplier by phone to discuss the options.

Picking & Packing – After the parts have been delivered to the service central warehouse (SCW), the order is picked and packed, so it can be shipped to the customer. The SCW is operated by DHL. They operate the warehouse, against a fee that Vanderlande has to pay. In total the SCW handles around half of the total orderliness. The rest of the orders are delivered directly from the supplier to the customer. [Volume spare part orders]

Send Order – The shipment of the order is done by an external transportation company. For most destinations there is a preferred company. For the other destinations a company is chosen based on price and past experiences.

The process that is described above is the standard process. In certain cases the process differs slightly. This occurs for instance when the system or the failure is too complex for the customer to manage. In this case, an engineer is dispatched to locate the broken part. After the problem has been found the customer can order the necessary spare part and the standard process is followed. After the part is sent to the customer, the mechanic visits the customer again to install the new part. However, most customers have their own technicians who can take care of the failures. Sending a mechanic to locate and remove a broken part is an exception rather than standard.

3.3 RETURNED MATERIALS

Occasionally parts are returned from the customer to Vanderlande. This happens exclusively on the initiative of customers. They return parts for different reasons:

- There was a mistake in the order which they received
- The part is broken and they want it to be repaired
- The part is broken and falls under the warranty

When a customer wants to return a part for either of these reasons, they have to notify Vanderlande. The notification comes in on a fixed phone number or email address, which is currently managed by someone from the SCMS department. He creates a service order header and asks the customer to fill out the return material authorization (RMA) form. In appendix A this form is shown. The part can then be sent to the SCW together with a copy of the RMA form. When the part arrives in Veghel, Vanderlande requests an RMA from the supplier in case the part needs to be repaired. Together with a filled out RMA form the part is then shipped to the supplier. Currently around 95 percent of the returned parts first have to pass through the SCW in Veghel before they are sent to the supplier. The reason for this is that Vanderlande is afraid that the customer will cut out VI and deal directly with the supplier next time when a part breaks down. In this case Vanderlande misses out on the markup they are receiving for the repairs.

After the supplier received the part, they check the broken part. If the part is repairable, they send a quotation to Vanderlande. VI forwards the quotation (including a markup) to the customer, who has to decide whether to accept or deny the quote. Depending on that the decision, the supplier sends the part back to Vanderlande, either repaired or still broken. Finally, Vanderlande ships the part to the customer, accompanied with an invoice for the costs that have been made. [RMA process]

When the RMA comes from a customer with consignment stock, the process becomes administratively more complicated. When the part is sent to Vanderlande, a new part from the consignment stock is installed in the system. After the broken part is repaired, the part should be added to the consignment stock under a different item number in the ERP system. The price of this item should then be set to the repair costs. This does not always go well and therefore it happens that the customer pays the price of a new part for the repaired one.

When a certain part is returned repeatedly, this can indicate a structural problem. Therefore it is important to analyze the RMAs, in order to find structural problems as soon as possible. However, a detailed overview of the RMAs is not available. Vanderlande does not register the RMAs in the ERP system, but in an MS Excel file. After the RMA is processed, it is deleted from the file. Therefore, analyzing the RMAs is difficult. Recurring RMAs have to be recognized from memory.

DHL keeps track on the amount of RMAs that have been received in the SCW and the amount of RMAs that have been sent to the supplier for repair. In Figures 5 and 6 the incoming and outgoing RMAs are shown for the last year. From these figures it becomes clear that the RMAs are not handled well, since over a period of one year 87 out of 261 parts remained in the SCW while they should have been repaired and sent back to the customer, or in case they were returned due to a wrong delivery, they could be added to the regular inventory. The reason that so many parts are not successfully handled is that no one is responsible for the RMAs and because of the low priority of RMAs.

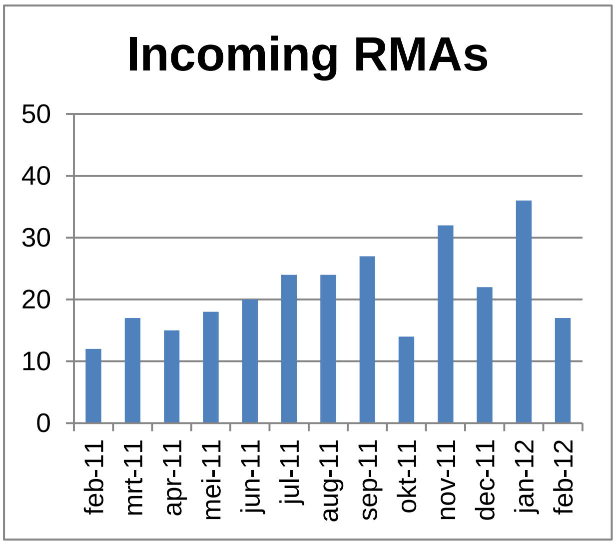

Figure 5 – Number of RMAs arriving at the SCW

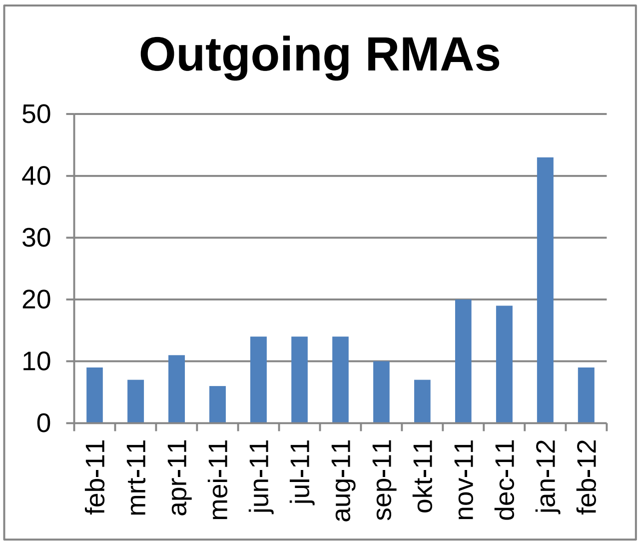

Figure 6 - Number of RMAs leaving the SCW

3.4 SUSTAINABILITY

Within Vanderlande there are currently already some initiatives for sustainability. The company has one person in charge of sustainability. This person has to organize and lead the efforts.
During the development of new products, the R&D department pays special attention to not use any materials that are harmful for the environment, or which are very scarce. A good example of such a development is the blueveyor. This is the newest conveyor belt in which unrecyclable materials, like PVC, are replaced with more environmentally friendly materials. Furthermore, it runs more energy efficient and weighs 80 kilograms compared to the 200 kilograms of its predecessor. This is one example of the cradle to cradle philosophy which Vanderlande is trying to implement.
Also in projects the cradle to cradle ideas pop up now and then. For instance when Schiphol ordered their new baggage handling system at Vanderlande, as much as possible of the old system was refurbished to save costs, as well as using materials and energy economically. However, this initiative did not come directly from Vanderlande. It was Schiphol who came with the idea and demanded Vanderlande to refurbish the old system. This shows clearly the lack of pro-activity for this topic. Similar to the case of returning spare parts for repair, the initiative has to be taken by the customer.

3.5 EOS PROCESS

An EOS can be initiated either by a supplier or by Vanderlande itself. For a supplier the reasons of the EOS could be the launch of a new version of the item, making a loss on the part, or a bankruptcy. Vanderlande can decide to announce an EOS when a part does not fulfill the quality requirements, when the conditions of supply become unfavorable or when the R&D department decides to use another part for a certain functionality.
An EOS can be identified by any employee of Vanderlande. When an EOS is identified, it should be reported to the item controller and an item change request form should be filled out. The item controller then accepts the EOS and changes the status of the part in the ERP system. He performs a quick scan to assess the severity of the problem and identifies the stakeholders. He then determines the planning for replacing the part and makes a draft of the phase out plan. After this he hands over the problem to the problem owner and the Steering committee Operational Products (SOP) team.

The problem owner coordinates actions for analyzing the problem in more detail and updates the phase out plan. He attempts to find a replacing item and checks the impact this item would have on the products and installed base. Hereby form, fit function plays an important role. This is the way the replacing item fits the current products. If it can be installed in the products without any adjustments and has the same functionality, the item satisfies the form, fit, function.

In case the proposed part does not respect the form, fit, function requirements, a solution has to be found. This is done by the problem owner and the SOP team. The solution could be to develop a work around to make the replacing item form fit function. Another option is to search for another part. In extreme situations it can be decided to make an LTB order for the rest of the service period.

From this procedure it becomes clear that the preferred option is to find a replacing part and that taking back failed parts, to give them a second life is not considered. This research aims to formulate an approach to reduce the LTB order by using reverse logistics. In order to fully implement it, this option has to be added to the EOS procedure.

When a solution is found or when the replacing item respects the form, fit, function, the problem owner informs the SOP team, writes an interchangeability document, initiates an items status in the ERP system, initiates stock taking for the new part and finalizes the phase out plan. He finally hands over the responsibility for making sure the new item can be used to the product manager services, the product manager engineering and the item controller.

Based on the solution that is decided on, an LTB order has to be placed. When a replacing item would be immediately available and it has no lead time, an LTB order is not necessary. In all other situations there exists time between the moment the original part is EOS and when the replacing part becomes available. This time is called the required transition time (RTT) and demand during this period has to be covered with an LTB order. The next paragraph summarizes the model that is currently used to determine the size of the LTB order.

3.6 LTB ORDER SIZE

In a previous research a model was constructed to determine the optimal LTB order size. This model was specially developed for Vanderlande and took into account the substitution of items, a service level and an uncertain transition time with a bounded distribution (Bakx, 2010). The model was defined as a dynamic programming (DP) problem. Multiple versions of the model were developed, in order to allow for a situation where the original part can be used after the RTT and where it cannot.

Furthermore there is a version which includes a remove down to level. This means that when the inventory level is above a specified amount at the end of a period, this excess inventory should be removed. In this paragraph the model is explained, where the original part cannot be used after the RTT and where there are no remove down to levels. In appendix B the used notation is shown and appendix C discusses this model in more detail. For the other models the reader is referred to Bakx (2010).

The model results in the optimal value for the LTB order size (Q), the corresponding fill rate and total estimated costs. The optimal order size is determined by calculating the total estimated discounted costs and fill rate for a given LTB order size (Q). It then iteratively increases Q by one item at the time, until the fill rate is equal to or larger than the desired fill rate. Since the costs increase with Q, the first solution which fulfills the fill rate requirement is the optimal solution. The solution is allowed if it is also larger than the minimum order quantity (MOQ) and a multiple of the batch size (BS_s).

The objective function for calculating the total costs is:

$$E[TC(Q)] = \sum_{t=minRTT_a}^{EOL} E'[TC(Q,t)] * P(RTTa = t) + \sum_{t=EOL+1}^{maxRTT_a} E'[TC(Q,t)] * P(RTT_a = t)$$

Where:

E[TC(Q)] = the total expected discounted cost during the entire planning horizon for a final order quantity that is equal to Q

E'[TC(Q,t)] = the total expected discounted costs for a final order quantity Q given the required transition time (RTT) equal to t

EOL = the End-Of Life (service) length of the planning horizon (#periods)

Min RTTa = the minimum required transition time for a given alternative a (#periods)

Max RTTa = the maximum required transition time for a given alternative a (#periods)

Put in words, the total costs with unknown RTT are made up of a summation of the total costs per possible length of the RTT (measured in t), multiplied with the possibility that the RTT is t. The summation is split in two, since there is a difference in the calculation between an RTT that is smaller or equal to the EOL and one which is larger.

In the total costs the holding costs, disposal costs, setup costs and the costs of purchasing both the original and the replacing parts are considered. All costs are discounted against a continuous discount rate α.
For calculating the fill rate the following formula is used:

$$Fill\ rate = 1 - \frac{Expected\ number\ of\ out - of - stocks\ during\ the\ RTT}{Expected\ demand\ during\ the\ RTT}$$

3.7 CONCLUSIONS

In this chapter the current situation at Vanderlande has been reviewed and important information has been found. This paragraph will sum up the most important findings.

From the revenue generated by spare parts (8,3 mil), 11% comes from repairable spare parts (0,9 mil).
Only sales which passed through the SCW are included in these numbers. These are the sales which SCMS can influence and therefore most interesting for this research.
The share of repairable parts is larger in reality, since not all parts are categorized. Moreover, among the parts that are categorized, some are simply said not to be repairable even though they are. Among the repairables, there are 4717 parts with a cost price over 100 euro. 100 euro is considered the lower boundary with respect to economic feasibility.

Last year 261 parts were returned for repair, on the customer's initiative, of which 34% not handled.
No one is responsible for the returned parts and therefore it is not a priority at SCMS. Also there is no clear overview of which parts have been returned and which are handled.

There is a tool to determine the LTB order size, but the option of repair is not (yet) considered.
In a previous research a tool has been developed which can determine the LTB order size in case of an EOS. Since Vanderlande does not use reverse logistics yet, the tool does not include this option in the calculations.

4 ISSUES IN REVERSE LOGISTICS

This research has to define a holistic approach for the organization of the reverse logistic process for spare parts of Vanderlande, as well as a method for indentifying for which parts reverse logistics is feasible. In this chapter, as well as the following, the focus is on the process. It aims to identify the different steps in a reverse logistic process. For every step, the issues that have are faced should be discussed. Together, the issues should form the organization of reverse logistics. Before this can be done, the chapter looks at the general process of reverse logistics, to get a better picture of what is involved with it. The chapter will start with a brief introduction of the concept reverse logistics.

4.1 INTRODUCING REVERSE LOGISTICS

Reverse logistics is a relatively recent addition to the field of supply chain management. Previously, supply chain management was only concerned with the coordination of activities that were necessary to get products to the consumers. Reverse logistics increase the scope to also encompass the activities which are necessary to take back the products from the consumers for reprocessing or proper disposal.

“Reverse logistics was first mentioned in the early 1990s. Two papers about reverse logistics from the American GLM (Council of Logistics Management) mark the start of research into reverse logistics.” (Xu and Zhou, 2011). From that moment on, the interest in reverse logistics from the academic world as well as the corporate world has been increasing. For the corporate world there are different motivations mentioned for engaging in reverse logistics. These can be summarized in four groups (Fleischmann, 2000).

- Economical — It can be economically beneficial to give products, parts or materials a second life and thereby saving costs
- Market triggers — On the one hand, growing competition may force companies to take back and refund excess products from their customers. On the other hand, used product take-back and recovery is an important element for building up a `green' profile, which companies are increasingly paying attention to.
- Regulation — Extended producer responsibility has become a key element of public environmental policy in several countries. In this approach manufacturers are obliged to take back and recover their products after use in order to reduce waste disposal volumes.
- Asset recovery — Companies seek to prevent sensitive components from leaking to secondary markets or competitors. Moreover, potential competition between original `virgin' products and recovered products is avoided in this way.

The increase of interest from the academic world is shown in Figure 7. There, the amount of papers published per year between 1995 and 2005 are shown, based on a study of Rubio et al. (2008).

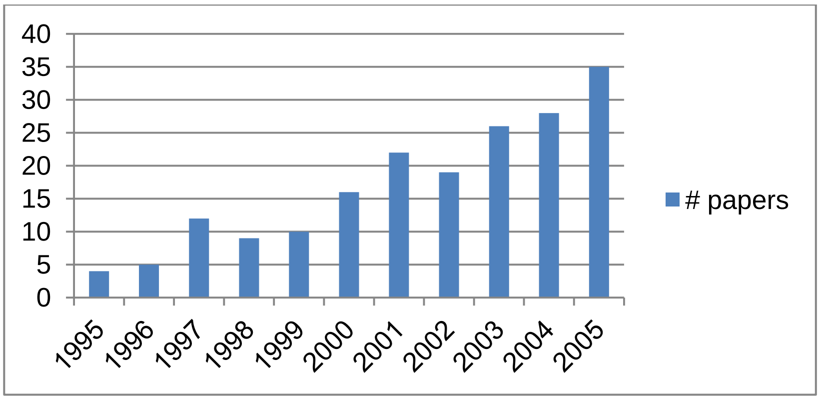

Figure 7 – Amount of papers written on reverse logistics per year

In the current body of literature there are many different definitions of reverse logistics. The first known definition of reverse logistics was published by the Council of Logistics Management in 1992 (de Brito and Dekker, 2003a). From there on, the definition developed over time until Rogers and Tibben-Lembke (1999) defined reverse logistics as *"the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal"*. This became a widely accepted definition and is the one which is currently used by the Council of Logistics Management. Also in this research this definition is used.

4.2 FRAMEWORK FOR REVERSE LOGISTICS

This paragraph has to provide a picture of the reverse logistics process. The reason for this is to get a good understanding of the process, which will make it easier to identify the issues that will be encountered and to divide them into a stepwise manual. In order to create this picture a framework is sought that considers the complete process of reverse logistics.

From the available frameworks there are some that are focused on a part of the issues, like network design and inventory management (Fleischmann, 2000), or general management issues (Bernon and Cullen, 2007). Other models, put more stress on the relation to the forward supply chain and the point of recovery, but neglect the activities that are necessary to get there (Thierry et al., 1995; Guide et al., 2000; Krumwiede and Sheu, 2002; Jayaraman et al., 2008; Srivastava, 2008; Lee and Chan, 2008; Zhou and Wang, 2008).
Finally there is a group of frameworks, which address reverse logistics as a separate process and focus on the different activities which are performed (Kokkinaki et al., 1999; Guide and van Wassenhoven, 2001; Koster et al., 2002; De Brito and Dekker, 2003a; Srivastava and Srivastava, 2006; Kim et al.. 2006; Pokharel and Mutha, 2009). The “process approach”, which is taken by this last group, takes the whole process into account, from the moment goods are returned until their re-use. Therefore, it fits to the purpose of this research. In appendix D the graphical representations of the retrieved frameworks are shown.

A closer look at this group of frameworks shows that they overlap to a great extent. In most frameworks, the returned goods are collected and separated, before they undergo a form of re-processing and/or disposal and finally find their second life.
In the frameworks, the reverse flows originate from either, the customers (Srivastava and Svrivastava, 2006; Kim et al., 2006), the market (De Brito and Dekker, 2003a), or the origin is not named (Kokkinaki et al., 1999; Guide and van Wassenhoven, 2001; Koster et al., 2002; Pokharel and Mutha, 2009).
In most frameworks the first activities are the collection and inspection/selection/sorting of the returned goods. Only Guide and van Wassenhoven (2001) do not mention the collection and Kim et al. (2006) leave out the sorting.
After sorting most models go straight to re-processing and/or disposal. Only Kim et al. (2006) distinguish a disassembly step, for goods which cannot be remanufactured as a whole. For the re-processing, all models include one or more of the recovery options of Thierry et al. (1995). Re-processing is therefore used here as an umbrella term for all different recovery options.
After re-processing Kokkinaki et al. (1999) address the redistribution of the goods before they are used again. The other models skip this step and go straight to the second life of the product. The second life is indicated differently by the models. De Brito and Dekker (2003a) argue that re-use happens in the market; Srivastava and Svrivastava (2006) differentiate between the primary and seconds’ market. Kim et al. (2006) send the re-processed parts first to the part inventory before it enters the forward supply chain again from manufacturing. The remaining models do not specify where the re-use takes place (Kokkinaki et al., 1999; Guide and van Wassenhoven, 2001; Koster et al., 2002; Pokharel and Mutha, 2009).

Based on these existing frameworks, a general reverse logistics process was constructed. The different activities that are included can be directly related to the existing frameworks. In addition, extra stress is put on the exchange of information and finances throughout the process. This is done, because many issues can be grouped in these flows. Moreover, in supply chain management it is already common to distinguish also these two flows besides the flow of physical goods (Mentzer et al., 2001).
The result is the framework which is graphically shown in Figure 8 and will now step by step be clarified.

4.2.1 Explanation of the process

The reverse process is triggered by an actor in the forward supply chain who wants to return goods. This can be done by practically any actor in the chain.

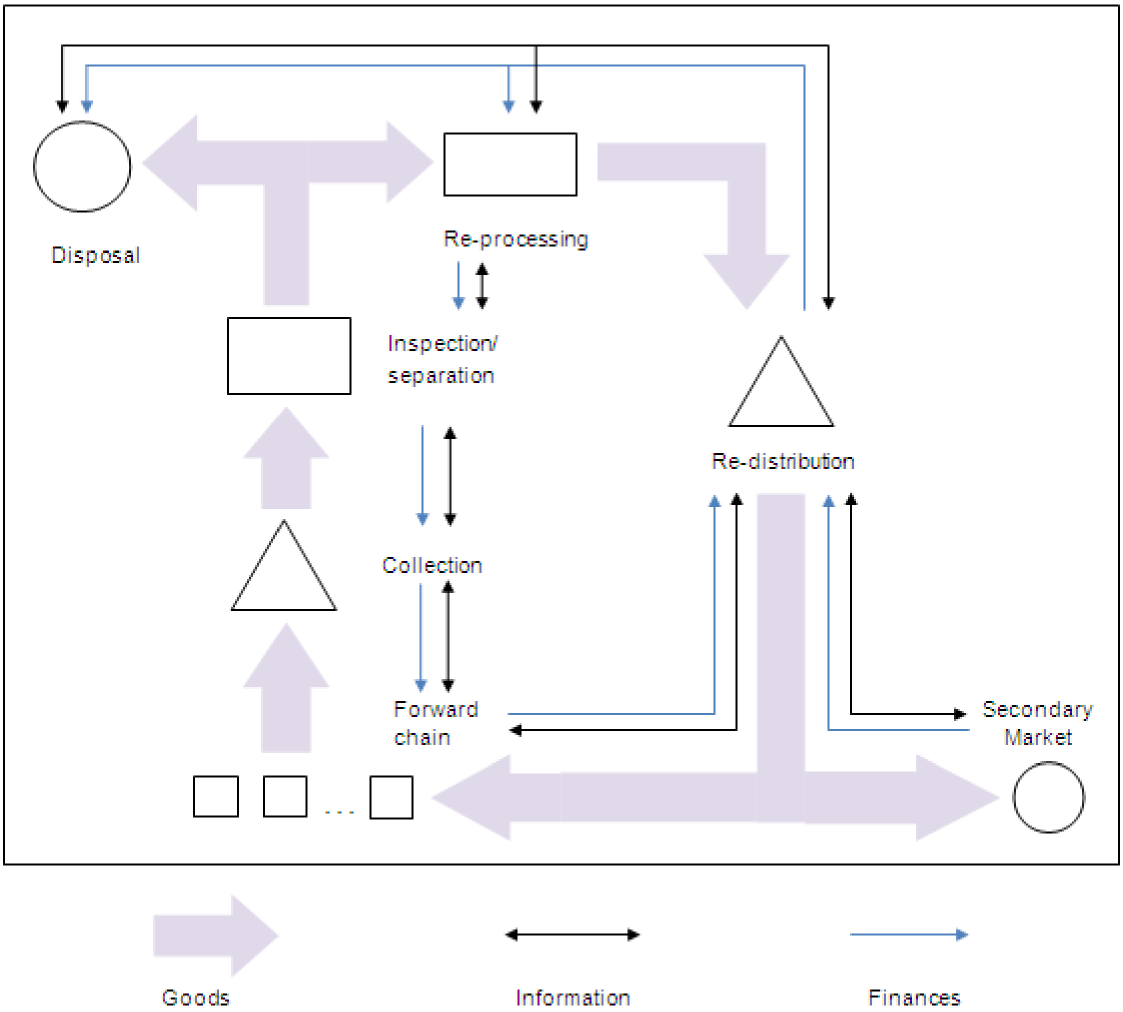

Figure 8 – General reverse logistics process

The returning goods first have to be collected. This is done at a collection center. The goods can be brought there by the returning party, or they can be picked up. Hence, arrangements have to be made within the supply chain, when and how the goods are going to be transported. In order to return the goods, an incentive is needed. This incentive is often financial and can be paid by different actors in the process. For the sake of generality, the finances flow between subsequent activities.

After being collected, the goods have to be inspected, to determine the degree of disassembly that is necessary in the re-processing. The inspection can be done at the collection center, but if the required knowledge is not available, the parts have to be shipped somewhere else.

After the inspection there are two options shown in the model; disposal and reprocessing. This is a rough division of the seven options that were identified by Thierry. In the framework, the first five are considered as re-processing and the last two as disposal. The options are ordered in the required degree of disassembly (Thierry et al., 1995).

1- Direct re-use (re-processing)
2- Repair (re-processing)
3- Refurbishment (re-processing)
4- Remanufacturing (re-processing)
5- Cannibalization (re-processing)
6- Recycling (re-processing)
7- Incineration (disposal)
8- Land filling (disposal)

Before re-processing the goods, Kim et al. (2006) distinguish a disassembly step. Here this step is not included. It is assumed that during the re-processing the goods are disassembled to the required level in order to perform the needed re-processing activities.

After re-processing the goods are ready for re-use. The goods can either go to the original customers, or be sold in a secondary market. The latter one is defined by Srivastava and Srivastava (2006) as "an outlet for sale of repaired and discounted goods". Here the goods can be sold with lower quality than is demanded in the original market. Before the goods can be re-used they have to be re-distributed. This can be integrated with the forward supply chain, but it is also possible to treat the re-processed goods separately.

4.3 ISSUES IN SETTING UP A REVERSE LOGISTICS PROCESS

In the previous paragraph a framework has been defined which shows a general reverse logistic process. Vanderlande wants to deploy a similar process in order to take failed spare parts back from the field for repair. In order to use re-processed parts as a source of supply, the process of reverse logistics needs to be organized. For an arbitrary part, determining the process can be done in four steps.
First of all, the network design has to be defined. This determines the rough lay out of the reverse logistics network. The second step is the organization of the goods that move through the network. The third step takes care of the practical organization and defines the information that should be shared and captured in the network. The final step determines the size and timing of financial transactions that take place during the process.

The different steps will now be treated in order to uncover the issues that are encountered. Thereby, in the end of each step, the applicability to Vanderlande will be discussed. An overview of the different issues is given in Table 2. The issues that are not relevant to Vanderlande at this point will be marked with a red font.

4.3.1 Network design

The network design has to be determined first when setting up reverse logistics. Network design revolves around determining the **location** and **capacity** of the facilities in the reverse network, and the **allocation** of goods to the different facilities (Fleischmann, 2000). The facilities include, collection points, separation facilities, re-process facilities and warehouses for re-distribution. In the literature there is a large variety of models that can solve these location/allocation problems for different assumptions and restrictions. Generally, the models are mixed integer formulations (e.g. Zhou and Wang, 2008; Fleischmann, 2000; Srivastava 2008; Krikke et al., 1999; El-Sayed et al., 2010; Pishvaee et al., 2010).

In addition to what is considered to be network design, three issues are added to this first step. First is the decision, if and where to perform the repair. It could for instance be that a certain assembly can economically better be repaired on site than at a supplier's site. For products consisting of multiple indentures, this problem has recently got increasing attention in the literature under the name "level of repair analysis", or "LORA" (Basten et al., 2009). A LORA aims to minimize the life cycle costs by optimizing the repair decision for products consisting of two or more indentures and have two or more possible repair locations (Gutin et al., 2006). For this problem different IP models have been formulated, which all take into account different constraints and assuming different situations (Alfredsson, 1997; Barros, 1998; Barros and Riley, 2001; Saranga and Dinesh Kumar, 2006; Basten et al., 2009; Basten et al., 2011a; Basten et al., 2011b; Basten et al., 2011c).

Secondly, the **in/outsource decision** is added. This decision is concerned with outsourcing the entire, or part of the reverse logistics to a specialized company. There are companies which can take care of parts of the logistic activities, e.g. transport and warehousing. These companies are called third party logistic (3PL) providers (Vasiliauskas and Jakubauskas, 2007). In case a 3PL provider is used, the management of the process is still a responsibility of the original equipment manufacturer (OEM). Nowadays there are also companies which can take care of the management and aligning of the different logistic activities in reverse logistics. Those companies are called 4^{th} and 5^{th} party logistics (4PL/5PL) providers (Vasiliauskas and Jakubauskas, 2007). Besides outsourcing the logistics itself, the OEM has to consider whether they will re-process the goods themselves or let suppliers or other specialized companies perform the re-processing.

The third issue which will also be considered in the network design is the **routing** of the transportation between customers and the collection centers. For the routing problem there exist many models, since this is similar to the routing issue in forward logistics. Moreover, new models have been developed for simultaneous delivery and pickup (e.g. Gajpal and Abad, 2009; Alshamrani et al., 2007).

Vanderlande
As mentioned in the previous chapter, Vanderlande has already outsourced the transportation as well as the warehousing to a 3PL provider. At this point it is not preferable to change the current outsourcing policy and therefore these reverse logistic activities will be added to the current portfolios of their partners. Re-processing will also be outsourced, because Vanderlande does not possess the required knowledge and resources to in-source this activity. However, the coordination of the process will be done by Vanderlande, in order to keep control over their supply chain. Therefore the outsourcing decision will not form an issue at this point.

Since all re-processing will be done at the supplier's site, LORA is not applicable to this situation anymore since there is only one repair site. Therefore, LORA does not form an issue at this point in time for Vanderlande. This decision can be challenged in the future and Vanderlande could reconsider re-processing parts at different echelons.

Srivastava and Srivastava (2006) indicate that the network design (facilities and allocation) is the most important step in setting up reverse logistics. However, this is based on a business to consumer (B2C) environment. In that case the installed base is much dispersed and volumes are generally high. An efficient network design can then result in great benefits. In a business to business (B2B) environment, which generally has a smaller installed base, the network design is of less importance. Since Vanderlande operates in a B2B environment and the volumes of their spare parts are relatively low, the network design is of less importance for this research. With the same reasoning also the issue concerning the routing does not apply to Vanderlande.

Network design	Goods flow	Information flow	Finance flow
In/Outsource decision	Choosing control policy	Information sharing	Financial transactions
Determining facilities	Setting parameter values	Information capturing	Timing
LORA		Information analyzing	Quantity
Allocation of goods			
Routing of transportation			

Table 2 – Overview of the encountered issues

4.3.2 Goods flow

When the network design has been determined; the goods flows have to be addressed. In Figure 9 an overview of the movements of the goods is presented. The parts return with an arrival intensity "R" at the collection point (1). The parts are then first tested whether repair is possible and if not, they are disposed. Subsequently the "good" parts are re-processed and moved to the serviceable inventory (2), ready for re-distribution. In case there are not enough failed parts at the collection point, additional parts have to be ordered to fulfill demand, "D". Therefore the serviceable inventory consists of both re-processed and new parts.

An inventory control method has to be determined, which should dictate the timing and quantity in which new orders and the parts at the collection point move to the serviceable inventory. The different issues which are encountered during this step are briefly discussed below.

In order to define an inventory control method, there are two issues which need to be tackled; **choosing an inventory control model**, and **setting the parameters** for the chosen policy (Kiesmuller and Minner, 2003). An inventory model indicates when goods need to be moved to the next station and in which quantity. This is often done through different parameters. These parameters can be an order-up-to-level (S), a reorder point (s), a review interval (r), an order quantity (Q), or a combination of these. In some models also a remove-down-to-level is used, which indicates a maximum inventory level. In case the amount of parts exceeds this level they will also be disposed. Together with Vanderlande it has been determined not to use this parameter, since the amount of returns will not be that high.

There are roughly two types of inventory models; Deterministic models, which assume that information, like demand and lead times, is fixed, and stochastic models, which assume this information to be variable (Dong et al., 2005). The stochastic models can be further divided between periodic review, where stock levels are reviewed after a certain period; and continuous review period where the stock level are considered every time a mutation occurs (Dong et al., 2005).

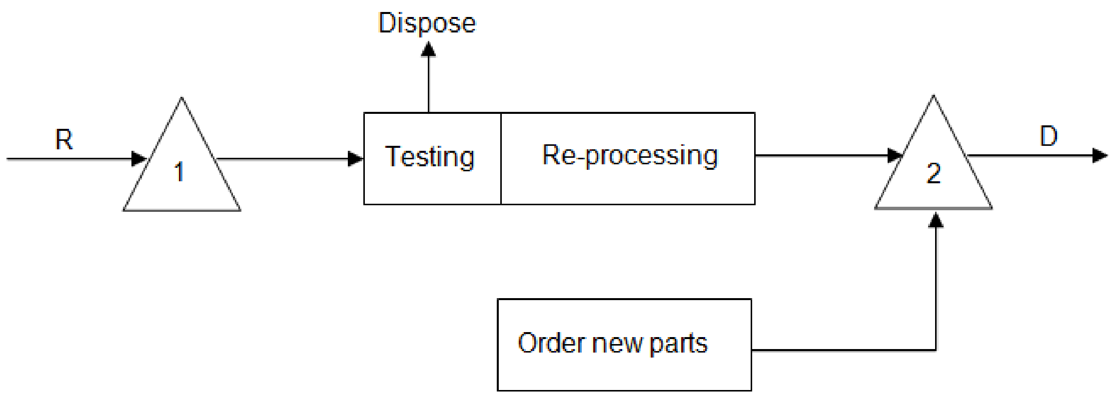

Figure 9 – Overview of the good flow

Different inventory models have been proposed and tested. The models are characterized by a combination of assumptions. These assumptions relate for instance to the “supply chain structure (single stock point, multi-echelon network), performance evaluation (cost structure and service measures), the demand process, the return process (its relation with the demand process, both processed may be independent or show some correlation, e.g. through a time lag: this factor is tightly linked to the type of return flow considered) and the re-entry point of returns in the supply chain (direct reuse, remanufacturing, recycling)” (Dong et al., 2005). Under certain assumptions, an optimal inventory model has been proven. Therefore an optimal inventory model is easily determined, when a previously researched set of assumptions holds for the good flow under consideration.

After the inventory model has been determined, the parameter values have to be set. Depending on the model, this can be relatively simple, but also complicated and time consuming. There are, for instance, different models that are based on EOQ (economic order quantity) calculations (Bruzzone et al., 2010). For those models, the parameters are easily determined. Contrarily, Van der Laan and Salomon (1997) consider models for which they derive the optimal parameter values by using a Markov chain approach. This is a complicated and time consuming calculation (Kiesmuller and Minner, 2003). Therefore, both the accuracy and the complexity of the calculation have to be considered when the parameters have to be set.

Vanderlande
It is important for Vanderlande to determine an inventory control method. Currently they do not have experience with returned parts and do not know how to deal efficiently with these goods. Therefore, these two issues are important to Vanderlande and will have to be addressed in the next chapter.

4.3.3 Information flow

After the physical aspects of reverse logistics are determined, the information flow has to be addressed. This includes more practical issues like what type of information should be shared, at what time and by whom. Information also has to be captured in order to enable analyses on the network performance as well as gathering and analyzing data to improve the final product, the material handling systems. For all issues concerning the information flow, it is important that the IT implementation is considered as well. The information should be centrally handled and available in the ERP system.

The first issue is concerned with **information sharing**. According to Daugherty et al. (2002), information support is especially important in reverse logistics operations, because "managers may not know when (or if) products will be coming back, they must be prepared to quickly process and handle the products on demand. Thus, prompt and accurate exchange and access to information should be considered a top priority".
In order to facilitate the prompt and accurate exchange of information, it has to be decided what information should be shared, at which time and by whom. The exchange of practical (administrative) information is studied by Parlikad and McFarlane (2006) and Lee et al. (2002). Lee et al. (2002) indicate that the information that is shared should be comprehensive. Therefore it is communicated through an RMA form, similar to the one which is currently used. On the RMA form, the information has to be filled briefly and clearly, to keep the communication efficient. In Appendix E a list of the required information is presented. Since information has to be added throughout different steps in the process, it is also indicated who is responsible for adding the correct information on the form.
Besides the administrative information, information is needed to coordinate the logistical process. This starts with the distinction between a rush order and a replenishment order. This will determine the priority that is given to processing the order. Secondly visibility of demand data and inventory allows different partners in the process to update their forecast (Simatupang et al., 2002). Finally lead times have to be clearly communicated so everyone knows when to expect certain orders.
Determining the timing of the information; is a relatively practical question and therefore no research has been done on this account. For this matter, a structured approach needs to be taken. This is preferably done by using a flowchart to displays the exchange of information between different actors and the triggers that induce the transfers.

The second issue is **information capturing**. Besides sharing information, it has to be captured for analyzing purposes. Capturing information from the reverse process facilitates both product and process improvements. According to Tibben Lembke (2002) information should be collected to help identify common problems with the returned products. The type of data that should be gathered for this is technical and statistical failure data (Tibben Lembke, 2002).
Capturing information on the statistics of the process is valuable feedback for the production and engineering and helps to create more accurate forecasts and supports the optimization of stock replenishment quantities. For process improvements the content of the data which should be captured is not explicitly mentioned, but useful data could be; throughput times at the different activities, actual cost, demand rates and return rates. Also CO_2 emissions and other environmental statistics could be collected to analyze the benefits of the reverse logistics for the environment.

After capturing the information it has to be **analyzed**. The analysis should result in improved forecasts, processes and products. Therefore, companies need to develop "data management capabilities, i.e., be able to integrate manufacturer and retailer data, create invoices, generate store credits, detail accounts receivable, and issue management reports. Finally, companies must be able to strategically apply the information gathered to streamline internal processes and support supply chain-level planning" (Daugherty et al., 2005)

Vanderlande

The issues connected to this step have a high priority for Vanderlande. They have indicated not to know exactly how they can get the right information, at the right time, at the right person Also identifying which data should be captured is an issue that has to be addressed. For both issues, it needs to be clear how this can be enabled in the ERP system. Therefore the issues in this step will all be treated in Chapter 5.

4.3.4 Finance flow

The final step in formulating a reverse logistics approach is determining the financial flow. This step should provide insight in the financial transfers that are occurring in the reverse logistic network. It should be determined which financial transfers should take place, the quantity and the timing of the transfers.

In the process that was constructed at the beginning of this chapter the **financial transactions** are indicated to occur between the consecutive activities, opposite to the direction of the goods. Hereby the costs of an activity are charged to its successor. This implies that the activities are all performed by different organizations, who all buy the part from their predecessor. This situation is not desirable for Vanderlande, because they want to keep the property rights. Therefore the finance flow will deviate from the flow shown in Figure 9. Because the parts remain property of Vanderlande, they will receive the revenue from selling the re-processed parts, and will pay the other organizations for their services. Vanderlande will therefore be involved in all financial transactions. One extra transaction can be added, in case Vanderlande wants to use a financial incentive for their customers to return their failed parts. They could offer their customers a compensation fee for returning the failed part (Guide et al., 2003), or encourage returns by using a deposit (Goldsby and Closs, 2000).

The **timing of the financial transactions** has to be arranged between Vanderlande and the organization which provides a service. Payment can be done periodically or per every service provided. Moreover it has to be specified whether they pay in advance or afterwards. The same applies to the financial transactions between the customer and Vanderlande, in case a customer buys a re-processed part as well as when Vanderlande transfers a compensation fee for a returned part. These arrangements can be contractually determined or with a gentlemen's agreement.

The **quantity of the financial transactions** can be either a fixed fee per service or period, or it can be variable. The price of transportation could for instance depend on the price of fuel, or a quantum discount can be received over larger batches.
Concerning the quantity of the financial flows, Vanderlande has to determine the price of a re-processed part. Kotler (2000) mentions 7 different methods to determine the price of a product. From these methods there are three that could be suitable for re-processed goods at Vanderlande.

Markup pricing	This is the method which they currently used by Vanderlande for their spare parts. Hereby, the cost price is increased with a mark up.
Perceived value pricing	This method bases the price on the perceived value of the customers. This means that you avoid the risk of setting the price higher or lower than what the customers want to pay for it.
Value pricing	This method charges fairly low prices in order to create loyal customers.

Determining the size of a financial incentive for returns is fairly complicated. It should be high enough to convince customers to return their failed parts, but it should be as low as possible to optimize the profit. At the same time returned parts are of different quality. Therefore fees might be influenced by the quality of the returned part.
Michaud and Llerena (2006) indicate that the right incentive depend on the perception of the customer. They call it the willingness to receive. However, it is not mentioned how this should be measured.
Guide et al. (2003) develop a framework for determining optimal acquisition prices of used products. Hereby they take into account both the acquisition price and the sales price. Hereby they assume the reaction of the customer to a certain price as a given.
Klausner (2000) considers different relations between parameters influencing the acquisition price. Based on these relations he optimal acquisition price can be determined.

Vanderlande

For Vanderlande it will not be an important issue to identify the different transactions and also the timing of the transactions will not be significantly different from the current business practice. In contrast, the quantity of the transactions with the customers, do form an important issue for Vanderlande. They do not have any experience with selling re-processed goods or acquiring failed parts. Both the sales as well as the acquisition price form therefore important issues for Vanderlande and in the next chapter it will be addressed how Vanderlande should set the price for re-processed parts, as well as how they can determine the compensation fee towards their customers.

4.4 CONCLUSIONS

In this chapter the second research question has been addressed. The conclusions which can be drawn are as follows.

Four steps define the process; Network design, Goods flow, Information flow, and the Finance flow.

The reverse logistic process can be split up in the following four steps. The network design determines the rough lay out of the reverse logistics network. The goods flow dictates the timing and quantity in which the goods move through the network. The information flow takes care of the practical organization and defines the information that should be shared, captured and analyzed in the network. The finance flow determines the size and timing of financial transactions that take place during the process.

An inventory control model has to be chosen and parameters have to be set

For Vanderlande it is important that they know how to decide when parts have to be repaired in order to fulfill demand in time. In both Dong et al. (2005) and Bruzzone et al. (2010) literature reviews can be found for inventory models with remanufacturing.

It has to be made specific which information has to be shared, by whome and at what time

In order to coordinate the process, effective communication of information needs to take place. Therefore it needs to be clear which information needs to be communicated, when it should be communicated and by whome. Additionally, the flow of information should be enabled in the ERP system.

It should be indicated which information has to be collected and how this can lead to improvements

In order to evaluate the process, information needs to be collected. Based on the results of the evaluation, action might be undertaken to improve the process, or the product. It has to be made clear which information has to be collected, how this can be done and how this information should be interpreted.

The price of re-processed parts should be determined as well as the compensation fee to customers

Since Vanderlande does not have experience with selling re-processed goods, they do not know what would be the best method to determine the price of the re-processed parts. From the work of Kotler (2000) different pricing strategies have been retrieved. Secondly a compensation fee might be paid to customers for returning their failed part. This would be fair since it is their property and apparently there is economic value left in them. However, also for this, Vanderlande does not know how to determine the right amount.

5 REVERSE LOGISTICS APPROACH FOR VI

This chapter specifies how Vanderlande could organize the reverse logistics process for a certain part. Hereby it is assumed that reverse logistics is feasible for the part. This assumption will be further challenged in the Chapter 6. Chapter 5 addresses the issues that were identified in the previous chapter. Hereby the network design is considered to be fixed, since it was concluded in the previous chapter that this is not a relevant issue for Vanderlande, at this moment. Nevertheless, a brief overview of the network design will be presented for informative reasons.

5.1 NETWORK DESIGN

Because the network design and the in/outsource decision are currently not relevant issues for Vanderlande, the situation is mirrored to the forward supply chain. This means that the collection, re-processing and redistribution activities are performed by the same partners who take care of transportation, warehousing and manufacturing in the forward supply chain. Besides the fact that it can enhance the relationship with the current partners, it is practical for Vanderlande and minimizes the required efforts that would have been needed to start new business relationships.
The network design, based on the current situation, is graphically shown in Figure 11. The SCW will serve as collection point and for the redistribution facility. Furthermore the factory of the supplier is the re-process facility.

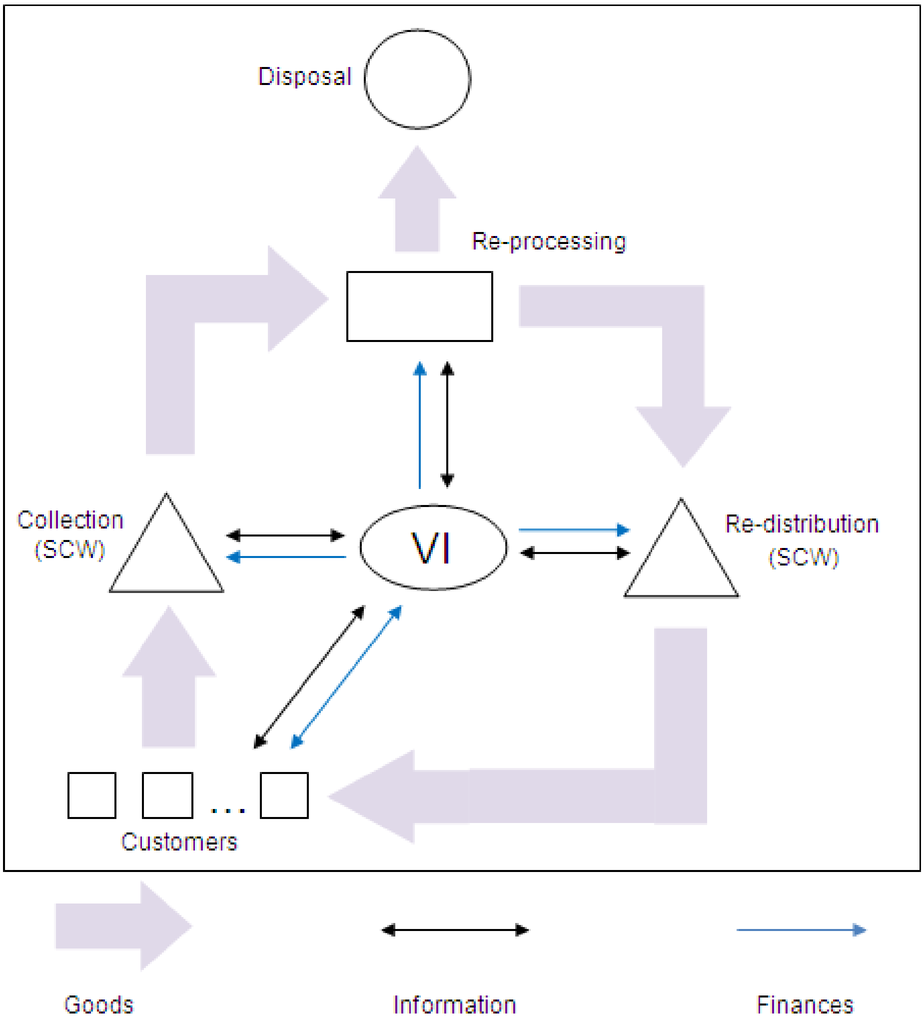

Figure 10-Network design for reverse logistics at Vanderlande

5.2 GOODS FLOW

In the second step it has to be determined how to control the flow of goods throughout the reverse logistics network. Therefore the inventory control model has to be determined as well as the parameters for the model. The inventory model has to control the decision to repair failed parts and order new parts. The returning failed parts are not included in the inventory model. Returns are considered to take place at the earliest possible moment. The following paragraphs will treat the inventory model that should be used and its parameters, respectively.

5.2.1 Inventory model

In the previous chapter it has been mentioned that under different assumptions, optimality of models has been proven. In case these assumptions hold for Vanderlande, the associated model will be optimal for Vanderlande. However, certain assumptions which are often used in the literature cannot be applied to Vanderlande. For instance, most models assume that demand and returns are independent. At Vanderlande there will be a correlation, since failed parts will be returned with the same shipment the new parts arrive. Also, whereas re-processing and procurement lead times are often assumed zero, this does not apply to the spare parts of Vanderlande. Most parts have a significant lead time. Finally, most models use backorder costs as part of the performance evaluation. For Vanderlande this is not possible, since the costs of a backorder cannot be estimated (Bakx, 2010). These three characteristics form a combination which has not been researched yet (Dong et al. 2005; Bruzzone et al. 2010). Therefore no optimal model is available from literature.

Since proving optimality for an inventory model does not belong to the scope of the research, an inventory model will be determined without proof of optimality. However, this model has to result in an efficient flow of parts throughout the network.

Van der Laan and Teunter (2004), provide different heuristics for the inventory policy with reverse logistics. They describe both a push and a pull policy for controlling the re-processed parts. Unfortunately they use backorder costs in their approach and therefore the policies cannot be directly copied. However, in line with Van der Laan and Teunter (2004), different strategies are proposed for the re-processed parts. Additionally to the push and a pull model which they use, a re-process to order model is formulated which does not keep any serviceable inventory. Since Vanderlande uses a wide variety of spare parts, the model which is preferred, might depend on the type of part.

All of the models consider two sources of supply; new parts and re-processed parts. New parts can be ordered in the preferred quantity, but the re-processed parts are limited to the amount of failed parts which are available. Failed parts become available in case the customer decides to return them. The probability of a return is the return yield (rt). When parts are re-processed, the probability that this is successful is the repair yield (ry).

The first model is a **re-process-to-order** (RTO) model. Hereby the decision to send a part to re-processing, or ordering a new part, is postponed as long as possible. Only upon customer demand, failed parts are sent to re-processing in order to fulfill the demand. In case there are not enough failed parts on inventory, additional new parts can be ordered. Until demand occurs, the failed parts are taken back from the customer and stored at the SCW.

Lead times are long for this approach, since re-processing only starts after demand has occurred. This model therefore applies to parts for which lead time is not an issue. Currently 91% of the repairable spare parts with a value over 100 Euro are not kept on stock. This model might therefore be applicable to these parts. However, in case the lead time of re-processing is significantly larger than the lead time of procuring a new part, the decision not to stock that part might be reconsidered. Whether a lead time is acceptable or not does not belong to the scope of this research. This has to be based on a value judgment of people from Vanderlande.

The biggest risk of re-process-to-order lies in the repair yield (ry). This is the probability that the failed part can be repaired. In case the repair yield is smaller than 1, parts which are sent to the supplier might not be repairable. Sending extra parts to compensate for this probability is not a proper solution, since this can result in too many parts being successfully re-processed, whereby the excess has to be kept on stock. The preferred solution is to extend the lead time and send other failed parts to re-processing in case parts are not repairable. If there are no other failed parts on stock, or in case also the additional failed parts are not repairable, new parts will be supplied instead. This solution is acceptable for Vanderlande, given that the repair yield is close to 1, so it would not happen too often.

The second and third model can be applied to the parts for which it is not feasible to have a long lead time. Therefore both models keep serviceable stock. Serviceable stock concerns both the new parts and the re-processed parts. The difference between the two models is the way of replenishing serviceable stock.
For both models continuous review is used. With continuous review the replenishment moment can be determined more accurately compared to periodic review. However, the inventory levels should be known in order to use continuous review. Since the inventory position is automatically updated after every mutation, the necessary information is already available and therefore continuous review is easily applicable and is the preferred method to replenish the inventory position.

The second model is a **push** model. In this model the decision to repair is made upon the return of the part. When a customer returns a failed part, it is immediately sent to the supplier for re-processing. Hereby the parts are not first stored till a certain batch size is reached, since the spare parts at Vanderlande consist mainly of slow movers. Batching would therefore take a long time and the model will start to resemble the pull model. After re-processing, the parts are kept in inventory at the SCW until demand occurs. Since demand is expected to be higher than returns, and not all parts are repairable, the re-processed parts will not be sufficient to fulfill all demand. In case there are not enough re-processed parts available, new parts have to be ordered in time to prevent a stock out.
Since the model automatically determines the timing and quantity of re-processing, only the timing and quantity of purchasing additional new parts has to be determined. This can be done with two parameters. One parameter needs to indicate when new parts need to be ordered and one parameter needs to indicate the size in which quantity the new parts need to be ordered. Because the model is based on a continuous review strategy, a reorder point (s_{push}) is used to indicate the inventory level at which an order needs to be placed for new parts. This is both in line with the current practice as well as more accurate than periodically placing an order.
The order size can be either fixed or variable. Based on a discussion with a manager at Vanderlande it was decided to use a variable order size. Since customer orders occur in different sizes, it might happen that due to a large order the inventory position drops below the reorder point. In that case a fixed order size cannot bring the inventory level back to the level it should be. When using a variable order size this problem is avoided. Therefore an order up to level (S_{push}) is used. Setting the values of the parameters is further discussed in the next paragraph.

The third model is a **pull** model. Here the decision to re-process or order new parts is postponed as long as possible, while remaining a sufficient inventory position in order to fulfill demand directly. The failed parts from the customer are first returned to the SCW. There they are kept on stock until the serviceable inventory needs to be replenished. In the first place this is done with re-processing failed parts, because that is assumed to be the preferred source of supply. Additionally new parts might be needed to prevent a stock out. Therefore different decisions have to be made in this model. The timing and quantity of both re-process orders and purchase orders have to be determined. For this a deliberate choice is made to use only one reorder point and one order up to level, similar to the push model. This choice is made to keep the model easy to implement and use. Different parameters will lead to a more error-prone and time-consuming solution. Thereby, the re-processing is preferably done by the original supplier. Placing one order for both re-processing and purchasing therefore has its advantages, like lower fixed order costs and lower transportation costs.

The pull model is therefore operated by only two different parameters which control the flow of goods. The first parameter is a reorder point, which determines again the moment at which a replenishment order needs to be placed. Hereby the difference is that the replenishment order refers to both the new as well as the re-processed parts. The second parameter determines the size of the replenishment order. This is just like in the push model an order up to level. This is chosen for the same reasons. How these parameters can be set will be discussed below.

Which of these three models should be applied at Vanderlande has to be determined on a part level. This depends in the first place on the urgency of the customer orders. If the part has to be available from stock, re-processing to order is not an option. When the lead time is not an issue all three model can be applied. A choice between the remaining models depends on the costs involved. The costs will be treated in the next chapter and a tool will be developed which determines the total costs. This tool can be used to determine and compare the total costs of the models.

Both the push and pull model assume that re-processed parts are preferred over new ones. This is an acceptable assumption, because the price of a re-processed part has to be set in such a way that using re-processed parts is a lucrative decision for the customers. However, companies might have prejudices towards re-processed part and not want them under any circumstances. In that case, Vanderlande will be stuck with re-processed parts, especially in the case of the push model. In order to find out how the customers respond to reprocessed parts, a market research has to be done before the decision to start reverse logistics is made.

5.2.2 Inventory model parameters

The second issue which had to be tackled for the goods flow is setting the model parameters. From the above mentioned inventory models there are four different parameters; $s_{push}, S_{push}, s_{pull}, S_{pull}$.

Reorder point

Both in case of the push and the pull model, the inventory level has to be raised when the inventory position drops below the reorder point. The inventory position is determined by the on hand inventory of both re-processed and new parts as well as the parts which are on order.

The reorder point needs to be set at such a level that the remaining parts can cover demand until the replenishment order arrives. This is the expected demand during the lead time ($E[DL]$). Additionally safety stock should be kept in order to cover demand, in case it is higher than expected. Therefore the reorder point can be written as:

$$reorder\ point = E[DL] + safety\ stock$$

Currently Vanderlande determines the expected demand during lead time by the weighted average demand and the safety stock consists of one time the square root of the expected demand. Hereby demand is assumed to be Poisson distributed, since the variance of the Poisson distribution is equal to the mean.

This method is only correct if the demand is actually Poisson distributed. Therefore, statistical tests were performed in order to prove the underlying demand distribution. Unfortunately, the historical demand that is available was not sufficient for a reliable Chi-Square test. The alternative, Fisher's exact test, can also not be applied to the data since the total expected and total observed values should be equal, which is not necessarily the case for the demand data. Due to the unreliable Chi Square test no definitive statement can be made regarding the distribution.

Based on the fact that it concerns spare parts and since the Chi Square test pointed in the direction of a Poisson distribution, it can be assumed that the demand occurrences are Poisson distributed. However, the Poisson distribution assumes that the demand size is one for each occurrence. This assumption must hold for the demand data; otherwise the demand might be underestimated. This would lead to a too low reorder point, which leads to a bad service level.

From the demand data of Vanderlande's spare parts, it can be concluded that for 42 percent of the parts, which had demand in the last two years, the assumption holds and the demand size is maximum one per demand occurrence. This automatically means that for 58 percent of the parts, there has been a demand size exceeding one. For those parts the current method is less applicable. However, in case the demand size above one is an exception, the method can still be used. For 30 percent of the parts there was only one demand occurrence with a demand size exceeding one. If those were exceptions, the method can be successfully applied to 72 percent of the parts. For the parts where the demand size can be larger than one, a different method of calculating the reorder point is required. Therefore these cases will be treated separately.

Demand = 1

First a method for determining the reorder point is determined, which works for parts with demand sizes equal to one. For these parts the expression for the reorder point (s) becomes:

$$s = E[DL] + k\sqrt{E[DL]}$$

Hereby the safety factor (k), which is currently fixed at one, is made explicit by adding it to the equation. The safety factor can be set at a certain value in order to reach the preferred service level. For this purpose a type 1 service level has been used. This indicates the probability that all demand occurrences are completely filled. Therefore k is set at such a value that the probability that the inventory will be sufficient until the replenishment order arrives is at least equal to the preferred service level. A Poisson distribution is used to determine the probability. This can be written as:

$$service\ level = P\left[E[DL] + k\sqrt{E[DL]} \geq DL\right]$$

In the current situation the value of the safety factor (k) is one. In order to get an insight in the resulting service level, Table 3 shows the service levels for different values of the lead time demand ($E[DL]$) and a safety factor of one.

$E[DL]$	0,1	0,5	1	5	10	25	50
$service\ level$	0,90	0,91	0,92	0,87	0,86	0,86	0,85

Table 3 – Service levels realized with safety factor 1 for different lead time demands

It can be concluded that a safety factor of one does not lead to extremely bad service levels. However, in case a part is critical, a high service level might be required. Therefore it is recommended to determine the safety factor for each part separately. This can be easily implemented in a spread sheet program.

In order to arrive at the final formulas for s_{push} ands_{pull}, it has to be decided which lead time applies. The push model only orders new parts and therefore the replenishment order will arrive after the lead time for new parts (L_{order}). This is the time during which the remaining parts at the reorder point need to be able to cover demand. The reorder point for the push model can therefore be written as:

$$s_{push} = E[DL_{order}] + k\sqrt{E[DL_{order}]}$$

The pull model orders a combination of new and re-processed parts. In order to reduce transportation costs, the order is sent to Vanderlande as a whole. This means that the longest lead time determines the lead time of the combined order. Since it is assumed that the lead time for re-processed parts (L_{repro}) is at least as long as the lead time for new parts, this is the decisive lead time. This results in the following expression for the reorder point under the pull model:

$$s_{pull} = E[DL_{repro}] + k\sqrt{E[DL_{repro}]}$$

Demand size > 1

For the parts where the order size exceeds one, a different approach needs to be taken. For these parts it is assumed that the demand is compound Poisson distributed. This means that the demand occurrences are Poisson distributed and the demand sizes have a separate distribution. Therefore the distribution of the demand sizes needs to be determined in order to calculate the reorder point. This led to the same problem as previously encountered. The historical data of the parts is not sufficient to determine the distribution of the demand sizes with a significant reliability. At this point it is assumed that the demand sizes are exponentially distributed. That means that the probability of a small demand size is significantly larger than big demand size. That is in line with the available data of different parts. In case there are demand sizes higher than one, the majority of the values are one or two.

The reorder point was written as the expected lead time demand plus the safety stock, which consists of "k" times the standard deviation of the lead time demand. For the compound Poisson distribution, with the uniform distribution for the underlying demand size, the reorder point becomes as follows:

$$s = E[DOL] * E[DS] + k\sqrt{E[DOL] * (E[DS] + VAR[DS])}$$

Where the expected demand occurrences during the lead time ($E[DOL]$) is based on the weighted average number of demand occurrences from historical data. The expected demand size ($E[DS]$) and the variance of the demand size ($VAR[DS]$) are given by the following equations:

$$E[DS] = \frac{1}{\lambda}$$

$$VAR[DS] = \frac{1}{\lambda^2}$$

Lambda in turn is one divided by the sample mean.

In order to determine the appropriate level of the safety factor (k), the same formula can be used as for the case with normal Poisson demand. The difference is in the way the probability is calculated. Whereas for normal Poisson it is relatively easy to calculate the probability for different values of k, with compound Poisson the calculations become more extensive due to the combination of two probability distributions. The solution to this is an enumeration of probabilities. Hereby the probability that the lead time demand is smaller than the reorder point is calculated for increasing values of the reorder point. The first value, for which the probability exceeds the minimal required service level, is the reorder point which is used and thereby also the value of k is found. These calculations can be implemented in a spread sheet program.

Similar to the case where the demand size equals one, the reorder point differs under the push and pull model, since different lead times are taken into account. Therefore the formulas for s_{push} and s_{pull} (for parts with demand sizes which can be larger than one) are as follows:

$$s_{push} = E[DOL_{order}] * E[DS] + k\sqrt{E[DOL_{order}] * (E[DS] + VAR[DS])}$$

$$s_{pull} = E\left[DOL_{repro}\right] * E[DS] + k\sqrt{E\left[DOL_{repro}\right] * (E[DS] + VAR[DS])}$$

Order up to level

Vanderlande does currently not use a structured approach to determining the order quantity. This is determined per situation by the employee who places the order. Therefore there are no order-up-to levels, neither a fixed order quantity. Since there is no previous method which can be taken into account, a new method will be recommended for both the push as well as the pull model. The two order-up-to levels will now be separately treated.

Push

In case of the push model, a replenishment order consists exclusively of new parts. Additionally, re-processed parts form a source of supply, but their exact arrival is not predictable. It is not possible to predict when a demand occurrence will include a return, neither the success of re-processing can be predicted before a part actually fails and often it cannot be predicted before tests are performed. Therefore only the expected number of re-processed parts over a period of time can be determined. The difference between the total expected re-processed parts and the expected customer demand is the number of new parts which is needed to fill demand. Since the moment when re-processed parts arrive cannot be precisely predicted, it is expected that their arrival, and thereby also the demand for new parts, will be equally spread over time. The order quantity problem is thereby reduced to an equally spread demand for new parts, where the demand for new parts is the difference between the total demand (D_{year}) and the number of re-processed parts ($\#rp$).

This problem can be easily solved with the economic order quantity (EOQ) formula. This formula determines the optimal balance between fixed order costs (FP) and holding costs for new parts (H_{new}). The order up to level for the push model is determined by adding the optimal order quantity to the reorder point. Thereby the expression of S_{push} becomes:

$$S_{push} = \sqrt{\frac{2 * (D_{year} - \#rp) * FP}{H_{new}}} + s_{push}$$

Here the holding costs (H_{new}) consist of storage costs for a location (LC), whereby it is taken into account that multiple parts can be stored at one location (pl), and a cost for the required investment. The investment is the purchase price of a new part (NP). The cost for this investment is determined by the weighted average cost of capital ($WACC$). The WACC includes a cost for the time value of money as well as the risk of stocking a part. The risk consists mainly of the obsolescence risk. The holding cost can thereby be expressed as:

$$H_{new} = \frac{LC}{pl} + WACC * NP$$

The fixed order costs (FP) are the costs which are charged by the supplier for placing an order. Additionally transportation costs can be included, in case the cost of transporting a batch is equal to the cost of transporting a single part. In case there are no fixed order costs the order quantity is one, since it is then most beneficial to order a new part every time demand occurs.

Pull

In case of the pull model the replenishment order consists of both re-processed and new parts. Previously it was explained that only one parameter indicates the order quantity. Since re-processed parts are preferred over new parts, the order quantity consists in the first place of re-processed parts. However, the number of parts which can be re-processed is limited by the number of failed parts which are available in the SCW. Additionally new parts are ordered to achieve the preferred order quantity.

Also for the pull model the EOQ formula is used to determine the order quantity. Compared to the push model, the formula deviates at two points. In the first place, the order quantity has to cover all demand, considering the fact that both re-processed and new parts are combined in one order. Secondly, the holding costs are not based solely on new parts. Since also re-processed parts are considered in the equation, the holding costs should consider them as well. Since the holding costs only make up for a small part of the overall costs (see also chapter 6), the average holding costs are based on a fifty-fifty relationship between the re-processed and new parts. Apart from that, the situation is the same as for the push model. Therefore the order up to level for the pull model can be written as:

$$S_{pull} = \sqrt{\frac{2 * D_{year} * FP}{H}} + s_{pull}$$

Where the holding costs consist, as mentioned before, of a combination of the holding costs for new (H_{new}) and re-processed parts (H_{repro}). The holding costs of the re-processed parts are determined in the same way as for the new parts, with the only difference that they consider the re-process costs (RP) and compensation fee (CF) instead of the new price of a part. The expression for the holding costs is hereby:

$$H = \frac{H_{new} + H_{repro}}{2} \qquad H_{repro} = \frac{LC}{pl} + WACC * (RP + CF)$$

5.3 INFORMATION FLOW

This paragraph is focused on the information flow which occurs with the reverse logistic activities. In the first place it is concerned with organizing the communication between the different actors in the reverse flow. Secondly the information that needs to be captured is discussed, as well as the analyses that can be conducted with it.

5.3.1 Organizing the inter firm communication

In order to create a well working process the right information has to be available to the right actor at the right time. The different actors in the reverse logistic process are:

- Vanderlande
- Customer
- Transportation Company
- Service Central Warehouse (SCW)
- Supplier

There are different moments when these actors have to communicate. Before reverse logistics are started, initial communication has to take place. At that time the different actors should be informed about, and prepared for, returning parts. Also the information system has to be prepared to cope with the return flows of a part. Subsequently there are different events which might occur, which will trigger the need of communication between the actors. Which triggers occur and which communication has to take place depends on the inventory model which is used. In the previous paragraph three inventory models where introduced. For each of these models, the communication is explained below. This is preceded by the initial communication which will be described first. In Appendix H flowcharts with swim lanes can be found for the initial communication and for the different inventory models.

Initiation

In order to enable reverse logistics it should be possible to distinguish the different physical states in which a part can reside. In the SCW, the same part can be stored failed, repaired or new. In order to keep them separated they have to be treated separately in the ERP system. However, it should still be clear that it concerns the same part. When a customer places an order, it should be easy to recognize that it concerns a part which has to be returned and whether a re-processed part can be offered.
Based on discussions with different employees, different solutions were found.

- Different branches could be created to host the failed and re-processed parts. A branch defines the physical location of the parts. This way the original item number could be maintained, the different states can be separated and the inventory position of the different states can be checked. However, the different branches are not shown automatically, so it requires the employees to click on another branch to identify possible re-processed parts. Secondly, because the parts share the same item number, it has to be physically shown in which state a part resides in order to be handled correctly in the warehouse.
- An extension of the item number could be used in order to indicate the condition of the part. In case an item is requested and the original version has a suffix, the sales person knows there could be failed parts, knows the item number of the failed/repaired parts and knows that the part should be returned. This method requires quit some additional effort since for each item, three new item numbers need to be created, but separate item numbers are preferred for the handling in the warehouse. The problem with this method is that the ERP system does not allow item numbers longer than the current ones.

- Separate items could be created to represent the failed and repaired state of a part. The different item numbers could be linked in the ERP system as alternative source of supply for the new version of the item. The different item numbers will allow the different states of the part to be handled separately. Upon a request of a customer, this method makes it possible to recognize that there might be other sources of supply, but with analyzing the sales it will be more difficult to get a clear overview, because the parts are not connected when they are exported in a spreadsheet. Moreover, for every item number, there should be an entry in Smart Team with detailed information on the part. This should then be created for every new item number.

From the different options, the third is the least practical and therefore will not be used. The second one is very practical, but unfortunately it is currently not feasible to extend an item number. Therefore the first option would be preferred. In order for the method to work, the failed and re-processed parts need to be clearly marked with an attached card or sticker that indicates the state they are in and in this way preventing handling errors in the warehouse.

After the different branches are created in the ERP system, Vanderlande needs to inform the SCW to create a location for the failed parts and the refurbished ones, according to the new branches. It is important to keep the failed parts separated from the serviceable inventory and the re-processed parts from the new ones. When this gets mixed up the wrong part might be sent to a customer.
At this point the parts can come back from the field. Therefore all customers with the corresponding part have to be informed. They have to know about the return procedure, and the incentive. The return procedure will be described below. The incentive has to convince the customers to return their failed parts. The incentive will be a credit which is received upon arrival of the failed part and is settled with the following invoice.

Re-process-to-order
In case the parts are re-processed to order, there are two triggers which can occur: A customer order and an RMA request. The communication which follows these two triggers will be now discussed.

In case a customer orders a part for which reverse logistics is applicable, Vanderlande has to point out that this part should be returned and that there is a compensation fee in case the customer cooperates. In case the customer wants to return their failed part, they have to indicate this to Vanderlande, by filling out the RMA form from Vanderlande (RMA-form (VI)). Furthermore the customer has to be offered a re-processed part in case there are sufficient failed parts available at the SCW. After this information the customer can place their order.
Based on the customer's order, either failed parts have to be shipped to the supplier for re-processing, or an order for new parts has to be placed with the supplier. In order to let parts be re-processed, the RMA form of the supplier (RMA-from (S)) has to be filled out and sent. Subsequently, the supplier has to confirm the return shipment, after which Vanderlande can send the failed parts. When a batch of failed parts has left the SCW, Vanderlande has to be informed in order to update their stock levels.
At the supplier, the parts will first be tested to formulate a prognosis for the failure and the repair activities. When from the initial testing of the parts it turns out that they are not repairable, the supplier will inform Vanderlande about the situation and bill them for the inspection costs. Vanderlande then has to send other failed parts, or in case there are none left, order additional new parts. In case also the second consignment of failed parts is not repairable, new parts are ordered.
When the re-processed and/or new parts are available, they have to be shipped to the customer's site. In case the customer has returned the RMA-form (VI) to Vanderlande, a joined delivery and pickup will be arranged with the transportation company. They will bring the failed parts back to the SCW after they have dropped of the serviceable parts. This requires clear communication, because the courier has to know about the pickup and the customer has to prepare the failed part for shipment and have it waiting for the courier at the same location where the serviceable parts are received.
After the failed parts are received by the SCW, they have to confirm this to Vanderlande, upon which the failed parts inventory can be updated.

In case the customer did not return the RMA-form (VI) to Vanderlande, or did not return it in time, the failed parts will not be returned with the delivery of the serviceable parts. If the customer still wants to return the parts, it will be on their initiative and they have to fill out and send an RMA-form (VI) to Vanderlande. When Vanderlande receives the RMA-form (VI), they can authorize the return of the parts upon which the customer has to arrange transportation. Vanderlande has to communicate the date of the shipment to the SCW, so they can reckon with this in their planning.
When the SCW has received the shipment, they have to confirm this to Vanderlande so the inventory position can be updated.

Push
In case the push model is used, there are three possible triggers which might occur; a customer order, an RMA request, or when the serviceable inventory drops below s_{push}.

In case a customer orders a part for which reverse logistics is applicable, Vanderlande has to point out that this part should be returned and that there is a compensation fee in case the customer cooperates. In case the customer wants to return their failed part, they have to indicate this to Vanderlande, by filling out the RMA-form (VI). Furthermore the customer has to be offered a re-processed part in case there are sufficient re-processed parts available at the SCW. After this information the customer can place their order.
After the order has been placed, the serviceable parts have to be shipped to the customer's site. In case the customer has returned the RMA-form (VI) to Vanderlande, the failed parts also have to be picked up. The failed parts will be directly sent to the supplier, and therefore this has to be communicated with them as well. This is done through their RMA-form (S), which has to be filled out and sent.
When the supplier approves the shipment, Vanderlande can organize a joined delivery and pickup with the transportation company. This requires clear communication, because the courier has to know about the pickup and the customer has to prepare the failed part for shipment and have it waiting for the courier at the same location where the serviceable parts are received. Moreover, Vanderlande does not want the customers to know the supplier. Therefore it is important that the ship to address of the return shipment is not communicated to the customer.
After the failed parts have been delivered at the supplier, they have to confirm this to Vanderlande, upon which the (pipeline) inventory can be updated.
At the supplier, the parts will first be tested to formulate a prognosis for the failure and the repair activities. When from the initial testing of the parts it turns out that they are not repairable, the supplier will inform Vanderlande about the situation and bill them for the inspection costs. Vanderlande then has to update the (pipeline) inventory accordingly.
When the parts have been re-processed they have to be transported back to the SCW. Depending on the conditions that were agreed upon between Vanderlande and the supplier, this is organized by either one of the two actors. In both cases, the SCW has to confirm to Vanderlande when the parts have been received, so the inventory position can be updated.

In case the customer did not return the RMA-form (VI) to Vanderlande, or did not return it in time, the failed parts cannot be picked up with the delivery of the serviceable parts. If the customer still wants to return the parts, it will be on their initiative and they have to fill out and send an RMA-form (VI) to Vanderlande. When Vanderlande receives the RMA-form (VI), they can authorize the return of the parts upon which the customer has to arrange transportation. Because the transportation is arranged by the customer and they are not allowed to know the supplier, the parts are returned to the SCW first. Vanderlande will subsequently forward the failed parts to the supplier for re-processing. This extra transportation is inefficient, but unfortunately it has to be organized in this way. Vanderlande has to communicate the date of the shipment to the SCW, so they can reckon with this in their planning. Vanderlande also has to organize the successive shipment from the SCW to the supplier.
When the SCW has received the shipment, they have to confirm this to Vanderlande so they know where the parts are. At that point Vanderlande can fill out and send the RMA-form (S) to the supplier. They can better wait until the parts have been received, to make sure that there won't be an unexpected delay. After the supplier approved the return shipment, the parts are transported to the supplier.

At the supplier, the parts will first be tested to formulate a prognosis for the failure and the repair activities. When from the initial testing of the parts it turns out that they are not repairable, the supplier will inform Vanderlande about the situation and bill them for the inspection costs. Vanderlande then has to update the (pipeline) inventory accordingly.
When the parts have been re-processed they have to be transported back to the SCW. Depending on the conditions that were agreed upon between Vanderlande and the supplier, this is organized by either one of the two actors. In both cases, the SCW has to confirm to Vanderlande when the parts have been received, so the inventory position can be updated.

When the serviceable inventory drops below s_{push}, Vanderlande has to place an order for Q_{push} new parts at the supplier. The communication after this trigger will be the same as in the current situation when an order is placed and will therefore not be further discussed here.

Pull
In case the pull model is used, there are three different triggers which might occur. These are the same as with the push model, but the communication which follows the triggers is slightly different.

In case a customer orders a part for which reverse logistics is applicable, Vanderlande has to point out that this part should be returned and that there is a compensation fee in case the customer cooperates. In case the customer wants to return their failed part, they have to indicate this to Vanderlande, by filling out the RMA-form (VI). Furthermore the customer has to be offered a re-processed part in case there are sufficient re-processed parts available at the SCW. After this information the customer can place their order.
After the order has been placed, the serviceable parts have to be shipped to the customer’s site. In case the customer has returned the RMA-form (VI) to Vanderlande, a joined delivery and pickup will be arranged with the transportation company. They will bring the failed parts back to the SCW after they have dropped of the serviceable parts. This requires clear communication, because the courier has to know about the pickup and the customer has to prepare the failed part for shipment and have it waiting for the courier at the same location where the serviceable parts are received.
After the failed parts are received by the SCW, they have to confirm this to Vanderlande, upon which the failed parts inventory can be updated.

In case the customer did not return the RMA-form (VI) to Vanderlande, or did not return it in time, the failed parts cannot be returned with the delivery of the serviceable parts. If the customer still wants to return the parts, it will be on their initiative and they have to fill out and send an RMA-form (VI) to Vanderlande. When Vanderlande receives the RMA-form (VI), they can authorize the return of the parts upon which the customer has to arrange transportation. Vanderlande has to communicate the date of the shipment to the SCW, so they can reckon with this in their planning.
When the SCW has received the shipment, they have to confirm this to Vanderlande so the inventory position can be updated.

When the serviceable inventory drops below s_{pull}, Vanderlande has to send Q_{pull} failed parts to the supplier for re-processing. In case there are less than Q_{pull} failed parts, all failed parts are sent and additionally new parts are ordered.
In order to let parts be re-processed, the RMA-form (S) has to be filled out and send. Subsequently, the supplier has to approve the return shipment, after which Vanderlande can send the failed parts. When a batch of failed parts has left the SCW, Vanderlande has to be informed in order to update their stock levels.
At the supplier, the parts will first be tested to formulate a prognosis for the failure and the repair activities. When from the initial testing of the parts it turns out that they are not repairable, the supplier will inform Vanderlande about the situation and bill them for the inspection costs. Vanderlande then has to send other failed parts, or in case there are none left, order additional new parts. In case also the second consignment of failed parts is not repairable, new parts are ordered.
When the parts have been re-processed they have to be transported back to the SCW. Depending on the conditions that were agreed upon between Vanderlande and the supplier, this is organized by either one of the two actors. In both cases, the SCW has to confirm to Vanderlande when the parts have been received, so the inventory position can be updated.

5.3.2 Data collection and analysis

The second part of the information flow is to capture and analyze data in order to facilitate both product and process improvements.

With reference to the research topic, the additional data that can be collected due to reverse logistics is mainly part specific data, which becomes clear when a failed part is physically available. By studying the failed part the cause of failure can be more accurately determined. When a certain pattern emerges in the failure data, this can point to a weakness in either the part itself, or in the system design. It can for instance be the case that a part is overburdened. Corrective action can then be taken by for instance using a different part, or changing the workload of the part in the system. In the current situation such information is not collected. And although it might be valuable, the engineers do not have the time to look at every returned part. Therefore this check is performed by the engineers of the supplier when the parts are being re-processed. The information can be filled on the RMA form and sent back to Vanderlande, where it can be processed.

The reverse logistic process can be gradually improved as more experience is gained with the process. In order to make improvements, data is a crucial asset to recommend, underline, or contradict possible improvements. Although collecting data is important, it is not efficient to collect and analyze all possible data. Data which is most important for process improvement and what is recommended to be collected and regularly analyzed will now be discussed.

The **demand for re-processed parts**. Since a separate item number is create for a re-processed part, the demand for this part is automatically collected. However, it is important to include this in the analysis. It has to be compared with the demand for new parts. In case that there is still more demand for the new parts than for its re-processed counterpart, corrective action might be taken. This can be done by further lowering the price of re-processed parts. It might also motivate further market research to the customer’s attitude towards re-processed parts. It might be that the customers need to be taught about re-processing and that the quality is not necessarily worse.

The **number of returned parts**. Currently the return flows are not well measured by Vanderlande. The do not keep track of the amount of parts that are returned by customers. When they want to pursue an efficient control of the reverse logistic process, they need to keep track of the number of parts that are returned. This can also be achieved relatively easy, because also failed parts will get a separate item number. This way the mutations will be stored in the ERP system and the number of returned parts is easily found. The number of returned items has to be compared with the demand for the item (both new and re-processed). In case the number of returns is significantly lower than the demand, the compensation fee might have to be increased in order to provoke more returns. Interviews with the customer can also clarify the problem.

The **repair yield**. This statistic is also captured with the current system. By dividing the incoming re-processed items by the outgoing failed items, the repair yield is determined. The repair yield has to be compared to the repair yield which was estimated beforehand by the supplier. In case this differs significantly a meeting with the supplier can provide a solution to the problem. In case the returned parts are of very low quality, Vanderlande has to be stricter in their return policy. In case the supplier made a wrong estimation, the repair yield has to be adjusted and the feasibility of reverse logistics has to be reconsidered.

The **lead time of repair**. This has to be captured by the coordinators. Currently they already keep track of the lead times of new parts. They enter the order date, the promised delivery date and the actual delivery date in the system. For the re-processed parts this can be done in the same way, since they will be set up as a separate item in the ERP system. It is important to keep track of the lead times of re-processing, because it is a different process from manufacturing, and the reliability of the quoted lead times has to be checked. If it turns out that the actual lead times are significantly higher than the quoted lead times, meetings with the supplier should clarify the reason and determine whether this will improve over time. Based on the meeting actions can be undertaken to reduce the lead time, or the inventory levels should be adjusted to compensate the longer lead time.

The **time** which employees spend coordinating the process. There are different ways to measure this parameter. An exact approach can be used whereby the employees write down the amount of time they spend on coordinating reverse logistics. Another possibility is to do a time studies where someone observes the employees and measures the time spend on reverse logistics. A third option is to conduct short interviews or let the employees fill out a questionnaire where the time they spend on reverse logistics is assessed. Both the first options are rather demanding and might lead to frustrations among the employees. Therefore the last and least exact option is recommended. If it turns out that employees spend too much time on reverse logistics, further interviews with the interviews have to clarify whether this is due to the process being more demanding than was originally thought, due to a lack of training the employees, or because the initial estimation of the time was wrong.
The **total profit.** Probably the clearest indicator of the success of reverse logistics will be the total profit. When all costs that are made on reverse logistics are summed and compared to the revenue from selling the re-processed parts, it can be determined whether reverse logistics is also profitable in reality. In case it is not, this parameter does not help a lot in locating the problem. In case the other parameters which are discussed are close to their estimated values, the cause of the problem has to be found by further analyzing the process.

These parameters can be analyzed periodically, e.g. semiannually, and compared to the estimated values. When they differ significantly, the indicated actions have to be taken. Furthermore, the feasibility of reverse logistics might be reconsidered after the incurred parameters are adjustments. In the worst case, it might turn out that reverse logistics is not profitable and the program needs to be stopped.

5.4 FINANCE FLOW

The final step in determining the reverse logistic process is the finance flow. In the previous chapter it was determined that paying for the received services of other organizations is not an issue for Vanderlande. Therefore no attention will be given on the timing of the financial transactions. The focus will be on how to determine the quantities of transactions, which are new to Vanderlande. Throughout the reverse logistics process, different transactions can occur. This is also indicated in the network design in Figure 11. The different transactions from the perspective of Vanderlande are

- Paying for transportation
- Paying for re-processing
- Paying for warehousing
- Paying a compensation fee (incentive)
- Receiving payment for the re-processed part

For transportation, re-processing and warehousing standard tariffs will be charged for respectively certain distances, repairs and the receipt/storage/shipment of parts. These tariffs are discussed with the different actors. For the last two transactions, Vanderlande needs to determine the quantity themselves and this forms the actual issue. The compensation fee has to be large enough to motivate customers in returning their failed parts, and as small as possible since it is directly taken from Vanderlande’s profit. The price of a re-processed part has to be significantly lower than the price of a new part, so it becomes more attractive for customers to buy a re-processed part, but is should be as high as possible, to maximize profit for Vanderlande.

5.4.1 Price of a re-processed part

Concerning the pricing of the re-processed parts, three methods have been proposed in the previous chapter. Currently a percentage markup is used on top of the cost price of spare parts. Although a markup is easy to apply and in line with the current practice, this method is not recommended. The reason for this is that a fixed markup can lead to very low prices, when reverse logistics is organized efficient and the re-processing can be done cheap. In that case, the customer will benefit most of this, while the risk is taken by Vanderlande. For value pricing, where the price is set as low as possible, the same reasoning holds.

In order to benefit optimally from the reverse logistic efforts, a perceived value pricing method is recommended. Hereby the price is set at the value which the customers believes the parts are worth. Measuring this value is complicated, since it includes the customers' values and believes. Moreover, when the customers are asked directly at what price they value the re-processed part; they will mention a lower price than the one they actually value the part at. This way they try to influence the price to be lower. Due to the difficulties in measuring the perceived value directly, a different approach will be taken. This method determines the perceived value of a part, by adjusting the objective value with the customer's attitude towards reverse logistics. The more skeptical customers are towards reverse logistics, the lower their perceived value, and therefore the lower the price they are willing to pay for it.
The objective value of the re-processed part is determined by its quality. The quality of the re-processed parts refers both to the functionality, as well as the expected time to failure compared to that of a new part. For instance, if a re-processed part both has 90% of the functionalities and the time to failure of a new part, the objective value of that part is 81% of the new price. Both functionality and the time to failure should be determined by the supplier. They can base this either on previous experience, tests, or expert judgment. Subsequently the objective value should be compensated with the customer's attitude towards reverse logistics to arrive at the perceived value. The customer's attitude towards reverse logistics is measured as a group and is placed in either of three categories; Skeptical, neutral or positive. Based on the outcome of this division, the objective score can be adjusted with an extra discount. The size of this discount and the categorization should be determined by a market research among Vanderlande's customers. Besides the extent to which they trust re-processed parts, it can also be measured how environmentally aware they are, since this can also impact the decision to use re-processed parts. The market research is not included in the scope of this research and will therefore not be treated in detail here.

5.4.2 Compensation fee

In the previous chapter three articles were retrieved which are concerned with determining the acquisition price of used parts. The problem with all of these methods is that they need a lot of data input which is not available. So do Guide et al. (2003) assume that the approximate quality of the failed parts is known. They divide the quality in different groups and per group a price is set. In Vanderlande's case testing is done at the supplier and except when the push model is used, it will take too long to wait for the testing to determine the compensation fee. Moreover, determining the compensation fee after the testing might put pressure on the relationship with the customer when the fee turns out lower than expected. Therefore, the price should be fixed per part, so it can be granted the moment the part is picked up.

All of the methods assume that it is known how a customer responds to a certain fee. Michaud and Llerena (2006) use a model to determine a customer's willingness to receive on which the response of a customer to different fees is based. At Vanderlande the response of a customer to different fees is not known. They have never before bought back failed parts and therefore there is no experience, let alone data, on the response of customers to different compensation fees. Using a model to determine the willingness to receive goes beyond the scope of this research and is also not preferred by Vanderlande, since it will be too time consuming and burdensome for the customers.

Because there is no simply applicable method available in the literature which can be applied at Vanderlande, a simple approach to determining the compensation fees is defined. This is done in cooperation with an employee from the marketing and sales department. The method should set the compensation fee to a certain percentage of the new value of the failed part. Three factors which impact the compensation fee have been identified together with the marketing department.
In the first place the effort that it takes on the customer's account to return the part has to be taken into account. This effort is minimal when the failed part is returned immediately with the shipment of the serviceable part. The only effort is to fill out the RMA form.
Secondly the compensation fee depends on the value this failed part represents for the customer. In case they currently sell failed parts to a broker the value is higher for them than when they sell it for the raw materials, which in turn has more value than when it is simply discarded.

Finally, the environmental awareness of a customer plays a role in determining the compensation fee. When the environment has a high priority for a customer, they appreciate the effort Vanderlande does to reuse failed parts and thereby minimizing the impact on the environment. In that case they will accept a lower compensation fee compared to when they do not consider the environment a priority.

Based on the experience of different Vanderlande employees, or a questionnaire among the customers, these three factors are used to derive a compensation fee. This amount is preferably presented in the form of a credit, which the customer can use when they purchase spare parts at Vanderlande. This would be recommendable since the customer will have to buy at Vanderlande in order to redeem the compensation fee.

5.5 CONCLUSIONS

Three inventory models are proposed, which can be deployed depending on the part involved
The re-process to order model postpones the decision to repair until customer demand occurs. Therefore it does not fulfill orders from inventory. The push model does keep serviceable inventory. The failed parts are repaired immediately upon return and new parts are ordered additionally when the inventory level drops below a certain point. The pull model postpones the decision to repair and/or purchase new parts as long as possible, while maintaining the preferred service level. Both the push and the pull model are operated with a reorder point and order up to level.

The reorder point is determined similar to the currently practice and order sizes should be variable
For both the push as well as the pull model the reorder point can be calculated with the same formula as is currently used. The difference is that the total serviceable inventory has to be taken into account. For the pull model the lead time of repair should be used, whereas the pull model uses the lead time of new parts equal to the current situation. The order size is determined along an order up to level. This allows the order size to be variable, since demand can be a bit lumpy. Simple heuristics are proposed for both models to determine the order up to level.

Reverse logistics should be enabled in the ERP system, preferably by creating different branches
In the information flow the biggest obstacle seems to be, enabling the reverse logistics in the ERP system. The solution is to use separate branches for the failed and repaired parts. This will allow the separation of the items, both physically and digitally. It also provides a clear overview for the employees who have to sell the spare parts. Moreover, since per branch a different price can be maintained, the financial processing of the orders will also be relatively simple.
In order to keep track of the compensation fee and make sure the customers who return their failed parts get the right compensation fee, the failed parts branch will have negative prices equal to the compensation fee. This way the return of a failed part can be entered in the system as an order and the customer can easily get his compensation fee. Upon arrival of the part(s) the order is marked complete and the compensation fee is settled with the next order the customer places.

The coordination of reverse logistics will not require large changes compared to the current situation
There are not many changes in the communication when reverse logistics is applied. An order has to be entered at another branch, and for a return a separate purchase order has to be created. The most important and time consuming difference are the RMA forms which have to be filled by the customer and Vanderlande and the coordination of a joined delivery and pickup of spare parts.

Technical failure data, costs and demand, return, and repair-rates, have to be collected and analyzed
The technical failure data is collected by the supplier upon re-processing. The information is then communicated through the RMA form. The other parameters follow naturally from the process. All data is stored in the ERP system and analyzed periodically.

The price is set at a certain percentage of the original price, based on quality and customer demand
A value based pricing method is recommended. This method should lead to profit maximization for Vanderlande, where the other methods suggested in chapter 4 would not. In order to determine the percentage a market research has to determine whether the customer is skeptical, or open, towards re-processed parts. The performance and expected time to failure will also influence the price.

The compensation fee is set at a certain percentage of the original price and disbursed as a credit
Three factors influence this percentage; the amount of effort it will take a customer to return the failed part, the value the part represents to the customer and the environmental awareness of the customer. Based on a small research among the customers, the compensation fee can be determined. This fee is disbursed in the form of a credit with which the customers can buy spare parts at Vanderlande. This aims at binding the customers to Vanderlande for their service.

6 THE ECONOMIC FEASIBILITY OF REVERSE LOGISTICS

After the process for reverse logistics has been thoroughly discussed for Vanderlande, it has to be possible to determine for which part reverse logistics will lead to an increased profit. This chapter will do just that by developing a method which determines the economic feasibility on a part level. Based on different input parameters, the economic feasibility is determined for the three different inventory models. This is done separately in order to facilitate a choice between the different models.

In paragraph 6.1 the logic of the method is explained. This will lead to a general understanding of the method, but in order to apply it, certain factors have to be further specified depending on the inventory model which is used. Therefore paragraph 6.2 is dedicated to specify the method for the re-process to order model, the push model and the pull model. In paragraph 6.3 the required input for the model is discussed. Hereby special attention is paid to the way the input can be determined by Vanderlande. After the method is sufficiently explained, in 6.4, a case study will illustrate the method and show the potential of reverse logistics. Paragraph 6.5 is dedicated to the verification and validation of the method. Then, in 6.6, a sensitivity analysis is performed to test to what extent the method depends on uncertain input parameters. Finally paragraph 6.7 will present the conclusions which can be drawn from this chapter.

In order to understand the formulae better, an overview of the notation that is used, can be found in Appendix G

6.1 GENERAL METHOD TO DETERMINE THE ECONOMIC FEASIBILITY

In this section the general method to determine the economic feasibility is explained. In the most simplistic way of viewing it, reverse logistics is economically feasible when the profit is larger with, rather than without reverse logistics. Therefore reverse logistics is economically feasible when:

$$Profit_{rev} - Profit_{cur} > 0 \qquad (1)$$

The profit is in both cases determined by distracting the costs from the generated revenue. The expression then becomes:

$$(Revenue_{rev} - Cost_{rev}) - (Revenue_{cur} - Cost_{cur}) > 0 \qquad (2)$$

Subsequently the costs and the revenue can be further split up in components. These components are the same for the situation with reverse logistics as well as the situation without. Therefore the costs and revenue will now be treated, without making a difference between the two situations.

6.1.1 Costs

The costs of supplying spare parts are divided over different categories. There are six different cost categories which make up for the total costs. These are the following:

- Transportation
- Inventory
- Warehousing
- Re-processing/Purchasing
- Coordination
- Compensation fee

Together, the different categories make up for the total costs, both in case reverse logistics is used, as well as in the current situation. The expression for the costs can therefore be written as:

$$Cost = Transportation + Inventory + Warehousing + Reprocessing + Coordinating + Compensating \qquad (3)$$

Each cost category will now be discussed.

Transportation

The transportation of the spare parts is done by a third party logistic provider (3PL). Therefore the costs for transportation are based on the tariffs which the 3PL upholds. In the case of Vanderlande there are fixed tariffs negotiated based on the weight of the shipment and the country of destination. For each time in the process when goods need to be transported a tariff is determined based on the weight for the average transport quantity and the average distance.

Throughout the process there are four possible transportation moments. Therefore, four different tariffs apply; the average weighted pickup costs (PU) for picking up the failed parts from the customer; the transportation costs for failed parts from the SCW to the re-process location ($ScSu$); the transportation costs for bringing the serviceable parts from the supplier to the SCW ($SuSc$); and finally the cost for delivering serviceable parts to the customer (DE).

All four tariffs have to be multiplied with the amount of times it is expected to occur, in order to arrive at the total transportation costs. This results in the following expression of transportation costs:

$$Transportation = PU * \#PU + ScSu * \#ScSu + SuSc * \#SuSc + DE * \#DE \qquad (3a)$$

Inventory

Depending on the model which is used, inventory is kept of failed, re-processed and new parts. This inventory requires a certain investment. Since companies expect a return on their investments, the value of the inventory has to be taken into account as a cost. Additionally, a risk factor is included in this cost. This cost is determined by valuing the investment in inventory against the weighted average cost of capital ($WACC$).

The value of the inventory is determined for all possible forms of inventory, failed, re-processed and new parts. Each has an own value per part ($value_{\_}$). These values have to be multiplied with the average inventory ($\overline{iv}_{\_}$) of the different types of parts. The cost can therefore be written as:

$$Inventory = WACC * \left(\overline{iv}_{fail} * value_{fail} + \overline{iv}_{repro} * value_{repro} + \overline{iv}_{new} * value_{new}\right) \qquad (3b)$$

Warehousing

The inventory is kept at the SCW. The SCW is operated by a 3PL provider, with whom Vanderlande has a contract for their spare parts. In the contract the tariffs for warehousing are determined. The 3PL charges a cost per period for the required storage location (PL) and a cost for both inbound (POL_{in}) and outbound order lines (POL_{out}).

A location can be either a pallet or shelf. A pallet offers more storage space than a shelf and therefore also a different tariff applies. This makes the cost per period for a storage location ($\#loc$) dependent on the type of location which is used. Besides the type of location, the required number of locations influences the storage costs. The number of locations is determined separately for the failed, re-processed and new parts, since they have to be strictly separated in the warehouse in order to prevent mistakes.

The costs for the inbound and outbound order lines are fixed and do not depend on the size of the order. Therefore the total costs only depend on the number of incoming (OL_{in}) and outgoing (OL_{out}) orders.

The costs for warehousing can therefore be written as:

$$Warehousing = PL * \left(\#loc_{fail} + \#loc_{repro} + \#loc_{new}\right) + POL_{in} * \#ol_{in} + POL_{out} * \#ol_{out} \qquad (3c)$$

Re-processing/Purchasing

This cost category represents all costs which are made in acquiring serviceable parts. Therefore the costs for re-processing a failed part (RP) as well as purchasing a new part (NP) are taken into account. These costs are paid for respectively the number of re-processed parts ($\#rp$), and the number of purchased parts ($\#pp$). Also fixed order costs (FP) might be included. This is a cost which is charged per order which is placed at the supplier ($\#os$). Finally, the supplier can charge an inspection costs (IP). This has to be paid for the parts which turn out not to be repairable ($\#nr$).

The costs for acquiring serviceable parts can therefore be written as:

$$Re\,processing/Purchasing = RP * \#rp + NP * \#np + FP * \#os + IP * \#nr \qquad (3d)$$

Coordinating

The coordination costs consist of the work hours that Vanderlande employees need to control the process. For every hour a fixed labor cost (LC) is included. The required amount of time is estimated based on the flowcharts which are shown in Appendix F. The coordination activities are the consequence of four possible triggers. Therefore for all four trigger, the coordination time per trigger (TT_i) has to be multiplied with the number of times the trigger occurs ($\#to_i$).
Therefore the total coordination costs can be written as:

$$Coordinating = LC * \sum_{i=1}^{4} TT_i * \#to_i \qquad (3e)$$

Compensation fee

The compensation fee (CF) to the customers is paid for every failed part which is returned. The total amount of compensation fees granted to customers will therefore be the expected number of returned parts ($\#ri$).
Therefore the total costs on compensation fees can be written as:

$$Compensation\ fee = CF * \#ri \qquad (3f)$$

6.1.2 Revenue

The revenue from selling spare parts can be split in two sources; new parts and re-processed parts. Since the sales price will be different for new and re-processed parts, the distinction has to be made. Subsequently, the total revenue can be easily determined by multiplying the number of sold parts with the corresponding sales price. Therefore the total revenue can be written as:

$$Revenue = SP_{new} * \#ns + SP_{rp} * \#rs \qquad (4)$$

6.2 CALCULATING THE PROFIT UNDER THE DIFFERENT MODELS

In the previous paragraph the general method is explained. Hereby certain factors were purposefully generalized. However, in order to apply the method, all factors should be specified in detail. This will create differences between the models. In this section these differences are shown as the method is completely worked out for all models. Therefore the different costs and revenue are specified for respectively the re-process to order (RTO), the push and pull model. Finally the profit in the current situation is treated.

6.2.1 Re-process to order

The first model for which the method is fully specified is the RTO model. This is done by explaining all elements of the equations 3a, 3b, 3c, 3d, 3e, 3f and 4 respectively. In case an element, or part of the element, concerns an input parameter, a reference will be made to paragraph 6.3. There the input parameters will be discussed in more detail.

Transportation costs (Equation 3a)

Weighted average pickup cost (PU), is determined by taking the weighted average off the transportation tariffs to all customers. These tariffs depend on the weight of the average pickup.
The average weight of a return shipment is in the first place determined by the average number of items which is returned. A return shipment is assumed to be of the same quantity as the demand size, because it is assumed that a customer orders as many new parts as have previously failed. Subsequently the average demand size ($\overline{ds}$) has to be multiplied with the weight of a single part. The average demand size is determined by two input parameters, the demand per year and the demand occurrences per year.

$$\overline{ds} = \frac{D_{year}}{DO_{year}} \qquad (5)$$

When the average weight is determined, the correct weight class can be selected, from which the transportation tariffs are taken. When the transportation tariff (TR_i) is retrieved for every customer (i), the tariffs are weighted with the number of the specific part (sp_i), present in the system of customer i. This is done because the probability that a part fails at a certain customer increases with the amount of parts in their system. From these weighted tariffs, the average value is taken to be the weighted average pickup costs.

$$PU = \sum_{i=1}^{N} TR_i * \frac{sp_i}{TP} \qquad (6)$$

Where, TP is the total number of parts in the field.

Number of pickups ($\#PU$), is equal to the number of demand occurrences with a return, or in other words, the number of return occurrences per year (RO_{year}). This can be derived from the total number of demand occurrences (DO_{year}) multiplied with the return yield (rt), the probability that the customer returns the failed parts. The return yield as well as the demand occurrences are input to the model and will be further treated in 6.3.

$$RO_{year} = DO_{year} * rt \quad (7)$$

Average SCW – Supplier cost ($ScSu$), depends also on the weight. The weight of the average shipment is assumed to be equal to the weight of the average order size. The explanation for this is that a return is expected to be equal to the average order size. Therefore, the inventory of failed parts is expected to be a multiple of the average order size. This leads to the assumption that there are either enough failed parts on inventory to fill the average order, or there are none and the order is filled with new parts only.
Based on the weight and the country where the supplier is located, the average SCW-supplier cost can be retrieved from the table with transportation tariffs.

Number of SCW-Supplier shipments ($\#ScSu$), is determined by the number of demand occurrences which can be (partly) filled with re-processed parts. Since it is assumed there are either enough failed parts to fill an order, or none at all, the number of shipment is equal to the number of return occurrences, as defined in formula (7)

Weighted average delivery costs (DE) are equal to the weighted average pickup costs, as defined in formula (6). The average transportation quantity is equal to the average order size and also the destinations are the same as the pickup locations. The difference is that the delivery starts from the supplier. If this is in the Netherlands, the price is exactly the same. If the supplier is located in a different country, different tariffs apply. These tariffs have to be requested at the transportation company. At this moment it is assumed that the supplier is located in the Netherlands.

Number of deliveries ($\#DE$), are equal to the number of demand occurrences (DO_{year}). For each time demand occurs, a delivery is done.

Average Supplier-SCW cost ($SuSc$) and *Number of Supplier-SCW shipments* ($\#SuSc$) are not taken into account for the RTO model. No transportation of parts from the supplier to the SCW occurs, since no inventory of serviceable parts is kept.

Inventory (Equation 3b)
Average inventory of failed parts ($\overline{iv}_{fail}$), is one of the more complicated figures to calculate and will therefore be more extensively discussed.
In the RTO model, the failed parts are kept on inventory in the SCW until demand occurs. At that time the failed parts are sent to re-processing. In case there are no failed parts on inventory, demand is filled with new parts which are ordered at the moment demand occurs. Upon delivery of the serviceable parts, the failed parts are picked up and returned to the SCW. Therefore there is time between the moment failed parts leave for re-processing and the arrival of the returned failed parts. This time is assumed to be equal to the lead time of re-processing (L_{repro}). In this lead time also some time for the transportation can be included.
The above mentioned process is shown in Figure 11, where the physical inventory of failed parts over time is displayed. The vertical axes presents the amount of failed parts on inventory and the horizontal axes shows the time. Hereby it is assumed that the demand occurrences are equally distributed over the year and that parts are returned with a probability equal to the return yield (rt). In case of Figure 11, the expected number of demand occurrences (DO_{year}) is 5 and the return yield is 0,8.

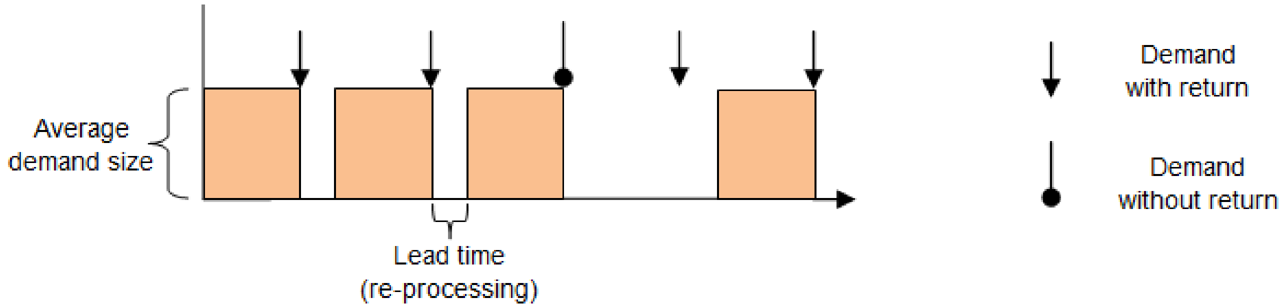

Figure 11 – Physical inventory of failed parts over time

The number of failed parts which is returned equals the average demand size ($\overline{ds}$).

Based on Figure 11, the average inventory of failed parts can be determined by calculating the surface of the different “blocks” of inventory in the figure. The surface of one block is the product of the average demand size ($\overline{ds}$) and the time between demand occurrences ($\frac{1}{DO_{year}}$) minus the lead time of re-processing (L_{repro}). The number of blocks per year is equal to the number of return occurrences, as it was defined in formula 7. When the lead time is expressed in days, the average inventory level of failed parts can be expressed as:

$$\overline{iv}_{fail} = \overline{ds} * R_{year} * \left(\frac{1}{DO_{year}} - \frac{L_{repro}}{365}\right) \quad (8)$$

Hereby it is expected that the lead time of re-processing is smaller than the time between demands. In case the lead time is longer, this method cannot be used since the parts stay a negative amount of time in the SCW which is not possible. At Vanderlande, most parts are slow movers and are not sold very often. Therefore this method is expected to work for the majority of parts.

The method which is used to calculate the average inventory of failed parts is not completely accurate. Since the method uses averages, the number of returns or the demand, might be higher or lower in reality. This could result in a high number of returns followed by several low demand occurrences. Thereby there will be inventory left. This is normal when averages are used; the higher values are compensated with values which turn out lower than expected. Unfortunately that is not possible, since it is not possible to have a negative inventory level. Therefore the formula underestimates the inventory level. However, the difference will only be large when there is a low return yield and a high lead time, since those factors determine the time where the “leftover” inventory is not taken into account in the formula. Especially with the slow moving parts of Vanderlande this will not lead to a high difference.

Value of failed part ($value_{fail}$), is equal to the compensation fee (CF) which Vanderlande pays to the customer. This value is chosen since it is the investment that Vanderlande has made to acquire the failed part. This is also in line with the way Vanderlande would like to value their inventory. The compensation fee is set at a certain percentage (cf) of the sales price for which the customer has bought the part earlier. The sales price of a new part is determined by adding a markup (mu) to the purchasing cost (NP). Both the markup and purchasing cost for a new part, as well as the percentage for the compensation fee are input parameters and will be further discussed in paragraph 6.3.

$$CF = NP * (1 + mu) * cf \quad (9)$$

Average inventory of new parts ($\overline{iv}_{new}$), *Average inventory of re-processed parts* ($\overline{iv}_{repro}$), *Value of new parts* ($value_{new}$) and *Value of reprocessed parts* ($value_{repro}$), are not taken into account here, since in the RTO model there is no serviceable inventory.

Weighted average cost of capital ($WACC$), is an input variable. This will be treated in paragraph 6.3.

Warehousing (Equation 3c)
Number inbound order lines ($\#ol_{in}$), is the number of times parts that arrive at the SCW. In the case of the RTO model, only failed parts arrive there, when they are returned by the customer. This means that the number of inbound order lines is equal to the number of return occurrences (RO_{year}), as defined in formula 7.

Number outbound order lines ($\#ol_{out}$), is the number of times parts leave the SCW. In case of the RTO model this happens exclusively when failed parts are sent to re-processing. This is, just like for the inbound order lines, equal to the number of return occurrences (RO_{year}).

Average required number of locations for failed parts ($\#loc_{fail}$), is determined in a similar way as the average inventory. In Figure 11 it was shown that the inventory level forms "blocks". The easiest way to calculate the required number of locations is by determining how many locations are needed to keep the inventory in such a block and subsequently multiplying it with the length of time of one block as well as the number of blocks per year. Compared to formula 8, only the "height" of a block differs. The height is determined by the required number of locations for keeping the inventory. In order to determine this, the number of parts which fit one location (pl) have to be known. This is an input parameter which is discussed in paragraph 6.3. This leads to the following expression for the required number of locations:

$$\#loc_{fail} = round\ up\left(\frac{\overline{ds}}{pl}\right) * R_{year} * \left(\frac{1}{DO_{year}} - \frac{L_{repro}}{365}\right) \tag{10}$$

Average required number of locations for new parts ($\#loc_{new}$) and *Average required number of locations for re-processed parts* ($\#loc_{repro}$), are not taken into account here, since in the RTO model there is no serviceable inventory.

Cost per location (PL), *costs per inbound order line* (POL_{in}), and *cost per outbound order line* (POL_{out}) are input variables, which will be treated in paragraph 6.3.

Re-processing/purchasing (Equation 3d)
Number of reprocessed parts ($\#rp$), depends on the number of failed parts which is returned and the probability of success of the re-processing. From the demand per year (D_{year}), it is assumed that a share equal to the return yield (rt) is returned and from these failed parts, re-processed is successful with the probability of the repair yield (ry).

$$\#rp = D_{year} * rt * ry \tag{11}$$

Number of new parts ($\#np$), is the difference between the total demand and the number of re-processed parts. The new parts are used to complement the supply of re-processed parts, since they are assumed not to be sufficient to fill all demand.

$$\#np = D_{year} * (1 - rt * ry) \tag{12}$$

Number of orders ($\#os$), is the number of times that an order is placed for either re-processing or new parts. Since it is assumed that the supplier also performs the re-processing, there is one order per demand occurrence. Therefore the number of orders is equal to the number of demand occurrences (DO_{year}).

Number of unrepairable parts ($\#ip$), is determined by the number of returned failed parts and the probability that a part is not repairable. This probability is equal to one minus the repair yield.

$$\#ip = D_{year} * rt * (1 - ry) \tag{13}$$

Re-processing cost (RP), *Purchasing cost* (NP), *Fixed order cost* (FP) and *Inspection cost* (IP), are all input parameters. These will be treated in paragraph 6.3.

Labor costs (Equation 3e)
Number of demand occurrences without return ($\#to_1$), is derived by multiplying the number of demand occurrences with the probability that a customer does not want to return their failed parts. This probability is equal to one minus the return yield.

$$\#to_1 = DO_{year} * (1 - rt) \tag{14}$$

Number of demand occurrences with return ($\#to_2$), is equal to the number of returns, as defined in formula 7.

Coordination time per demand occurrence without return (TT_1) and *Coordination time per demand occurrence with return* (TT_2) are fixed input parameters which are discussed in paragraph 6.3.

Number of replenishment orders ($\#to_3$) and *Coordination time per replenishment order* (TT_3) are not applicable for the RTO model, because no serviceable inventory is kept. Therefore no replenishments are needed.

Compensation fee (Equation 3f)
Number of returned parts ($\#ri$) this is equal to the total demand multiplied with the return yield.

$$\#ri = D_{year} * rt \tag{15}$$

Compensation fee (CF), see formula 9.

Revenue (Equation 4)
Sales price of a new part (SP_{new}), is derived from the purchase cost and the mark up which is applicable for the part. These are both input parameters and will be further discussed in paragraph 6.3.

Sales price of a re-processed part (SP_{repro}), is derived from the sales price of a new part. This price is lowered with the re-processing discount. The discount is an input parameter and will be discussed in paragraph 6.3.

Number of new parts (#np), is defined in formula 12.

Number of re-processed parts (#rp), is defined in formula 11.

6.2.2 Push model

In order to determine the economic feasibility of reverse logistics under the push model, the same method is used as for the RTO model. When input parameters are used, no specific reference is made. For further explanation on the input parameter the reader is referred to paragraph 6.3. Furthermore, certain parameters or variables might be equal to the RTO model. In that case a reference to that specific formula is made.

Transportation
Average Supplier-SCW cost ($SuSc$), is split up between the transportation of re-processed parts and that of new parts. This is done, since the push model does not necessarily combine the two types of parts in an order. The transportation therefore occurs separately from each other. Like all transportation costs, it depends on the weight of the average shipment. The location of the SCW and the supplier are fixed and therefore no weighted average has to be determined, compared to the pickup and delivery costs.
The weight of the re-processed parts is determined by the number of successfully re-processed parts per return. Previously, it has been stated that the average number of failed parts per return is equal to the average demand quantity. A share equal to the repair yield is expected to remain after re-processing.
The weight of the new parts is that of the average order size. The average order quantity (Q) is determined by the difference between the reorder point (s) and the order up to level (S). The order up to level and the reorder point are both input variables.

$$Q = S - s \tag{16}$$

With the weights of the average shipments the cost parameter can be retrieved from the standard tariff for the respective weights. Hereby two cost parameters are determined; $ScSu_{repro}$ and $ScSu_{new}$.

Number of Supplier-SCW shipments ($\#SuSc$), is also split between re-processed and failed parts for the same reasons as above.
The number of shipment for re-processed part is determined by the number of return occurrences (RO_{year}).
The number of shipments for new parts depends on the required amount of new parts ($\#np$) and the order quantity (Q). Where, the number of new parts has been defined in formula 12 and the average order quantity in formula 16. This leads to the following expression for the number of supplier SCW shipments:

$$\#SuSc = \frac{\#np}{Q} \tag{17}$$

Average SCW-Supplier cost ($ScSu$) and *Number of SCW-Supplier shipments* ($\#ScSu$), are not applicable in the push model. Failed parts are re-processed immediately upon return and therefore they do not have to be transported to the supplier.

Weighted average pickup cost (PU), see formula 6

Number of pickups ($\#PU$), is equal to the number of return occurrences (RO_{year}), see formula 7

Weighted average delivery costs (DE), is equal to the weighted average pickup costs, for the same reason as under the RTO model.

Number of deliveries ($\#DE$), is equal to the number of demand occurrences (DO_{year})

Inventory

Average inventory of new parts ($\bar{iv}_{new}$), is determined by the s,S policy that is used to control the timing and quantity of the replenishment orders. In the s,S policy an order is placed when the inventory position drops to the reorder point and is then raised to the order up to level. The inventory position fluctuates between the reorder point and the order up to level. However, the physical inventory level is only raised at the moment the replenishment order arrives at the SCW. This is after the lead time for purchasing new parts. The resulting inventory levels over time are sown in Figure 12.

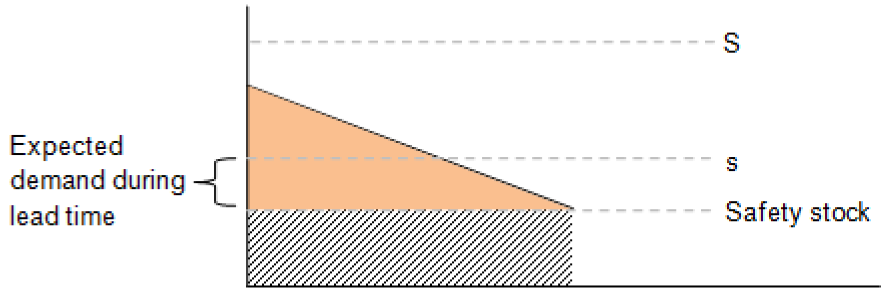

Figure 12 – Inventory of new parts over time

In order to determine the average inventory position of new parts, the average cycle stock has to be added to the safety stock. This can be written as:

$$\bar{iv}_{new} = \frac{S - s}{2} + Safety\ stock \tag{18}$$

Average inventory of re-processed parts ($\bar{iv}_{repro}$), is expected to follow the pattern as it is shown in Figure 13. Upon demand the re-processed parts on inventory are used to fill the demand. At the moment the serviceable parts are delivered, the failed parts are picked up and directly sent to re-processing. Subsequently the successfully re-processed parts are added to the inventory. In case the customer does not return their parts the inventory is expected to be zero.

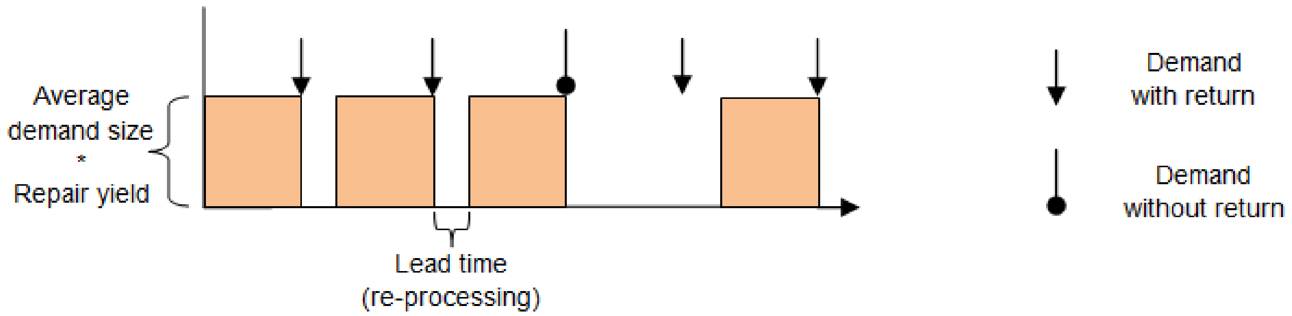

Figure 13 – Physical inventory of re-processed parts over time

Figure 13 show the same pattern as in Figure 11. The average inventory level of re-processed parts will also be calculated in the same way as formula 8. The only difference is that under the push model the parts are re-processed before they are added to the inventory. Since not all parts are successfully re-processed, the height of the blocks is lower with the repair yield as factor. This can be written as

$$\overline{iv}_{repro} = \overline{ds} * ry * RO_{year} * \left(\frac{1}{DO_{year}} - \frac{L_{repro}}{365}\right) \tag{19}$$

For this formula the same drawbacks apply as for the average inventory of failed parts under the RTO model. However, also in this case, the given formula is preferred over alternatives, since it is relatively accurate and simple.

Value of new parts ($value_{new}$), is equal to the purchase price. This is the value for which the parts have been acquired and therefore this is value which they represent to Vanderlande.

Value of reprocessed parts ($value_{repro}$), is determined similar to that of new parts. In order to acquire a re-processed part, Vanderlande buys a failed part from a customer and subsequently pays for the re-processing. Therefore the value of a re-processed part is the compensation fee plus the re-process price.

Average inventory of failed parts ($\overline{iv}_{fail}$) and *Value of failed part* ($value_{fail}$), are not applicable for the push model, since failed parts are immediately re-processed and are therefore not kept in inventory.

Warehousing

Number inbound order lines ($\#ol_{in}$), are the incoming orders of re-processed and new parts. This is equal to the number of Supplier-SCW shipments ($\#SuSc$), as defined in formula 17.

Number outbound order lines ($\#ol_{out}$), is determined by the number of demand occurrences (DO_{year}). Every time a customer orders parts, this creates an outbound order line.

Average required number of locations for new parts ($\#loc_{new}$), is determined along the average inventory ($\overline{iv}_{new}$) that was defined in formula 17. By dividing the average inventory level by the parts per location (), the required number of locations is found by rounding up the result. This can be written as:

$$\#loc_{new} = round\ up\left(\frac{\overline{iv}_{new}}{pl}\right) \tag{20}$$

Average required number of locations for re-processed parts ($\#loc_{repro}$), follows the same reasoning as in formula 18, where the average inventory level of re-processed parts is determined. The only difference is that the height of the blocks is expressed as the number of locations instead of the number of parts. This results in the following expression:

$$\#loc_{new} = round\ up\left(\frac{\overline{ds} * ry}{pl}\right) * RO_{year} * \left(\frac{1}{DO_{year}} - \frac{L_{repro}}{365}\right) \tag{21}$$

Average required number of locations for failed parts ($\#loc_{fail}$), is not applicable to the push model, since there is no inventory of failed parts.

Re-processing/purchasing

Number of reprocessed parts (#rp), *Number of new parts* ($\#np$) and *Number of unrepairable parts* ($\#ip$), see respectively formula 11, 12 and 13.

Number of orders ($\#os$), is determined by the re-processing orders, which occur with every return occurrence (RO_{year}) and orders for new parts which occur when the inventory position drops below the reorder point. This leads to the same expression as for the number of inbound order lines in formula 19.

Labor costs

Number of demand occurrences without return ($\#to_1$), see formula 14

Number of demand occurrences with return ($\#to_2$), is equal to the number of returns, as defined in formula 7.

Number of replenishment orders ($\#to_3$), is previously discussed and determined by the difference between demand and successfully re-processed parts divided by the average order quantity.

$$\#to_3 = \frac{D_{year} - \#rp}{Q} \tag{22}$$

Coordination time per demand occurrence without return (TT_1), *Coordination time per demand occurrence with return* (TT_2) and *Coordination time per replenishment order* (TT_3), are fixed input parameters which are discussed in paragraph 6.3.

Compensation fee

Compensation fee (CF), see formula 9.
Number of returned parts ($\#ri$), see formula 15

6.2.3 Pull model

In order to determine the economic feasibility of reverse logistics under the pull model, the same method is used as for the RTO and the push model. There were input parameters are required, no explanation is given. For further explanation on the input parameters the reader is referred to paragraph 6.3. Furthermore, certain parameters or variables might be equal to previously treated formulas. In that case a reference to that specific formula is made.

Transportation

Average Supplier-SCW cost ($SuSc$), can be retrieved from the standard tariffs which are used by the 3PL. These standard tariffs depend on the weight of the shipment. For the transportation of serviceable parts from the supplier to the SCW, the weight is determined by the order size (Q). In the Pull model an order is placed for both re-processing and new parts at the same time. Therefore the weight of a shipment is determined by both types of parts. The average order quantity of both re-processing and new parts together is the difference between the order up to level and the reorder point.

Number of Supplier-SCW shipments ($\#SuSc$), is equal to the number of orders which is placed ($\#os$). The number of orders per year depend on the demand (D_{year}) and the average order quantity (Q). Where the demand is an input parameter and the order quantity is defined in formula 16.

$$\#os = \frac{D_{year}}{Q} \tag{23}$$

Average SCW-Supplier cost ($ScSu$), can be retrieved from the standard tariffs of the transportation company. These tariffs, as previously discussed, depend on the weight of the shipment. In this case the shipment consists of the failed parts which are sent to re-processing. Since it is assumed that less failed parts return than new parts are needed, all failed parts on inventory are sent to re-processing. The number of failed parts on inventory is determined by the number of returned parts since the previous order. The number of returned parts is estimated as a fixed share (rt) of the demand and demand between orders is equal to the order quantity (Q). Therefore the number of failed parts per SCW – Supplier transportation can be expressed as

$$\#failed\ parts = Q * rt \tag{24}$$

The combined weight of these failed parts determines the tariff which is the average SCW-Supplier cost.

Number of SCW-Supplier shipments ($\#ScSu$), depends on the number of orders placed and is therefore equal to the number of Supplier-SCW shipments, as defined in formula 23.

Weighted average pickup cost (PU) and *Weighted average delivery costs* (DE), are both defined by formula 6.

Number of pickups ($\#PU$), is equal to the number of return occurrences (RO_{year}) as defined in formula 7.

Number of deliveries ($\#DE$), is equal to the number of demand occurrences (DO_{year}), which is an input parameter.

Inventory

Average inventory of failed parts ($\overline{iv}_{fail}$) is build up throughout the inventory cycle. It starts at zero and the final inventory level is, as previously discussed, given by formula 24. Therefore the average inventory level during a replenishment cycle can therefore be written as:

$$\overline{iv}_{fail} = \frac{1}{2} * Q * rt \qquad (25)$$

Average inventory of re-processed parts ($\overline{iv}_{repro}$) is related to the inventory of new parts, since they are ordered at the same time and controlled with the same parameters. The joined inventory of the two types of parts is shown in Figure 14. The figure shows one full replenishment cycle, where the duration of the cycle is given by:

$$T = \frac{Q}{D_{year}}$$

The cycle starts with the arrival of a replenishment order and ends when the next replenishment order is about to arrive. At the start of the cycle, the inventory of both the re-processed and new parts is at a maximum.
The inventory of re-processed parts equals $ry * rt * Q$ at the beginning of the cycle. This follows from the number of parts which have been sent to re-processing, given by formula 24, and the probability that a part is successfully re-processed (ry). At the end of the cycle the inventory is zero, since the re-processed parts are assumed to be preferred over new ones and there are not enough to fulfill demand. During the time there is inventory of re-processed parts, the average inventory is $\frac{1}{2} * ry * rt * Q$. However, since the inventory last only part of the replenishment cycle, it has to be multiplied with the fraction of time at which re-processed parts are on inventory. This fraction is equal to ($ry * rt$), since that is the share of demand which can be filled with re-processed parts and demand is assumed to be equally spread over time. Therefore the average inventory of re-processed parts can be written as:

$$\overline{iv}_{repro} = \frac{1}{2} * ry * rt * Q * rt * ry \qquad (26)$$

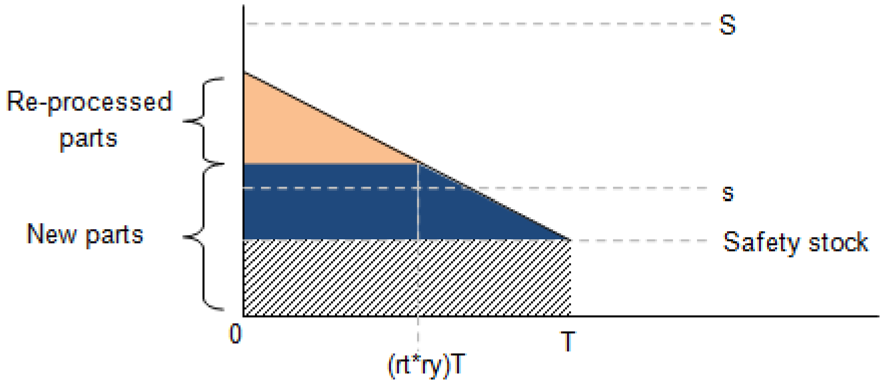

Figure 14 – inventory of re-processed and new parts during one replenishment cycle

Average inventory of new parts ($\overline{iv}_{new}$), is in turn related to the inventory of re-processed parts. Previously it was mentioned that the re-processed parts fulfill demand for $ry * rt$ share of the replenishment cycle. This is also shown in Figure 14. During that time the inventory of new parts remains stable. Excluding the safety stock this includes $(1 - ry * rt) * Q$ parts. That is the amount which complements the supply of re-processed parts to make up for the order quantity. After the re-processed parts are consumed, demand is fulfilled with new parts. Until the end of the replenishment cycle, the additional parts should be exactly finished. Therefore the average inventory of new parts can be written as:

$$\overline{iv}_{new} = \left(rt * ry + \frac{1}{2} * (1 - rt * ry) \right) * (1 - ry * rt) * Q + safetystock \qquad (27)$$

Value of new parts ($value_{new}$), is equal to the purchase price, just like for the push model

Value of reprocessed parts ($value_{repro}$), is equal to the compensation fee plus the re-process cost, just like for the push model.

Value of failed part ($value_{fail}$), is equal to the compensation fee just like in the RTO model.

Warehousing
Number inbound order lines ($\#ol_{in}$), is equal to the amount of orders and the return occurrences (RO_{year}). Based on formulas 7 and 24 it can be written as:

$$\#ol_{in} = \frac{D_{year}}{Q} + RO_{year} \tag{28}$$

Number outbound order lines ($\#ol_{out}$), is equal to the number of demand occurrences (DO_{year})

Average required number of locations for failed parts ($\#loc_{fail}$), depends on the average inventory of failed parts ($\overline{iv}_{fail}$), which was defined in formula 25, and the number of parts which can fit a location (pl). The average required number of locations for failed parts can be written as:

$$\#loc_{fail} = \frac{\overline{iv}_{fail}}{pl} \tag{29}$$

Average required number of locations for new parts ($\#loc_{new}$), is steady over the fraction ($rt * ry$) of time where the re-processed parts fill the demand. After the re-processed parts are finished the inventory of new parts will gradually reduce to the safety stock level at which point the inventory is replenished. The average inventory during these moments has to be divided by the number of parts that fit a location (pl) in order to arrive at the required number of locations. Thereby the average required number of locations for new parts is:

$$\#loc_{new} = (rt * ry) * \frac{(1 - ry * rt) * Q + safetystock}{pl} + (1 - rt * ry) * \frac{\frac{1}{2} * \big((1 - ry * rt) * Q\big) + safetystock}{pl} \tag{30}$$

Average required number of locations for re-processed parts ($\#loc_{repro}$), is based on the average inventory during the fraction of time that re-processed parts are available. For the other part, no locations are required. Re-processed parts are kept on inventory during an $rt * ry$ fraction of time. During that time the inventory level is assumed to decreases steadily from the maximum inventory level, just after the replenishment order arrives, till zero. This results in the following expression of the average required number of location for re-processed parts:

$$\#loc_{repro} = (rt * ry) * \frac{\frac{1}{2} * ry * rt * Q}{pl} \tag{31}$$

Re-processing/Purchasing
Number of reprocessed parts (#rp), *Number of new parts* ($\#np$) and *Number of unrepairable parts* ($\#ip$), see respectively formula 11, 12 and 13.

Number of orders ($\#os$), has been defined in formula 23.

Labor
Number of demand occurrences without return ($\#to_1$), see formula 14

Number of demand occurrences with return ($\#to_2$), is equal to the number of returns, as defined in formula 7.

Number of replenishment orders ($\#to_3$), has been defined in formula 23.

Coordination time per demand occurrence without return (TT_1), *Coordination time per demand occurrence with return* (TT_2) and *Coordination time per replenishment order* (TT_3), are fixed input parameters which are discussed in paragraph 6.3.

Compensation fee
Compensation fee (CF), see formula 9.
Number of returned parts ($\#ri$), see formula 15

6.2.4 Current situation

In order to determine the economic feasibility as it was defined in formula 2, also the costs and revenue under the current situation have to be known. Since the accounting at Vanderlande does not allocate the different costs to spare parts, there is no available overview of costs per spare part. Therefore, the profit needs to be calculated. Hereby a distinction is made between the current situation with and without inventory. In the current situation the majority of parts are not kept on inventory at the SCW. However, there are parts which are kept on inventory. Therefore the calculations for the situation with and without inventory will now be briefly discussed.

Without inventory
Without keeping inventory at the SCW, the costs in the current situation are the same as in case of the RTO model with a return yield of zero. In the RTO model there is also no serviceable inventory and the costs structure is the same. When the return yield is then set to zero, the option of reverse logistics is disabled. This leads to the costs of the current situation, except that in the current situation the parts which are ordered are first transported to the SCW before they are delivered to the customer. Therefore additional transportation and handling costs have to be taken into account. These additional costs amount to:

$$DO_{year} * (SuSc + POL_{in} + POL_{out})$$

With inventory
When in the current situation inventory is kept, the total profit can be easily retrieved by setting the return yield to zero for either the push or the pull model. Both models will return the same result since they both use a pull strategy for the new parts. Since in this case the parts anyway pass through the SCW, no additional costs are made in the current situation.

6.3 INPUT PARAMETERS

In this paragraph the input parameters are discussed. They are treated one by one. A distinction is made between the parameters which depend on the part and parameters which are independent of the part. This distinction is important since the “fixed parameters” do not have to be changed when the method is applied to different parts, whereas the “part dependent parameters” do need to be changed.

6.3.1 Part dependent parameters

Parts per location (pl), is dependent on the size of the part and the type of the location. The location can be either a shelf or a pallet. The storage capacity in dimension of a pallet and a shelf is shown in Table 3. The dimensions of the part can be found in SmartTeam. Based on that information, the number of parts per location can be easily calculated by dividing the surface of the location by the surface of the part. However, this will not lead to an exact answer, since it does not take into account how the parts have to be arranged. Therefore the most precise way of determining the part per location is too calculate based on the length and width of the part and the location how many parts can be located at the location.

Type of location	Dimensions (l*w*h)
Shelf	80*40*20
Pallet	120*87*40

Table 4 – Dimensions of storage locations (in cm)

Re-processing cost (RP), *Fixed order cost* (FP) and *Inspection cost* (IP), are made at re-processing. These prices can be requested at the supplier, assuming that the supplier performs the re-processing, which is the initial intention.

Purchasing cost (NP), is the price for which Vanderlande buys the part at their supplier. The purchase costs for all parts can be found in the ERP system.

Markup (mu), is the percentage by which the purchase price is increased in order to arrive at the sales price. The markup can be found in the ERP system.

Compensation fee (CF), is the amount of money which is offered to the customers for their failed part. The compensation fee is a percentage of the sales price, for which the customer has bought the part when it was new. The compensation fee is new, since previously parts where not taken back by Vanderlande. Therefore there are no values available. The compensation fee has to be determined based on the different factors which influence the fee. These factors and how they can be determined have been discussed in paragraph 5.4.2.

Re-processing discount, is the discount which Vanderlande offers their customers on a re-processed part compared to the price of a new part. Such a value is not yet determined by Vanderlande, since they do not sell re-processed parts yet. In paragraph 5.4.1 it was discussed how this discount can be determined.

Demand occurrences (DO_{year}), is the expected number of demand occurrences for the next year. This is determined by taking the weighted average over the historic demand.

Demand (D_{year}), is the expected demand over the next year. This is determined by a weighted average over the historic demand.

Reorder point (s), depends on the model which is used. The reorder point for the push and pull model can be determined through the formulas given in 5.2.2.

Order up to level (S), depends on the model which is used. The order up to level for the push and pull model can be determined through the formulas given in 5.2.2.

Safety stock (ss), depends on the model which is used. The safety stock for the push and pull model can be determined through the formulas given in 5.2.2.

Minimal service level, is based on a value judgment of the management of Vanderlande. They can base their decision on the criticality of the part.

6.3.2 Fixed parameters

Weighted average cost of capital ($WACC$), is the percentage at which Vanderlande values a certain investment. In the context of the research the WACC is used to value the inventory of failed, re-processed and new parts. Currently Vanderlande uses a value of 4 percent for the consignment stock. Since in both cases it concerns an investment in inventory, the same value will be used for the WACC in the context of this research.

Cost per location (PL), are quoted by the 3PL which operates the SCW. The prices per shelf or pallet are based on the period of a week and are respectively € 0,59 and € 0,87.

Cost per inbound order line (POL_{in}) and *Cost per outbound order line* (POL_{out}), are both variable costs, in the sense that they are determined per period based on the number of man hours which were needed to process the order lines. Also fixed costs for using material like forklifts is included. However, as a rule of thumb the 3PL provided a cost per inbound and outbound order line which can be seen as the expected value. This is €3,75 per inbound order line and €9,77 per outbound order line.

Coordination time per demand occurrence without return (TT_1) and *Coordination time per replenishment order* (TT_3), are activities which are currently performed by the employees of Vanderlande. Therefore these coordination times were relatively easy to estimate. Table 5 provides an overview of all coordination times under the RTO model.

Labor cost (LC), is the cost for one hour of the time of an employee. This value is estimated based on the average wage of the employees at the SCMS department. Here an additional costs needs to be taken into account, since the costs for an employer are always higher than the gross income of an employee. This results in an estimated labor cost per hour of €50.

Coordination time per demand occurrence with return (TT_2), is based on the expert opinion of employees at Vanderlande. The employees do not have experience with some aspects of the activities, since currently parts are not returned. Based on the flowcharts it was explained what the activities exactly consist of and based on their experience the employees have estimated the time that this will take them. This has been done by different employees and independent of each other they came to approximately the same result. Therefore, this result is deemed a good estimation. The values can be found in Table 5 where an overview is presented of all coordination times.

Notation	Activity	RTO model (time in minutes)	Push model (time in minutes)	Pull model (time in minutes)	Currently (time in minutes)
TT_1	Demand occurrence without return	15	10	10	15
TT_2	Demand occurrence with return	25	25	20	n.a.
TT_3	Replenishment order	n.a.	5	5	n.a.

Table 5 – Coordination times per trigger

Transportation tariffs are quoted by the 3PL which primarily handles the transportation. As mentioned before, the tariffs depend on the countries between which the transport takes place and the weight of the package which is sent. Therefore the tariffs are quoted for different weight intervals towards different countries. Since all packages which are sent by Vanderlande originate from the Netherlands, only tariffs between the Netherlands and other countries are provided.

6.4 CASE STUDY

In order to illustrate the method for determining economic feasibility as well as for showing the potential of reverse logistics, a real life example has been worked out. The subject of this case study is an electronic part which currently went end of supply (EOS). With this part the discussion started within Vanderlande, whether it wouldn't be beneficial to apply reverse logistics in order to avoid a large last time buy. In this thesis the scope has been broadened, to not focus on the last time buy in itself, but look at the savings which can be realized by applying reverse logistics in general. Therefore the economic feasibility will be determined for this electronic part along the formulas which have been treated previously in this chapter. First the costs and revenue under the RTO model will be calculated, followed by the costs and revenue under the current situation. Finally the economic feasibility can be determined.

6.4.1 RTO model

The costs of the RTO model are now determined along formula 3 after which the revenue is determined along formula 4.

$$Cost = Transportation + Inventory + Warehousing + Reprocessing + Coordinating + Compensating \quad (3)$$

$$Revenue = SP_{new} * \#ns + SP_{rp} * \#rs \quad (4)$$

Transportation

$$Transportation = PU * \#PU + ScSu * \#ScSu + SuSc * \#SuSc + DE * \#DE \quad (3a)$$

The transportation costs of the electronic part fall in the lightest weight category. Since the weight of the part is rather low and the part is a slow mover, the weight of a shipment will not exceed 35 kg which marks the border of the lightest weight category. In order to determine the weighted average pickup costs, the transportation costs towards the different customers which use the electronic part are retrieved from the table with transportation costs. These costs are weighted per customer with the number of the electronic part, which they have in their system. Thereby the weighted average pickup cost for the electronic parts are €9,57. Since the weighted average delivery costs are equal to the pickup cost, this is also €9,57.
The supplier of the part is located in the Netherlands and therefore the tariff for the average SCW-supplier cost can be easily retrieved from the table and is €4,32.

As discussed previously, the number of pickups and SCW-supplier shipments equal the expected number of return occurrences and the number of deliveries is equal to the number of demand occurrences. The number of demand occurrences is a weighted average of historic demand from previous the previous five years. In case of the electronic part, this is 22,9. Thereby the return yield is estimated by a manager at Vanderlande at 0,8. That means that the expected number of returns occurrences is 22,3.
When these values are entered in equation 3a, the following result is reached:

$$9{,}57 * 22{,}3 + 4{,}32 * 22{,}3 + 9{,}57 * 27{,}9 = 576{,}75$$

Inventory

$$Inventory = WACC * \left(iv_{fail} * value_{fail} + iv_{repro} * value_{repro} + iv_{new} * value_{new}\right) \qquad (3b)$$

The weighted average cost of capital which is applicable for the inventory at Vanderlande is 4 percent, as it was previously discussed.
In the RTO model the only inventory which is kept are the failed parts. On average it is expected that there are 1,22 parts on inventory over the year. This comes forth from an average order size of 1,52, which is the quantity that is returned an expected 22,3 times and arrives at the SCW after a lead time for re-processing of 10 days and subsequently remains there until the next order arrives.
The value of a failed part is set at the compensation fee. In this case it was set by a manager at Vanderlande at 2,5 percent of the sales price of a new part. This was done without following the procedure that was explained in chapter 5. When reverse logistics would be operationalized, it is recommended to research this value along the recommendations.
The sales price of the electronic part is determined by the price which Vanderlande pays to the supplier plus a markup. Since the markup is confidential information, a fictional markup is set at 25 percent. The price of the part is €432,24, which brings the sales price to €540,30. This makes the compensation fee, and therefore the value of a failed part, €13,51.

When these values are entered in equation 3b, the following result is reached:

$$0{,}04 * 1{,}5 * 22{,}3 * \left(\frac{1}{27{,}9} - \frac{10}{365}\right) * 13{,}51 = 0{,}15$$

Warehousing

$$Warehousing = PL * \left(\#loc_{fail} + \#loc_{repro} + \#loc_{new}\right) + POL_{in} * \#ol_{in} + POL_{out} * \#ol_{out} \qquad (3c)$$

In the SCW only failed parts are kept under the RTO model. The average number of required locations is deducted from the number of parts per location (8), the average demand size (1,52), the expected number of returns (22,3) and the average time the parts are stored until the next demand occurs ($\frac{1}{27{,}9} - \frac{10}{365}$).

The electronic parts are stored on a shelf, since they are relatively small and more space is not needed. The price per location is therefore €0,59 per week.

The cost for the handling is respectively €3,75 and €9,77 per inbound and outbound order line.

The number of inbound and outbound order lines equals the expected returns and is therefore 22,3 per year.

When these values are entered in equation 3c, the following result is reached:

$$0{,}59 * 52 * 1 * 22{,}3 * \left(\frac{1}{27{,}9} - \frac{10}{365}\right) + 22{,}3 * (3{,}75 + 9{,}77) = 307{,}27$$

Re-processing/Purchasing

$$Re\,processing/Purchasing = RP * \#rp + NP * \#np + FP * \#os + IP * \#nr \qquad (3d)$$

The costs for re-processing, purchasing, inspection and fixed order costs are input parameters and in this case the values are respectively €250, €432,24, €122,5 and €0,00.

The number of re-processed parts is determined by the number of returned parts, which in turn is the product of the total demand (42,4) and the return rate (0,8). The probability that a failed part can be re-processed is safely estimated by a manager at Vanderlande at 0,8, which leads to an expected number of re-processed parts of 27,1. This automatically means that the other 6,8 parts cannot be re-processed.

The fraction of the demand which is not filled by re-processed parts is filled with new parts. Therefore an expected 15,3 part needs to be purchased.

Finally the number of orders which has to be placed at the supplier is equal to the number of demand occurrences; in this case 27,9.

When these values are entered in equation 3d, the following result is reached:

$$250 * 27{,}1 + 432{,}24 * 15{,}3 + 0{,}00 * 27{,}9 + 122{,}5 * 6{,}8 = 14221{,}27$$

Coordinating

$$Coordinating = LC * \sum_{i=1}^{4} TT_i * \#to_i \qquad (3e)$$

Under the RTO model there are no replenishment orders which need to be placed. Furthermore it is expected that customers do not send back the parts on their own initiative. Therefore only two triggers occur which require the time of Vanderlande staff. These triggers are a demand occurrence with return and a demand occurrence without return. The time these triggers consume is respectively 25 and 15 minutes.
The number of demand occurrences with return is 22,3 and the number of demand occurrences without return is 5,6.
The cost of one man hour has been estimated previously at €50.

When these values are entered in equation 3e, the following result is reached:

$$50 * \left(22{,}3 * \frac{25}{60} + 5{,}6 * \frac{15}{60}\right) = 534{,}58$$

Compensation fee

$$Compensation\ fee = CF * \#ri \qquad (3f)$$

The compensation fee has been previously determined and comprises off €10,81. The number of returns for which the compensation fee is paid is 33,9.

When these values are entered in equation 3f, the following result is reached:

$$13{,}51 * 33{,}9 = 457{,}99$$

Revenue

$$Revenue = SP_{new} * \#ns + SP_{rp} * \#rs \qquad (4)$$

The sales price of a new part has been previously discussed and is €540,30. On the re-processed parts, a discount of 10% is offered compared to the new price. This leads to a sales price for re-processed parts of €486,27. The discount is in this case determined based on an estimation of a manager at Vanderlande. It is recommended to follow the procedure of chapter 5 when the reverse logistics is further operationalized.
As explained before, the number of new parts and re-processed parts which are sold is equal to the number of parts purchased and re-processed respectively. That makes the number of new parts sold 15,3; and the number of re-processed parts sold 27,1.

When these values are entered in equation 4, the following result is reached:

$$540{,}30 * 15{,}3 + 486{,}27 * 27{,}1 = 21444{,}51$$

6.4.2 Current situation

After having treated the RTO model rather extensively, the profit under the current situation is given with little explanation. As previously explained, the costs in the current situation are calculated with the same formulas as for the RTO model, except that the return yield is set to zero. Additionally some transportation and handling costs are added, since in the current situation new parts are first transported to the SCW before they are delivered to the customers. This results in the following profit:

$$22908{,}72 - (18942{,}73 + 497{,}74) = 3468{,}26$$

6.4.3 Economic feasibility

The final step in the case study is to determine the economic feasibility by filling in formula 2.

$$\boxed{(Revenue_{rev} - Cost_{rev}) - (Revenue_{cur} - Cost_{cur}) > 0 \qquad (2)}$$

$$(21444{,}51 - 16098{,}02) - (22908{,}72 - 19440{,}47) = 1878{,}24$$

From this it can be concluded that applying reverse logistics would result in a profit under the RTO model. Compared to the profit which is made without reverse logistics, a 54,16 percent increase in profit can be realized. This is a large improvement and therefore reverse logistics proofs to be a large opportunity.

6.4.4 Push and pull model

For the push and pull model the economic feasibility has also been determined. The results can be found in Table 4. In the first column the profit with reverse logistics is shown. The second column shows the profit in the current situation. Hereby the assumption is made that in the current situation inventory is held at the SCW. The third column shows the absolute increase in profit, whereas the last column shows the percentage increase of profit compared to the current situation. In order to derive at these outcomes a minimal service level of 90 percent was required. Therefore the reorder point is 2 for the push model and 3 for the pull model. The service level which can be reached with these reorder points is respectively 93 and 95 percent.

Model	$Profit_{rev}$	$Profit_{cur}$	Profit increase (abs)	Profit increase (%)
Push	5176,57	3614,70	1561,87	43
Pull	5151,36	3614,70	1536,66	43

Table 6 – Results of the economic feasibility

6.5 VALIDATION AND VERIFICATION

The previous paragraphs explain how the economic feasibility of reverse logistics can be determined. A general method was developed and it was specified for the RTO model. In order to make sure that the results of the method are correct, this section aims to validate and verify the tool.

The validation of the method makes sure that all costs are included, which are needed to make a good comparison on which the decision to use reverse logistics can be based. As mentioned previously, currently Vanderlande does not allocate different costs to the individual parts. Therefore the answer cannot be found in their accounting information. Therefore, the validation is performed based on expert opinion. A manager at Vanderlande, who has plenty of experience with the spare parts, was asked to list the different cost components which can be allocated to an individual part. Subsequently the different cost components that are used in the method have been discussed. From this session, it became clear that all cost components are included in the method. Therefore it can be concluded that the method is valid.

Using all the right cost components does not guarantee a correct outcome. The different cost components also have to be calculated correctly. Therefore the verification of the method focuses on the content of the method. It determines to whether the outcome of the method is correct. A good way of verifying the method is to compare the outcomes with real data which has been previously collected. However, reverse logistics is a new concept for Vanderlande and therefore no data is available.
Due to this lack of data, the verification of the method had to be carried out alternatively. It was chosen to perform the verification on expert opinion. An authoritative and experienced employee of Vanderlande has

been asked to evaluate the values of estimated parameters and the outcome of the different cost components.
Conformation was given on how most of the parameters were determined. The parameters which could not be verified were the return yield, the discount on re-processed parts and the compensation fee. Since Vanderlande does not have any experience with reverse logistics, these parameters were outside of the expertise of the manager.
The outcome of the costs components and the revenue were to a large extent in line with the expert's expectation. Only the inventory costs were lower than expected. The reason for this is that due to the lead time, the inventory is only briefly present at the SCW. Even though there was a slight discrepancy between the expectation and the result of the method concerning the inventory value, this difference can be trivialized in proportion to the total costs. With respect to the total costs, the re-processing/purchasing cost component is of great importance, since it represents almost 90 percent of the total costs. Therefore extra attention was directed to this cost component. Besides the doubt concerning the return yield, both the outcome and the calculations were verified.

Overall the conclusion can be drawn that the method provides a reliable estimation of the total costs.

6.6 SENSITIVITY ANALYSIS

After the method has been validated and the outcomes have been determined, the sensitivity of the method towards the input needs to be determined. Hereby the focus is on parameters which are uncertain. In case these parameters turn out different than expected, it is important that this does not cause surprising results regarding the economic feasibility. If for instance the demand in a year is lower than expected, it should not result in a loss.
By varying the input variables and observing the changes it causes in the result, the sensitivity is determined. Below the sensitivity of respectively; demand, return yield, repair yield, direct return yield and coordination times, are researched.
Additionally, the sensitivity for the compensation fee and the sales price of re-processed parts are analyzed. These parameters are not subject to external uncertainties, but previously it was concluded that these parameters are set based on incomplete information. Therefore it is interesting to see whether different outcomes for these parameters have a significant impact on the result.
In Table 5 the results are shown under the RTO model. For each variable the input value is both increased and decreased with 5 and 10 percent. The factor, with which a variable is changed, is shown at the top of the column. For instance, the first column shows the results when the variable is decreased with 10 percent. The middle column, indicated with a "0" shows the results under the expected values of the variables. The outcomes which are shown in the table, represent the increase in profit which is realized by using reverse logistics.

Variable	-10%	-5%	0	+5%	+10%
Demand	1657,28	1785,69	1878,24	1995,84	2088,37
Return yield	1742,97	1823,14	1878,24	1958,40	2009,90
Repair yield	1201,32	1552,31	1878,24	2229,32	2555,15
Coordination time	1896,81	1887,53	1878,24	1868,94	1859,65
Compensation fee	1924,05	1901,14	1878,24	1855,33	1832,42
Sales price repro	560,44	1219,34	1878,24	2537,13	3196,03

Table 7 – results of the sensitivity analysis

From the results in Table 7 it becomes clear that the largest impact is created by altering the sales price. The reason for the large impact is that changing the sales price of the re-processed parts directly influences the profit of the RTO model, whereas it does not influence the profit of the current situation. The minimum price for which the re-processed parts need to be sold in order to generate a larger profit than the current situation is €417,21. This corresponds to a discount on the sales price of a new part of 14,2 percent. A higher discount would still result in a profit, but the profit would be less than in the current situation.

The second largest impact is caused by the repair yield. It was expected that this could be explained with the inspection costs, which are relatively high. These costs have to be paid for each part which is not repairable. The influence of the inspection costs is illustrated in Table 8. Here the same sensitivity analysis is performed on the repair yield, only this time the inspection costs are decreased to €22,50 and €0,00 respectively, compared to the current €122,50. This large decrease in inspection costs causes the profit with reverse logistics to be a lot higher than the profit without. More importantly, the sensitivity of result towards the return yield is a lot lower for the smaller values of the inspection costs. The conclusion is therefore that high inspection costs because the results to be more sensitive to the repair yield.

Variable	-10%	-5%	0	+5%	+10%
Repair yield (€22,5 inspection costs)	2352,97	2463,14	2558,24	2668,40	2759,90
Repair yield (€0 inspection costs)	2490,22	2607,14	2711,24	2828,15	2928,65

Table 8 – Sensitivity to the repair yield for different values of the inspection costs

The impact of the other variables is relatively small and large deviations of the estimated values have to occur, before it would lead to a change regarding the economic feasibility of reverse logistics. Therefore this sensitivity analysis proofs the opportunity of reverse logistics.

6.7 CONCLUSIONS

The method which was developed to determine the economic feasibility has proven to be reliable
The economic feasibility of reverse logistics can be determined by comparing the profit that is generated with and without using reverse logistics. In order to make a reliable comparison, a method has been developed which calculates the total costs and revenue based on certain input parameters and data. The method has been validated and verified based on expert judgment and has been declared accurate. Only three input parameters cause a slight doubt; return yield, compensation fee and the sales price for the re-processed parts. The reason for this is that due to a lack of experience with reverse logistics, Vanderlande cannot say with certainty whether the estimated values are correct. However, before reverse logistics is applied, further research, like described in chapter 5, can clarify these issues.

There are five different cost components which together form the total cost of supplying a spare part
The cost components are: transportation, inventory, warehousing, re-processing/purchasing, labor and compensation fee. These components have been proven to cover all costs which are made in order to supply a certain spare part to the customers.

The case study showed a 54 percent increase in profit when reverse logistics was applied
In order to illustrate the method that was developed to determine the economic feasibility, a case study was performed. The subject of the case study was an electronic part, which recently lighted up the discussion on reverse logistics, when the supplier announced the end of supply. Although it might not be the most ideal subject for the case study, this part was used for its actuality. The method was applied to the part and showed large increases in profit. The increase is largest for the re-process to order model. Here the outcome was a 54 percent increase in profit compared to the current situation.

The results are most sensitive to the sales price of re-processed parts and the repair yield
A sensitivity analysis has been performed on the method in order to determine to which extent the result is influenced in case a variable deviates from its expected value. The previously discussed parameters, which could not be validated, are also included in the analysis in order to determine the effect when they are not determined correctly. The results showed that the biggest impact is caused by the sales price of re-processed parts. The maximum discount which can be given while maintaining an increased profit compared to the current situation, is 14,2 percent. The second largest influence is the repair yield. However, this is a mainly due to the high inspection costs. When these are reduced, the sensitivity towards the repair yield is comparable to the other parameters and does not have a high impact.

7 IMPLEMENTATION AND FUTURE OPPORTUNITIES

In this final chapter an implementation plan will be formulated for the reverse logistic process. This will be done in the first paragraph. Here the different steps which need to be taken before the reverse logistic process is operational, are treated chronologically. Subsequently this chapter will treat possible extensions to the process as it has been described in this thesis. These are opportunities which Vanderlande might want to consider in the future.

7.1 IMPLEMENTATION PLAN

In this paragraph an implementation plan will the drawn up. It consist of different activities, which are recommended to perform in order to run a successful reverse logistics process.

Before the implementation of the reverse logistic process is started, it is recommended to wait for approximately half a year. Currently there are multiple affairs going on at the department, which need to be handled before the implementation of reverse logistics can get the required attention. Probably the most important affair is the relocation of the SCW. Currently it is located close to Vanderlande's office in Veghel and now it will relocate to a different location further away from the Vanderlande office. Vanderlande employees foresee some difficulties with this relocation and the current process of supplying spare parts might become unstable for a while. Since introducing a new process might also lead to some difficulties and demands extra attention of the 3PL as well as the Vanderlande employees, it is not recommendable to add this extra uncertainty and workload on top of the relocation of the SCW.
Another affair which might cause difficulties in the near future is the changed composition of the department. Several of the more experienced employees have left the department and in order not to overwhelm the new employees, it is recommended to postpone the implementation of the reverse logistic process.

Pilot projects

After the processes in the SCW become stable after their relocation, the implementation of the reverse logistic process can start. In order to test the process on a limited scale, pilot projects should be performed for a limited amount of parts. In order to get significant results from the pilot projects, the parts should be relatively fast moving. It is also preferable to use the RTO model, since this shows the best results and the lowest risk.

In order to set up the pilot projects, the first step is to perform a small scale research to gather the required information which is needed to determine the process and the economic feasibility.
The research starts with a consultation with the supplier. The most crucial information at this point is whether re-processing can be done without quality issues. When re-processing is technically feasible, other factors need to be addressed. These are factors like; the price and lead time of re-processing, inspection costs, required information (RMA form) and the repair yield.
The next part of the research focuses on the customers. By asking them, for instance, about the destination of their failed parts and their attitude towards the environment, the price for a re-processed part and compensation fee can be determined. In chapter 5 it has been described in more detail, how this can be approached.
With this input, supplemented by internally known or estimated data, the method for determining the economic feasibility can be applied.

In case the result is positive and reverse logistics is economically feasible for the part, the customers which own a system with the specific part have to be notified about the pilot project and asked for their cooperation. Hereby it is important to explain their role in the process. They need to be filled in on the RMA form, the joint pickup and delivery, as well as the way their compensation fee is transferred to them. Other important information which they need to receive is on the quality of the re-processed parts. The customers need to be reassured that the quality of a re-processed part is not inferior to a new part. Finally some information might be added on the environmental benefits of this initiative.

At this point the employees at Vanderlande need to be prepared for the additional process. Responsibilities need to be divided among the employees and they need to learn how they can see whether they can offer a re-processed part to the customer, how to arrange the joint pickup and delivery, how to process the returns and sales administratively and which documents are required from the customers and also from suppliers side.

When all preparations are done, the pilot projects can start and the process can be tested.

Evaluation

After sufficient experience has been gained with the pilot projects, the results have to be evaluated. The moment at which the pilot projects have resulted in sufficient data is hard to determine exactly. Because the spare parts at Vanderlande are virtually all slow movers, it is recommended to continue the pilot project for a relatively long period.

For the quantitative part of the evaluation; the information that is gathered throughout the process needs to be analyzed. This information, like discussed in chapter 5, is:

- Demand for re-processed parts
- Number of returned parts
- Repair yield
- Lead time of repair
- Time spend coordinating
- Total profit

If the information is approximately equal to the expected values, the process runs well and should therefore also result in an increased profit. This means that the pilot projects are a success and reverse logistics can be applied on a larger scale.
In case some of the values deviate from the expected values, the underlying problem needs to be determined. Based on the problem, changes to the process might be required. If the changes have been drastic, new pilot projects might be needed. In case only small misconceptions about certain parameters have been the cause of deviating values, the method for determining economic feasibility might need to be re-applied in order to determine the impact of the aberrant parameter.

Besides the quantitative part, a qualitative evaluation needs to be performed. Meetings might be planned with the suppliers, customers and employees involved, in order to learn from their experience with the process.

Roll out

When the pilot projects have been successfully completed, reverse logistics can be implemented on a large scale. This starts again with a research. Only this time the research will be focused on multiple parts and requires the input from more stakeholders than with the pilot projects. The research consists of the following actions:

- A list has to be created with the items for which it would be technically feasible to use reverse logistics. This has to be discussed with the different suppliers. Based on the input of the suppliers, the technical feasibility can also be updated in the ERP system.
- The suppliers need to be asked for the price and lead time of re-processing, inspection costs, required information (RMA form) and the repair yield. This serves the same purpose as during the pilot projects
- A research needs to be performed among the customers in order to determine the prices for the re-processed parts, the compensation fees and an estimate for the return yields.
- The method for determining the economic feasibility can then be applied to all parts for which it is technically feasible to give them a second life.

The result of this research is a list with parts to which reverse logistics can be applied while making a profit. Based on this list the total expected profit, required storage space and man hours can be estimated. This has both consequences internally on the staff occupation at the SCMS department as well as externally for the SCW. At the SCW it is important that the additional space will be available when it is required and also additional staff might be needed for handling the additional goods flow.

Subsequently the employees need to be informed about the items to which reverse logistics will be applied. Since they already gained experience with the process during the pilot projects, they do not need additional training before the process can be started on a large scale.

After care

After the process has been deployed on a large scale, it is important to keep track on the performance of the reverse logistic process. This should be done by periodically evaluating the process. The evaluations are done in the same way as for the pilot projects. It is also recommended to search for ways to improve or extent the benefits that are realized by the reverse logistic process. In the following paragraph some possible extensions are mentioned.

7.2 EXTENSION OF THE REVERSE LOGISTICS

In this thesis the focus was on reverse logistics for spare parts. Moreover an easy solution was recommended which requires minimal adaptation to the current situation and minimal investments. In the future this could be extended in order to gain more benefits from reverse logistics.

A large opportunity for reverse logistics might lie in the re-use of complete systems. Currently, Vanderlande does not offer a solution for customers, who want a new system. There are different solutions which Vanderlande could offer to this end. They could take back the whole system and sell (parts of) it on a secondary market. They could also refurbish the old system, in order to offer their customers an upgraded system against a smaller investment.
The opportunities of reverse logistics for complete systems need to be mapped out and further research is required in order to realize the benefits from it.

Other possible extensions lie in improving the process as it has been currently described. In the current approach the inventory policy has not been proven to be optimal. Further research efforts might be directed towards finding an optimal inventory policy for the spare parts.
Another possible way to improve the efficiency of the process is by using RFID tags on the parts. This is a commonly mentioned approach in the literature and it can help to create a higher transparency in the supply chain. In this thesis the RFID tags have not been considered since it is associated with a high investment in the equipment that is needed to use the RFID tags.

Besides the process improvements, the reverse logistics efforts might be used for product improvement. Through the information which is gathered from the returned parts, better evaluations can be done on both a part as well as a system level. Therefore this could be also a fruitful area of further research.

Finally an additional improvement is given, which is not connected to the logistical processes. The reverse logistics program which Vanderlande will start can be used to create goodwill among existing customers, possible customers as well as among society. Therefore it is highly recommended to get the word out on the new “sustainable” projects which Vanderlande has introduced.

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APPENDIX

A - RMA Form

Customer :

Address :

Country :

Date :

Contact :

Phone :

RMA nr. :

Return Material Authorisation

- [ ] Return materials
- [ ] Materials for repair
- [ ] Other :

1

Item description : | VI item nr. : | Serial number :

Problem description :

2

Item description : | VI item nr. : | Serial number :

Problem description :

3

Item description : | VI item nr. : | Serial number :

Problem description :

Please send the Return Material Authorisation form by e-mail to:
spareparts@vanderlande.com

Working method:
1. Request RMA number at Vanderlande Industries before shipping materials
2. If material needs to be repaired only one RMA number per type material (e.g. motor, scanner) can be used, for different types of material different RMA numbers must be requested
3. Always ship, completely filled in, form with the materials to Vanderlande Industries **and** mail the filled in form to: spareparts@vanderlande.com

(see sheet 'working method' for extensive explanation)

Delivery adress:
DHL Supply Chain Veghel
Attn. Vanderlande Industries
Huygensweg 10
5466 AN Veghel
The Netherlands

E-mail: spareparts@vanderlande.com
Phone: +31 413 495 610

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B – Notation in LTB order size model

An overview is given of the notation that is used in this research. Note that item 1 is the original part and item 2 the replacing part.

EOL	Length of the End-of-Life (service) period (EOL)/planning horizon (#periods)
Q	The LTB order quantity, i.e. the quantity of item 1 that is ordered to satisfy demand during the RTT (#units)
RTT	Length of the required transition time (RTT) (#periods)
m	User specific length of a period (years) Example: when each period is 6 months, m=1/2
d_k	Demand in period k = 1, …, EOL (#units)
t	A specific value for the length of the RTT, which can range between $minRTT_a$ and $maxRTT_a$ (#periods)
I_k	The inventory of item 1 directly at the beginning of period k, where k = 1, …, t.
a	Fixed yearly discounting factor
α	Fixed discounting factor per period $\alpha = -\ln\,(a^{1/m})$
$\widehat{CDi_k}$	Estimated disposal costs of item I in period k (€) i ∈ {1,2}, where i = 1 denotes item 1 and i = 2 denotes item 2 k = 1, …, EOL
$\widehat{CHi_k}$	Estimated holding cost rate for item i in period k (€/unit/period) i ∈ {1,2}, where i = 1 denotes item 1 and i = 2 denotes item 2 k = 1, …, EOL
CN1	Purchasing cost of tem 1, i.e. the price that is paid per unit of item 1 (€)
CO1	Fixed order costs per order for item 1 (€)
MOQ	The minimum order quantity for item1 (units) Q ≥ MOQ
BS_s	The batch size that is specified by the supplier of item 1 (units) Q should always be a multiplication of BS_s
$maxRTT_a$	The maximum possible value for the length of the RTT for a given alternative α (#periods)
$minRTT_a$	The minimum possible value for the length of the RTT for a given alternative α (#periods)
$P(RTT_a = t)$	The probability that the RTT for a given alternative α is equal to t periods
$E[CN2_k]$	Expected value of the purchasing cost of item 2 in period k (€)
$E[CO2]$	Expected value of the setup costs for item 2 (€)
$E[TC(Q)]$	Total expected discounted demand costs during the entire planning horizon for a simple policy using a final order quantity Q (€)
$E'[TC(Q,t)]$	Total expected discounted costs using final order quantity Q, given that the RTT is equal to t periods (€)
$E[TC_k(I_k)]$	The total expected discounted costs during the periods k, …, t. These costs are calculated f or a specific value for $I_{k.}$
$E'[TC(Q,t)] = E[TC_1(Q)]$	
$E[fillrate(Q)]$	The expected fillrate for a given final order quantity Q
$E[OOS_k(I_k)]$	The expected number of out-of-stocks during the period k up to and until t, given an inventory at the start of period k that is equal to I_k. This number is used to calculate $E'[OOS(Q,t)]$
$E'[OOS(Q,t)]$	The expected number of out-of-stocks during an RTT of length t. This number is used to calculate fillrate(Q,t)

C - Model for determining LTB order size

The current model that is used to determine the LTB order size was studied and summarized below. For an overview of the used notation see Appendix B.

The model works by calculating the total expected discounted costs and the fill rate for a certain order level (Q). When the fill rate is larger than, or equal to the desired fill rate, the order level is optimal. When it is smaller, Q is iteratively increased with one unit until the desired fill rate has been reached.

Total expected discounted costs

The objective function for the total expected discounted costs is:

$$E[TC(Q)] = \sum_{t=minRTT_a}^{EOL} E'[TC(Q,t)] * P(RTT_a = t) + \sum_{t=EOL+1}^{maxRTT_a} E'[TC(Q,t)] * P(RTT_a = t)$$

The function determines the total costs taking into account that the RTT is unknown. It does this by summing the product of the total costs per possible length of the RTT (measured in t), and the possibility that the RTT is t. The summation is split in two parts. The first part calculates the costs for the periods before the EOL and the second summation calculates the costs after the EOL. Since Vanderlande does not offers service after the EOL, the outcome of the second summation is always 0. The second summation will therefore not be further analyzed.

Within the first summation there are two terms, the cost for a specific amount of periods and the probability of the specific length. The parameters for the probability distribution have to be specified by the user, since this depends on the part that is EOL and the replacing part.

In order to determine E'[TC(Q,t)] for a certain t, a deterministic programming (DP) problem is formulated. This means that the costs per period are determined working backwards from the last period, towards the first. The last period is always the EOL. However, two different scenario can be distinguished, the first scenario occurs when EOL=RTT, and the second when EOL>RTT. When EOL=RTT, there are no setup costs for the replacement part and it never has to be bought. This causes slightly different formulas from when EOL>RTT.

EOL = RTT

First the costs of the last period are calculated. Here the holding costs of the previous period are calculated, plus the disposal costs of the left over parts. If demand in the last period is larger than the inventory, there are no disposal costs. The combined costs are discounted against α, to compensate for the time until t. The formula is therefore the following:

$$E[TC_t(I_t)] = \alpha\left(\widehat{CH1_{t-1}} * I_t + \sum_{j=0}^{I_t} \widehat{CD1}_t * (I_t - j) * P(d_t = j) + \sum_{j=I_t+1}^{\infty} 0 * P(d_t = j)\right)$$

Then the costs for the periods t-1, …, 2 are calculated. This has to be done one period at the time. Per period the holding costs from the previous period are calculated, as well as the cost for the next period(s) dependent on the stock levels that are left after the current period. This level depends on a stochastic demand and the inventory level from the end of the previous period. The total is again discounted against α. This is shown in the following formula:

$$E[TC_k(I_k)] = \alpha\left(\widehat{CH1_{k-1}} * I_k + \sum_{j=0}^{I_k} E[TC_{k+1}(I_k - j)] * P(d_k = j) + \sum_{j=I_k+1}^{\infty} E[TC_{k+1}(0)] * P(d_k = j)\right)$$

Finally the costs for period 1 are calculated. Here the costs of acquiring Q parts are included, as well as the cost for the next periods dependent on the stock levels that are left after the first period.

$$E[TC_1(Q)] = CO1 + CN1 * Q + \sum_{j=0}^{Q} E[TC_2(Q - j)] * P(d1 = j) + \sum_{j=Q+1}^{\infty} E[TC_2(0)] * P(d1 = j)$$

This final equation results in the total expected discounted costs when EOL = RTT

RTT<EOL.

The formulas are almost the same as when EOL = RTT. The most important difference is that after the RTT there is are more periods until the EOL. For these periods the costs are calculated by two formulas. The first calculates the costs for the last period. The second formula is for the periods between the RTT and the last period.

$$E[TC_{EOL}(I_{EOL})] = \alpha\left(\widehat{CH2_{EOL-1}} * I_{EOL} + \sum_{j=0}^{I_{EOL}} \widehat{CD2_{EOL}} * (I_{EOL} - j) * P(d_{EOL} = j)\right.$$
$$\left. + \sum_{j=I_{EOL}+1}^{\infty} E[CN2_{EOL}] * (j - I_{EOL}) * P(d_{EOL} = j)\right)$$

The last period calculates the holding costs for the previous period, disposal costs if there are left over parts and costs for ordering more parts when there is more demand than inventory.

$$E[TC_k(I_k)] = \alpha\left(\widehat{CH2_{k-1}} * I_k + \sum_{j=0}^{I_k} E[TC_{k+1}(I_k - j)] * P(d_k = j)\right.$$
$$\left. + \sum_{j=I_k+1}^{\infty} (E[CN2_k] * (j - I_k) + E[TC_{k+1}(0)]) * P(d_k = j)\right)$$

The costs for the periods between the RTT and the last period are determined by the holding costs, the costs of the following period(s) depending on the left over inventory and, in case of a shortage of on hand inventory, costs for ordering extra parts.

The periods before the RTT are calculated almost identical as in the situation where RTT = EOL. In the last period of the RTT the difference is that the costs of the following periods are included, where in case of EOL = RTT there are no more periods after the RTT. In the first period setup costs for the replacing part are included. Below the formulas are shown, with the differences highlighted in red.

The last period in the RTT (t), is calculated by:

$$E[TC_t(I_t)] = \alpha\left(\widehat{CH1_{t-1}} * I_t + \sum_{j=0}^{I_t}\left(\widehat{CD1_t} * (I_t - j) + E[TC_{t+1}(0)]\right) * P(d_t = j) + \sum_{j=I_t+1}^{\infty} E[TC_{t+1}(0)] * P(d_t = j)\right)$$

Periods t-1, …, 2 are calculated by the following formula:

$$E[TC_k(I_k)] = \alpha\left(\widehat{CH1_{k-1}} * I_k + \sum_{j=0}^{I_k} E[TC_{k+1}(I_k - j)] * P(d_k = j) + \sum_{j=I_k+1}^{\infty} E[TC_{k+1}(0)] * P(d_k = j)\right)$$

The first period is calculated by the following formula:

$$E[TC_1(Q) = CO1 + CN1 * Q + E[CO2] + \sum_{j=0}^{Q} E[TC_2(Q - j)] * P(d1 = j) + \sum_{j=Q+1}^{\infty} E[TC_2(0)] * P(d1 = j)$$

Finally, the parameters of the probability distribution for the demand per period are determined by the user.

Fill rate

For the fill rate there is no difference between the situation where RTT = EOL and RTT < EOL. This is caused because after the RTT there is always the option to order the replacement parts. The fill rate is determined by dividing the expected number of out-of-stock situations, by the total amount of orders. This number is subtracted from one to get the fill rate. The formula is as follows:

$$Fill\ rate = 1 - \frac{Expected\ number\ of\ out-of-stocks\ during\ the\ RTT}{Expected\ demand\ during\ the\ RTT}$$

The number of out of stock situations is determined by a DP problem. For the last period in the RTT the expected number of stock outs is determined by summing the product of the shortage caused by a certain demand and the probability that this demand occurs. The formula is as follows:

$$E[OOS_t(I_t)] = \sum_{j=0}^{I_t} 0 * P(d_t = j) + \sum_{j=I_t+1}^{\infty} (j - I_t) * P(d_t = j)$$

For the periods t-1, …,2, stock outs are determined by two summations. The first one is for when demand is equal to, or smaller than the inventory. In that case there are no stock outs during the period, but it influences the inventory in the next period and stock outs from then are added to the stock outs of the period. In case of demand higher than the on hand inventory, stock outs are created, dependent on how large the demand is. The formula is as follows:

$$E[OOS_k(I_k)] = \sum_{j=0}^{I_k} E[OOS_{k+1}(I_k - j)] * P(d_k = j) + \sum_{j=I_k+1}^{\infty} ((j - I_k) + E[OOS_{k+1}(0)]) * P(d_t = j)$$

For the first period (k=1), the calculation is the same as for the periods t-1, …, 2. There is only a difference in the notation for the on hand inventory. At times 2, …, t, this is shown with I_k,in the first period the inventory is shown with Q, since it is the LTB amount. Therefore the formula for the first period is:

$$E[OOS_1(Q)] = \sum_{j=0}^{Q} E[OOS_2(Q - j)] * P(d_1 = j) + \sum_{j=Q+1}^{\infty} ((j - Q) + E[OOS_2(0)]) * P(d_1 = j)$$

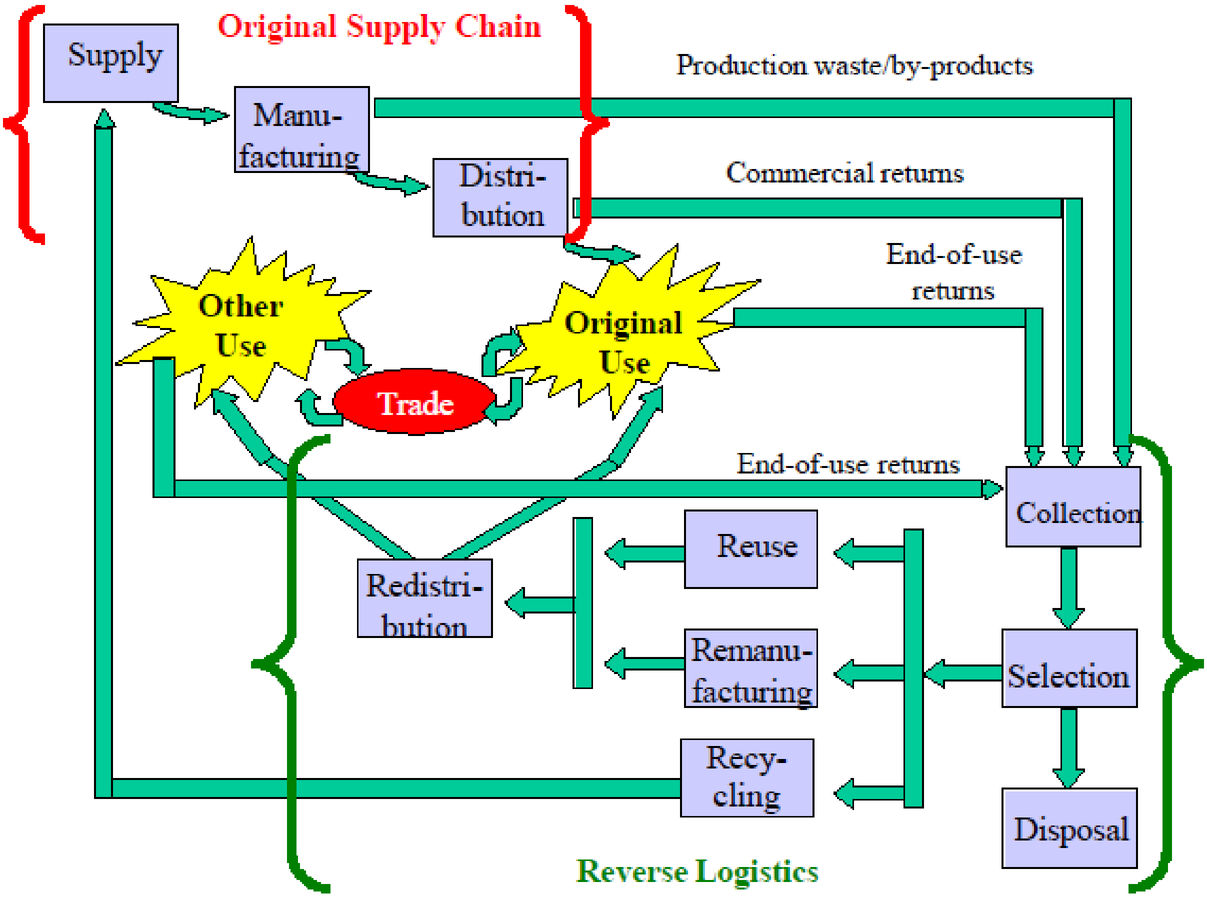
The total expected number of out-of-stocks is:

$$E[OOS(Q, RTT = t)] = E[OOS_1(Q)]$$

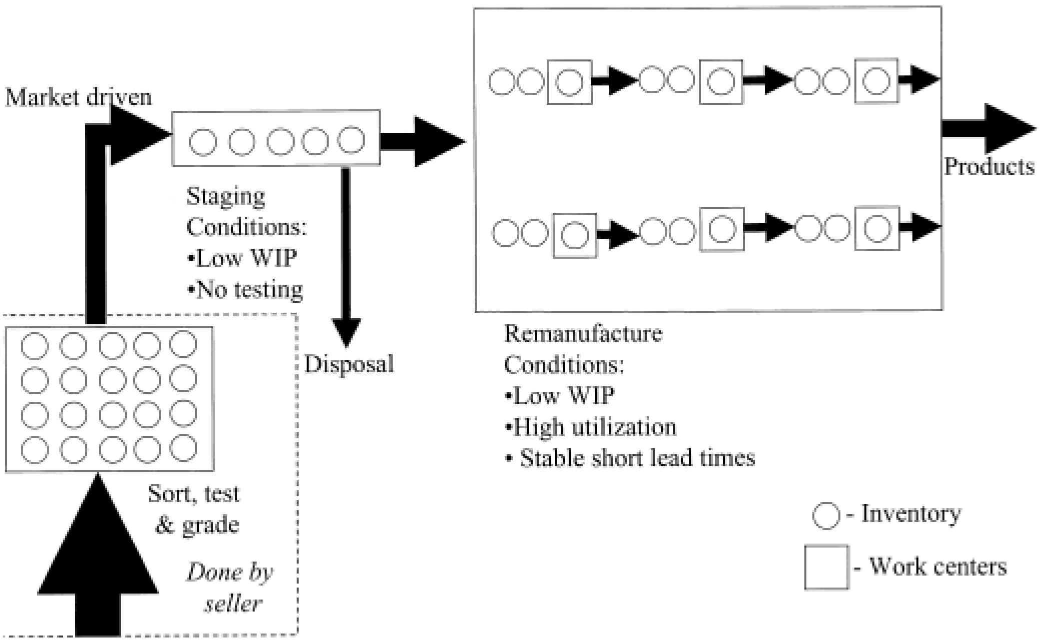
Subsequently the fill rate is determined by:

$$Fillrate(Q, RTT = t) = 1 - \frac{E'[OOS(Q, RTT = t)}{\sum_{k=1}^{t}\left(\sum_{j=0}^{\infty} j * P(d_k = j)\right)}$$

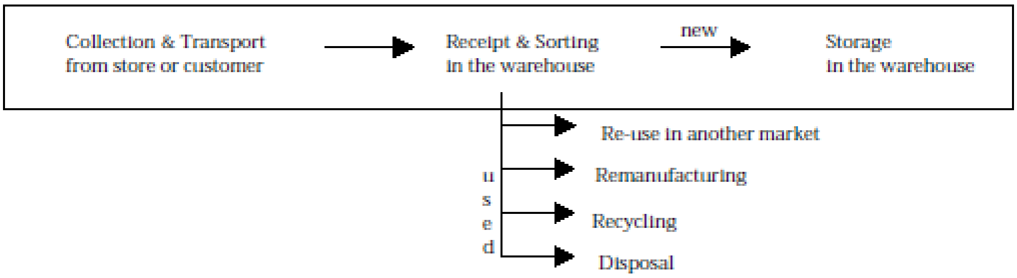
D - Reverse Logistics frameworks



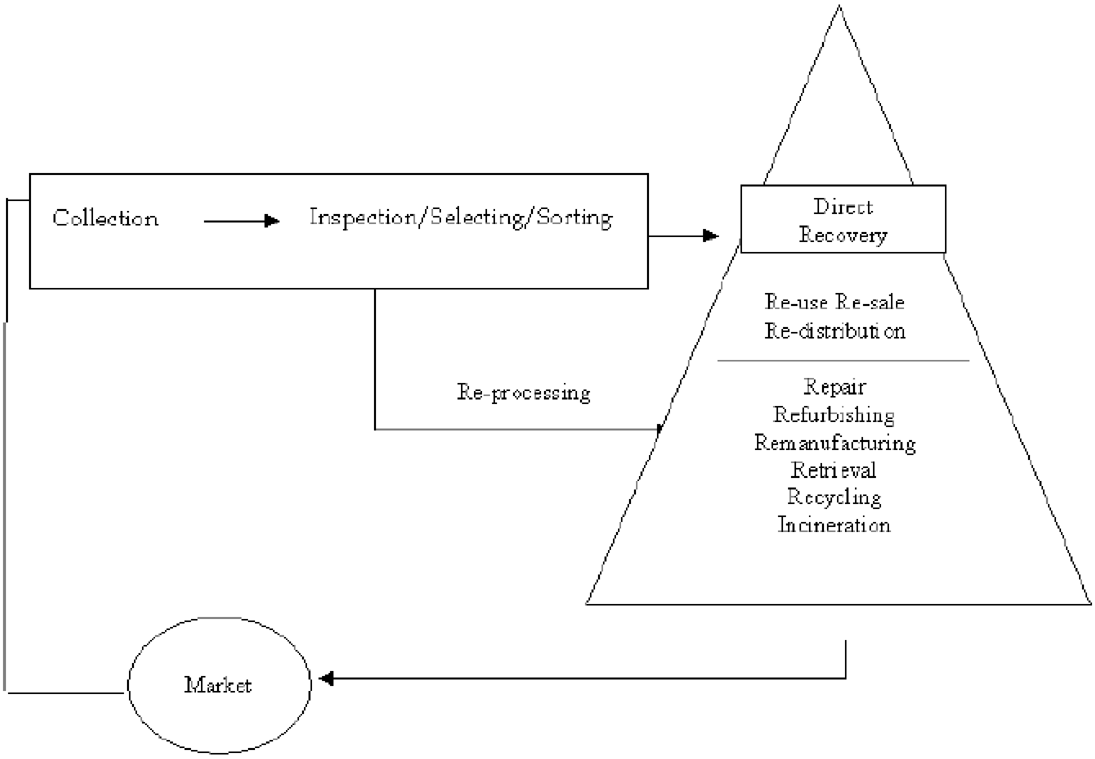
Kokkinaki et al. (1999)



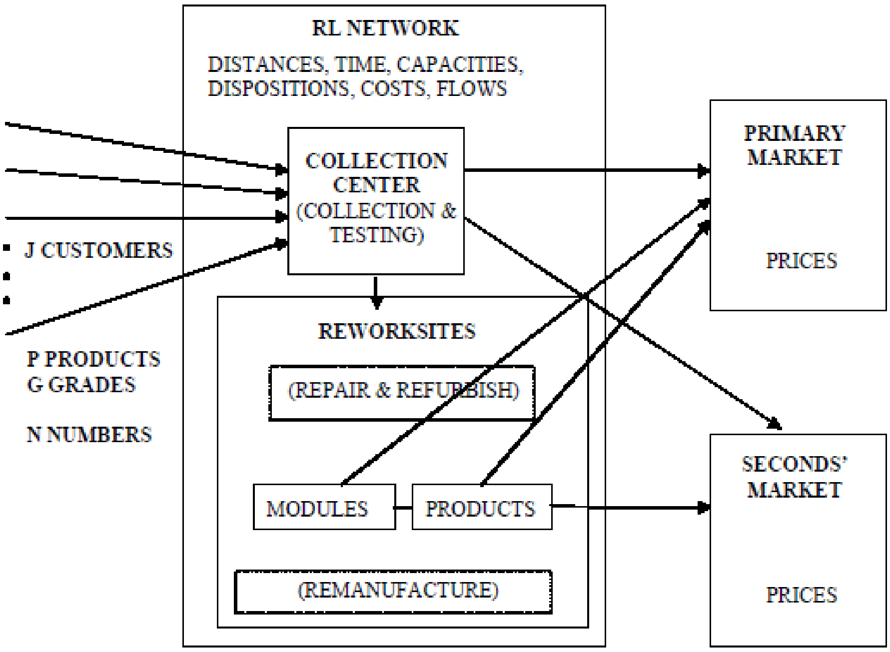
Guide and van Wassenhoven (2001)



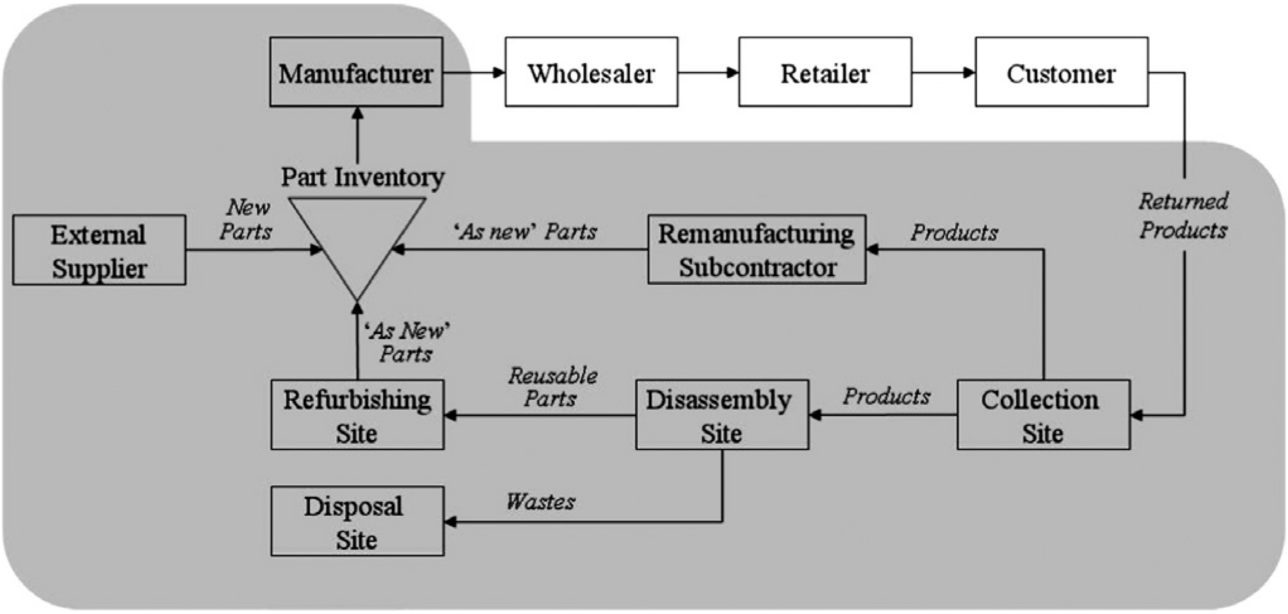
Koster et al., 2002



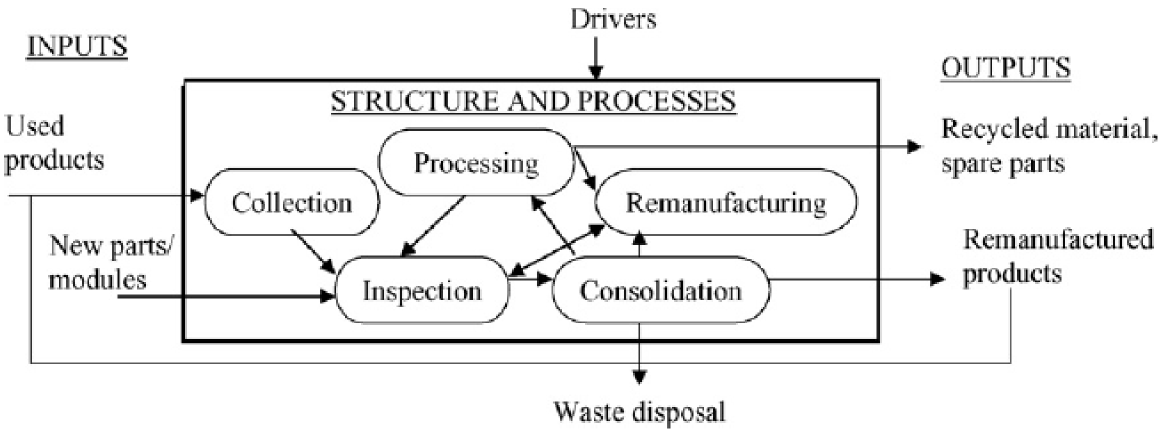
De Brito and Dekker (2003a)



Srivastava and Svrivastava (2006)



Kim et al. (2006)



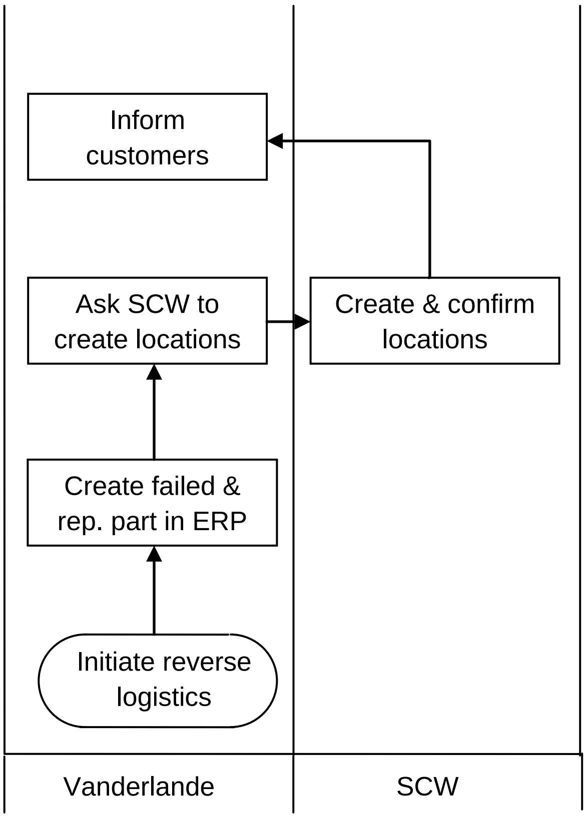
Pokharel and Mutha (2009)

E – RMA form required information

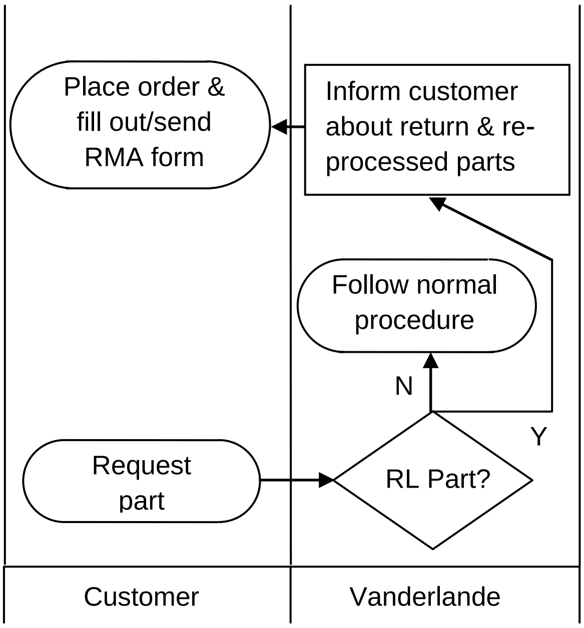
Information on an RMA form	Responsible
Return Party's company name, location, contact person and number	Customer
Return reason	Customer
RMA (Return material authorization) number generation	Customer
Volume, Product, Model, Serial Number	Customer
Early failure information/condition of the part	Customer
Sales and Marketing Agreement terms and allowances	Vanderlande
Warranty terms	Vanderlande
Credit conciliation	Vanderlande
BOL (bill of lading) number or transportation carrier track number	Vanderlande
"Return to" location	Vanderlande
Legislative constraints	Vanderlande
Receiving date	SCW
Records on inspection, testing, parts retrieval, parts replacement, parts order fulfillment, repair, refurbish, re-packaging and redeployment.	Supplier

F- Flowcharts for activities during reverse logistic process

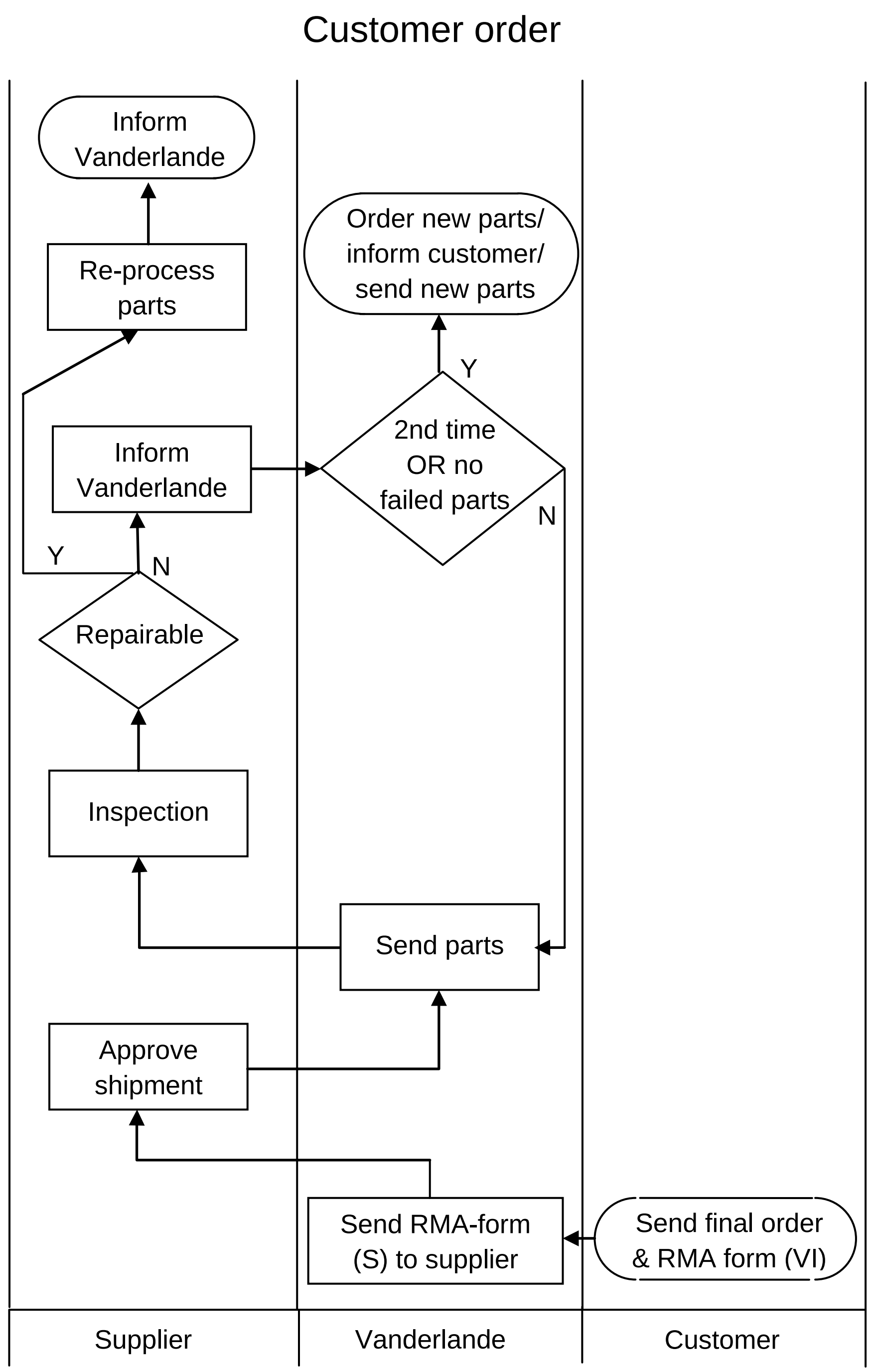
1 - Initialization



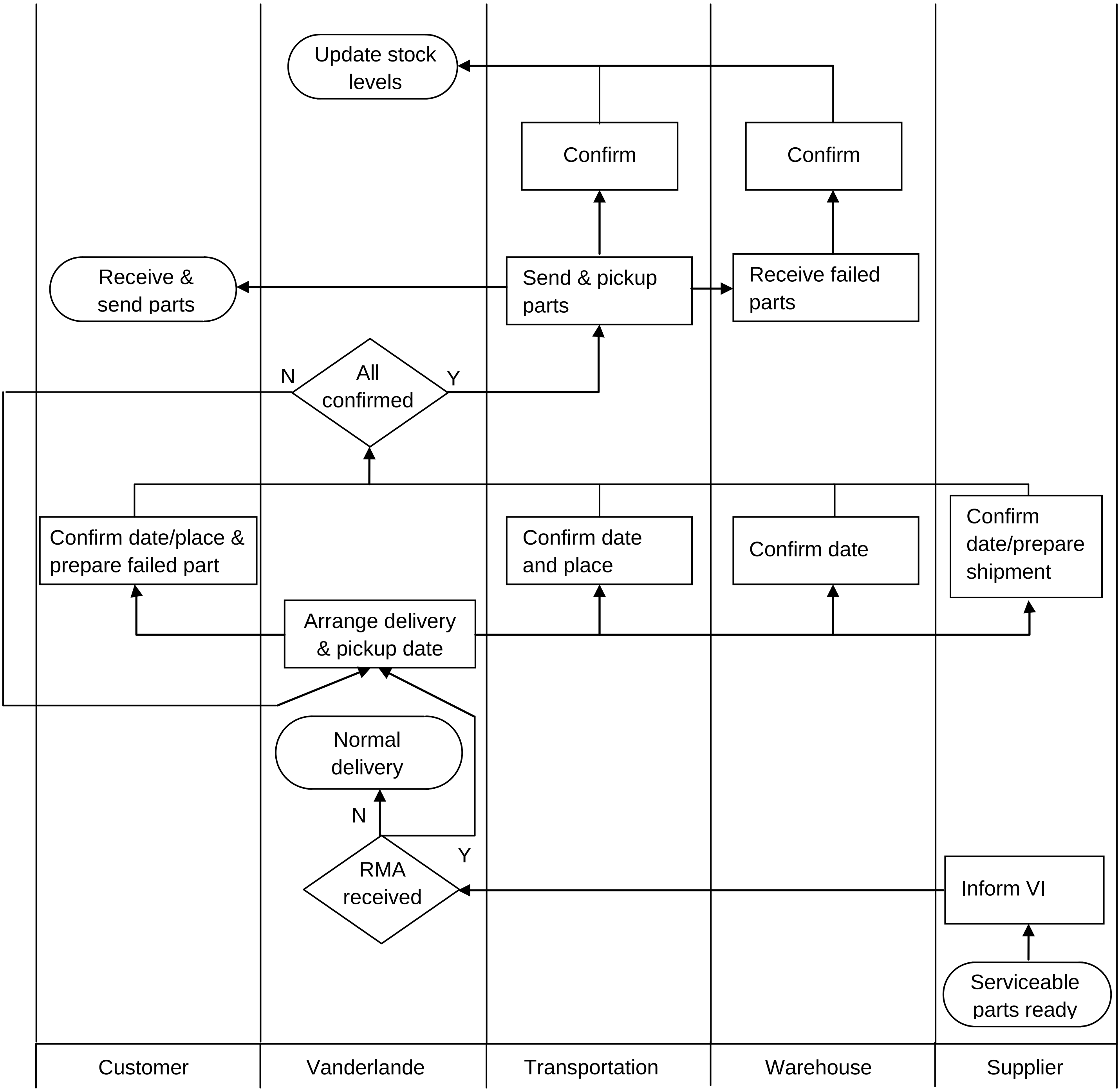
2 - Inform customers about reverse logistics



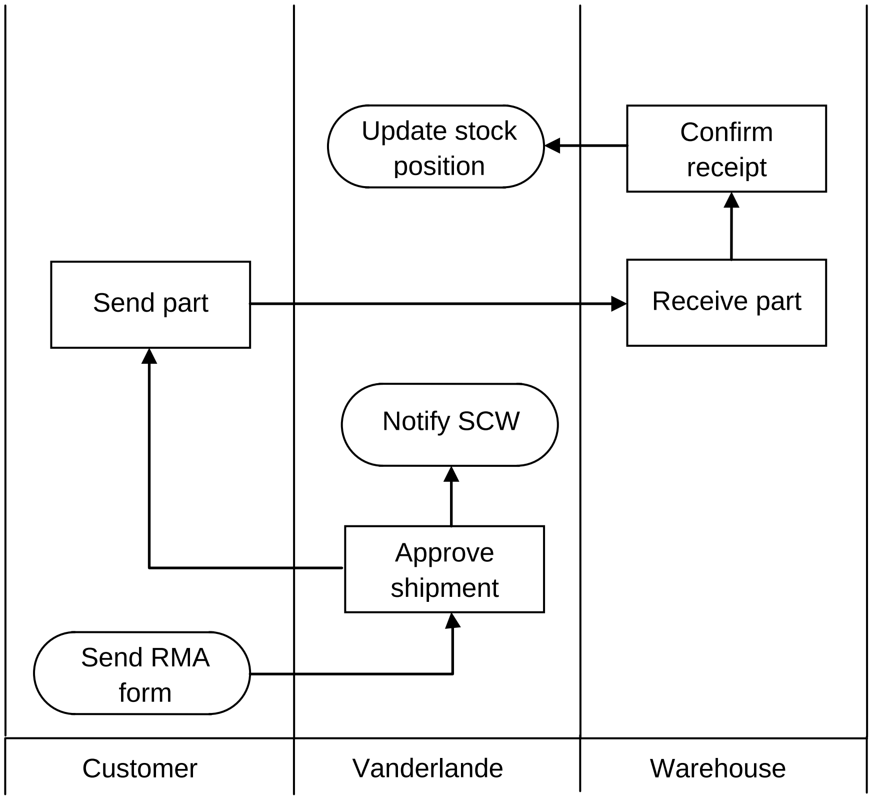
3 – Re-process to Order



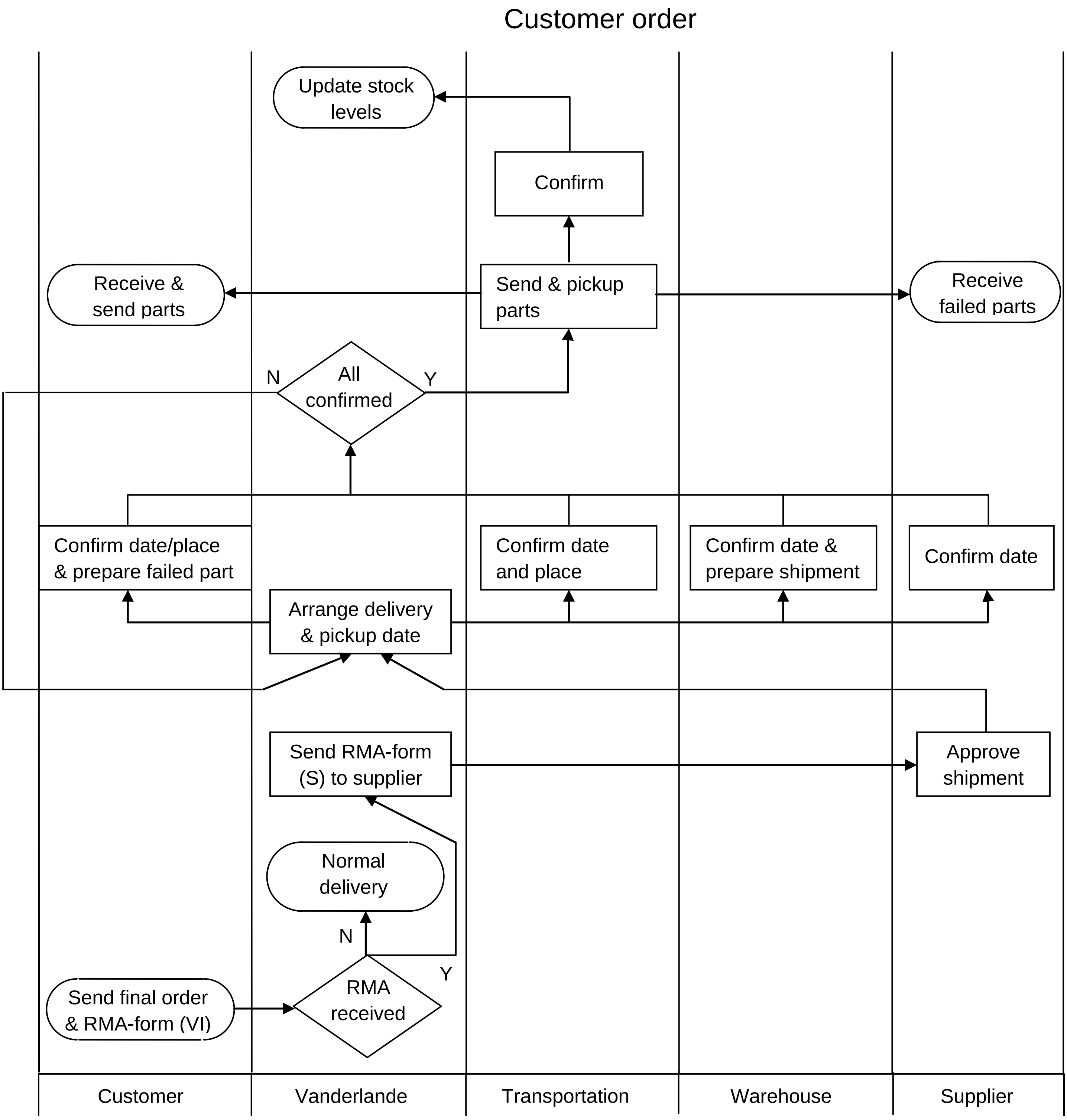
Serviceable parts ready



Receive RMA-form (VI) from customer

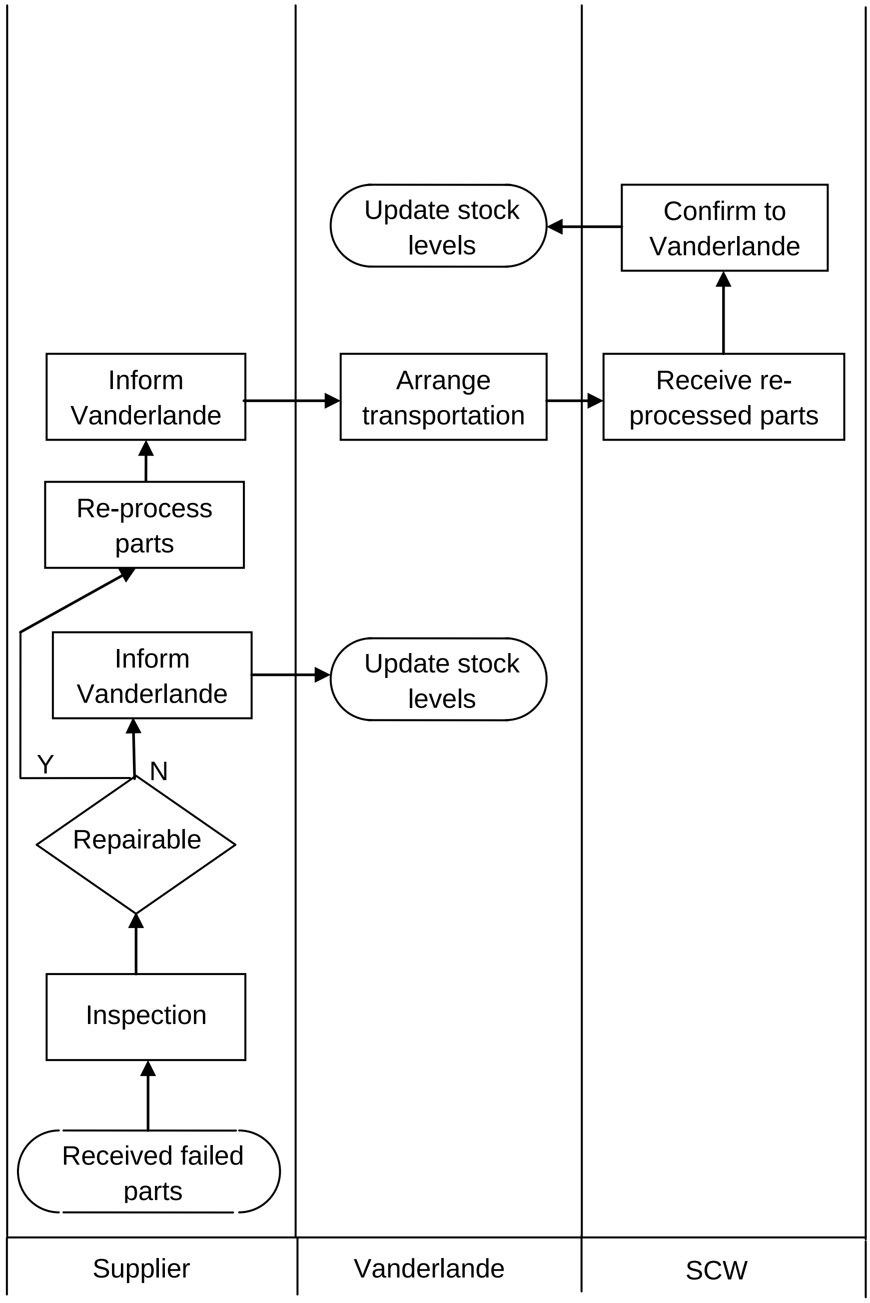


4 - Push

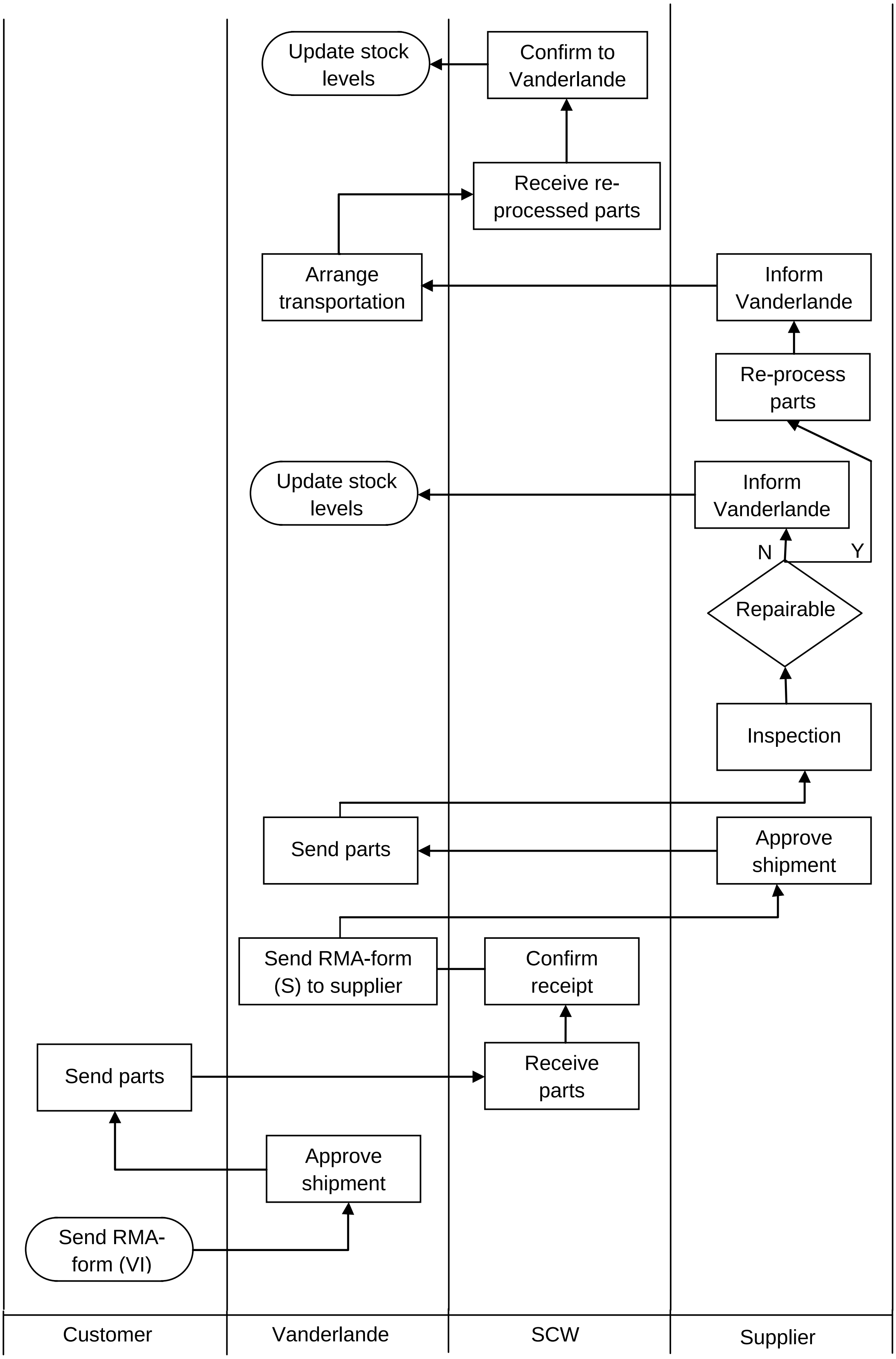


Customer order
Update stock levels
Confirm
Receive & send parts
Send & pickup parts
Receive failed parts
N
All confirmed
Y
Confirm date/place & prepare failed part
Confirm date and place
Confirm date & prepare shipment
Confirm date
Arrange delivery & pickup date
Send RMA-form (S) to supplier
Approve shipment
Normal delivery
N
Y
Send final order & RMA-form (VI)
RMA received
Customer
Vanderlande
Transportation
Warehouse
Supplier

Supplier received failed parts

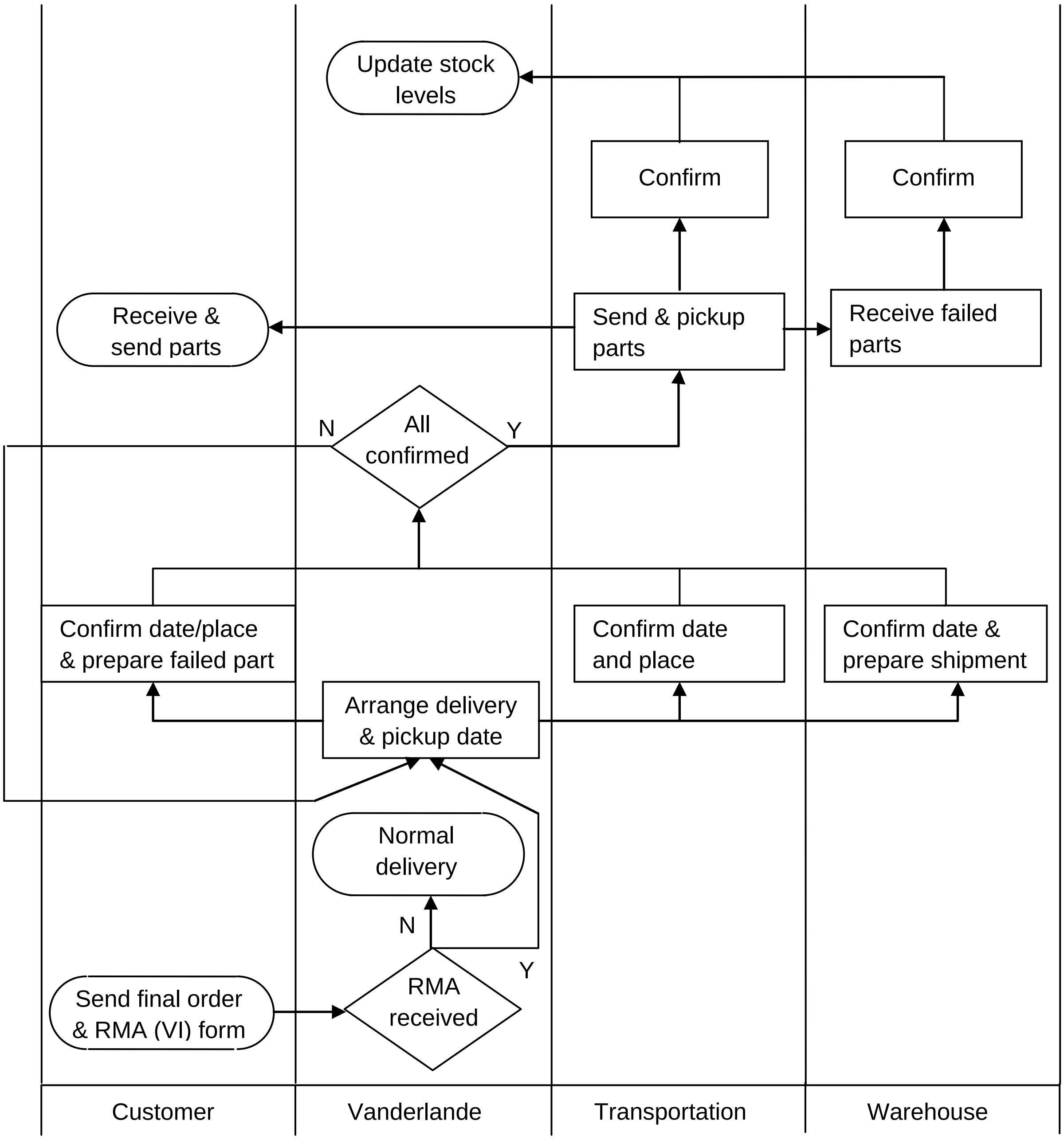


Receive RMA-form (VI) from customer

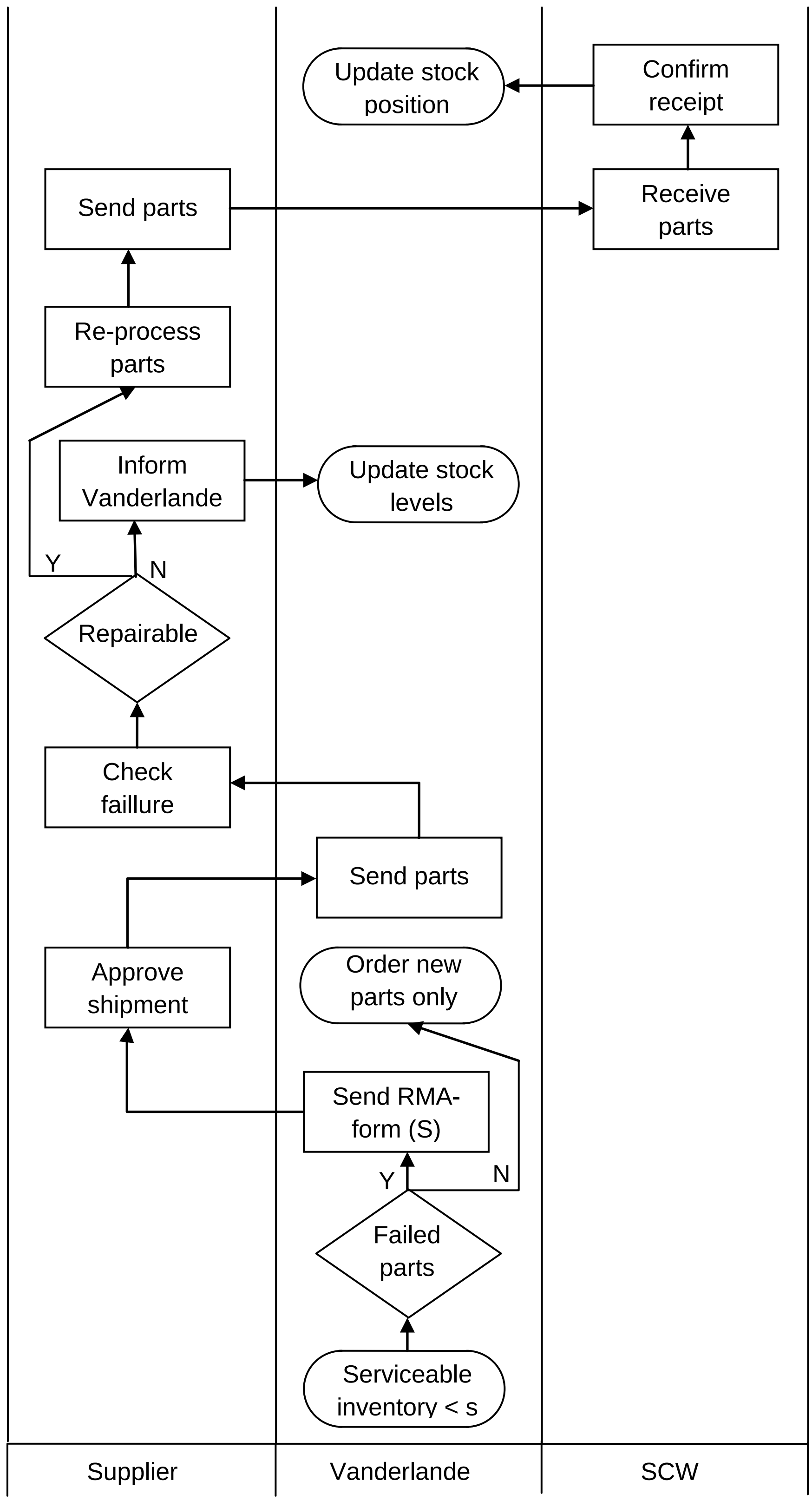


5 - Pull

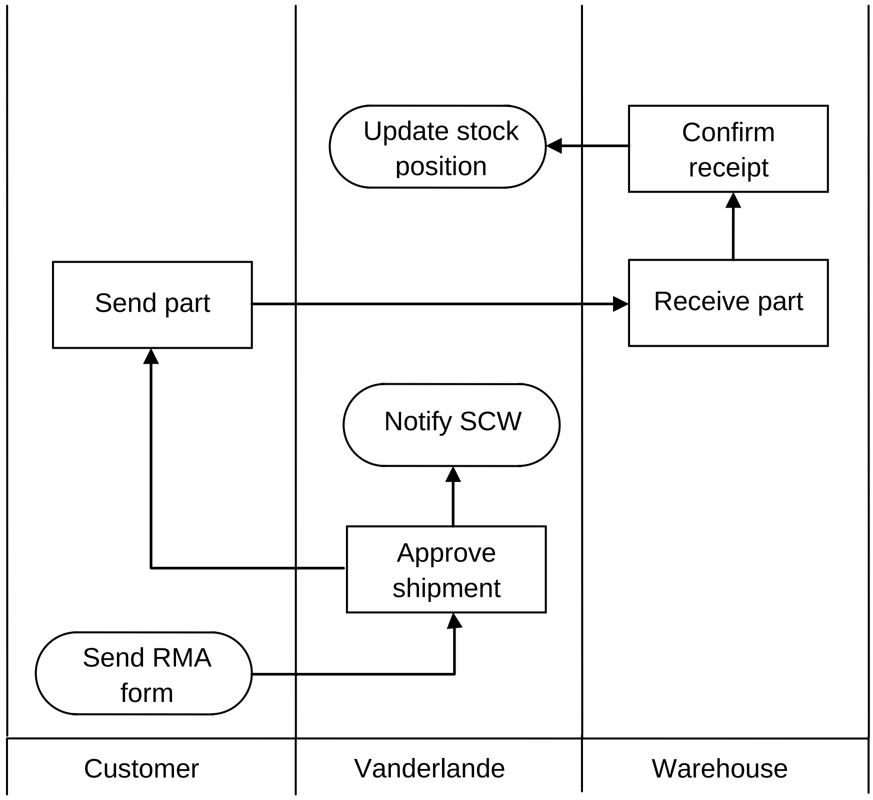
Customer order



Serviceable inventory < s_{pull}



Receive RMA-form (VI) from customer



G- Notation

Notation	Meaning	Explanation
$Cost_{rev}$	Cost with reverse logistics	The expected total yearly costs for supplying a certain spare part in case reverse logistics would be applied
$Revenue_{rev}$	Revenue with reverse logistics	The expected yearly revenue that is generated by supplying a certain spare part in case reverse logistics is applied
$Cost_{cur}$	Cost under current situation	The expected total yearly costs for supplying a certain spare part under the current situation (without reverse logistics)
$Revenue_{cur}$	Revenue without reverse logistics	The expected yearly revenue that is generated by supplying a certain spare part (without reverse logistics)
SP_{new}	Sales price new parts	The price for which the new parts are sold to the customers
SP_{new}	Sales price re-processed parts	The price for which the re-processed parts are sold to the customers
$\#ns$	Number of new parts sold	The expected number of new parts which are sold
$\#rs$	Number of re-processed parts sold	The expected number of re-processed parts which are sold
PU	Pickup Cost	The cost to transport the average return from the average customer to the SCW
$ScSu$	SCW - Supplier	The cost for the average shipment from the SCW to the supplier
$SuSc$	Supplier - SCW	The cost for the average shipment from the supplier to the SCW
DE	Delivery	The cost for delivering the average order from the SCW to the average customer
$\#PU$	Number of pickups	The expected yearly number of pickups of failed parts from the customers
$\#ScSu$	Number of SCW-Supplier	The expected yearly number of shipments of parts between the SCW and the supplier
$\#SuSc$	Number of Supplier-SCW	The expected yearly number of shipments of parts between the Supplier and the SCW
$\#DE$	Number of deliveries	The expected yearly number of deliveries of serviceable parts to the customer
PL	Price Location	The cost per year for a location in the SCW
POL_{in}	Price Order Line Inbound	The cost for receiving a return at the SCW
POL_{out}	Price Order Line Outbound	The cost for sending an order at the SCW
$\#loc_{fail}$	Number of locations failed	The average required number of locations to hold the failed parts
$\#loc_{repro}$	Number of locations re-processed	The average required number of locations to hold the re-processed parts
$\#loc_{new}$	Number of locations new	The average required number of locations to hold the new parts
$\#ol_{in}$	Number of inbound order lines	The expected yearly number of inbound order lines
$\#ol_{out}$	Number of outbound order lines	The expected yearly number of outbound order lines
$WACC$	Weighted Average Cost of Capital	The percentage against which an investment is set off
$\bar{iv}_{fail}$	Average inventory of failed parts	The average inventory of failed parts over a year
$\bar{iv}_{repro}$	Average inventory of re-processed parts	The average inventory of re-processed parts over a year
$\bar{iv}_{new}$	Average inventory of new parts	The average inventory of new parts over a year
$value_{fail}$	Value of failed	The value against which the failed parts are accounted

	parts	
$value_{repro}$	Value of re-processed parts	The value against which re-processed parts are accounted
$value_{new}$	Value of new parts	The value against which new parts are accounted
RP	Re-process Price	The cost for re-processing one part
IP	Inspection Price	The cost for inspecting one part in case it cannot be repaired
NP	New Price	The cost for one new part
FP	Fixed Price	The cost for placing an order for re-processing, new parts, or a combination
$\#np$	Number of new parts	The average number of new parts which is purchased from the supplier
$\#rp$	Number of re-processed parts	The average number of parts that is re-processed
$\#os$	Number of orders	The average number of orders placed at the supplier for purchasing and/or re-processing
$\#nr$	Number of not repairable parts	The average number of not repairable parts
CF	Compensation Fee	The cost for one failed part returned by a customer
$\#ri$	Number of returned items	The average number of failed parts that is returned by the customers
LC	Labor Cost	The cost for one employee spending one hour on coordinating the process
TT_i	Time per trigger i	The required coordination time each time trigger i occurs. There are 4 possible triggers, therefore I is 1 to 4
$\#tt_i$	Number of times trigger i occurs	The number of times trigger i is expected to occur
rt	Return yield	Probability that a customer returns its failed parts
dt	Direct return yield	Probability that a customer returns its failed parts immediately given that they return their failed parts
ry	Repair yield	Probability that a failed part can be re-processed
DO_{year}	Demand occurrences	The expected number of demand occurrences per year
D_{year}	Demand per year	The total amount of demand for a part per year
R_{year}	Returns per year	The number of return shipments per year
L_{repro}	Lead time re-processing	The lead time for re-processing failed parts
L_{new}	Lead time new	The lead time for purchasing new parts
$\overline{ds}$	Average order size	The average demand size
ss	Safety stock	Additional inventory kept to buffer against uncertainty
s	Reorder point	The level at which a replenishment order is placed
S	Order up to level	The size of the replenishment order is set to raise the inventory position to this level
Q	Order quantity	The difference between the reorder point and the order up to level