



Spring of 2009  
Lund

## LUND UNIVERSITY

Lund Institute of Technology

Department of Industrial Management and Logistics

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# Benefits and challenges with coordinated inventory control at Volvo Parts

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## **ACKNOWLEDGEMENT**

This Master thesis work was performed during November 2008 and June 2009 as a last step in the completion of our education towards Master of Science degrees at Lund Institute of Technology. The thesis project came to our attention in September 2008 through a discussion with Johan Marklund, Associate Professor at the Division of Production Management, who was one of the lecturers of the last course in production management given in the spring of 2008. Prof. Marklund presented the thesis project as an important part of a larger ongoing research project that would demand extensive and challenging work. We believed that this would be an interesting and rewarding finale of our education and accepted the challenge.

We would like to thank the people involved in the process of this project. We would especially like to thank our supervisor at Lund Institute of Technology Christian Howard for all input and discussions throughout the project and also Gert Svensson, Christian Claesson, Alf Lennerstad, Bertil Prissberg and Annika Twedmark at Volvo Parts for always taking time and effort to help us with our questions and thoughts. Finally, a thanks to all the people at Volvo Parts who, despite the current financial situation and heavy workload, always took the time to talk to us.

Uppsala and Jönköping, 2009-07-09



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## **ABSTRACT**

Coordinated inventory control is a concept within inventory management where decisions are based on stock and demand situations throughout a whole system of interconnected warehouses and inventories, and where control parameters are simultaneously determined and set at all installations.

This thesis is a part of a larger research collaboration project in coordinated inventory control where NGiL (Next Generation Innovative Logistics), a Lund based research institute, and Volvo Parts AB in Gothenburg participate. Volvo Parts handles the aftermarket distribution, sales and related services for the Volvo Group companies and has centrally controlled complex multi-level warehouse structures and routines. These warehouse structures are well suited for a coordinated inventory control approach.

A new multi-level inventory control model has been developed by NGiL especially for the Volvo Parts supply chain in Europe. The model utilizes advanced mathematical concepts to mimic Volvo Parts inventory systems consisting of several dealers and warehouses on a market. The model optimizes the reorder points at all locations with the aim of minimizing the total costs of the system while still maintaining or increasing today's service to end customers.

The purpose of this thesis is to prepare for this pilot study by analyzing the information systems, processes, structures and routines at Volvo Parts, design methods for extraction and calculation of the necessary parameters, select an appropriate market and to perform a selection of suitable spare parts and accessories to be included in the pilot study. A suitable market for the pilot study and a method to select and classify 100 parts with all necessary parameters are the main results of the thesis. The study is performed as an action research project, meaning that the authors are stationed at Volvo Parts headquarters in Gothenburg and observe the daily work, perform the necessary data extractions from the IT systems themselves and conduct interviews on a daily basis. The gathered data is a combination of primary and secondary quantitative data from the IT systems and calculations, as well as a lot of primary qualitative data from interviews and observations. The authors also function as mediators between NGiL researchers and Volvo Parts personnel.

The developed model is concluded to be a good representation of the reality of Volvo Parts' supply chain on the selected market Spain, and the authors do not see any large obstacles in a generalization to other Volvo Parts markets with the same structure or even other companies. The one major discrepancy between the NGiL model and current Volvo Parts control methods is how service levels are measured and how goals on these service levels are achieved. We have also performed a simulation study for some of the selected parts and found that the potential for cost reductions is significant and that the optimized solution fulfills target service levels in almost all cases. We also found out that there are no clear correlations or patterns between the cost reduction and any of the part characteristics that were studied, implying that a larger simulation study or a real life pilot study is necessary in order to further investigate the full potential of the NGiL model.

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# 1 INTRODUCTION

This chapter presents the background to the master thesis followed by the objectives and directives of the thesis. Finally the delimitations, target group and disposition of the thesis are presented.

## 1.1 Background

This master thesis project is part of an NGiL inventory control research collaboration between the department of Industrial Management and Logistics at Lund University and Volvo Parts AB in Gothenburg.

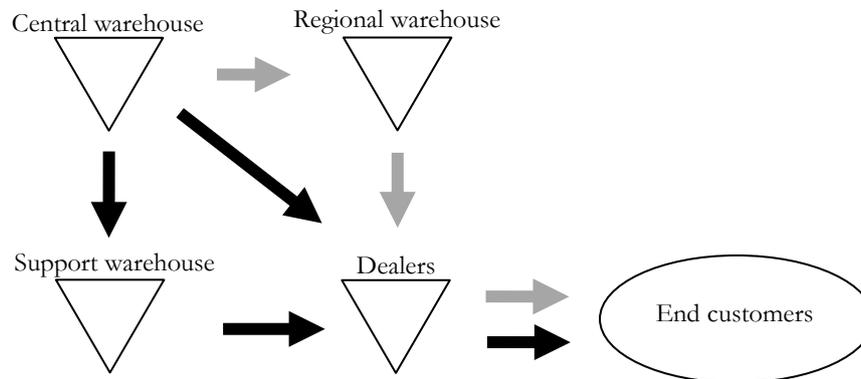
NGiL<sup>1</sup> (Next Generation Innovative Logistics) is a VINNOVA financed research center<sup>2</sup> based at Lund Institute of Technology, Lund University where industry, public sector, universities, research institutes and researching organizations collaborate in both basic and applied research towards creating new products, processes and services within engineering logistics, production management and packaging logistics.

Volvo Parts (in this report also denoted as VP) is a Business Unit within the Volvo Group. It is a provider of aftermarket tools and services for the companies within the Group with main operational areas in Supply Chain Management, product support development, customer support and remanufacturing. Its main goal is to ensure high availability of spare parts and accessories for the Group's end customers, i.e. the end users of Volvo Group equipment and products. This is done by taking full responsibility for the whole supply chain, from manufacturer, via dealers, to end customer and by utilizing a global warehouse structure. The warehouse structure consists of three types of warehouses that supply dealers on the markets with spare parts and accessories: central warehouses (CWs), regional warehouses (RWs) and support warehouses (SWs). The dealers on the markets are supplied by either: a CW and supported by an SW or by a RW only, as Figure 1.1 illustrates.

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<sup>1</sup> Retrieved from <http://www.ngil.se>, 2008-12-11

<sup>2</sup> Retrieved from <http://www.vinnova.se>, 2009-01-21



**Figure 1.1** Illustration of the warehouse structure. Black arrows illustrate the structure of a CW and SW supplied market while the gray arrows illustrate the structure of a RW supplied market.

Central warehouses supply several markets on different continents with a complete range of spare parts and accessories. Regional warehouses act as local CWs on isolated markets or on markets where the distance to a CW is significant. The RWs are supplied from a CW with the range of spare parts and accessories active on the market or markets that the RW in question supplies. Support warehouses are located on CW supplied markets. These hold a narrower range of parts and supply the dealers on the market with urgent orders, referred to as day orders, in cases of stock-out at the dealers. The intention is that such an order is to be delivered to the dealers within one day.

The purpose of the NGiL and Volvo Parts collaboration is to investigate the potential of coordinated inventory control on Volvo Parts' market and warehouse structures. A project investigating two different markets was initiated in 2007; see Marklund (2008) for the full report. The investigated markets were: the Australian market supplied by an RW and the CW supplied British market supported by a SW. Mathematical coordinated inventory control models were developed for the two different market and warehouse structures. Calculations and computer simulations on a selection of spare parts and accessories showed potential of significant cost and inventory reductions at the warehouses and dealers on both markets while still maintaining the same service to end customers as today.

The preliminary theoretical results of the project were interesting for Volvo Parts. They therefore wanted to evaluate the possibilities and potential further

by doing a practical implementation of one of the models in their inventory systems on a wider range of spare parts and accessories in a pilot study. A continuation project was therefore initiated in 2008 focusing on the support warehouse structure on one of Volvo Parts European markets with the aim of optimizing and balancing the reorder points at the SW and dealers simultaneously; for a full project description see Andersson, Axsäter, Howard & Marklund (2008) or Marklund & Axsäter (2008).

This project can be divided into three major parts (ibid):

*Part I: Model development, validation and evaluation*

To implement the model for a pilot study, further development is needed. This includes scalability of the model so that it can handle all dealers on a market and programming of a decision support tool. Also some basic assumptions need validation and potential relaxation.

*Part II: Initiation of pilot study, analysis of cost structure and other basic assumptions*

The initiation of the pilot study includes analyzing and finding the current costs, selection of suitable parts to be included in the study, gathering of data for the parts and finally initiation of the pilot study in Volvo Parts inventory systems.

*Part III: Observing, ending, and evaluating the pilot study*

The evaluation of the pilot study is to be done in a second Master Thesis project. That project will evaluate the results of the pilot study in terms of possible reductions in inventory levels and the effects on Volvo Parts performance measures. The way in which a full scale implementation in Volvo Parts systems should be done is possibly also to be investigated.

Part I of this project is performed by NGiL researchers at Lund University. Master thesis projects at Lund University are responsible for Part II and III of the project. The preparation for the initiation of the pilot study described in Part II is the main purpose of this thesis. The work is done on location of Volvo Parts headquarters in Gothenburg starting in November of 2008.

## **1.2 Objectives**

The main objective of this thesis is to prepare for the pilot study in order to investigate the potential of the developed NGiL model. This objective can be seen from two viewpoints: From the viewpoint of NGiL the objective is to investigate and validate the assumptions made, the potential and applicability of the developed model in a real world inventory systems. From the viewpoint of Volvo Parts the objective is to see the potential for improvements and cost savings a coordinated inventory control approach could provide, as well as the applicability of such an approach in today's and future inventory systems.

A secondary objective of this thesis is to perform a simulation study on some of the selected part to quantify the potential of the developed model and to get a picture of how the model is supposed to work in the Volvo Parts supply chain.

### **1.2.1 Directives**

The directives provided from NGiL for the initiation of the pilot study can be summarized in the following points:

1. Analyze and document the functions of Volvo Parts inventory systems and ensure that the study can be performed.
  - In what systems and how are the inventory control parameters set today?
  - How should the new inventory control parameters for the selected parts be implemented in Volvo Parts systems?
2. Perform selection and classification of parts to include in the study.
  - Set up appropriate selection criteria for parts to include in the study.
  - Define classification dimensions for the parts.
  - Define boundaries for the classification dimensions.
  - Ensure a good spread in important classification dimensions.
3. Extract and identify parameters and data for the parts.
4. Perform calculation of the new inventory control parameters for the selected parts using the model with the parameters extracted in (3).
5. Prepare for the implementation of the new inventory control parameters (4) for the selected parts in Volvo systems.
  - How should the implementation be done?
  - How to set the new parameters in the systems?
6. Perform a simulation study for a representative selection of parts to see the potential improvements the new model could provide.

### **1.3 Delimitations**

The major limitations for this thesis are:

- The focus of the thesis is on Volvo Parts business functions on the European markets and parts for Volvo Truck Corporation and Volvo Bus Corporation.
- The study involves a single market with a single support warehouse on which the study is to be conducted over a period of six months.
- The study includes 100 parts which have to pass certain criteria imposed by Volvo Parts and Lund University, simulation is performed for 20 of these parts.
- The quantitative data in the form of interviews and parts specific data are extracted from Volvo Parts employees and information systems. The data from the information systems is based on 12 months of historical data.
- Due to the amount of data and parts to analyze, these are studied using general decision tools. If each piece of data or spare part were investigated individually the results would possibly improve but such an approach would however greatly exceed the time available for the thesis.
- The practical implementation of the pilot study is not performed as part of this master thesis.

### **1.4 Target Group**

The primary target group for this thesis is Volvo Parts employees and the NGiL researchers at Lund University as well as students at Lund University, Faculty of Engineering. The secondary target group is companies utilizing similar distribution system and researchers in the field of inventory control.



## **2 METHODOLOGY**

This chapter describes the methodology theories and methods used in this thesis when preparing for and performing the study as well as addressing different problems and information sources.

### **2.1 Viewpoint and study approaches**

This section addresses the different viewpoints and study approaches in a research project depending on the goals, objectives and type of research the project is aimed towards.

#### **2.1.1 Viewpoint**

Based on a person's fundamental approach to knowledge, the goals of research can differ. As presented by Björklund & Paulsson (2003) this can be described using three viewpoints:

##### *Analytical viewpoint*

The researcher strives after explaining the truth as objectively and completely as possible looking for cause and effect relations. The subjective opinion is ignored and the knowledge is seen as being independent of the observer. The reality as a whole is here seen as nothing more than the sum of its parts.

##### *Systematic viewpoint*

The researcher strives after objectivity but the whole is seen as separate from, and often larger than, the sum of its parts. Synergy effects between the parts are emphasized and the relations between the parts are just as important as the parts themselves.

##### *Operator viewpoint*

Emphasis is laid upon that the reality is a social construction that influences and is influenced by humans. The explanations made by the researcher are therefore dependent of the researcher's actions and experiences.

In this thesis the viewpoint is strived towards being analytical. Keeping objectivity and be alert of possible cause and effect relations is of outmost importance to gain an accurate view of the reality and to be able to correctly analyze and perform the work stated in the directives in Chapter 1.

### **2.1.2 Qualitative and quantitative studies**

Björklund & Paulsson states that a quantitative study is based on measurable numerical observations and is thus limited to phenomena that can be measured. According to Holme & Solvand (1997) such studies are often performed on a shallow overall scale without dwelling into details, also, results from a pure quantitative study can be hard to generalize if the data used comes from a very specific set of conditions. The main data collection methods when performing a quantitative study are statistical processing, and mathematical models (Björklund & Paulsson).

A qualitative study on the other hand does not use numerical figures but instead focuses on describing, analyzing or understanding a specific topic, event or situation. By this it is possible to show the whole picture of the current situation, its background and consequences. The study is performed in-depth and emphasizes the systematic and operator viewpoints (ibid). The main data collection methods when performing a qualitative study are interviews and observations (Holme & Solvang).

The objective of the study decides whether a qualitative or quantitative approach should be used. Furthermore Björklund & Paulsson discusses that the different approaches lead to the use of different data collection methods and different results. It is often possible to mix the two types of studies and their respective methods by applying different approaches at different phases of the study.

Since the primary objective in this thesis is to perform the selection of parts and parameter calculation, the main parts of this study are performed using quantitative methods and quantitative data. Qualitative approach is however used when deciding on which parts are suitable for the pilot study and setting specific limits for different selection criteria or when designing different cost parameters and performance indicators.

The end result of this thesis is a selection of parts with demand and cost characteristics and other numerical data acquired by different quantitative methods, but the decisions on how to set up this demand and cost characteristics have been performed using qualitative methods. As such the study can be considered a combination of the two approaches, using the

general workflow of a quantitative study but throwing in a good portion of elements of qualitative studies and methods during its course.

Example: the cost analysis uses quantitative data (Volvo Parts budget) but the decisions on how this data is to be used to construct cost parameters for the pilot study is performed by qualitative methods.

### **2.1.3 Case research and case studies**

According to Voss, Tsikrikis & Frohlich (2002) in case research the unit of analysis is a case study. Case studies are often field-based, which gives the opportunity for the observer to see real problems in real contexts and be able to use insights of people from different levels of the organization. It has the potential to give full understanding of the nature and complexity of the complete phenomenon.

Some of the characteristics of case studies are as Meredith (1998) describes:

- The phenomenon is examined in a natural setting, by observing actual practice.
- Data is collected by multiple means, focusing on contemporary events.
- Only one or few entities are examined, but the complexity of the unit is studied intensively.

Although case studies are generally considered to be qualitative studies, quantitative methods can be used as well. As such, case research should be seen as a research strategy and does not imply a particular data collection method (Yin, 2003).

Voss et al states that case research is primarily to be used when the purpose of research is exploration, theory building, testing or refinement. The key research questions asked at this stage are: What are the key variables? What are the patterns or linkages between variables? How do the theories survive the test of empirical data?

According to Näslund (2002) a multi-method research approach is very useful in case research operations management and logistics problems, especially when developing new theory. The disadvantages of case research are however that it is time consuming, and that it needs skilled interviewers to be performed well (Voss et al).

Since the purpose of the NGIL project at this point in time can be seen as a mix of theory building and theory testing, field case study is a viable method to use. The research questions that this thesis helps to answer are primarily to test the new theory with empirical data, but also to analyze the key variables and patterns of linkage between them.

#### **2.1.4 Action research**

In logistics the problems are often real-world, managerial or organizational. According to Näslund such problems are often unstructured, not easily defined, more of a problem situation than a specified problem which are hard to force into traditional, structured form of research. Action research is an approach for tackling these kinds of problems. Näslund also states that it is thus necessary to get first-hand knowledge of the subject under investigation and to understand the phenomenon in its context. The only possible way to gain this kind of understanding is for the researcher to spend significant amount of time in the organization that faces the problems, participating in the creation of the solution. The core idea of action research is that the researcher goes from being only an observer to becoming an active participator in the change process in the organization.

Action research avoids problems associated with a purely quantitative research methods (such as surveys): risk of misinterpretation of questions, past oriented instead of future oriented, simplification of complex real world problems etc., which all lead to small benefits to practitioners and the results not being relevant in practical situations (ibid).

Many of the objectives for this thesis (see 0) are of a problem solving nature, with emphasis on detailed analysis of a small number of entities, which makes the action research approach a good option for this part of the project. By having the thesis authors stationed at Volvo Parts in Gothenburg both observing and participating in the work at a daily basis a lot of detail can be obtained about the analyzed systems, routines and concepts used.

## **2.2 Data collection and information sources**

This section describes different data collection methods and information sources and how these are implemented and used in this thesis.

### **2.2.1 Data collection methods**

The first steps of the thesis (see 1.2.1) are to “get a feeling” for the systems and characteristics of the different markets and spare parts. This type of exploratory study is performed mainly as a qualitative study using qualitative data collection methods such as interviews and literature studies (documents from NGiL and VP) but also some quantitative methods such as statistical analysis of numerical data on market levels in order to get a complete picture of the situation.

In the later steps of the project the focus is shifted towards data extraction and analysis, making the quantitative data collection- and analysis methods more suitable. However in order to set up the selection criteria or design the performance indicators some qualitative methods are also used.

### **2.2.2 Primary and secondary data**

Primary data is data created specifically for the study at hand by the researchers. Secondary data is data created for a different purpose or by someone else. As Lundahl & Skärvad (1999) describes secondary data is quicker to obtain but carries the risks of being outdated or lacking in credibility or relevance. According to Höst, Regnell & Runeson (2006) secondary data thus often needs to be completed or confirmed using primary data.

The main sources of the quantitative data for the study are existing data from different VP systems. This data is secondary data from the perspective of this study since its main purpose is inventory control or budgeting at VP. Also some data from other related projects and theses performed at VP is used.

A lot of new quantitative data is introduced as some calculations or measuring units are modified from the "status quo" at the company. For instance the cost parameters and many of the demand based measures used for the filtering and classification of parts are calculated specifically for this thesis and thus can be seen as primary data.

The main source of primary data is however the qualitative data collected by interviews and literature study which is used as a basis for decisions about the

filtering, classification and cost parameter calculations. This data is mainly collected by interviews performed in different ways: by email, phone or in person (with one or several people at one). Most interviews are performed as semi-structured interviews (a couple of questions are prepared) in person with one or two VP employees and often with a more structured follow-up by email.

The main source of written information for the literature study comes from VP documents, scientific papers and books in the field of inventory control.

## **2.3 Statistical credibility and triangulation**

When collecting data from information sources the data needs to be accurate in order to be interpreted, analyzed and used correctly. Implementing statistical credibility in terms of high reliability, validity and objectivity ensures to a higher extent that this accuracy can be achieved.

One method to ascertain high statistical credibility is to, whenever possible, investigate the information gathered using triangulation. Björklund & Paulsson describes the different types of triangulation available. This thesis has applied the perspective and method triangulation, data triangulation and evaluator triangulation which are described in this section.

### **2.3.1 Reliability**

The definition of reliability stated by Bell (2006) is the absence of random errors on repeated measurements on an object under the same circumstances. Lundahl & Skärvad determines that good reliability thus means that the same results are obtained regardless of when, by whom or why the measurements take place. The reliability of a measurement can be increased by standardizing the execution of every measurement occasion, eliminating as many factors for errors as possible.

### **2.3.2 Validity**

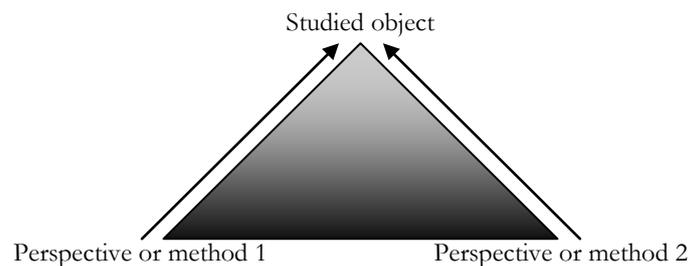
According to Patel & Davidsson (2003) validity refers to the ability of the measurement instrument to measure what it is intended to measure and for the measurement tool to avoid systematic errors. To ensure good validity it is, as Wallén (1996) explains, paramount to clearly define concepts, have a sound foundation of the background and thorough planning.

### 2.3.3 Objectivity

When facing a situation, the understanding and interpretation of the situation is according to Holme & Solvang based on previous experience, interests, frame of reference and principles. Lundahl & Skärvad further states that the distinction between facts and values are keynotes to objectivity and when objective and neural facts are available these facts and relationships should be presented without being distorted or falsified by values. Keeping objectivity not only when observing a situation, but also when a situation is actively influenced, e.g. when interviewing, is important as the outcome of the situation could be affected by the manner in which and why it is influenced (Björklund & Paulsson).

### 2.3.4 Perspective and method triangulation

The information from or about a studied object can be reviewed from different perspectives or by different methods. If the two perspectives or methods produce the same results the reliability is high and if not, the reasons for not producing the same results should be investigated, see Figure 2.1.



**Figure 2.1** Triangulation using different perspectives or methods on a studied object. Figure adapted from Björklund & Paulsson

As mentioned in 2.1.2 both qualitative and quantitative methods are used during this study and sometimes a combination of methods is possible in order to validate data. For instance a qualitative examination of quantitative data can be made by going through the extracted data during an interview, and vice versa; statements made during interviews can be checked by performing calculations in the quantitative data extracted from the IT-systems.

### **2.3.5 Data triangulation**

The data is reviewed and compared by using different sources. The type of information suitable for this triangulation method is quantitative data not subject to interpretations from either the supplier or receiver of the information.

In the thesis we strive to, whenever possible and applicable, triangulate the extracted information by comparing the results using multiple data sources in VP information systems or by interviewing more than one person using the same questions or about the same data.

### **2.3.6 Evaluator triangulation**

This triangulation uses multiple reviewers or evaluators on the same piece of information and compares the interpretation from those to ascertain high reliability. The type of information that this triangulation is applicable on is typically qualitative data such as interviews, statements or other printed information.

Applicable information gathered in this thesis is triangulated through discussions between the authors themselves, between the authors and VP employees and between authors and NGiL researchers. Another form of evaluator triangulation is performed by writing documents for review by those mentioned above.

## **2.4 Critique of sources**

The information gathered in this thesis is as describes in 0 attained from VP information systems or based on structured and unstructured interviews with VP employees.

During information gathering and analysis there is potential for errors on many levels. According to Lekvall, Wahlbin & Frankelius (2001) these potential errors need to be identified and addressed at an early stage to avoid affecting the quality and credibility of the work done. Described below are the potential errors identified in this thesis.

### **2.4.1 Objective errors**

If the objective or purpose of the work is not clearly, correctly or fully defined, the result of the completed work can be inadequate or even useless, even though it meets this objective and purpose.

Since this thesis is part of a larger research project with stakeholders from both NGiL and VP, the objectives and deliverables of the thesis are well defined. The authors of the thesis were supplied with information from NGiL before the work began both through meetings and literature (such as reports from the preceding research project, the ongoing research project and a list of defined objectives and guidelines the thesis should address). Also, a meeting and a presentation were held at VP in Gothenburg where the project was presented and discussed by representatives from NGiL and VP. The risk of objective errors in this thesis is therefore thought to be low.

#### **2.4.2 Data and analysis errors**

Errors in the data used are a potential threat to the results. These errors can arise in different ways such as out of date information, poorly designed information systems, misinterpretation and human factors. Analysis errors can be due to incorrectly processed or used data.

In this thesis vast amount of quantitative data from VP information systems is extracted, handled and manipulated. Early on errors were found, often in the form of missing data or easily distinguishable errors such as non logical or apparent outlier values. These types of errors are fairly easily found, but errors on values that seem to be reasonable or rational are much harder to identify and the risk of such errors are high. To reduce the risk of data and analysis errors to as large extent as possible the quantitative data was consolidated in a database specifically designed for this thesis (for more information see Appendix 4) and also evaluated using the triangulation methods described in 2.3.

#### **2.4.3 Interview errors**

An interviewee might in situations not be able to, know or be willing to provide the correct information. Errors also emerge from what perspective the interviewee has on the questions asked.

The risk of errors due to the interviewee not to be willing to provide the correct information is in this thesis assumed low based on that the interviewee has no gain in or reason to consciously provide misleading or incorrect information since it does not conflict with or add any significant extra load to the interviewee's current work.

It was however observed that the interviewee's answers in some cases were influenced by factors such as; in what department or at what location the interviewee works, previous experience, what stake the interviewee had in the project and in what way the interview was made. It was also noticed that the interviewee in a few cases gave an unsure answer or guessed rather than saying that he or she did not know the answer. By using the triangulation methods described in 2.3 these errors are believed to have low impact on the thesis results.

## **3 THEORY**

This chapter describes the theoretical framework used in this thesis. The main goal is to present the inner workings of the analytical NGiL model by starting with the fundamentals of inventory control and basic definitions. This is followed by theories on how to model customer demand and descriptions of simpler inventory control models, which are used as components in the NGiL model. The NGiL model's assumptions, structure and functionality are then described. Finally the total costing model concept is described which is used for cost calculations in Chapter 5.

### **3.1 Inventory management and control**

Keeping inventory is an essential part of being able to satisfy demand from customers without experiencing too many shortages and keeping good service. As Axsäter (2006) describes inventories cost money, both in the sense of tied up capital and also running and administrating the inventory itself. To run an inventory efficiently it is thus important to balance the service to customers against these costs. This is the purpose of inventory management, which focuses on the decisions on when to replenish the inventory and how many units to replenish it with. The time from ordering to delivery of replenishments for the inventory, referred to as the lead time, is often long and the demand from customers is almost never completely known. For these reasons the demand has to be forecasted, modeled and approximated using mathematical inventory control methods and theories. The NGiL model is one such and will be described in detail in 3.4 and 3.5. It can be seen as a combination of several simpler inventory control models, namely the backorder and lost sales models, which will be described in 3.4.1 and 3.4.2, respectively. The theory presented in this section is based on Axsäter (2006) and Axsäter (1991).

#### **3.1.1 A simple inventory system**

A simple inventory system can be modeled by looking at the amount of stock in the inventory over time. The amount of stock can be expressed in different ways where the most common are the inventory level and inventory position. The inventory level  $IL$  is a measure of the stock on hand in inventory, i.e. the number of units readily available, at a certain point in time. When demand cannot be satisfied immediately due to shortage in stock, this demand could be placed on hold and be satisfied as soon as the inventory is replenished. These

orders are known as backorders, and if such exists, they are subtracted from  $IL$  since these units are not readily available for sales.

$$IL = \textit{stock on hand} - \textit{backorders}$$

The inventory position  $IP$  also includes outstanding orders, which are replenishment orders that have been placed but still have not arrived.

$$IP = \textit{stock on hand} + \textit{outstanding orders} - \textit{backorders}$$

When making ordering decisions, this should not be based on the  $IL$  as it is also relevant to know the amount of outstanding orders since these will arrive sometime in the close future. The review of the  $IL$  or  $IP$  needs to be done on a regular basis and can be done continuously, at all times, or periodically, at some predetermined time intervals. These review policies are described in further detail in 3.2.1.

The decisions themselves can be made according to a couple of different ordering policies. For the purpose of this example an (R,Q) ordering policy is used since this is also the case within Volvo Parts inventory control (the policy is described in further detail in 3.2.2).

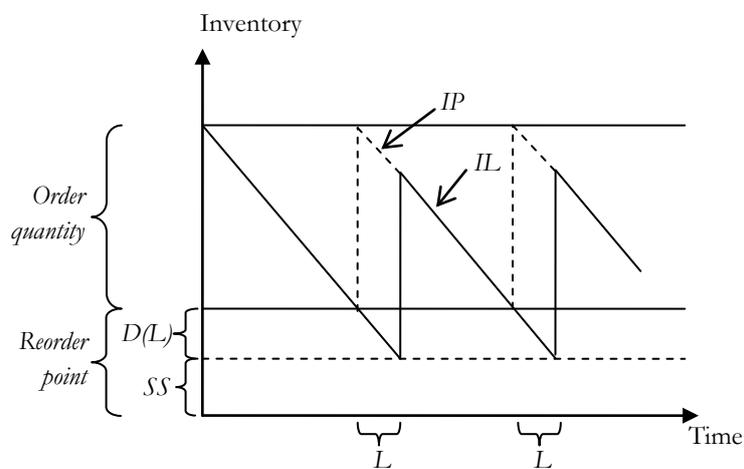
Demand of units will decrease the inventory over time and sooner or later a replenishment order has to be placed. The decision on when to make the replenishment order is governed by a inventory control parameter called the reorder point  $R$ . When the inventory position drops to a point equal to or below this reorder point a replenishment order is placed that will arrive in the lead time  $L$ . This reorder point can in turn be divided into two components; the safety stock  $SS$  and the demand during the lead time  $D(L)$  waiting for the placed order to arrive.

$$\textit{reorder point} = SS + D(L)$$

The safety stock works as a buffer to avoid shortage covering the variations of the real demand and is set to a value that with a given service level requirement will prevent shortage under the given circumstances. Service levels are explained further in 0. The demand during the lead time covers the expected average demand waiting for the replenishment to arrive and is needed to ensure that shortage will be prevented.

The replenishment order is placed for a number of units called the order quantity  $Q$ . For the  $(R,Q)$  ordering policy this is a predetermined fixed value for which the Wilson formula (see e.g. Axsäter, 1991) is widely used. Despite the fact that the Wilson formula is based on very simplifying assumptions, using a deterministic system with constant and continuous demand that do not reflect the reality in a very good way, it has proven to still give satisfying results.

Using the concepts described above the inventory level in a simple inventory system can be illustrated as seen in Figure 3.1.



**Figure 3.1** A simple inventory system illustrated using the described concepts

The inventory has (for simplicity in this example) continuous review and constant demand over time. When the inventory position reaches the reorder point an order of new units, equal to the order quantity, is placed. During the lead time, waiting for the order to arrive, the inventory level has dropped by a number of units, equal to the demand during the lead time, down to the safety stock. After the lead time, the placed order arrives and replenishes the inventory with an amount of units equal to the order quantity.

The reorder point and order quantity used also depend on the costs involved in keeping inventory and the costs for placing orders. The costs for keeping inventory are expressed as the inventory holding costs. By keeping inventory, capital that otherwise could be used for other investments is tied up. The cost for this tied up capital consists of several parts, where the return on alternative

investments and risks are the major parts. Also included could be insurance, taxes, material handling, storage, damage and obsolescence or other costs that are variable with the amount of inventory held. This is called the holding cost  $h$  and is usually set on a per stock keeping unit and time unit basis as a percentage of the value of the unit. The costs for placing an order are often referred to as the ordering or setup cost  $A$  and includes all costs that could be associated with the order setup, administrative, transportation setup and order handling costs. Also, when placing orders to a supplier, costs for order forms, authorization, receiving inspection and invoice handling could be included.

## **3.2 Further discussions of inventory concepts**

In the simple inventory section above a few concepts that need further explanation are presented. These concepts are described in further detail in this section (Axsäter, 2006).

### **3.2.1 Review policies**

The decision when to make a replenishment order is based on the inventory position. It is therefore necessary to monitor this position, which can be done continuously or periodically.

#### *Continuous review*

With continuous review, the inventory position is observed continuously and as soon as it drops to or below the reorder point, the order is triggered directly. The order will then arrive after the lead time. The advantage of having continuous review is the ability to react instantly when the inventory position reaches the reorder point. Therefore, a continuous review policy often requires lower safety stock than a periodic review policy, but it also requires more advanced technology in order to monitor the inventory.

#### *Periodic review*

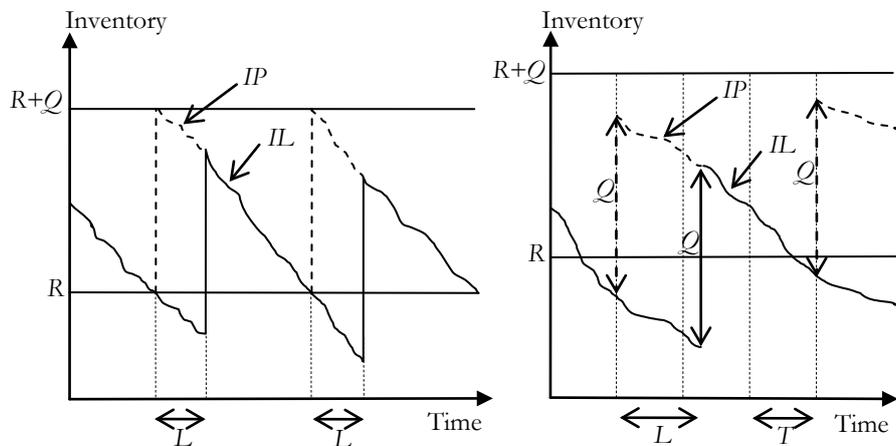
With periodic review, the inventory position is only observed at periodic intervals with the review period  $T$ , i.e. the stock level is unknown between the reviews and an order can only be placed in connection with a review. This means that there is some uncertain time before the order is placed after the inventory position has dropped to or below the reorder point and hence the time before order arrival is longer, at the most  $T + L$ . The advantages with periodic review are that it is easier to coordinate orders for different items and also that the technology systems requirements are not as high as for

continuous review. When the review period gets shorter the two review policies become very similar.

### 3.2.2 (R,Q) ordering policy

The ordering policy is based on the reorder point  $R$  and the ordering quantity  $Q$ . When the inventory position reaches  $R$  an order of  $Q$  units is triggered. In the case of continuous review and if every demand occurrence is in single units, i.e. one unit at a time, the inventory position will never be below  $R$  and will thus always be between  $R$  and  $R + Q$ . Also, with continuous review the ordered quantity will arrive within the lead time. This is illustrated in the left half of Figure 3.2.

In the cases with demand in multiple units (i.e. a customer can order several units at a time) or periodic review the inventory position can reach below  $R$  before an order is triggered. This situation is sometimes referred to as an  $(R, nQ)$  system, where a multiple of  $Q$  is ordered ensuring that the inventory position gets larger than  $R$ . The arrival of the ordered item(s) will besides the lead time also involve some uncertain time between 0 and  $T$  due to the periodic review. This situation is illustrated in the right half of Figure 3.2.



**Figure 3.2** The (R,Q) policy with continuous review and single demand of units (to the left) and the (R,Q) policy with periodic review and/or demand of several units (to the right). Continuous demand is assumed in both situations.

### 3.2.3 Service levels

When measuring performance of an inventory system or when setting parameters (such as reorder point and safety stock) satisfying a given performance level towards the customers, it is common to define service levels. Within inventory control, three different service levels measurement are commonly used.

$SERV_1$  (or  $S_1$ ) measures the probability that a placed order arrives to replenish the inventory before stock out, thus keeping a positive stock. Although it is used in many practical applications it has some big disadvantages. It does not take the order quantity into account and hence could be very low if the order quantity is large (and vice versa) but the service perceived by the customer can still be good.

$SERV_2$  ( $S_2$  or fill rate) measures how much of the demand that is immediately satisfied from the stock at hand. It gives a picture of the immediate customer service since it measures the service experienced when demand occurs and whether this demand could be satisfied right away or not.

$SERV_3$  (or  $S_3$ ) is similar to  $SERV_2$  but focuses instead on the fraction of time the stock is positive. In the case of continuous demand in single units these measurements are equivalent, but they do differ when the demanded quantity is larger compared to the stock on hand. Although the stock is positive a large proportion of the time giving high  $SERV_3$ , the  $SERV_2$  measure could be low since a single demand occurrence now has a large probability of depleting the stock on hand.

In later sections only  $SERV_2$  and  $SERV_3$  are used to determine the customer service in the two described reorder point models and the NGiL model.

## 3.3 Modeling customer demand

In order to determine inventory control parameters using mathematical models and theories it is appropriate to begin with modeling of the customer demand. A suitable demand model should mimic the real demand as good as possible and therefore the characteristics of the real demand determine the best suitable model to use. According to Axsäter (2006) when demand is low and close to integer values during a time period a discrete model is most suitable, such as a compounding Poisson model. If the demand instead is rather high a

continuous model might be more suitable and in these cases the normal distribution model is commonly used.

### 3.3.1 Compounding Poisson model

In the Compounding Poisson model customer demand is modeled by a Compound Poisson process. The Compound Poisson process can be seen as an extension of the Poisson process, made by taking into consideration the number of items demanded by each customer (or the ordered quantity of an order) as a stochastic variable.

Axsäter (2006) states that with small and integer values of each customer's demand, the cumulative demand during a time period may be expressed as a compounding Poisson process. The customers arrive according to a discrete Poisson process and the size of the individual customers' demand is modeled using a compounding distribution.

#### 3.3.1.1 Discrete Poisson distribution and Poisson process

The discrete Poisson distribution can be interpreted as the probability of a number of events occurring in a period of time if the events occur at a given average rate  $\lambda$ . If a stochastic variable  $X$  is Poisson distributed it has the probability density function

$$P(X = k) = f_k(\lambda) = \frac{\lambda^k e^{-\lambda}}{k!} \quad (3.1)$$

with mean and variance

$$E(X) = Var(X) = \lambda. \quad (3.2)$$

A Poisson process is defined as a stochastic process in continuous time  $\{X(t), t \geq 0\}$  such as

$$X(t) = \frac{(\lambda t)^k e^{-\lambda t}}{k!}. \quad (3.3)$$

The discrete Poisson process is easy to work with; its mean and variance are equal and it depends on only one parameter ( $\lambda$ ). It can also be shown that a sum of Poisson processes is a Poisson process which is especially useful in inventory control where demand from many sources easily can be combined.

### 3.3.1.2 Compound Poisson process

If the customers arrive as a Poisson process, as in Eq. (3.3), the probability of  $k$  customers arriving during a period  $t$  is given by the probability density function of the customer arrivals  $K$

$$P(K = k) = f_k(\lambda t) = \frac{(\lambda t)^k}{k!} e^{-\lambda t}, \quad k = 0, 1, \dots \quad (3.4)$$

The probability of each customer to have a demand of  $j$  units is given by the probability function of the compounding distribution  $J$ .

$$P(J = j) \equiv f_j. \quad (3.5)$$

This gives the following expression for the probability that  $k$  customers will arrive with the total demand of  $j$  units

$$f_j^k = \sum_{i=k-1}^{j-1} f_j^{k-1} f_{j-i}, \quad k = 2, 3, \dots \quad (3.6)$$

with the initial values

$$f_0^0 = 1, f_j^1 = f_j.$$

From Eq. (3.4) the probability of a total demand  $D(t)$  of  $j$  units is thus

$$P(D(t) = j) = \sum_{k=0}^{\infty} \frac{(\lambda t)^k}{k!} e^{-\lambda t} f_j^k. \quad (3.7)$$

It can then be shown (see e.g. Axsäter, 2006) that the mean  $\mu$  and variance  $\sigma^2$  of the total demand can be expressed as

$$\begin{aligned} \mu &= E(K)E(J) = \lambda E(J) = \lambda \sum_{j=1}^{\infty} j f_j \\ \sigma^2 &= \dots = \lambda E(J^2) = \lambda \sum_{j=1}^{\infty} j^2 f_j. \end{aligned} \quad (3.8)$$

### 3.3.1.3 Compounding distributions

From Eq. (3.8) the only thing left in order to have the full expression for the total demand is to decide on the compounding distribution of the individual customers' demand. Two such distributions are commonly used; the logarithmic and the delayed geometric distribution, respectively.

#### Logarithmic compounding distribution

A stochastic variable  $X$  that follows the discrete logarithmic distribution has the probability density function

$$P(X = k) = f_k(p) = \frac{-p^k}{\ln(1-p)k}, \quad k = 1, 2, \dots \quad (3.9)$$

where  $p$  is the probability of a successful outcome ( $0 < p < 1$ ) with the mean and variance

$$E(X) = -\frac{p}{(1-p)\ln(1-p)}, \quad \text{Var}(X) = -\frac{p(\ln(1-p) + p)}{(1-p)^2(\ln(1-p))^2}. \quad (3.10)$$

From the probability density function, the distribution for each occurrence of demand can be expressed as

$$f_j = -\frac{p^j}{\ln(1-p)j}, \quad j = 1, 2, \dots \quad (3.11)$$

It can then be shown that Eq. (3.8) results in a negative binomial distribution

$$P(D(t) = j) = \frac{r(r+1)\dots(r+j-1)}{j!} p^r (1-p)^k, \quad j = 1, 2, \dots \quad (3.12)$$

#### Delayed geometric compounding distribution

The probability density function of the delayed geometric distribution is

$$P(X = k) = f_k(p) = (1-p)^{k-1} p, \quad k = 1, 2, \dots \quad (3.13)$$

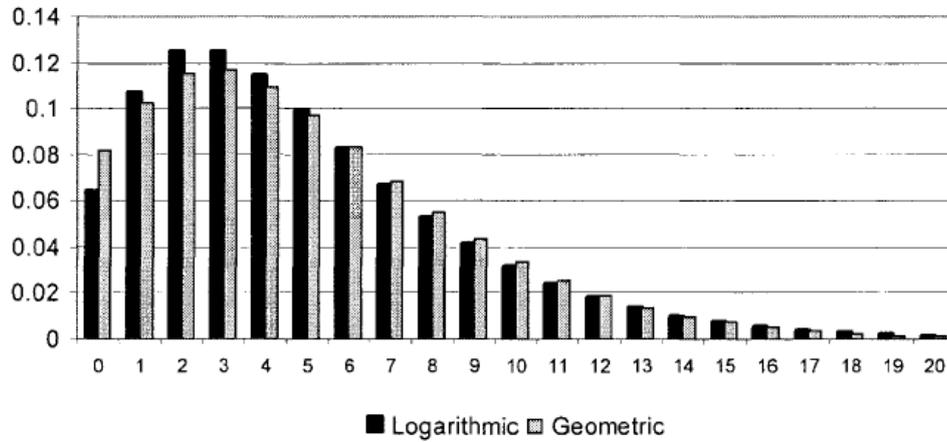
with mean and variance

$$E(X) = \frac{1}{p}, \quad \text{Var}(X) = \frac{1-p}{p^2} \quad (3.14)$$

From this probability density function the distribution for each occurrence of demand can be expressed as

$$f_j = (1 - p)^{j-1} p, \quad j = 1, 2, \dots \quad (3.15)$$

The delayed geometric distribution as the compounding distribution gives very similar results as the logarithmic compounding distribution. This similarity of the resulting compound Poisson distributions are shown in Figure 3.3.



**Figure 3.3** Comparison of the resulting distribution when compounding with the logarithmic versus geometric distribution. Reprinted from Axsäter (2006)

### 3.3.2 Normal distribution model

If however demand is high Axsäter (2006) states that a more suitable model can be obtained by using a continuous distribution, such as the normal distribution, to model the total demand over a time period. The normal distribution, or the Gaussian distribution, is the most widely known and used distribution due to its simplicity and the central limit theorem (see e.g. Blom, 2005), which extends its applicability to a large range of situations. A stochastic variable  $X$  that is normally distributed has the probability density function and cumulative density function

$$f_X(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \quad (3.16)$$

$$F_X(x) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^x e^{-\frac{(t-\mu)^2}{2\sigma^2}} dt$$

where  $x$  is an observation of  $X$ . The mean and variance are then estimated using

$$\begin{aligned}\hat{\mu} &= \bar{x} = \sum_{i=1}^n x_i / n \\ \hat{\sigma}^2 &= \frac{1}{n-1} \sum_{i=1}^n (x_i - \bar{x})^2,\end{aligned}\tag{3.17}$$

given  $n$  number of observations.

With  $\mu = 0$  and  $\sigma = 1$ , this gives a special case called the standardized normal distribution with the probability density function and cumulative density function

$$\begin{aligned}\varphi(x) &= \frac{1}{\sqrt{2\pi}} e^{-\frac{x^2}{2}} \\ \Phi(x) &= \frac{1}{\sqrt{2\pi}} \int_{-\infty}^x e^{-\frac{t^2}{2}} dt.\end{aligned}\tag{3.18}$$

The values of the cumulative density function  $\Phi(x)$  can be found tabulated in detail for  $x$ . The probability density function and cumulative density function of any normally distributed stochastic variable  $X$  can be expressed as

$$\begin{aligned}f_X(x) &= \frac{1}{\sigma} \varphi\left(\frac{x - \mu}{\sigma}\right) \\ F_X(x) &= \Phi\left(\frac{x - \mu}{\sigma}\right).\end{aligned}\tag{3.19}$$

This mean that the tabulated values for  $\Phi(x)$  can be readily used and no explicit calculations are needed which makes computation much faster.

Axsäter (2006) further discusses that one problem with the normal distribution is however that the probability for negative outcomes is never equal to zero. In the cases where demand is high this is though rarely a problem since the probability of negative outcomes then becomes negligibly small. If the demand is small and a continuous model still wants to be used the gamma distribution is more suitable (see e.g. Axsäter, 2006).

### 3.4 Determining the reorder point – Two models

The reorder point determination for a system with non-deterministic demand, i.e. stochastic demand, can be done using several models. Two such models; a model with backorders and a model with lost sales are presented here. These models are components in the NGiL model used to optimize the reorder points in the inventory system.

#### 3.4.1 Backorder model

Axsäter (2006) describes this model for determining the reorder point  $R$ . It assumes that the order quantity  $Q$  is deterministic and that any demand not satisfied directly from stock on hand is backordered and delivered as soon as a replenishment of the inventory has arrived. Given that the inventory is continuously reviewed (see 3.2.1) using a  $(R, Q)$  policy (see 3.2.2) and that the replenishment lead time  $L$  is constant the following simple relationship between the inventory position  $IP$  and the inventory level  $IL$  apply

$$IL(t+L) = IP(t) - D(t, t+L) = IP(t) - D(L) \quad (3.20)$$

where  $t$  is some arbitrary time and  $D(L)$  is the demand during the lead time. Axsäter (2006) shows that the expected total holding costs  $C$  per time unit then can be expressed as

$$C = bE(IL)^+ = bE(IL) + bE(IL)^- \quad (3.21)$$

where  $E(IL)^+$  is the expected amount of positive stock,  $E(IL)$  is the expected inventory level,  $E(IL)^-$  is the expected amount of backorders and  $b$  is the holding cost per stock keeping unit. This total holding cost can be shown to be a function of  $R$  and also that it is convex in  $R$  (see e.g. Axsäter, 2006 or Rosling, 2002) which means that a single minimum of the cost function can be found by setting

$$\frac{\partial C}{\partial R} = 0. \quad (3.22)$$

For the solution to be useful it also has to meet a given service constraint goal. Thus, the lowest  $R$  that also satisfies the service constraint is the optimal solution. In a situation where demand is in whole units, only integer values of  $R$  are valid.

$E(IL)$  and  $E(IL)^-$  depend on the distributions used to model the demand. This is shown for two distributions; the compound Poisson distribution and the normal distribution.

### 3.4.1.1 Compound Poisson demand

The assumption is that the customers arrive according to a Poisson process and that the size of the demand from each customer is modeled with a compounding distribution (see 3.3.1). If the logarithmic distribution is used as the compounding distribution it can be shown that the demand during the lead time follows a negative binomial distribution. This gives a probability density function for  $IL$  as

$$P(IL = j) = \frac{1}{Q} \sum_{k=\max(R+1, j)}^{R+Q} P(D(L) = k - j), \quad j \leq R + Q. \quad (3.23)$$

It can then be shown that the cost function is

$$C = bE(IL) + bE(IL)^- = b \sum_{j=1}^{R+Q} j P(IL = j). \quad (3.24)$$

As a service constraint the fill rate (see 0) can be used, which in this case is expressed as

$$S_2 = \frac{\sum_{k=1}^{\infty} \sum_{j=1}^{R+Q} \min(j, k) f_k P(IL = j)}{\sum_{k=1}^{\infty} k f_k} \quad (3.25)$$

where  $f_k$  is the probability of demand size  $k$ , given by the logarithmic distribution, see Eq. (3.11).

Finding the optimal  $R$  is done by starting at  $R = -Q$  in Eq. (3.24) and increasing  $R$  one unit a time until the cost function increases. When this minimum is found the optimal  $R$  is then the lowest one also satisfying the service constraint

$$\text{in Eq. (3.25). } G(x) = \int_x^{\infty} (v - x) \varphi(v) dv = \varphi(x) - x(1 - \Phi(x))$$

### 3.4.1.2 Normally distributed demand

When demand follows the normal distribution (see 3.3.2) with mean  $\mu$  and standard deviation  $\sigma$  the mean  $\mu'$  and standard deviation  $\sigma'$  during the lead time  $L$  is defined as

$$\begin{aligned}\mu' &= L\mu \\ \sigma' &= \sqrt{L}\sigma.\end{aligned}\quad (3.26)$$

The probability density function for  $IL$  then is

$$P(IL \leq x) = F(x) = \frac{1}{Q} \int_R^{R+Q} \left[ 1 - \Phi\left(\frac{u-x-\mu'}{\sigma'}\right) \right] du \quad (3.27)$$

By using the loss function  $G(x)$

$$(3.28)$$

Eq. (3.27) can be rewritten as

$$P(IL \leq x) = F(x) = \frac{\sigma'}{Q} \left[ G\left(\frac{R-x-\mu'}{\sigma'}\right) - G\left(\frac{R+Q-x-\mu'}{\sigma'}\right) \right]. \quad (3.29)$$

The advantage with rewriting the probability density function using the loss function is that it is readily tabulated which decreases the computation time considerably. For determining the probability of having  $IL = j$  it is reasonable to express it as

$$P(IL = j) = P(j-0,5 \leq x \leq +0,5) = F(j+0,5) - F(j-0,5)$$

Using  $H(x) = \int_x^\infty G(v) dv = \frac{1}{2} \left[ (x^2 - 1)(1 - \Phi(x)) - x\phi(x) \right]$  and Eq. (3.29) the

cost function can be written as

$$\begin{aligned}C &= bE(IL) + bE(IL)^- = b\left(R + \frac{Q}{2} - \mu'\right) + b\frac{(\sigma')^2}{Q} \int_R^{R+Q} G\left(\frac{u-\mu'}{\sigma'}\right) du \\ &= b\left(R + \frac{Q}{2} - \mu'\right) + b\frac{(\sigma')^2}{Q} \left[ H\left(\frac{R-\mu'}{\sigma'}\right) - H\left(\frac{R+Q-\mu'}{\sigma'}\right) \right].\end{aligned}\quad (3.30)$$

As service constraint the fill rate or, in this case equivalently, the ready rate can be used

$$S_2 = S_3 = 1 - \frac{\sigma'}{Q} \left[ G\left(\frac{R - \mu'}{\sigma'}\right) - G\left(\frac{R + Q - \mu'}{\sigma'}\right) \right]. \quad (3.31)$$

The optimal  $R$  can then be determined in analogy to that explained in the compounding Poisson distribution situation.

### 3.4.2 Lost sales model

According to Rosling (2002) the lost sales model describes a situation where demand that cannot be satisfied from stock on hand is seen as lost sales. Using a continuous review and  $(R, Q)$  policy this means that  $IL$  and  $IP$  never can become negative and hence the reorder point  $R \geq 0$ . The demand is assumed to follow a normal distribution with mean  $\mu$  and standard deviation  $\sigma$ . The mean  $\mu'$  and standard deviation  $\sigma'$  during the lead time  $L$  are still defined as in Eq. (3.26). Every unit lost carries a shortage cost  $b$  and stock keeping units carries a holding cost  $h$  per unit and time unit. When  $R$  is reached, the order quantity  $Q$  will arrive in  $L$  time units. The expected number of lost sales during an order cycle can be expressed as

$$E(R - D(L))^- = \int_R^{\infty} (u - R) \frac{1}{\sigma'} \varphi\left(\frac{u - \mu'}{\sigma'}\right) du = \sigma' G\left(\frac{R - \mu'}{\sigma'}\right). \quad (3.32)$$

The expected stock on hand just before delivery at the beginning of the order cycle is

$$\begin{aligned} E(R - D(L))^+ &= E(R - D(L)) + E(R - D(L))^- = \\ &R - \mu' + \sigma' G\left(\frac{R - \mu'}{\sigma'}\right). \end{aligned} \quad (3.33)$$

With an expected length of an order cycle of  $\frac{1}{\mu} \left[ Q + E(R - D(L))^- \right]$  the cost function, containing both a holding cost component and a lost sales component, can be expressed as

$$C = \frac{bQ \left[ R - \mu' + \sigma' G \left( \frac{R - \mu'}{\sigma'} \right) \right] + b\mu\sigma' G \left( \frac{R - \mu'}{\sigma'} \right)}{Q + \sigma' G \left( \frac{R - \mu'}{\sigma'} \right)}. \quad (3.34)$$

This cost has a single minimum in  $R$  and together with the service constraint in Eq. (3.35) an optimal  $R$  can be found in analogy with the methods used in the backorder model.

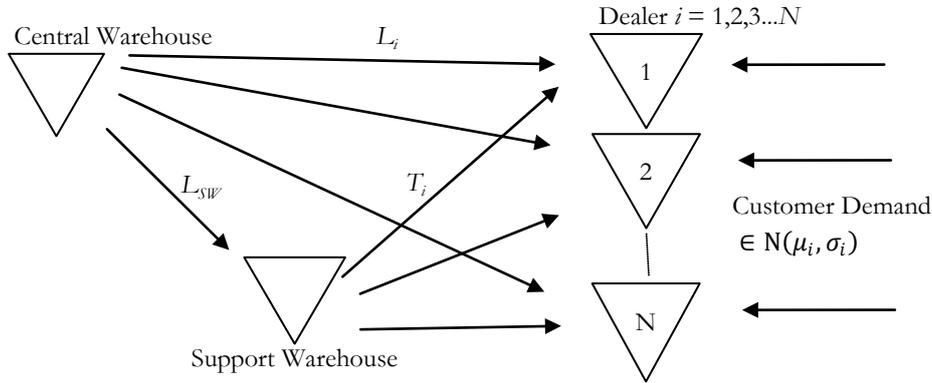
$$S_2 = \frac{Q}{Q + \sigma' G \left( \frac{R - \mu'}{\sigma'} \right)}. \quad (3.35)$$

### 3.5 The analytical NGiL Model

The analytical model is developed by NGiL researchers at Lund University. The goal of the model is to minimize the total costs in the Volvo Parts supply chain on a market with a SW-structure, while ignoring the costs related to the CW. This is done by calculating optimal reorder points at all installations simultaneously, while being constrained by a target fill rate at each dealer. The model combines the theory for the backorder model described in 3.4.1 and the lost sales model described in 3.4.2 and performs inventory level optimization for a single stock keeping unit at a time but at all inventories in the system simultaneously.

#### 3.5.1 Structure of the modeled inventory system

The inventory system consists of a single market with a central warehouse (CW) that distributes replenishment order to both a support warehouse (SW) and to the dealers on the market, see Figure 3.4.



**Figure 3.4** Illustration of the single market of the inventory system

Customer demand is handled by the dealers and when this demand cannot be satisfied directly by the dealers themselves, it is transferred to the SW. If this transferred demand can be satisfied fully at the SW, the customer demand is treated as fulfilled and the additional service contribution from the SW is included in the total fill rate of the dealers.

### 3.5.2 Basic assumptions and input parameters

The model focuses on the dealer and SW inventories only by assuming a fill rate of 100 % at the CW. This implies that every order made to the CW is also satisfied within the lead time. All Customer demand occurs at the dealers and is assumed to be normally distributed with mean  $\mu_i$  and standard deviation  $\sigma_i$  per time unit for dealer  $i$ . The occurrence of negative customer demand, i.e. customer returns, is however disregarded.

All dealers are replenished from the CW using continuous (R, Q) policies (see 3.2.2) with no backordering and constant lead time  $L_i$ . This structure follows the lost sale model and gives a cost function  $C_i$  at the dealers according to Eq. (3.34) and a fill rate  $a_i$  according to Eq. (3.35). Any customer demand that cannot be satisfied directly from stock on hand at the dealers is transferred to the SW and invokes a shortage cost  $b_i$  per unit of transferred demand.

If the transferred demand can be fully satisfied by the SW, the demand is regarded as being satisfied directly by the dealers, i.e. the lead time  $T_i$  from SW to dealers (see Figure 3.4) is assumed to be short enough to be ignored ( $T_i \approx 0$ ). The amount of demand transferred from a dealer to the SW is equal to  $(1-a_i)\mu_i$ , i.e. the fraction of the demand that could not be satisfied directly at

the dealer. The total demand at the SW is thus equal to the sum of the demand transferred from all of the dealers and has the mean  $\mu_{SW}$  and approximated standard deviation  $\sigma_{SW}$

$$\mu_{SW} = \sum_{i=1}^N (1 - \alpha_i) \mu_i$$

$$\sigma_{SW} = \left( \sum_{i=1}^N (1 - \alpha_i) \sigma_i \right)^{1/2}.$$

The SW is replenished from CW using a continuous (R, Q) policy with complete backordering and constant lead time  $L_{SW}$  and follow the backorder model structure. This means that the cost function  $C_{SW}$  and fill rate  $\beta$  at the SW depends on the distribution of the demand. In cases where the variance-to-mean ratio is smaller than one, i.e.  $\sigma^2/\mu < 1$ , the demand is approximated to follow the normal distribution described in 3.4.1.2. If the variance-to-mean ratio instead is larger than one, the demand is approximated to follow the logarithmic compound Poisson distribution described in 3.4.1.1.

To complete the cost and fill rate functions the holding cost  $b$  for each stock kept unit and time unit also has to be included as well as the order quantity  $Q$  at all installations (SW and dealers). The total costs  $TC$  of the whole inventory system per time unit can then be defined as the sum of the costs at SW and all dealers

$$TC = C_{SW} + \sum_{i=1}^N C_i$$

Any costs involving CW are however disregarded since the model assumes that everything ordered from CW will immediately be shipped, which makes the CW costs constant in all situations and thus they do not need to be considered.

To sum up the requirements of the cost and fill rate functions in order to define the total costs the following parameters need to be provided for the model:

- Mean and standard deviation of demand per time unit at all individual dealers.
- Lead times from the CW to the dealers and to the SW.

- Order quantities at the dealers and the SW.
- Shortage cost per unit at the dealers.
- Holding cost per unit and time unit at the dealers and the SW.

The mean and standard deviation of the demand at the SW does not need to be provided since this is calculated from the demand at the dealers. Further details on the NGiL model can be found in Axsäter, Howard, & Marklund (2008) and Axsäter, Howard, Marklund, Svensson, & Twedmark (2009).

### 3.5.3 Optimizing the reorder points

With the input parameters given, the problem to solve is to optimize the reorder points  $R$  at all installations. The optimal solution is found by finding the combination of reorder points that minimizes the total cost of the system. This solution yields a total fill rate  $\gamma_i$  at the dealers, consisting of two components; the fill rate  $a_i$  from the dealers themselves, and the additional fill rate contribution  $(1-a_i)\beta$  from the SW on the transferred demand

$$\gamma_i = \alpha_i + (1 - \alpha_i)\beta.$$

This total fill rate has to be equal to or larger than the specified target fill rate  $T_i$  at each dealer, i.e.  $\gamma_i \geq T_i$ . If this constriction is not satisfied the solution is not optimal and a new combination of reorder points has to be found.

Optimizing the reorder points that minimize the total costs by doing a complete search of all possible combinations of reorder points at all dealers and SW is not a viable approach due to the long computational time needed. A heuristic method, that gives close to optimal reorder points and is more computational efficient, is therefore used. Details on this heuristic method can be found in Axsäter, Howard & Marklund (2009).

### 3.5.4 Analytical Model in Excel

The analytical model is constructed as a Visual Basic Macro in Microsoft Excel. It has a couple of modes of operation implemented as switches in the Excel document.

The selection of the stochastic distribution of demand at SW can be switched to be regarded as a pure normal distribution (normal approximation) or as different distributions based on the variance-to-mean ratio (as described in

3.5.2), also the mode of estimating the variance of the demand at SW can be toggled between different modes.

Optimization of reorder points can be performed as a cost evaluation, using a heuristic method or by performing a complete search. The complete search method tries all possible combinations of reorder points and is for validation purposes only.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
# of Problems	1	Run		Input											Output Data							
# of Dealers	10			Data											Analytical							
Analytical	1			Installation	L	T	h	b	R	O	Mu	Sigma	Target FR		Installation	hC	SC	C	TC	Beta/Alpha	Gamma	Optimal R
SW Dist	1			CW	0	-	0	-	0	1	-	-	-	-	CW	-	-	-	33.385	-	-	-
SW Variance	0			SW	0.197	-	0.125	-	-100	100	-	-	-	-	SW	0	-	0	W Gamma	0	-	-100
Optimization	1			D1	0.179	0	0.125	10.98	13	24	3.25	4.18	0.94		D1	4.69632	0.249	4.94503	0.995865	0.995789	0.99579	15
Stepsize (H)	0.005			D2	0.179	0	0.125	10.98	23	43	7.08	7.54	0.94		D2	0.41014	0.031	0.44079		0.98436	0.98436	1
Non-negative Rts	0			D3	0.179	0	0.125	10.98	15	25	2.42	3.42	0.94		D3	5.81655	0.358	6.17436		0.996849	0.99685	30
Simulation	0			D4	0.179	0	0.125	10.98	8	10	2.5	7.44	0.94		D4	3.9840	0.212	4.187		0.995255	0.99527	13
SimTime	110			D5	0.179	0	0.125	10.98	29	85	6.67	6.36	0.94		D5	2.1509	0.076	2.22697		0.997214	0.99721	7
Start-up	10			D6	0.179	0	0.125	10.98	107	153	58.9	85.51	0.94		D6	3.84725	0.233	4.08068		0.991452	0.99145	9
Time block	10			D7	0.179	0	0.125	10.98	8	10	0.08	0.29	0.94		D7	0.24077	0.004	0.24441		0.986078	0.98608	0
				D8	0.179	0	0.125	10.98	8	12	9.33	28.70	0.94		D8	2.74598	0.143	2.8899		0.995122	0.99512	10
				D9	0.179	0	0.125	10.98	8	10	0.75	1.48	0.94		D9	7.0884	0.791	7.87926		0.998467	0.99847	87
				D10	0.179	0	0.125	10.98	7	8	0.17	0.39	0.94		D10	0.30154	0.015	0.31659		0.976967	0.97697	0

Figure 3.5 The frontend sheet of the Excel version of the analytical model

The Excel document consists of a frontend sheet into which the required parameters for all the dealers and are entered. The optimization is performed by running a macro see Figure 3.5. After the optimization is done the new reorder points are outputted in the sheet, as well as some other details from the optimization such as the expected holding and shortage costs at each installation, the total expected cost, the expected fill rate of the solution at each installation and the resulting mean and standard deviation of the demand at SW.

The Excel model also has the ability to automatically run the simulation model after the optimization is done. The results from the simulation run are also shown in the sheet.

### 3.5.5 Simulation Model

The purpose of a simulation models is to describe the studied system as close as possible with methods available in probability and queuing theory. Such models thus lack many of the approximations necessary in analytical models, where quick calculations are needed in the optimization processes. Simulation studies are performed to verify and validate analytical models and to facilitate comparisons between current and optimized states of the system. For more details see Laguna & Marklund (2005) or Hillier & Lieberman (2005).

The simulation model of the VP system is created by NGiL researchers. It does not implement the normal approximation of the customer demand but instead uses an approach with a compound Poisson process (see 3.3.1) for the occurrence of customer demand. The compounding distribution is a delayed geometric distribution with the  $p$ -parameter set as

$$p = \begin{cases} 1 & \text{if } \frac{\sigma^2}{\mu} < 1 \\ \frac{2}{1 + \frac{\sigma^2}{\mu}} & \text{otherwise} \end{cases} \quad (3.36)$$

This distribution outputs the integer number of units that an occurrence of customer demand is for. If  $p = 1$  this number is always equal to 1 unit and the compound Poisson process becomes a pure Poisson process.

This model is constructed in commercial simulation software called Extend<sup>3</sup> as a discrete event model meaning that each customer demand, order and delivery is individually created in the model with a given arrival time and destination. It performs no optimization of reorder points but rather simulates the system given a set of parameters. These parameters are the same as for the analytical model plus the set of reorder points to be analyzed (e.g. the optimized reorder points generated by the analytical model or data from a real world scenario).

The output of results of the simulation model is analogous to the analytical model but also includes the standard deviation of the total costs and dealer fill rates based on the multiple observations. The standard deviation can be analyzed in order to determine an adequate simulation time and start-up time as well as number of simulation runs needed to achieve statistically correct results.

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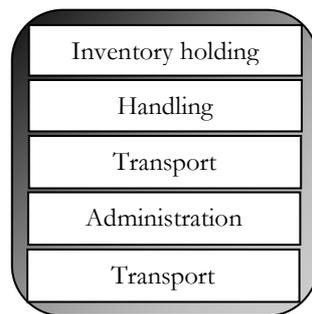
<sup>3</sup> Registered trademark of Imagine That Inc ([www.extendsim.com](http://www.extendsim.com))

### 3.6 Total costing model

According to Oskarsson, Aronsson & Ekdahl (2006) when making a decision to a change in a certain economically dependent situation it is important to evaluate all the costs involved in making that decision, not only the immediate costs on one level. The reason for this is that in general, reducing some costs will raise other costs, and it is thus necessary to look at the total consequences to determine whether a decision is economically justifiable or not.

The costs involved are not always easily determined. If for example a certain decision reduces the tied up capital, it can at the same time reduce the customer service. This will in turn invoke increased costs due to lost sales and lost goodwill, just to name a few, and is certainly a cost that needs to be taken into consideration but the magnitude is not that easily determined.

The total costing model can be applied on most levels and applications within a company, but in this thesis this is applied from a logistics perspective which in most cases can be divided into five larger costs, See Figure 3.6.



**Figure 3.6** The total costing model applied from a logistics perspective

#### *Inventory holding*

Refers to the costs in keeping stock and includes the costs for binding capital, risk, incurrence, and insurance as previously mentioned in 3.1.1.

#### *Handling*

The costs concerned here are the costs for running the inventory and includes costs for buildings, equipment, personnel and internal transports. Closely related to these costs is also the ordering cost described in 3.1.1.

### *Transport*

The transport costs involve all costs for administration and carrying out the transports. This includes both transports between own facilities and external suppliers and customers.

### *Administration*

This involves the costs for administration of the logistics in the company and includes goods receiving and registering, invoicing, payment of wages, economic follow ups and other administrative costs.

### *Other*

This can involve a large variety of different costs such as information systems costs, packaging materials costs, indirect logistics costs and material costs.



## **4 COMPANY PRESENTATION AND DESCRIPTION**

This chapter aims at giving a good presentation and overview of Volvo Parts as a company, its role in Volvo Group, the business areas and the systems used within the company. The chapter will also present the distribution and warehouse structure and the some concepts used at of Volvo Parts focused on giving a detailed view of the order structures, processes and routines vital for understanding the specifics of the pilot study initiation process presented in Chapter 5 and Chapter 6. The chapter is mainly focused on Volvo Parts business functions for Volvo Truck (VTC) and Volvo Buses (VBC) on the European market which is the area of interest for the pilot study initiation.

The information and IT systems used by Volvo Parts, spare part and accessory specific information and key performance indicators are included in Appendix 1, Appendix 2 and Appendix 3 respectively. These appendices are not of interest for the general reader but give a detailed view for the reader interested in this information.

### **4.1 Volvo Parts and its role in Volvo Group**

The goal of this part of the chapter is to get a grip of the size and characteristics of the supply chain in which Volvo Parts operates. Then in increasing detail the Volvo Parts organization is described, starting from a global perspective, through a look at the operations performed at the headquarters in Gothenburg, and the routines, concepts and processes which are of special interest for this thesis. The information in this section is gathered from the annual report 2007 for Volvo Parts AB (Volvo Parts AB (2008)), internal Volvo documents from the VIOLIN intranet and respondent group 2 (Gothenburg).

Volvo Parts AB is part of the Volvo Group with Volvo AB as main parent company. The Volvo Group is a commercial transport solutions provider and shares the Volvo brand with Ford-owned Volvo Cars.

### **4.1.1 Volvo Group**

The Volvo Group is a global provider of commercial transport solutions (trucks, buses, construction equipment, drive systems for marine and industrial applications, aircraft engine components) and related services (financial, logistics, IT). Volvo was founded in 1915 as a subsidiary of AB SKF and produced its first series-manufactured car in 1927. The first truck was manufactured one year later and the first bus in 1934. In 1935 the marine engine manufacturer Pentaverken was acquired and in the 1940s aircraft engines were added to the range of products.

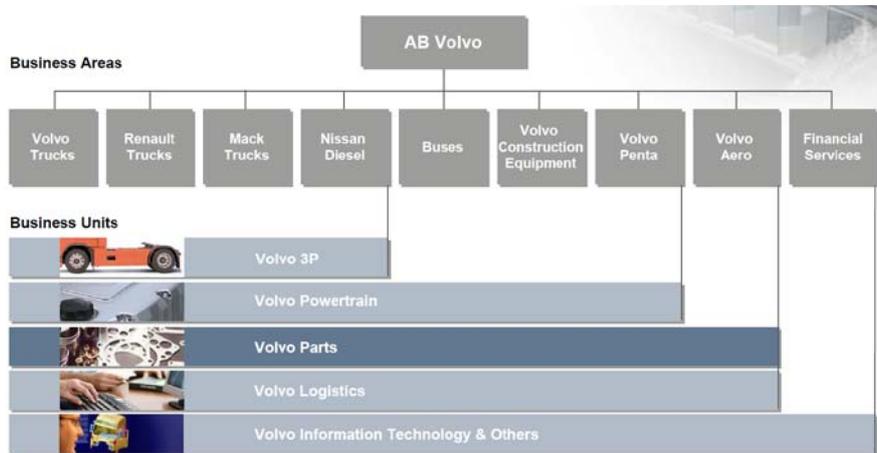
The Group is organized in product-related Business Areas (Volvo Trucks, Renault Trucks, Mack Trucks (North America), Nissan Diesel (Asia), Buses, Construction Equipment, Volvo Penta, Volvo Aero, Financial Services) and supporting Business Units which provide functions such as technology development, business administration, logistics, IT and aftermarket services to the Business Areas.

Volvo Group employs 101,400 people, as of March 2009, and has production facilities in 19 countries. The products are sold in 180 countries, mainly in Europe, Asia and North America.

#### ***4.1.1.1 Business areas and business units***

Each Business Area manufactures and maintains its core product lines (trucks, buses, construction equipment etc). Financial Services provides customer and dealer financing. 70 % of the employees work in the Business Areas.

The five main supporting Business Units are Volvo 3P, Volvo Powertrain, Volvo Logistics, Volvo IT and our focal company Volvo Parts. Their main customers are the Business Areas and the general relationships between Business Units and Business Areas is shown in Figure 4.1.



**Figure 4.1** The business units of Volvo Group and their relation to the business areas

Volvo 3P supplies the Group's truck companies with product planning, product development and purchasing services. By bringing these functions together for all truck areas economies of scale can be obtained. The unit has about 4,000 employees.

Volvo Powertrain coordinates the Group's driveline operations ensuring a common engine platform. It is responsible for the development and manufacturing of engines, gearboxes and drive shafts. It is the largest Business Unit with over 9,000 employees.

Volvo Logistics develops and provides transport and logistics solutions. Its customers come from inside and outside the Volvo Group. The unit designs logistics systems, packaging, insurance and distribution solutions for finished products, and employs 1,200 people.

Volvo Information Technology manages the Group's IT systems. It delivers solutions and expertise for all segments of the industrial process as well as for logistics and supply chain management. Its customers are mainly the Business Areas, but also come from outside the group. It has 5,300 employees.

Other business areas include Business Services (administrative), Real Estate (property management and development), Technology (develops new technology and concepts), Technology Transfer (invests in companies with technical and commercial interest), Treasury (in-house bank) and NAP (non-automotive purchasing of goods and services).

### **4.1.2 Volvo Parts**

Volvo Parts provides tools and services for the aftermarket. This includes planning, purchasing, shipping and storing spare parts and accessories to the core products almost all of the other Business Areas. Volvo Parts currently employs 4,400 people and is owned to 100% by the parent company Volvo AB. About 60 % of the employees work in Europe and 25% of them work in Sweden.

Its main goal is to be a provider of aftermarket tools and services for the core products of the Business Areas and to ensure high availability of spare parts and accessories for the end customers. This is done by taking full responsibility for the whole supply chain, from manufacturer to end customer, and by making sure that all warehouses, dealers and workshops along the way are using the same support tools and systems.

The company's primary customers are eight of the Business Areas of the Volvo Group: Volvo Trucks, Renault Trucks, Mack Trucks, Nissan Diesel, Volvo Buses, Volvo Construction Equipment, Volvo Penta and Volvo Aero. Other customers are identified as the Business Area's dealers, and these dealers' end customers.

#### **4.1.2.1 Main operations**

Volvo Parts' main operational areas are:

- Supply Chain Management of spare parts and accessories (Parts logistics).
- Product Support Development.
- Customer support (Volvo Action Service).
- Remanufacturing of spare parts.

The Supply Chain Management operations, which is the main focus of this thesis, involves purchasing, procurement, refill, ordering, transporting and warehousing spare parts and accessories for the core products of the Business Areas. It also involves logistics development (processes and systems), dealer inventory management and reverse logistics.

Some key facts about Volvo Parts' supply chain are presented below to give present a picture of the size of the company's operations:

- More than 750,000 parts stocked.
- About 2000 parts are renewed or replaced each year.
- Parts stocked up to 15 years after production of core product.
- 40 warehouses/facilities worldwide.
- 510,000 square meters of storage space.
- 34,000,000 order lines per year.
- 15,000 distribution points in 120 countries.
- 450,000 customer support cases per year.
- Purchases 350,000 parts from 4,000 suppliers globally.
- Remanufactures 1,900,000 components of parts per year.
- Serves more than 50,000 mechanical workshops and facilities globally.

## **4.2 Structures and concepts**

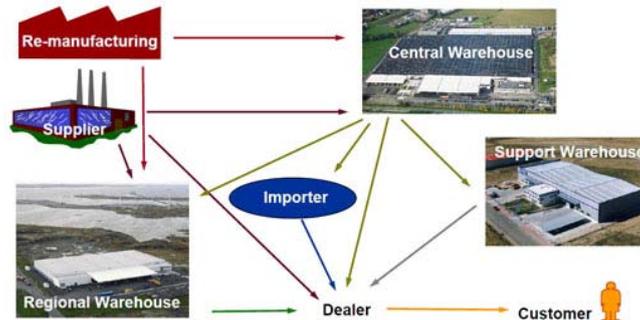
Volvo markets are generally structured in one of two ways: either a structure with a support warehouse (SW) refilled from a central warehouse (CW) or a structure with only a regional warehouse (RW) performing the functions of both a CW and a SW. These warehouses supply the markets with replenishments to the dealers which are responsible for all end customer interaction and sales. These dealers are often connected to Volvo Parts' centrally managed inventory control systems (i.e. a vendor managed inventory, or VMI, situation) and referred to as the logistic partnership agreement (or the LPA-concept).

All orders are handled in an organized manner within the LPA concept in these market structures with the exception of emergency orders within the Volvo Action Service concept. The distribution, warehouse and order structures as well as the LPA concept and Volvo Action Service and are described in this section.

### **4.2.1 Distribution and warehouse structures**

The spare parts and accessories are mainly produced at one of 1200 VP suppliers. These parts are predominantly delivered by Volvo Logistics to a central warehouse. There are minor material flows directly from suppliers to dealers, this is however very small in comparison. Besides getting parts from

suppliers, the CW and RW receives remanufactured and reconditioned parts (see Appendix 2) from one of its remanufacturing plants. The importers have historically handled large portions of VP markets. Nowadays most of the markets are handled by VP and no pure importer controlled markets exist in Europe besides in Portugal. The distribution structure of VP aftermarket of spare parts and accessories is presented in Figure 4.2.



**Figure 4.2** The main material flows in Volvo Parts distribution structure of its aftermarket spare parts

#### **4.2.1.1 Central warehouse**

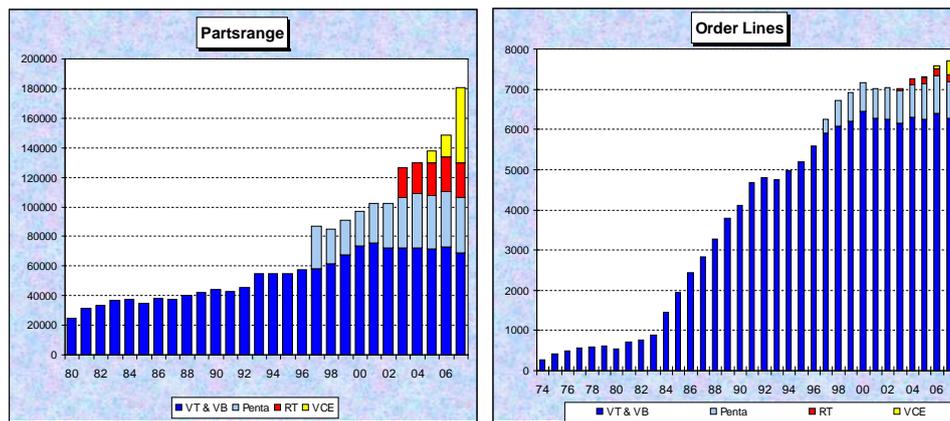
The central warehouse is the main provider of spare parts and accessories to the regional warehouses, support warehouses (SW) and dealers in VP's distribution network. The CW stocks the majority of the total parts needed and contains the whole parts range for the markets which it is responsible for. At CW the parts coming from supplier are handled, pre-packed if needed and stocked. When orders are placed by dealers, RW, SW or importers the order is prepared, picked, packed and loaded onto trucks leaving CW multiple times a day. The CW is also responsible for assembling kits of multiple parts (see Appendix 2) and the painting of certain parts if this is not provided by the suppliers.



**Figure 4.3** Overview of the central warehouse in Ghent, Belgium

For Volvo Truck Corporation (VTC) and Volvo Bus Corporation (VBC) spare parts and accessories the central warehouse in Europe is located in Ghent, Belgium. This CW opened in 1973 as a complement to the CW in Torslanda, Gothenburg. The location in Belgium made it possible to reach importers in both Europe and other continents quickly. In 1993 a separation of parts ranges was started as a consequence of calculations showing cost reduction potential. All central warehouse operations for VTC and VBC in Europe were moved to Ghent and all car parts were moved to Gothenburg. As of 2006 Ghent had a total parts range of 134 000 parts and handled over 7.1 million order lines per year within its 82 hectare large facilities, see Figure 4.3.

Besides handling VTC and VBC parts the CW in Ghent also handles parts to other business areas such as Volvo Penta, Renault Trucks and Volvo Construction Equipment (VCE).



**Figure 4.4** The parts range and order line distribution over time at the central warehouse in Ghent

Figure 4.4 illustrates the parts range and order line distributions between the VTB & VBC, Volvo Penta and VCE spare parts in Ghent (data from 2006). Although VBC & VTC only stands for about one third of the parts range, it stands for the vast majority of the order lines in Ghent.

#### **4.2.1.2 Regional warehouse**

A regional warehouse (RW) acts as a local central warehouse for a market (or markets) where the distance to the regular central warehouse is too large, resulting in too long lead times to get deliveries within reasonable time. The RW then replenishes the dealer inventories just as a CW would, with the

distinction that RW only has full service for the parts range active on the market(s) it provides. The RW also distributes priority orders, commonly known as day orders, to the dealers. The replenishment of the RW, also called refill orders is mainly supplied with parts from a CW, but also (although small by comparison) by suppliers whose location is closer to the RW than the CW.

The western and central European market does not contain a RW due to the proximity to CW in Ghent. There are however two RWs in the eastern parts of Europe, in Moscow and Istanbul.

#### **4.2.1.3 Support warehouse**

A support warehouse (SW) distributes the priority orders (in the future referred to as day orders) to dealers on a market (or markets). These day orders should arrive to the dealer the very next day after the order is placed. The location of the SW is therefore located much closer to the dealers than the CW and hence has shorter transportation times. The shorter transportation times are the main reason for having an SW, since the costs of transportation from an SW is significantly smaller than of a day order from the CW that often has to be transported by taxi or airplane in order to arrive the very next day. In Europe there are currently a total of eight<sup>4</sup> operational SWs at the following locations: Rugby in the UK, Helsinki in Finland, Wroclaw in Poland, Gothenburg in Sweden, Lyon in France, Madrid in Spain, Bologna in Italy and Vienna in Austria.

The parts range at a SW is much narrower than at the CW. The parts stocked at SW are typically parts with low demand, parts that exist in low stocks at the dealers (or not at all) but should be available on short notice. There is also be a small buffer of high demand parts so that in cases where the demand at the dealers suddenly gets very high there is an opportunity to quickly replenish the dealer inventories while waiting for replenishments from CW to arrive.

The SW is replenished by the CW, with so called refill orders, and is managed by the Refill department and a Regional Inventory Manager (RIM) responsible for the market that the SW supplies.

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<sup>4</sup> A SW in Bucharest, Romania has opened in 2009, but this SW is not included in this thesis

#### **4.2.1.4 Dealers**

It is the dealers that satisfy all demand from end customers. The characteristics of dealers vary greatly. A dealer could be a simple retailer of parts with no mechanical workshops or a full service establishment that provides parts, repairs, services and sales. The dealers could also be small privately owned businesses or large business chains with multiple establishments owned either privately or by Volvo.

A dealer's inventory is generally replenished from CW, but if special need arises priority orders can be sent to SW.

#### **4.2.2 The Volvo Action Service concept**

Volvo Action Service (VAS) is an aftermarket service collaboration between Volvo Parts and some of the Business Areas (VTC, VBC, and Penta). These services include a free of charge, 24/7 roadside assistance support. If a vehicle breaks down anywhere in the world the driver can call the VAS hotline and talk to a support technician in his own language. If needed a mechanic will be dispatched and support the driver at the roadside. The parts needed for the repair are located at the nearest dealer in the VP dealer network. But if these dealers do not have the needed parts in stock the order is forwarded to the SW or to the CW. If the part is not even stocked at the CW the VAS team can go as far as to search the inventory of the production facilities of the Business Areas or order the part from its original manufacturer.

These Volvo Action Service "Vehicle Off Road" orders take priority of all order types and work entirely outside the given distribution structure as described in 4.2.4.

#### **4.2.3 The LPA concept**

The Logistic Partnership Agreement (LPA) is Volvo Parts' VMI concept, i.e. vendor managed inventory. In general, a VMI is a situation in which the supplier takes responsibility for the inventory at the point of sale. Responsibility and control is shifted backwards in the supply chain, while the main goal of the seller becomes to provide as valid information as possible as fast as possible.

The LPA concept covers the material flow between Volvo Parts warehouses (CW, RW and SW) and the dealers. It was introduced in the mid 1990s and is today used for about 80 % of all dealers and as many as 95 % on certain

markets (in Europe). It is realized by writing a contract with the dealer which lets Volvo Parts control the supply of parts to the dealer's inventory but at the same time obliging the dealer to regularly report its stock levels and sales figures and to purchase genuine parts. There is also cooperation regarding pricing and campaigns and VP has the ability to balance stock between dealers if shortages occur.

At the dealer level there is a Stock Holding Policy that governs which parts are automatically ordered by the systems (LPA managed stock) and which are to be manually reviewed. This Stock Holding Policy is based on the price of the part and the number of picks of the part (where one pick is defined as one order occurrence of an arbitrary number of units) at the dealer. Parts with no picks are considered dead stock, see Figure 4.5

Picks \ Price	0	1	2	3	4	5
< 2,5	<b>Dead Stock</b>	<b>Dealer Managed Stock (Manual stock orders)</b>	<b>LPA Managed Stock Automatic Stock Orders</b>			
< 8,5						
< 35						
< 107						
< 357						
<1190						
< 2975						
<5950						
< 9999999						

**Figure 4.5** The stock holding policy table

There are also tables that set the safety stock (reorder point) and order quantity for each part according to the price and frequency. All parts from the same price/frequency class get the same parameters. There is however different tables based on the size of the dealer or other characteristics.

The dealer has the possibility to perform manual orders on all parts and to exclude specific parts from the automatic refill. There is also a Regional (or National) Inventory Manager (RIM/NIM) in the LPA team that works in cooperation with the dealers with parameter settings and even parts blocking. In order to ensure sales data quality the dealer can flag certain sales as not forecast affecting. This flag is called “no history” or “category 2 sales”. If the quality of the data is not adequate the LPA team will perform adjustments.

#### **4.2.4 Order structures**

The order structure varies depending on whether it is a normal stock replenishment or an emergency order and to what destination the order is headed. The order structure is divided into five order classes which define the priorities of an order. Of these classes, Class 0 has the highest priority and Class 4 has the lowest priority. Class 5 is not included in the priority structure. The priorities are connected to the probability of loss of sales or goodwill if the order does not arrive in time.

- Class 0 Vehicle Off Road orders (Volvo Action Service emergency orders)
- Class 1 Day orders to dealers
- Class 2 Day orders to support warehouses
- Class 3 Stock orders or LPA orders planned to a dealer
- Class 4 Stock orders or LPA orders planned to an importer
- Class 5 Warehouse built kits

Kits are described in Appendix 2 and although Class 4 orders exist there are no importer warehouses active in VPs distribution network in Europe. Order classes 0 to 3 are used extensively on a daily basis in VPs distribution network on support warehouse included markets and the focus is therefore aimed towards these.

##### **4.2.4.1 Vehicle Off Road orders – Class 0**

Vehicle Off Road (VOR) orders are emergency orders that need to be sent out immediately and concerns parts to a vehicle that have broken down and cannot function without this part. Having a vehicle standing still can invoke large costs or losses of revenue for the vehicle owners. Therefore the search for and delivery of VOR orders takes precedence over all other orders and is transported from wherever the spare parts is found (CW, SWs, RWs, suppliers, production facilities or other dealers) to the needed location as quickly as possible regardless of the means of transportation or other costs involved. The VOR orders are handled within the Volvo Action Service concept described in 4.2.2.

##### **4.2.4.2 Day orders to dealers – Class 1**

Day orders are urgent orders for spare parts and accessories placed manually by dealers, that are needed the very next day or to the near future, often within a week, and that are essential to be delivered on time to avoid shortages. This

type of order is placed when the dealer has a probable or known demand for specific parts that cannot be satisfied in time by a stock order.

The day orders are placed to the SW and should, by VP policy, be picked, packed and shipped from SW on the same day and arrive at the dealer in the morning or mid day of the next day. This is under the condition that the order arrives before a cut off time in the day which is set so the SW can guarantee that the order is registered, handled and shipped that day. Day orders placed on working days (Monday through Saturday) will arrive at the dealers the next working day, but day orders placed on a Sunday (this is possible, but rarely happens since dealers normally are closed on Sundays) will be handled on Monday the following week and arrive at the dealer on Tuesday.

In the cases where the order placed to SW that cannot be fully satisfied at SW, the fraction of the order not satisfied is transferred to the CW and transported in the fastest way possible to arrive the very next day at the dealer. This is referred to as a split order.

The day order service provided by VP to the dealers does not invoke any extra costs for the dealers i.e. they do not pay anything extra for making a day order compared to a stock order. However, the price on parts is calculated using historical data on how orders were made and if dealers places too many day orders this will increase the price in the future.

#### ***4.2.4.3 Day orders to support warehouses – Class 2***

Orders placed by a SW to the CW, referred to as refill orders, follow a day order structure similar to that day orders placed by the dealers. They are registered, handled and shipped by truck that same day under the condition that a cut off time is made. Refill orders are placed every day automatically by the RHelp system or can be placed manually and approved. Automatic orders are assembled and placed to the CW at the evening of each work day and any manual orders placed before the cut off in the morning of the following day are also handled and shipped together with the automatic orders.

#### ***4.2.4.4 Stock orders to dealers – Class 3***

These orders are placed to the CW, referred to as stock orders, to replenish the stock at dealers to satisfy a forecasted demand.

For LPA connected dealers (described in 4.2.3) manual orders may be placed to the CW at any time but are only handled and shipped in conjunction with the automatic orders and also have to be placed before the cut off in the morning. Automatic orders are placed to the CW on a regular basis in the evenings of preselected days referred to as the call off days. For a dealer these call off days are determined by a several factors including; the size of the dealer, the demand at the dealer, the location of the dealer and also the properties of the surrounding dealers. Also, when the call off is on a Monday, the automatic stock orders are registered on Friday the week before. All orders making the cut off will be picked and packed on the same day and are ready for shipment (RFS) late on the evening of the following day.

Dealers not connected to LPA have to place all stock orders manually, and also have individual cut offs and call offs that need to be met for the order to be shipped in time.

### **4.3 Routines**

Given the structures of the installations (see 4.2.1) and the order types (see 4.2.3) the replenishment of spare parts and accessories in the VP supply chain is controlled by means of different routines. These routines, their technical implementation in the VP systems and some other technical information relevant for the pilot study is described in this section. Only routines for VBC and VTC are considered.

Due to the large amount of installations and stock held parts within these Business Areas the approach used by VP today is mostly table based, meaning that each part is flagged according to a certain class at any given moment in time and gets its control parameters from a corresponding cell value in a table.

The systems mentioned in this section are all described in Appendix 1.

#### **4.3.1 LPA stock order routines**

The LPA connected dealers communicate with DSP on a regular basis through the GDS-system. Information is sent and updated twice daily Monday through Friday and once on Saturdays. The stock situation of the dealers is then checked if an order should be placed according to an (R,Q) policy and if so a purchase procedure is initiated. The reorder point (R) and order quantity (Q) is determined by the use of standardized picks tables in DSP. The values in these tables are however individual for each dealer since they are based on the

individual lead time to, yearly sales of and number of picks at the dealer. Currently there are three standard tables defined that divide the dealers according to their characteristics into three groups; small, medium and large dealers. A standard picks table is built up by nine frequency classes (A to I) and nine price classes (1-9) that each defines an interval of number of picks per month and standard price, respectively, included in the class. See Figure 4.6 for an illustration of a standard picks table.

		Frequency class																	
		A		B		C		D		E		F		G		H		I	
		R	Q	R	Q	R	Q	R	Q	R	Q	R	Q	R	Q	R	Q	R	Q
		Pieces						Weeks of forecasted demand											
Price class	1																		
	2																		
	3																		
	4																		
	5																		
	6																		
	7																		
	8																		
	9																		

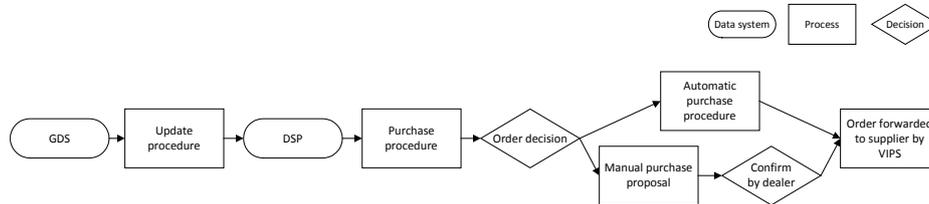
**Figure 4.6** A standard picks table for determining the R and Q for LPA connected dealer stock orders

Each combination of frequency and price class is referred to as a value-volume class or VVCL (81 classes in total). Each VVCL defines R and Q either in pieces (frequency class A to C) or in weeks of forecasted demand (frequency class D to I) of the part at the dealer. These VVCLs group together parts with similar properties with respect to frequency and price at a certain dealer. This also means that a certain part can be in different VVCL at different dealers and that the VVCL may change over time when demand fluctuates at dealers.

The standard picks tables can be replaced with custom picks tables for certain parts (and/or dealers) that need to be treated differently for various reasons. These parts are then flagged with a special code in DSP identifying that a custom table exists and should be used instead.

The decision whether a part is automatically ordered or manually confirmed by the dealer is controlled by the stock holding policy table described in 4.2.3. If the part should be automatically ordered the order goes directly to the VIPS-system where it is forwarded to the supplier which in most cases is the CW. If the part however is not to be automatically ordered the decision is made by the dealer who receives a purchase proposal generated by DSP that the dealer can

approve or deny. If approved it is sent to VIPS and similarly as an automatic order. The stock order procedure is illustrated in Figure 4.7.



**Figure 4.7:** The stock order procedure for LPA connected dealers

Besides letting DSP manage the stock order procedure the dealers also have the opportunity to place manual orders, e.g. for a customer, campaigns, vehicle services or abnormal sales. This is done to DSP through Volvo Vision-system.

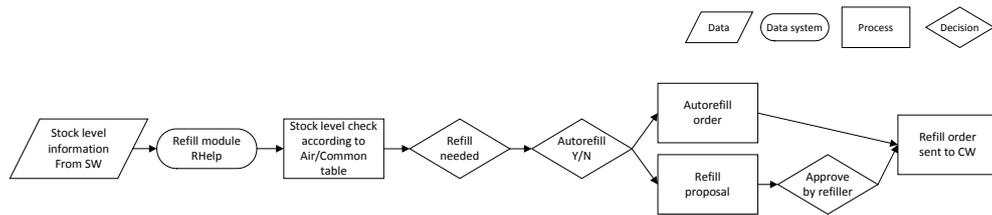
### 4.3.2 SW refill order routines

A SW supplies the RHelp-system with continuous information about sales and stock levels of spare parts which then makes refill order proposals. As for LPA connected dealers a SW uses an (R,Q) policy to initiate a refill procedure where R and Q is determined from a table. This refill table is however unique for the SW in question with respects to the number of VVCL and the intervals. In addition to R and Q an overstock point (O) is also present which represents the upper boundary for the total stock level allowed at the SW. Figure 4.8 shows the buildup of a refill table.

		Frequency class																										
		A			B			C			D			E			F			G			H					
		R	Q	O	R	Q	O	R	Q	O	R	Q	O	R	Q	O	R	Q	O	R	Q	O	R	Q	O			
		Pieces												Weeks of forecasted demand														
Price class	1																											
	2																											
	3																											
	4																											
	5																											
	6																											
	7																											
	8																											
	9																											

**Figure 4.8** A refill table for determining the R, Q and O for SW refill orders

All parts are by default set so they are not automatically refilled and the refill proposal needs to be approved manually by a refiller. The decision to automatically refill parts is made by the responsible refiller as soon as the parts show a stable demand pattern.

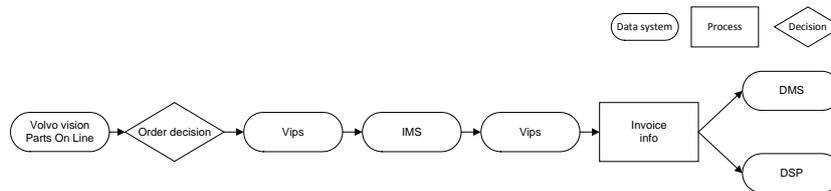


**Figure 4.9** The refill order procedure for a SW

Parts can also be labeled as direct delivery parts. This is used in cases when the cost of shipping the part directly from supplier to the SW is cheaper than first going via the CW. The whole refill order procedure is described in Figure 4.9.

### 4.3.3 Dealer day order routines

The decisions to place day orders are completely made by the dealers themselves. When the dealer decides to place a day order the dealer do so through either Volvo Vision (see 4.3.3) or Parts On Line. An invoice is created that is sent to DSP which in turn sends the order to the SW that handles the order and assuming the cut off is made the order will arrive at the dealer the next working day. Figure 4.10 below shows the complete day order procedure.



**Figure 4.10** The day order procedure for a dealer

Day orders can be placed every day, but orders placed on Sundays will not be handled at the SW until Monday and consequently arrives on Tuesday.

## **5 DATA COLLECTION AND ANALYSIS**

One of the main goals of this thesis, as described in Chapter 1 is to select spare parts and accessories from the range of all VP controlled parts that are suitable candidates for the pilot study. This work is presented first in this chapter where the steps are to: select a market on which to perform the study, gather all the necessary data and finally to filter out and classify the parts.

Another main goal of the thesis is to identify and determine the parameters needed in the NGiL model, described in Chapter 3, to optimize the reorder points for the pilot study. These parameters have to model VP's market characteristics, supply chain, distribution-, inventory- and order structures described in Chapter 4 as good possible so that the NGiL model accurately reflects the reality providing good conditions for the pilot study. The parameters include: demand parameters for the dealers, lead times, order quantities, shortage costs, holding costs and finally the target fill rates. These are presented after the sections about market and parts selection.

In order to point out the benefits and possible pitfalls of the NGiL model a small simulation study is performed for some of the selected parts which are presented in the last section of this chapter. Calculations of cost reduction potential, as well as service level achievement are calculated and analyzed. The characteristics of the selected parts are compared to these measures in order to determine if any easily identifiable correlations exist. The inventory balancing action of the NGiL model is also analyzed, i.e. how the model shifts the stock towards the dealers or towards the SW compared to the current situation.

The information and data in this chapter is collected from VP systems and through material provided by, and discussions with, respondent group 2 (Gothenburg) and respondent group 3 (International). The results and the process of achieving the results in this chapter have been verified, validated and discussed extensively and recurrently with the respondent group 1 (NGiL researchers), respondent group 2 and respondent group 3.

### **5.1 Market characteristics and selection**

The pilot study is to be performed on one market (as defined in 4.2.1) with a SW structure. Since the purpose of the project is to evaluate the NGiL model

and its ability to balance stock between dealers and a SW, a market is needed where the distance to CW in Ghent is significant. This gives a large lead time difference between stock orders and day orders and the potential cost benefits of having parts in the SW are increased.

Due to cultural and linguistic barriers as well as the amount of dealers controlled centrally by the LPA concept (see 4.2.3) only European markets are considered. European markets are also generally more “mature” meaning that the routines and concepts are well rooted and efficiently used.

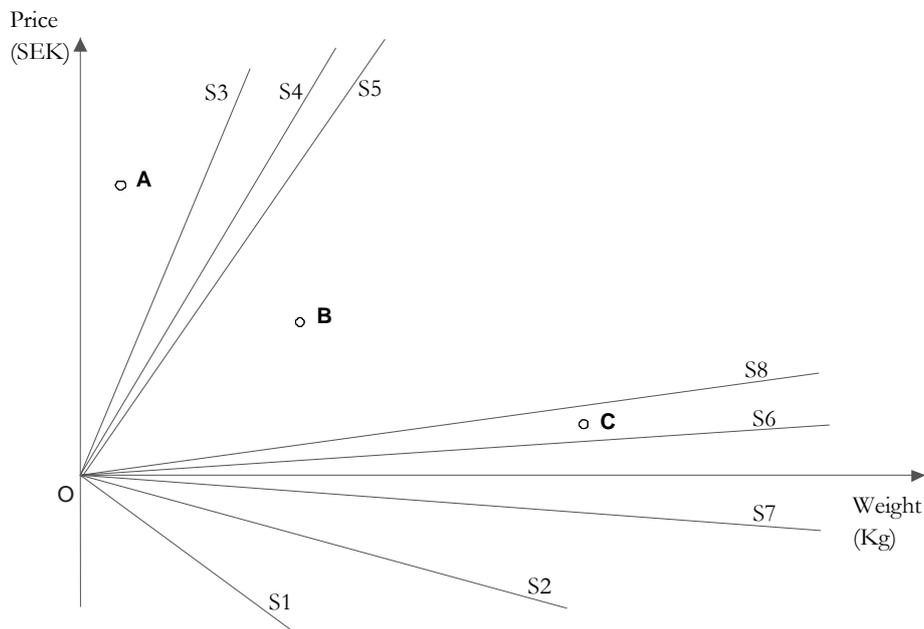
However a “market” by our definition does not necessary have to be equal to a national market. A support warehouse in a given country may support dealers in other countries in its vicinity. This does not necessary complicate the pilot study, but it turns out that most often these auxiliary markets are either not mature or are running different systems than the main market, which is problematic for the study.

In general, the best market to perform the pilot study on is one with a large distance to the CW, not too many auxiliary markets and relatively constant lead times. Having fewer dealers is also considered an advantage since it facilitates implementation and simulation of such markets.

When analyzing the European markets three emerge as good candidates, being both mature and having a large distance to CW as well as constant transportation times: Sweden, Finland and Spain. Of these Spain emerges as the most promising for the pilot study and is further analyzed. It turns out that the only problem with this market is the auxiliary market of Portugal, which runs a different IT system at the dealer level. It is however discovered that the parts sold at the Portuguese market are generally of different characteristics than the rest of the market and measures are taken to exclude them from the rest of the study.

### 5.1.1 Analysis of European markets

An earlier project has been carried out at VP (based on data from 2004-09 to 2005-09) in order to find out the relative importance of different SWs at different locations throughout Europe. The results of this project state that of the eight European SWs only five are economically justifiable from a pure cost perspective. Two of these warehouses have a much higher number of parts that are considered beneficial to store at that particular SW (in this project defined by a price – weight ratio). The results of this project are shown in Figure 5.1.



**Figure 5.1** Results from a study performed at VP analyzing the benefits of European SWs

*Example:* Part A is economically justifiable to stock at all SW since it is above all price-weight threshold lines for the SWs. Part B is justifiable to store on S3, S4 and S5 only and part C is also justifiable in S8 but not in S6, S7, S2 or S1. Only parts with a (theoretical) negative price are justifiable to store at S7, S2 and S1 according to this analysis. From this follows that it is beneficial for a SW to have as many parts as possible under its line and thus a steeper line equals a “better” SW.

The two least favorable markets for a SW structure are in this analysis the United Kingdom (S1) and France (S2), and the three most favorable are Sweden (S3), Finland (S4) and Spain (S5). This roughly corresponds to the geographical distance (lead time) between each market's SW and the CW in Ghent, Belgium, see map in Figure 5.2.



**Figure 5.2** Map of Europe with the CW and all SWs marked out

A further investigation of the different European markets reveals the following characteristics and benefits/disadvantages for performing the pilot study at the respective market as Table 5.1 displays.

**Table 5.1** Characteristics of the European markets

<b>Market</b>	<b>Benefits</b>	<b>Disadvantages</b>
United Kingdom SW S1 in Rugby	No language barrier Isolated market (no auxiliary markets attached to SW) Mature market	Short distance to CW Large number of dealers (90+)
France SW S2 in Lyon	Mature market	Short distance to CW Language barriers
Sweden SW S3 in Göteborg	Long distance to CW No language barrier Mature market	Auxiliary markets (Denmark, Norway) Large number of dealers Special activities at SW
Finland SW S4 in Helsinki	Long distance to CW Few dealers (28 in total)	Auxiliary markets (Russia and Baltic countries) Other projects exist
Spain SW S5 in Madrid	Long distance to CW Mature market	Auxiliary market (Portugal)
Italy SW S6 in Bologna	Mature market Average distance to CW	Language barriers Uncertain transportation times Auxiliary markets (Austria and Switzerland)
Poland SW S7 in Wroclaw	Average distance to CW	Auxiliary markets (Russia) Not a mature market
Austria SW S8 in Wien	Average distance to CW	Auxiliary markets in Eastern/Southeast Europe Uncertain transportation times

The Finnish market has a large distance to CW and relatively few dealers and no language barriers. But the main disadvantage is that another inventory control project is being performed on this market (as of December 2008) and it would thus be impossible to distinguish the results from the two simultaneous projects. Another problem with the Finnish market is the fact that the SW also serves the auxiliary markets of Russia and the Baltic countries. As much as 25 % of the deliveries from the SW are for these auxiliary markets.

The Swedish market has a large distance to the CW but also several disadvantages – the SW in Gothenburg serves Denmark and Norway (about 45 % of the deliveries from the SW are for these markets) the number of dealers is the largest (by history and tradition, over 130). Also, due to the proximity to the factories, the SW has some functions that the other SWs do not share; such as storing engines and gearboxes from the production lines and cross docking of VOR-orders that are satisfied from suppliers 4.2.2.

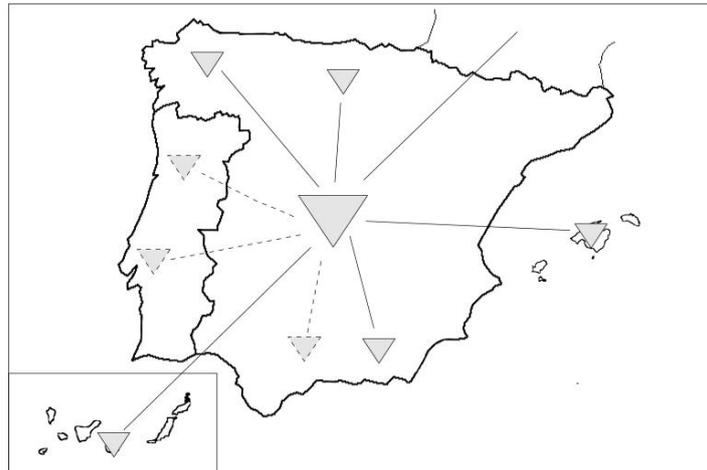
The Spanish market, consisting of the SW in Madrid and dealers on the Iberian Peninsula (both in Spain and in Portugal) and on the Spanish Islands (Balearic and Canary) emerges as the best candidate for the pilot study and is further analyzed.

### **5.1.2 The Spanish market**

The Spanish market consists of the SW in Madrid and 84 dealers (connected to VP systems) of which 21 are located in Portugal, two are on the Canary Islands and one is on the Balearic Islands. The market is mature, has a significant distance to the CW in Ghent and relatively stable transportation times. Its only disadvantage is the auxiliary Portuguese market, having some structural differences due to the fact that it earlier was an importer-market and not refilled from the SW. The Portuguese dealers are still owned by a private company (Auto Sueco) and thus a lot of trading between dealers occurs. However this auxiliary market is only one and has a rather distinct parts range than the rest of the Spanish market which makes it easier to exclude from the study.

A majority of the dealers in Spain are connected to the DSP-system (see Appendix 1) and almost all dealers in Portugal are connected through the VR-system. VP does not want to implement the model in two systems, due to the costs related to modification of the current systems and follow-up work in two different countries with different inventory managers etc. This problem exists on many other markets, for instance in Sweden where all the Swedish dealers have the VR system and the Danish and Norwegian dealers have the DSP system. It is however deemed that the Portuguese dealers will be easy to distinguish from the rest of the Spanish market and that it will be possible to distinguish parts that sell in Portugal from those that sell in Spain.

Another problem is that there exists significant sales from the SW to dealers that are not connected to any VP system at all. This is not something unique for Spain and takes place on almost every European market. These dealers can be anything from very small workshops or retailer to large bus fleet operators that for a variety of reasons are not connected to any centralized VP dealer systems.



**Figure 5.3** The Spanish market with non-controllable dealers marked with dashed outlines

Figure 5.3 summarizes the Spanish market. The dashed installations are dealers and other customers that are not connected with the DSP system and/or the LPA concept and thus not part of the study. Since these dealers cannot be controlled centrally during the pilot study there is a need to exclude their demand from the total demand. This is done by defining the “Controllable Quota”.

### 5.1.3 Controllable quota definition

In order to handle the distinction between the flows of demand to dealers where VP is able to control the inventory levels centrally from the flows to the non-controllable dealers and the Portuguese dealers we define the “Controllable Quota”. It is defined on a per part level as

$$\textit{Controllable quota} = \frac{\textit{Controllable demand}}{\textit{Total demand for this part at SW}}.$$

It is defined on orders from the SW and not the CW since it does not matter how and if the non-controllable dealers order from the CW for this study. The problem with controllability only arises when demand from controllable and non-controllable dealers is mixed at the SW where inventory levels have to be controlled as part of the pilot study.

The Controllable Quota gives the possibility to distinguish parts where the demand from controllable dealers is higher than a given threshold. These parts are more suitable to include in the study since interfering demand from dealers outside the scope of the model is kept to a minimum.

## **5.2 Selection of parts**

One of the main objectives of the thesis is to define and select parts suitable to be included in the pilot study. Since the pilot study is limited in time and possibility to fine tune the control parameters the selected parts should have relatively stable demand patterns. There are also other reasons for parts not to be included in the pilot study (e.g. technical or organizational reasons),

Several exclusion criteria are designed and applied, after which the remaining parts are classified and analyzed with respect to several classification dimensions in order to ensure good spread throughout the whole parts range. The classification is made for the purpose of evaluating for which parts the NGiL model works optimally, and to see if there are circumstances that the model does not handle well.

All part and dealer information relevant for the selection of parts are collected in a purpose designed SQL-database to facilitate analysis and easy access of information. For detailed information see Appendix 4.

### **5.2.1 Selection criteria**

Firstly, there are technical and organizational reasons to not include certain spare parts or accessories in the study. These can be hazardous goods, parts manually blocked from refill, parts of certain types (software, keys) etc.

Secondly, the characteristics of the pilot study are posing several limitations on the suitable parts. The study is limited in time (6 months) and there is also no ability to adjust the control parameters during this time. This leads to requirements on the demand characteristics of the selected parts.

As mentioned in 5.1.2 there exist significant trade between the SW and dealers that are not centrally controllable and whose inventory control parameters cannot be modified. It is thus best to ignore demand from these dealers. The Portuguese dealers are using a different IT system and should be treated as non-controllable as well.

One basic assumption made is that the selected parts will behave in the same way in the future as they have in the past – which of course is an approximation.

#### ***5.2.1.1 Technical and organizational criteria***

These filters either include or exclude a given part for technical or organizational reasons, i.e. they are not a limit or threshold that can be adjusted or tweaked. The filters applied are constructed in cooperation with key personnel at VP from different functions within the company. Information about the part specific information described in this section can be found in Appendix 1.

##### ***Only Volvo Truck and Volvo Bus parts***

A filter applied directly is to extract only parts sold by VTC and VBC Business Areas and parts supplied by Volvo Group's suppliers. This is done by utilizing the "prefix" and the "supplier group" fields in VP systems. The prefix for VTC and VBC is "VO" while other Business Areas have other prefixes and the supplier group for Volvo Group's suppliers is "73".

##### ***No manually blocked parts***

In order not to collide with current LPA stock holding policy parts that are blocked at certain dealers or the market as a whole (by the LPA team) are disregarded. This is done by filtering the parts on the "purchase code" in Past (see Appendix 1) as to only allow parts with code 0 (not blocked) and code 1 (temporarily blocked by the system, i.e. demand at certain dealers is close to zero, but the part is still active at the dealer).

##### ***Unit of measure, service quantity and hazardous goods***

Parts sold in units of length, weight and volume are ignored due to the fact that these types of parts can be stored at the CW and SW in bulk but delivered to dealers in other quantities. It is thus complicated to relate the demand at the dealers to that at the SW automatically. Software and some parts such as keys

that have to be individually handled or prepared and cannot be refilled in a normal way are also excluded.

Parts with a set service quantity are disregarded, since these are refilled using special logic in order to ensure multiples of service quantities stocked at each dealer. Hazardous goods are also excluded since it often needs special warehouse infrastructure and cannot be freely adjusted.

#### *Exchange parts excluded*

Exchange parts with code E, R are allowed since these are remanufactured parts that are back in the supply chain and can thus be treated as normal parts. All other exchange codes indicate either reverse flows or exchange links. Exception parts (special, military, alarms etc) are also excluded.

#### *Supersessions excluded*

In order to ensure availability of the parts during the whole study parts with supersessions as well as preliminary supersessions are excluded. Even though preliminary supersessions may be set a long time in advance it is believed to be best to exclude them all anyway since this time span is uncertain.

#### **5.2.1.2 Pilot study characteristics based criteria**

These filters are not simple include, or exclude, types of criteria, but a set of limits or thresholds on different characteristics that can be adjusted in order to achieve the optimal selection of parts suitable for the study. The levels are decided in cooperation with NGIL researchers and VP personnel. Information about the part specific information described in this section can be found in Appendix 2.

#### *Price selection criterion*

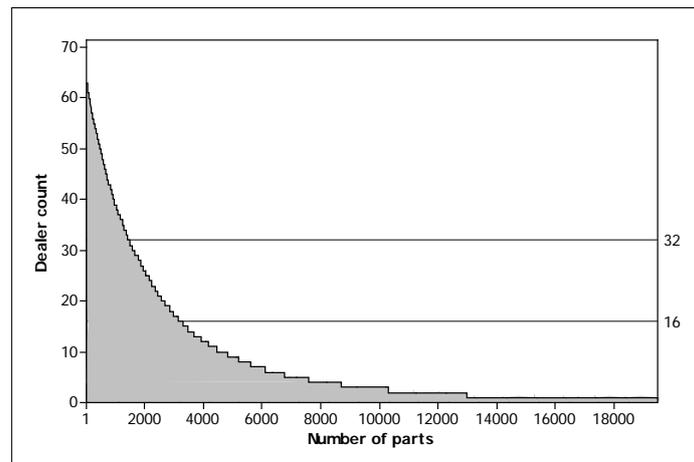
The first filter is on the monetary value of a part, based on the standard price for each part. Parts with low standard price are not good to include in the model for two reasons: the cheapest parts are often bulk parts such as screws, nuts and bolts and thus often sold and refilled in large quantities. Also a part with extremely low price has low inventory holding costs per units and the savings from balancing inventory will not be large and thus hard to measure and follow up.

It is decided to filter out parts with a standard price lower than 10 SEK and also to include some manually selected expensive parts with relaxed limits on

some of the other filter in order to more clearly see the impact of price on the NGiL model.

#### *Dealer count selection criterion*

In order for the model to have significant effect on the balancing between dealer stock and stock at the SW (see 3.5) a lower limit on the number of dealers that sell the part is necessary. This dealer count limit filters out parts that are not active (>1 pick last year) at a sufficiently large number of dealers.



**Figure 5.4** Number of parts left when filtering on dealer count

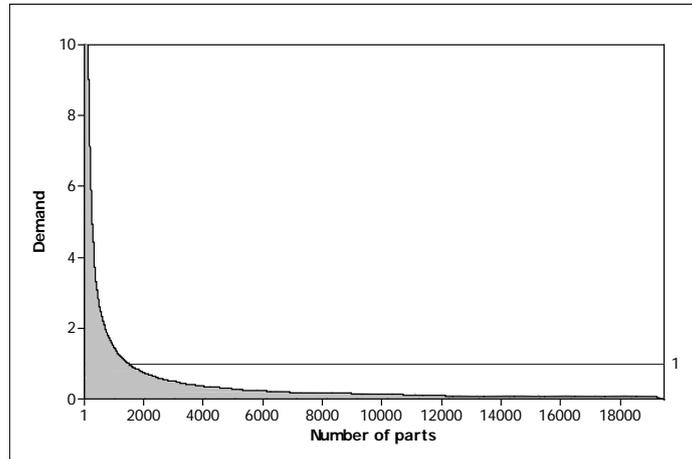
As Figure 5.4 shows about 1600 parts are represented at at least 50 % of the dealers and over 3000 parts are represented at 25 % of all dealers. It is decided that a part needs to be selling at 6 or more dealers in order to be included in the pilot study.

#### *Demand selection criteria*

In order for the selected parts to perform well during the study demand has to be high enough to occur a sufficient number of times during the 6 months, but also stable enough so that the parts' forecasts are less likely to change by much, thus eliminating the need to update the control parameters during the study.

Several measures are taken in order to ensure this stability: by filtering on the average monthly demand per dealer, a trend factor (on a per dealer basis), seasonality (on a aggregate level), service levels from the CW and Controllable Quota (as defined in 5.1.3).

Filtering on the monthly average demand ensures that only parts that sell at a given frequency will be included in the study. If this limit is set too low there is significant risk that the demand for the part will never occur during the 6 months of the pilot study.

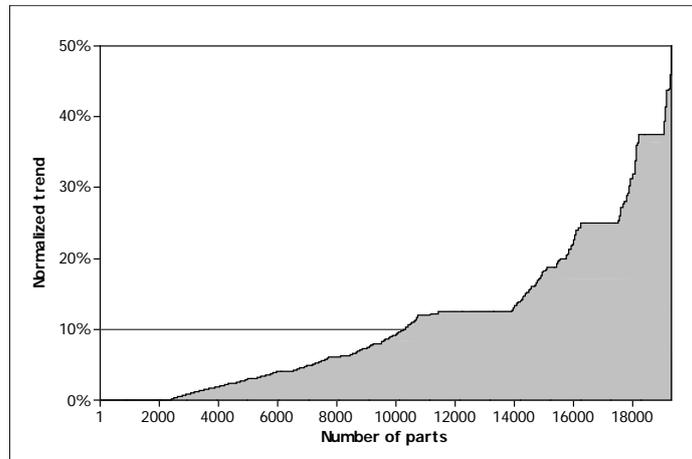


**Figure 5.5** Number of parts left when filtering on monthly average dealer demand

Figure 5.5 shows how fast the average monthly demand decreases with respect to the number of parts. About 1500 parts have demand  $> 1$  on average and only 100 have demand  $> 10$ . For the pilot a monthly demand of at least 0.5 units per dealer, on average, is deemed desirable and this is set as the limit for 85 of the parts. For the more expensive parts this limit is relaxed to 0.25 units per month, since there is strong correlation between demand and price.

To ensure demand stability additional filtering is performed on the absolute value of the normalized trend on a market level and on seasonality of the demand of the parts. However since only 12 month of data is available the seasonality criterion is considered to be of secondary importance and only used as a last tweak.

The trend is analyzed as the absolute value of the normalized (weighted by demand) difference between monthly demand for each part using linear regression (see Appendix 4).

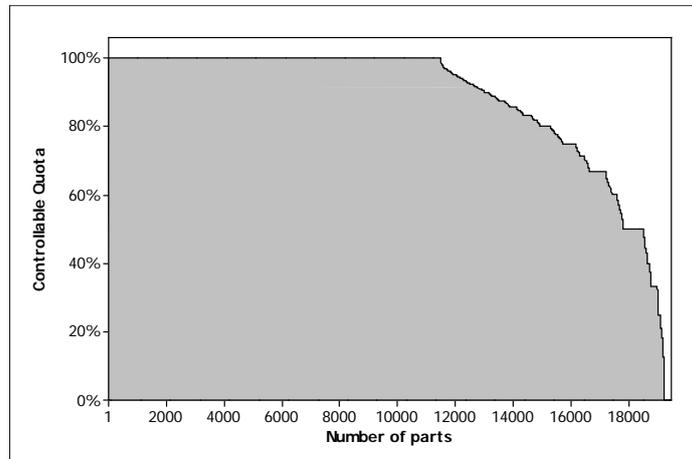


**Figure 5.6** Number of parts left when filtering on normalized trend

From this analysis and discussions with respondent group 1 it is decided that a trend of  $\pm 10\%$  is the largest allowed trend that the selected parts should have. This filter leaves about 10000 parts as seen in Figure 5.6.

Another measure that is investigated in order to ensure a good chance for stable demand during the study is the service level from the suppliers (parts manufacturers) to the CW during the last 12 months. However the current situation in the world (truck sales, as of the time of this thesis, currently at all time low) and the fact that only 12 last months of CW order data are available makes this measurement a secondary selection criterion.

In order to minimize the effect of the non-controllable dealers and other customers of the SW as described in 5.1.2 the parts are also filtered on Controllable Quota. Since having demand from non-controllable dealers interferes with the workings of the model and invalidates the set parameters during the pilot study this criterion is one of the most important.



**Figure 5.7** Number of parts left when filtering on Controllable Quota

It can be seen from Figure 5.7 that even when setting CQ to 100% more than 11000 parts pass the filter. The level for the CQ filter is thus decided to be set to 100% for 85 of the parts in order to minimize the impact from non-controllable buyers, and relaxed to 90% for the 15 more expensive parts.

### **5.2.1.3 Summary of selection criteria**

In order to reach the final count of 85 parts the filters for seasonality and service from CW are successively increased to arrive at the desired number of parts. A seasonality of  $\leq 10\%$  difference between summer and winter half year demand and a historical fill rate from CW of  $\geq 85\%$  is decided to be the final filter.

The selection criteria filter levels for the 85 parts are thus:

- Price > 10 SEK.
- Average annual demand per dealer  $\geq 6$  units.
- Controllable quota = 100 %.
- Trend  $\leq 10\%$ .
- Seasonality  $\leq 10\%$  difference between summer and winter demand.
- CW service level  $\geq 85\%$ .

This produces 88 parts of which 3 are manually removed in order to increase the spread of the parts in the classification dimensions as described in the following chapter.

For the 15 more expensive parts the filter on Controllable Quota is lowered to 90 % and demand limit is lowered to 3 units annually (0.25 per month). The filters for seasonality and CW service level are not applied at all. These parts thus have the following selection criteria filter levels:

- Price > 10 SEK, but preferably as high as possible (manual selection).
- Average annual demand per dealer  $\geq 3$  units.
- Controllable quota  $\geq 90$  %.
- Trend  $\leq 10$  %.

For a detailed overview of the 100 selected parts and some of their characteristics, please see Appendix 5.

### **5.2.2 Analysis of the disparity of the selected parts**

In order to ensure that the selected parts have different characteristics and represent the full range of VP spare parts and accessories as good as possible both a qualitative and a quantitative analysis is performed on the selected parts.

The qualitative analysis is performed by extracting all relevant data about the parts (description, price, dealer availability, value-volume classes etc., see Appendix 2, and discussing the selection with key personnel at VP in person (e.g. from the Refill and LPA processes) and by email (e.g. with the regional inventory manager for Spain and the SW inventory manager) as well as discussions with respondent group 1. From these talks the criterion for the standard price was tightened and the criterion for the stable demand was relaxed (as mentioned in 5.2.1).

The quantitative analysis is performed by constructing classes of classification dimensions and looking at how the selected parts (excluding the manually selected parts) are spread out in these dimensions. Four classification dimensions are set up in order to classify the parts according to the most important characteristics:

- Price (standard price from VP systems).
- Frequency (average demand per dealer and year).
- Dealer count (number of dealers that sell the part).
- Variance-to-mean ratio (of market demand).

The first three dimensions are the same as the selection criteria described in 5.2.1. Variance-to-mean ratio (VMR) is calculated by dividing the variance between each part's monthly total market demand with the monthly average demand. VMR is important since it allows distinguishing parts with stable demand patterns from parts with fluctuating demand patterns (of course with low trend and seasonality in both cases).

Each dimension is divided into three classes (high, mid and low) with equal numbers of parts in each class, as shown in Table 5.2. The upper limit of each class is excluded, so in the Low price class parts up to but not including 39 SEK are placed. The division is not as equal in the Dealers dimensions as in the others due to the discrete nature of the numbers of dealers (lowering the limit of the Low class to 35 resulted in only 26 parts).

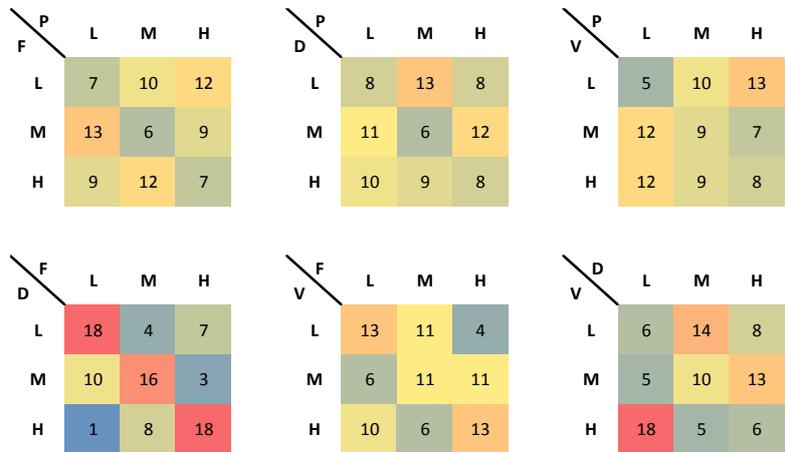
**Table 5.2** Definitions of classes for the four dimensions

Price Classes			Frequency classes		
Class	Price	# parts	Class	Frequency	# parts
Low	0-39	29	Low	0-27	29
Mid	39-105	28	Mid	27-55	28
High	105-	28	High	55-	28

Dealer count classes			VMR classes		
Class	Dealers	# parts	Class	VMR	# parts
Low	0-35	29	Low	0-1.21	28
Mid	35-50	29	Mid	1.21-2	28
High	50-	27	High	2-	29

For a complete list of covariance scatter plots of the selected parts please refer to Appendix 6. Here only the number of parts in each class is shown, the classes are abbreviated with their first letter (P = price, F = frequency, D = dealer count, V = VMR).



**Figure 5.8** Matrices of spread between pairs of dimensions

As these matrices indicate the spread is relatively good for all pairs of dimensions except for the frequency and dealer count dimensions. This is not surprising since the higher the average demand for a part the greater the probability of a larger number of dealers carrying the part. It is also noticeable that only one part is simultaneously low in frequency and high in dealer count.

Two of these dimensions correspond directly to the basis of VP systems tables; the price and frequency dimensions. From the first matrix in Figure 5.8 it is clear that the spread between parts in the Price/Frequency classes is good (averaging 9.44 parts per cell). However, in order to determine if the spread is good between these and the two other dimensions a two-by-two dimensions comparison matrix is set up, see Figure 5.9.

		Dealercount + VMR									sum	
		LL	LM	LH	ML	MM	MH	HL	HM	HH		
Price + Frequency	LL	1	2	1	1	1	1	0	0	0	7	(LLxx)
	LM	0	1	1	1	3	4	1	2	0	13	(LMxx)
	LH	0	0	2	0	0	0	1	3	3	9	(LHxx)
	ML	4	1	3	1	1	0	0	0	0	10	(MLxx)
	MM	0	0	0	0	2	0	3	1	0	6	(MMxx)
	MH	0	0	5	1	1	0	1	3	1	12	(MHxx)
	HL	1	0	5	4	1	0	1	0	0	12	(HLxx)
	HM	0	1	1	5	1	0	1	0	0	9	(HMxx)
	HH	0	0	0	1	0	0	0	4	2	7	(HHxx)
sum	6	5	18	14	10	5	8	13	6	85		
		(xxLL)	(xxLM)	(xxLH)	(xxML)	(xxMM)	(xxMH)	(xxHL)	(xxHM)	(xxHH)		

**Figure 5.9** Matrix of spread between the two VP inspired dimensions (price + frequency) and dealer count + VMR

From this matrix it can be seen that a lot of classes are empty and that the maximum part number of a class is 5. The empty classes are however not concentrated to any particular area of the matrix, the closest exception being the column of medium dealer count and high VMR as mentioned before. The average number of parts per class is 1.93.

### 5.2.3 Analysis of the market share of the selected parts

In order to get a better picture of how large piece of the total market the selected 100 parts are a comparison is made between the excluded and selected parts, see Table 5.3.

**Table 5.3** Market share of the selected parts

	Number of parts (pcs)	Sum of standard price (SEK)	Sum of demand (pcs / month)	Value of demand (SEK / month)
<b>All parts</b>	19485	3576286	271765	6547414
<b>Excluded parts</b>	19385	3561591	264769	6083600
<b>Selected parts</b>	100	14695	6996	463814
<b>% Excluded</b>	99,49%	99,59%	97,43%	92,92%
<b>% Selected</b>	0,51%	0,41%	2,57%	7,08%

Even though the selected parts represent only about 0.5 % of the number and value of the total parts range on the Spanish market, when weighting by demand and especially price multiplied by demand the ratio is increased significantly. To summarize, it can be concluded that we look at about 7 % of the total business on the Spanish market.

### **5.3 Identification and determination of parameters**

In order to apply the NGiL model, input all parameters (see 3.5.2) need to be determined. The demand parameters (average per month and standard deviation between months) as well as the order quantity  $Q$  are readily obtained from VP systems. The other parameters (lead time, shortage cost, inventory holding cost and target fill rate) as defined in the NGiL model in Chapter 3 are however not easily found and have to be constructed and identified specifically with VP in mind. This is done using the structures, data and information available as described in Chapter 4 and through discussions with key personnel at VP and NGiL researchers.

#### **5.3.1 Lead time**

The lead times are used to determine the mean and standard deviation of the demand during the lead time for dealer stock orders and SW refill orders, see 3.4.2, which in turn are used as parameters in the cost calculations, see 3.4. Although only the dealer stock orders and SW refill orders are used in the NGiL model, the day order lead times are also explained in detail since this is needed to understand the assumptions made when determining the shortage cost (see 5.3.2). It also gives a complete picture of all the order processes on the Spanish market.

The total lead time for any order is defined as the time frame starting from when the reorder point is reached, in the case of automatic orders, or when a manual order is placed until the order arrives at the dealer or the SW and is treated as ready for sales. This total lead time is divided into two components:

- The mean waiting time for an order before being registered in VPs ordering system.
- The lead time starting from the cut off until arrival, i.e. the latest time of placing an order into the ordering system that is to be registered and handled that day.

*Total lead time = mean waiting time + lead time from cut off until arrival.*

The lead time is measured in the unit of days and is rounded to half days as the minimum unit length. The day on which an automatic order is registered is denoted as Day 0 and the following days as Day 1, Day 2, etc. A work week of the dealers is defined as six days, Monday through Saturday. Sundays are therefore not included in any lead time calculations since no demand is generated or orders arrive on this day. Since the calculations in the NGiL model in this thesis has been chosen to be on per period, monthly, basis the number of total lead time days produced here is divided with the number of work days in an average month. An average month has 30 days including Sundays and therefore 4 days are subtracted from this to give an average work month of 26 days.

The lead time calculations are relevant for three different order processes; the stock order process for dealers, the refill order process for the SW and the day order process for dealers, see 4.3. A summary of the total lead times for these order processes can be found in Appendix 7.

#### **5.3.1.1 Determining the mean waiting time**

The NGiL model assumes continuous review policies at all installations (see 3.2.1). Since VP is using periodic review policies for the registration of orders this difference needs to be taken into account. This is done by adding the mean waiting time to the lead time.

The periodic review policy means that an order placed at an arbitrary time during the work week has to wait some time until it is registered. This waiting time depends on the number of days per week (call offs) on which orders coming from a dealer or the SW are registered. For the SW, orders are registered every day and hence has 6 call offs per week. For the dealers in Spain this varies from one to three times per week.

Using the number of call offs per week and assuming that orders are placed uniformly over time into VPs ordering system a common inventory control approach of adding half the review period to the lead time can be used to determine the mean waiting time. By calculating the number of days between the registrations of orders as

$$\text{days between orders registered} = \frac{\text{days in a work week}}{\text{call offs per week}}.$$

Assuming orders are placed according to a uniform distribution the mean waiting time then is

$$\text{mean waiting time} = \frac{\text{days between orders registered}}{2}.$$

This means that if a dealer for example has two call offs per week, the orders that the dealer places on average have to wait 1.5 days until they are registered.

### **5.3.1.2 Determining lead time from cut off until arrival**

The lead time from cut off until arrival is defined as the handling time at the warehouse (to which the order is sent) until the order is loaded on to trucks and shipped, plus the total transportation time until it arrives:

$$\text{lead time for cut off until arrival} = \text{handling time} + \text{total transportation time}.$$

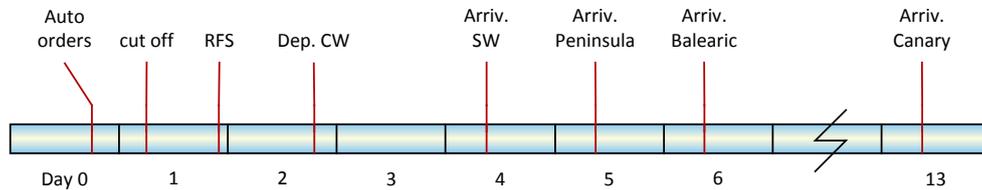
Since the three ordering processes are different with respect to the warehouse the orders are placed, the handling time and transportation time, the lead time needs to be individually determined for each ordering process.

### **5.3.1.3 Total lead time for stock orders**

Stock orders from an LPA connected dealer in Spain are done either automatically (for automatically refilled parts) or manually using the DSP system to the CW in Ghent.

Any manual orders must arrive to Ghent before the cut off time at 6 o'clock in the morning of Day 1 and those orders are ready for shipment (RFS) late on the evening of Day 1. Any orders arriving after this time will be handled in a later shipment. All orders going to Spain are consolidated and shipped by truck on the evening of Day 2 with the destination of the SW in Madrid. The shipment arrives at Madrid on the morning of Day 4, giving a transportation time from CW to SW of 1.5 days, and is there repacked for further shipment to each respective dealer. All dealers on the Peninsula will receive their orders before mid day on Day 5. For the dealers on the islands the transportation route is of course different and orders are shipped by truck to the coast and from there shipped by boat to the Balearic or Canary islands and will arrive on

Day 6 and Day 13 respectively. See Figure 5.10 for a summarizing illustration of the lead times for dealer stock orders.



**Figure 5.10** The lead times for dealer stock orders

The total lead time can thus be determined as

$$\text{mean waiting time} + \text{handling time} + \text{total transportation time.}$$

For a dealer on the Peninsula, Balearic Islands or Canary Islands, respectively, this equates to:

Peninsula:  $\text{mean waiting time} + 1,5 + 1,5 + 1 = \text{mean waiting time} + 4 \text{ days}$

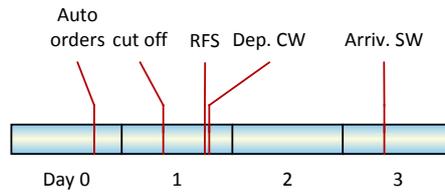
Balearic Islands:  $\text{mean waiting time} + 1,5 + 1,5 + 2 = \text{mean waiting time} + 5 \text{ days}$

Canary Islands:  $\text{mean waiting time} + 1,5 + 1,5 + 9 = \text{mean waiting time} + 12 \text{ days}$

Since the mean waiting time is different for the dealers the total lead time per individual dealer will not be stated here but can be seen in Appendix 7.

#### **5.3.1.4 Total lead time for refill orders**

Orders for refilling the SW are in Spain shipped together with stock orders to dealers. At arrival at SW the refill orders are handled, processed and put on the shelf at SW within a few hours. The main difference from the stock order handling in Ghent is that the cut off time is at 9 o'clock on the same day the order is RFS, giving a handling time in Ghent of 0.5 days instead of 1.5 days. See Figure 5.11 for an illustration of the lead times for refill orders to the SW.



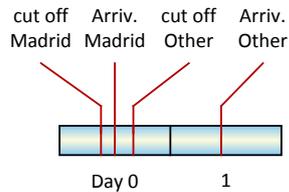
**Figure 5.11** The lead times for refill orders to the SW

Since refill orders to the SW are placed and registered every day, the mean waiting time can then be determined to 0.5 days. This gives a total lead time of

$$\text{mean waiting time} + 0,5 + 1,5 = 0,5 + 2 = 2,5 \text{ days}$$

### 5.3.1.5 Total lead time for day orders

As described in 4.3.3 a day order placed by a dealer that arrives before the cut off is handled and shipped from the SW that same day (except orders placed on a Sunday). In Spain the dealers have different cut off times and methods of distribution depending on geographic locations and thus have a different total lead times as illustrated in Figure 5.12.



**Figure 5.12** The lead times for day orders

#### *Dealers in Madrid*

Since the dealers in Madrid are close to the SW the transportation time is very short. These dealers have two cut offs they can meet. One is in the early morning and orders meeting this cut off time are distributed with a daily “milk run”-truck the same work day with a total lead time of half a day. The second cut off is later in the afternoon, at the same time as the other dealers, and is delivered in the following work day.

The total lead time for a Madrid dealer depends on which cut off the order meets. If the first cut off is met the total lead time is 0.5 days. If instead the second cut off is met the total lead time is 1 day. If neither cut offs are met the dealer has to wait for the first cut off the following work day, adding 0.5 days to the total lead time, giving a total lead time of 1 day.

### *Dealers on the Peninsula*

The dealers not located in Madrid, making the cut off times in the afternoon, will receive their day orders the following working day. This gives a mean waiting time of 0.5 days and a total lead time of 1.5 days.

### *Dealers on the islands*

Due to the location of the Balearic and Canary islands these dealers cannot be reached within a day using truck and boat deliveries. Instead day orders to these dealers have to be delivered by airplane. The orders making the cut off in the afternoon are transported to the Madrid airport and flown to the respective island to be delivered the following work day. The total lead time here is the same as for the non-Madrid Peninsula dealer, i.e. 1.5 days.

## **5.3.2 Shortage cost**

The shortage cost  $b_i$  is the cost per unit of a part at dealer  $i$  in excess of a normal stock order when a dealer instead makes a day order from the SW, i.e. the cost difference between placing a day order and a stock order. This cost is used in the NGiL model (see 3.5.2) to balance the reorder points at the dealers and the SW. A high  $b_i$  implies that it is much more expensive to place day orders than stock orders and hence the reorder points are shifted to be higher at the dealers and lower at the SW. A low  $b_i$  on the other hand implies the opposite, that it is relatively cheap to place day orders compared to stock orders and that the reorder point will now shift to being low at the dealers but high at the SW.

To calculate  $b_i$  a total costing model approach, described in 0, is used where all the costs that are different between a stock order and a day order are investigated. For this the detailed order flow structures for the Spanish market described in 5.3.1 are used. The costs involved are found to be the handling costs  $H$  (i.e. the order administration, preparation, picking, packing and getting the order ready for shipment) and the transportation costs  $T$  for transporting the order between the different installations. This means that  $b_i$  can be expressed as

$$\begin{aligned} b_i &= (H^{day} + T^{day}) - (H^{stock} + T^{stock}) = \\ &= (H^{day} - H^{stock}) + (T^{day} - T^{stock}) = \Delta H + \Delta T. \end{aligned} \tag{5.1}$$

The evaluation of the costs starts at the CW for both order types and ends at the final order arrival for each order type at the dealer. For a stock order the reason for this is obvious since a stock order originates directly from the CW, but for a day order the reason is maybe not as obvious since it originates from the SW. But even though the placement and delivery of a day order will not always invoke a refill order to the SW to be placed in close proximity to this order event, it will indirectly cause a refill order to be placed some time after. This makes the refill order costs relevant and motivates these to be included in the day order costs.

The handling costs used from and found in VP systems (supplied by VP personnel) are typically on a per order line basis, where an order line can be any number of units. Since the NGiL model expects  $b_i$  to be on a per unit basis a conversion of the handling cost parameters is necessary. This is done by converting the costs parameters to costs per kilogram which then easily can be converted further to costs per unit since the individual weight of each part unit is known from VP systems. The transportation costs do not need any conversion since these are already expressed as costs per kilogram.

### **5.3.2.1 Handling costs**

The handling costs can be divided into inbound and outbound handling. Inbound handling is all costs involved when receiving a shipment at an installation until it is put on the shelf, and the outbound handling involves all costs for getting an order ready for shipment when an order is placed.

The outbound handling costs at CW are denoted as  $H_{CW}^{stock}$  for stock orders and  $H_{CW}^{refill}$  for refill orders. At the CW a stock order undergoes the same stages and outbound handling as a refill order to the SW does. Although a refill order, as described in 5.3.1.4 and 4.2.4.3, is handled faster at CW this does not mean any large additional costs and the cost for outbound handling at CW is therefore assumed to be equal for the two order types, i.e.  $H_{CW}^{stock} \approx H_{CW}^{refill}$ .

The handling costs at the SW are the inbound handling cost for a refill order  $H_{SW}^{refill}$  and the outbound handling cost for a day order  $H_{SW}^{refill}$ . The repacking of a stock order at the SW does not invoke any costs since this is handled completely by the transportation company and is included in their total transportation fee. The inbound handling costs upon arrival of a stock order

$H_{D_i}^{stock}$  and that of an arrival of day order  $H_{D_i}^{day}$  to a dealer are also assumed equal since they are treated in a similar fashion, i.e.  $H_{D_i}^{stock} \approx H_{D_i}^{day}$ . The difference in handling costs then equates to

$$\Delta H = H_{CW}^{refill} + H_{SW}^{refill} + H_{SW}^{day} + H_{D_i}^{day} - (H_{CW}^{stock} + H_{D_i}^{stock}) = H_{SW}^{refill} + H_{SW}^{day}. \quad (5.2)$$

The handling costs on a per order line basis are extracted from a Volvo Penta project from 2005. Although the project is not explicitly for Volvo Truck and Volvo Bus spare parts there is no significant difference in the handling and routines between these business areas. Since the handling costs in the Penta project are from late 2005 the Swedish inflation rates<sup>5</sup> from 2006 to 2008 are taken into account. The conversion to handling costs on a per kilogram basis is done using figures of the average weight per order line at the SW in Madrid for inbound refill orders and outbound day orders provided by the General Manager at the SW in Gothenburg. The handling costs calculations are showed in detail in Appendix 8.

### 5.3.2.2 Transportation costs

The transportation costs involve all costs that arise during the transport of an order including taxes and fuel surcharges. A stock order to a dealer is first transported to the SW in Madrid, at a cost per kilogram  $T_{SW}^{stock}$ , where it is repacked for further transport to dealer  $i$ , at a cost  $T_{D_i}^{stock}$ . This cost depends on the location of the dealer. While all dealers on the Peninsula have the same costs, the dealers on the islands have different costs due to longer distances and the use of overseas transport.

For a day order the cost for the refill order  $T_{SW}^{refill}$  is added with the cost from the SW to the dealer  $T_{D_i}^{day}$ . Also here the locations of the dealers make a difference. Dealers on the Peninsula receive their shipments by truck but due to the long transportation time (see 5.3.1) to the islands dealers with truck and boat; these receive their shipments by air from Madrid airport. The transportation cost difference it thus dependent on the dealer and can be determined as

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<sup>5</sup> Retrieved from <http://www.scb.se>, 2009-02-17

$$\Delta T_i = T_{SW}^{refill} + T_{D_i}^{day} - (T_{SW}^{stock} + T_{D_i}^{stock}). \quad (5.3)$$

The transportation costs are all calculated from the transportation budget for 2009 provided by VP in Gothenburg. These figures are the basis for the contracts between VP and the logistics companies for 2009. For day orders on the Peninsula there is a range of different options available including daily “milk runs” to Madrid dealer, 2<sup>nd</sup> cutoff and Saturday deliveries and pickups. For these options a weighted average for the transportation costs is used based on the relative fraction of the options to the total transported weight. The details and calculation of the transportation costs are shown in Appendix 8.

### 5.3.2.3 The total shortage cost

The handling and transportation costs are now determined as dealer dependent constants giving a shortage cost as function of the weight of the part. Combining Eq. (5.1), Eq. (5.2) and Eq. (5.3) the shortage cost for a part with weight  $w$  at dealer  $i$  becomes

$$b_i(w) = \left( H_{IN\ SW}^{refill} + H_{OUT\ SW}^{day} + T_{SW}^{refill} + T_{D_i}^{day} - T_{SW}^{stock} - T_{D_i}^{stock} \right) w = (\Delta H + \Delta T_i) w \quad (5.4)$$

Using the fact that the dealers on the Peninsula all have the same transportation costs the number of shortage costs can be reduced to three; one for dealers on the Peninsula, one for dealers on the Balearic Islands and finally one for dealers on the Canary Islands. From the calculations shown in Appendix 8 this gives the shortage costs (in SEK)

$$\begin{aligned} b_{peninsula} &= 7,50 \cdot w \\ b_{balearic} &= 16,50 \cdot w \\ b_{canary} &= 34,00 \cdot w \end{aligned} \quad (5.5)$$

As expected the shortage cost is much higher for the islands, due to the longer transportation distance but mostly because of the need to ship the day orders by airplane.

### 5.3.3 Inventory holding cost

The inventory holding cost  $b$  is, as the shortage cost, a parameter used in the NGiL model to balance the reorder points. In the model  $b$  is defined as the cost directly dependent of keeping one spare part unit in inventory for one time unit. The number of parts in VP parts range does not allow for determining  $b$  explicitly for all spare parts. A standard approach (see e.g. Axsäter 2006) is therefore used where the price  $p$  of the spare parts is multiplied by an inventory holding interest rate  $i_b$  as

$$b = i_b \cdot p \quad (5.6)$$

where  $p$  is the standard price. VP uses an  $i_b$  of 30% per year in inventory holding calculations. This interest rate was investigated and determined in a Master Thesis project in 2003, Brodin & Sandberg (2003). In that thesis the following components were identified:

#### *Cost of capital*

Keeping a part in inventory binds capital that otherwise could be invested elsewhere. This cost of capital accounts for the minimum return of an alternative investment that could be made instead of binding capital in inventory.

#### *Warehousing cost*

The warehouse required can be rented or bought. In either way it costs money that otherwise could be invested elsewhere. This cost also involves costs for running the warehouse, such as electricity, heat and maintenance.

#### *Cost for insurance*

The stock in inventory needs to be insured for unforeseen events such as theft and fires.

#### *Cost for equipment*

The warehouse needs equipment for stocktaking such as racks, shelves and scaffolds. This cost covers the depreciation of the equipment.

#### *Cost for stocktaking*

The inventory in a warehouse regularly needs to be checked for discrepancies in stock levels. This is done manually by personnel.

### *Buyback cost*

According to the LPA concept VP buys back units not sold at the dealers after a certain period of time. These units need to be put back in inventory at CW or be scrapped. This cost covers both these events.

The individual interest rates are showed in Table 5.4.

**Table 5.4** Individual interest rates for all components identified in the inventory holding interest rate

<b>Cost:</b>	<b>Cap.</b>	<b>Wareh.</b>	<b>Insur.</b>	<b>Equip.</b>	<b>Stockt.</b>	<b>Buyback</b>	<b>Total</b>
Interest:	10%	15,68%	0,56%	1,14%	0,83%	1,47%	<b>29,86%</b>

As the holding cost  $b$  in the NGiL model only should concern the costs of keeping one part in inventory, not all of these costs should be included. The cost for warehousing and the cost for equipment are not dependent of keeping one extra unit of a part in inventory and should therefore not be included in  $b$ . Also  $b$  is on a monthly basis and not on a yearly basis and hence one twelfth of the total cost should be used. This gives an  $b$  according to Eq. (5.6) and Table 5.4 of

$$b = \frac{(0,10 + 0,0056 + 0,0083 + 0,0147)}{12} \cdot p = 0,0107 \cdot p. \quad (5.7)$$

### **5.3.4 Target Fill rate**

As described in 3.5.2 the NGiL model performs it's optimization under given service level constraints. These constraints are expressed as target fill rates (see 0) on a; per part and per dealer level.

The VP way of measuring end customer service is done by means of KPI1 (see Appendix 3) and is thus expressed and stored on an aggregated level. The target for KPI1 is 94 % world-wide and the current performance in Spain is 96 % for the whole spare parts and accessories range on these markets (for VTC and VBC Business Areas). Individual parts can have higher or lower service level outcomes and there are no targets for individual parts.

Since there are no measures in the systems that are directly usable in the model, this leads to the necessity to create an experience based “fictitious” target fill rates on a per part and dealer level, see Table 5.5. This is done by inquiring key personnel at VP such as the process owner for the LPA process and people involved in Stock Holding Policy decisions, referred to as respondent group 4 (Gothenburg: Stock Holding Policy Group).

**Table 5.5** Experience based target fill rate table. Target fill rates as a function of price and frequency

		Frequency (Picks)								
		A	B	C	D	E	F	G	H	I
Price [€]		0,3	0,7	1,4	3	8	15	30	60	9999
1	0,2	94 %		96 %		98 %				
2	0,7									
3	3	90 %		94 %		97 %				
4	9									
5	30	85 %		92 %		96 %				
6	100									
7	250	75 %		85 %		95 %				
8	500									
9	∞									

This table is based on the repurchase price and the forecasted number of picks for the part, thus utilizing the same dimensions as the LPA picks table (see 4.3.1). Since the current classification for each part at each dealer is known and stored in VP systems it is easy to map these target fill rates to each part at each dealer by just looking at the current VVCL flag.

## 5.4 Simulation study

The most important aspects of the simulation study are to analyze the potential results provided by the NGiL model and expected from the pilot study. In order to quantify these aspects data and statistics are collected from the simulation model for 20 of the selected parts and calculations of the cost reduction potential, target service achievement and balancing of stock are performed.

The cost reduction potential aims to give a picture of how large cost savings the use of the new coordinated approach could provide. The target service achievement looks at the fill rates from the simulation compared to the target fill rates the NGiL model used to constrain the optimization of the reorder points and how good these were satisfied. The balancing of stock looks at

how much the optimized reorder point from the NGiL model shifts the stock towards the dealers or towards the SW compared to the current situation. Also, correlation of these measurements with some part characteristics, such as price, demand, number of dealers and variance in demand between dealers, are calculated to see if there are certain types of parts that work better or worse in a coordinated inventory approach that can be identified.

A summary of the results from this analysis can be seen in Appendix 9 and the overall result is that this limited simulation study cannot reveal any clear correlations between the measurements and the parts' characteristics. The simulation does reveal that some parts do not meet their target service rates as defined Table 5.5 but equally many overshoot their targets resulting in, on average, control that fulfills target fill rates after optimization.

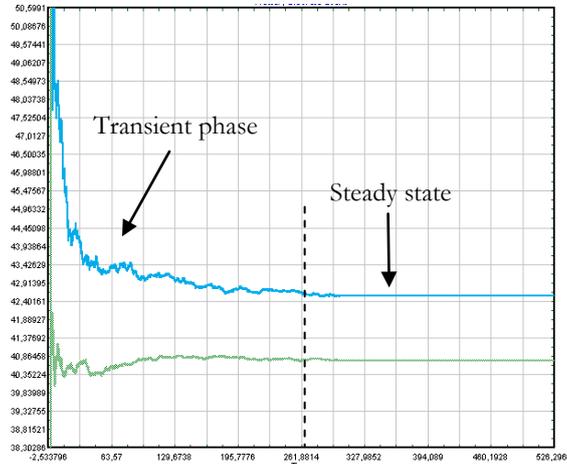
However these preliminary results can only serve as a rough estimate of the potential cost savings and inventory level reductions the NGiL model is capable of performing, and that could be expected during the pilot study. Also the pilot study will probably discover some areas that the simulation model does not cover, and thus the results from the simulation study have to be compared to the real life situation during the pilot study in order to validate the developed simulation model, i.e. how good this model actually reflects the reality of VP's supply chain.

#### **5.4.1 Preparation and performing of the simulation study**

The simulation study is performed on 20 of the 100 parts deemed as suitable for the study (as described in 5.2). This selection is performed by utilizing a data clustering algorithm that ensures that the 20 simulated parts are of as different characteristics as possible in all previously defined dimensions (price, total demand, number of dealers, and variance of dealers' demand). This method gives a good mix of extreme and average parts, for instance both the cheapest and the most expensive part is included, as well as the most frequent and the least frequent, but also some average priced and semi-frequent parts are selected, see Appendix 9, table 1.

The simulation model starts up with all inventories full ( $R+Q$  units in stock), so there is a transient phase in the beginning of each run during which the inventory levels stabilize. Initial simulation runs are performed during which inventory levels are analyzed in order to find a suitable start up time (to define

the length of the transient phase) and simulation time (during which statistics are calculated), see Figure 5.13.



**Figure 5.13** Definition of transient phase and steady state for a simulation run. Graphs show the inventory level of two arbitrary installations

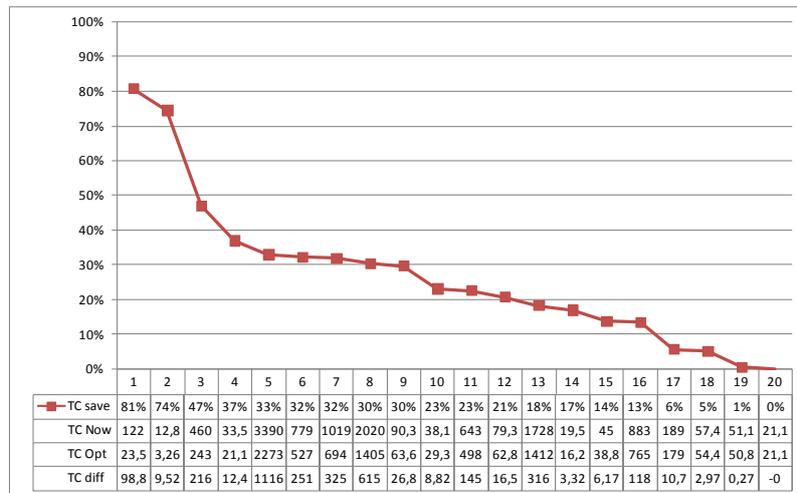
## 5.4.2 Results of the simulation study

The simulation model outputs the cost structure and realized fill rate for all installations ( $\alpha_i$  for the dealers and  $\beta$  for the SW). It also calculates a total cost and a total weighted fill rate ( $\gamma$ ) for the system as a whole. From the outputted cost structure it is also possible to calculate the average inventory levels during the steady state of the simulation run.

These results are collected from simulations for each of the 20 parts using both the current VP control parameters, and using the optimized reorder points delivered by the NGiL model. These results are consolidated and presented in Appendix 9, table 2-3 and the measures of cost reduction potential, target service achievement and balancing of stock are further analyzed.

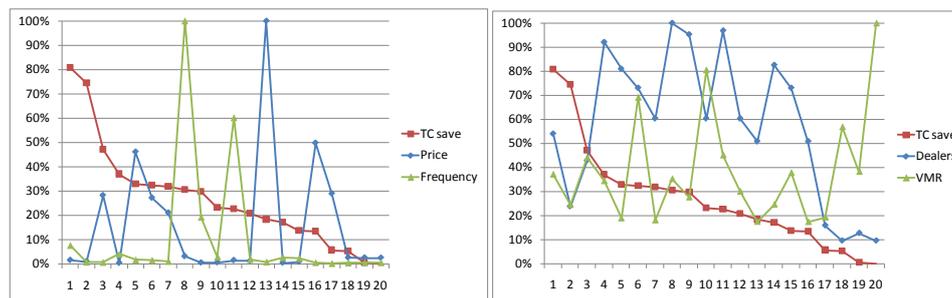
### 5.4.2.1 Cost reduction potential

Cost reduction potential is defined as the percentage reduction of the total cost  $TC$  per month (see 3.5.2) comparing the current situation (referred to as “Now”) with the one the NGiL model provides (referred to as “Opt”). From Figure 5.14 it can be seen that for the 20 simulated parts the reduction is about 75 to 80 % for the top two, down to about 1 and 0 % for the bottom two. The average cost reduction is 27 % and half of the parts have reductions of between 14 and 33 %.



**Figure 5.14** Graph of cost reduction for simulated parts, sorted by cost reduction size

In order to analyze the correlation between the cost reduction and the part characteristics the levels of the four dimensions are plotted together with the cost reduction, see Figure 5.15.

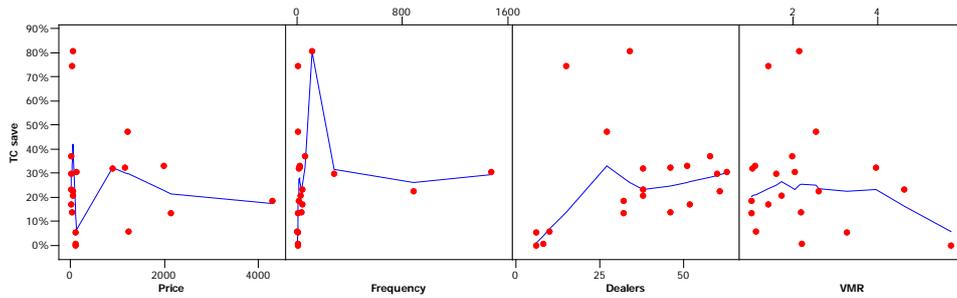


**Figure 5.15** Part characteristics compared to the cost reduction. To the left: part price and frequency. To the right: number of dealers having the part and part VMR

It is apparent from Figure 5.15 (left) that the highest reductions are not for the parts with highest price or frequency. The most frequent parts (e.g. parts 8 and 10) have average cost reductions and the most expensive parts (e.g. parts 5, 13 and 16) have varying degree of reduction.

From Figure 5.15 (right) it can be concluded that the parts with low or no cost reduction at all in general are those that sell at few dealers and have higher variance of demand. However, parts that sell at the highest number of dealers only show average cost reduction potential.

Analyzing the correlation between the cost reduction and each of the part characteristics no clear patterns are seen as Figure 5.16 illustrates. The previously mentioned correlations between low cost reduction potential and a low number of dealers or a high VMR can be observed to the right in Figure 5.16.

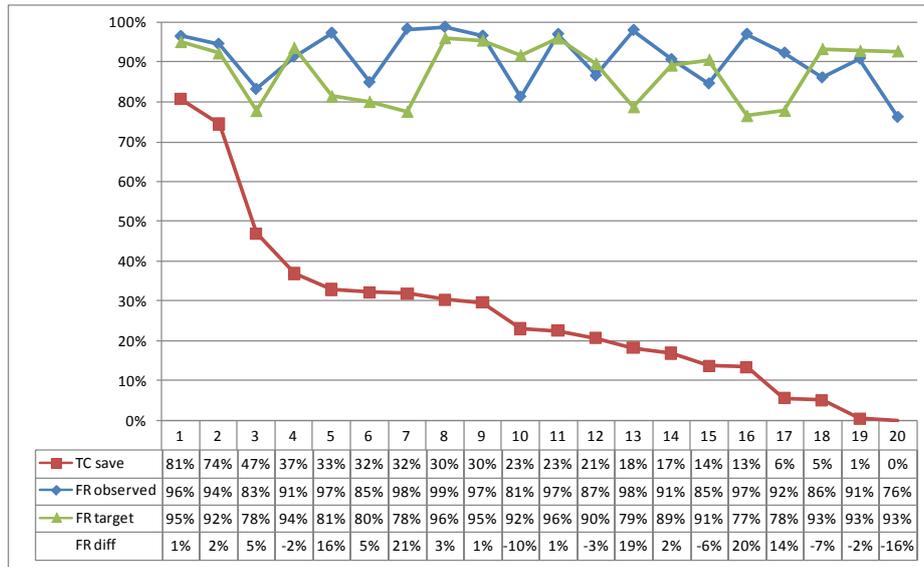


**Figure 5.16** Correlation graphs between the cost reduction and the part characteristics

However there seems to be some correlation between low cost reduction potential and simultaneously low demand, price and number of dealers. But these multivariate relationships are not further analyzed due to the limited nature of the simulation study.

#### **5.4.2.2 Target service achievement**

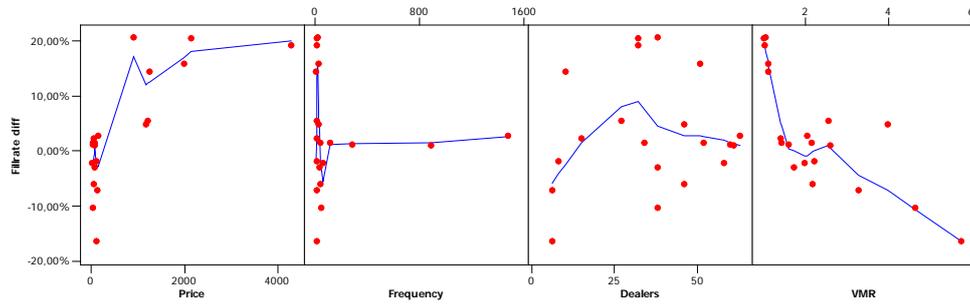
In order to check how the optimized solution fulfills the service goals the observed fill rate from the simulation on market level is compared to the target fill rates. Since the target fill rates given by respondent group 4 (see 5.3.4) are on a per dealer level these target fill rates are weighted using the method described in 3.5.2 enabling comparison with the observed fill rates. The results are presented in Figure 5.17.



**Figure 5.17** Comparison of observed fill rates from the simulation (FR observed) and target fill rates (FR target)

On average the observed fill rates from the simulation are equal to the weighted given target fill rates. On some occasions the simulation results differ from the targets, but these differences are both positive and negative for some parts and no extreme negative discrepancies are apparent except for part number 10 and 20. The parts with the highest cost reduction potential do however generally show no or positive difference (fill rates above target).

Looking at the correlation between target service achievement and the part characteristics, see Figure 5.18, a rather strong negative correlation between fill rate difference and VMR can be observed, meaning that low VMR leads to fill rates above target and high VMR leads to fill rates under target. There also seems to be some positive correlation between high price and positive fill rate difference. It can also be seen that the parts with the lowest target service achievement have simultaneously low price, low frequency and high VMR, although no general patterns can be seen in the price or frequency characteristics otherwise.



**Figure 5.18** Correlation graphs between the target service achievement and the part characteristics

### 5.4.2.3 *Balancing of stock*

In order to analyze how the model optimizes the supply chain by balancing stock towards the SW or towards the dealers, the changes in average inventory levels at all installations are compared.

This balancing action (denoted “movement”) is calculated by subtracting the inventory level (IL) change at the dealers from the IL change at the SW weighted with the market demand in order to facilitate comparisons.

$$Movement = \frac{IL\ change\ at\ SW - \sum IL\ change\ at\ dealers}{Market\ demand\ for\ the\ part}$$

A positive movement number is thus a shift towards more stock at SW, and a negative movement number is a shift towards more stock at dealers.

Results from the simulation, see Figure 5.19, show that the parts with the highest cost reduction potential are generally shifted towards the SW (part 1, 2, 3, 4 and 6).

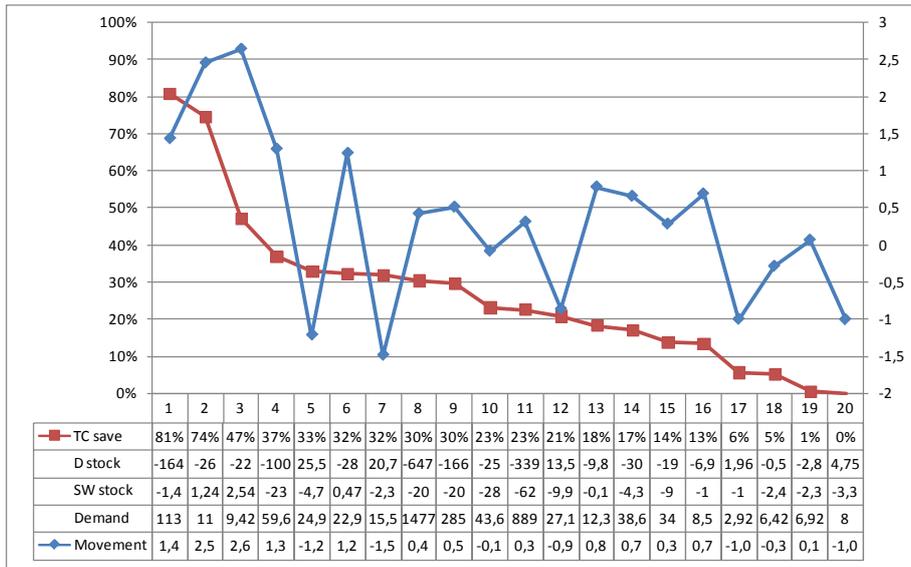


Figure 5.19 The movement of the balancing of stock compared to the cost reduction

Analyzing the correlation, see Figure 5.20, there is no indication of any clear patterns. There seems to be a small correlation between dealer count and a tendency to balance towards the SW, and between high VMR and balancing towards dealer inventory, but these correlations are not very clear and could be random.

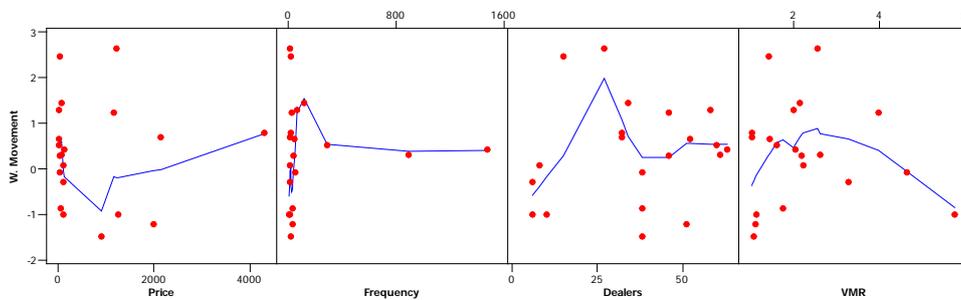
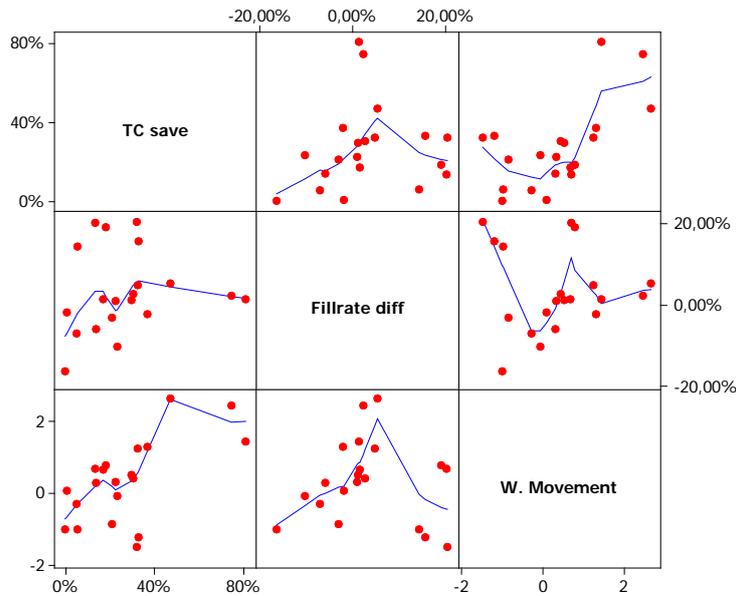


Figure 5.20 Correlation graphs between the movement of the balancing of stock and the part characteristics

#### 5.4.2.4 Correlation between the measurements

If the correlation between the cost reduction potential, target service achievement and balancing of stock is investigated some correlations can be observed, see Figure 5.21, mostly between cost reduction potential and the balancing of stock.



**Figure 5.21** Correlation between the measurements; cost reduction, targets service achievement and movement of the balancing of stock

The four parts with the highest cost reduction potential (parts 1, 2, 3 and 4) also have high movement numbers meaning that they should be shifted towards the SW. Their characteristics are however very different – one is expensive with low frequency, one is cheap with low frequency, and one is cheap with high frequency (see Appendix 9, tables 1 and 3).

From Appendix 9 it can also be concluded that the parts with the highest frequency (parts 8 and 11) are not in need of balancing, presumably because the current VP systems and stock holding policies are working well for them even from a coordinated perspective.

#### **5.4.2.5 Summary**

In monetary terms the cost reduction for the 20 parts is 3299 SEK per month (see Appendix 6, table 2). Since these parts are a representation of all the selected parts the cost reduction can be scaled accordingly to about 15000 SEK per month for all the 100 parts. Apart from the decrease in handling costs and backorder costs the NGiL model also leads to a decrease in tied up capital. From Appendix 6, table 3 this decrease sums up to about 188000 SEK for the 20 simulated parts, which scales up to 940000 SEK for the 100 selected parts.

It is however not easy to determine how good a representation of the total parts range in Spain the 100 selected parts are, since the selection of parts incurred constraints on the parts' characteristics (most noticeable demand and value) and thus does not give a complete representation of the whole range.

It is important to note that the simulation study is of very limited scope and depth. It is thus not possible to draw general conclusions from these results other than that there exists no clear correlation between parts characteristics and the cost reduction potential, target fill rate achievement or balancing of stock in the supply chain. But if this is due to the fact that the simulation study was so limited or due to a real absence of such trends remains to be analyzed in greater detail in bigger simulation studies or results from the pilot study itself.

## **6 DISCUSSION AND CONCLUSION**

In the previous chapters of this report and the appendices in Chapter 8 we have described how we selected a suitable support warehouse supplied market in Europe to perform the pilot study on. We have also described how we designed a way to extract all the necessary input for the model from VP systems and set up a series of rules and methods for a suitable selection and classification of spare parts and accessories to include in the pilot study. The most complicated and challenging part of this work was the determination of the cost parameters for the model and a lot of time and effort went into that particular part of the project.

In this chapter we discuss the necessary assumptions, approximations and other discrepancies between the model and reality, as results of many discussions with NGiL researchers, VP personnel and analysis of quantitative data in VP systems. Some reflections about the parameter determinations follow, mainly the cost parameter extraction and calculation, and then we discuss the potential of the NGiL model on the Spanish market as well as generalizations to other VP markets or even other companies. A short discussion about the risks and challenges with the pilot study that we feel should not be overlooked finishes the discussion part of this chapter. We round up the chapter with conclusions and our final thought of the thesis project. The contents of this chapter are our own reflections and comments unless stated otherwise.

### **6.1 Differences between the model and reality**

The NGiL model, as described in Chapter 3, has some differences from the reality of VP supply chain and markets, as described in Chapter 4. Some of these are pure mathematical or statistical approximations, and some are due to the fact that the ways of doing things in reality offer differ from theory. These assumptions and approximations are discussed under three general topics: structural and lead time related, demand and inspection related and service level related.

#### **6.1.1 Structure and lead time**

In general, the structure of the model mimics reality well for a VP market with a SW structure, such as the Spanish market, but also, as far as we can see, every

other VP market with this particular structure. The modeled installations and the flows between them are a close representation of VP structures and routines. The assumption that CW has a fill rate of 100 % is considered to be a feasible approximation for European markets from what we have concluded from discussions with VP personnel and from the feedback during the company presentation of the thesis.

The model assumes that all lead times are deterministic, i.e. constant. This works well for a mature market where transportation routes and routines are well established, and thus variations in lead times are at a minimum, such as the Spanish market. Several other markets in Europe are also considered to have relatively constant lead times (see Chapter 5), but there are markets where this assumption would not hold, such as Italy and Austria.

Reverse flows are ignored (buy backs, returns) by the model and VOR orders are not taken into consideration at all and can be seen as disturbing the general structure of the market and thus the assumptions of the model. However, analysis of order data in VP systems reveals that the amount of these orders can be regarded as negligible (e.g. about 0.5% of all demand from the SW).

The model also assumes that all dealers' inventories are centrally controllable, which turned out only to be true for LPA connected dealers at VP markets, which in turn turned out to be not all dealers on the markets supplied by the SW. For this reason the Controllable Quota (see Chapter 5) had to be defined and used to filter out parts suitable for the study. This limitation of the model needs to be taken into consideration in the future, i.e. an ability to include demand from non-controllable dealers in the optimization.

### **6.1.2 Demand and inspection**

The NGiL model assumes continuous inspection at the dealers. In reality, inspections of the sales data at LPA connected dealers are carried out on a daily basis which, according to VP personnel, constitutes no problem for the continuous inspection assumption. However the model also assumes continuous inspection from dealers to CW, i.e. customer demand that is satisfied directly at dealers (and not transferred to SW) can immediately trigger a replenishment order from the dealer to CW. One problem with this assumption is that replenishment orders to dealers in reality only are sent to CW at certain predetermined days (call off days) which varies between 1 and 3

times per week. This means that an order may be waiting several days before it is placed to CW. We do believe that the impact of this problem can be considered as small for most dealers since the majority has 2 or 3 call off days per week, which means that the mean waiting time for an order only is 1 to 1.5 days. For the dealers with only one call off per week the impact of this problem is also believed to be rather small since these dealers most often are dealers with general low demand patterns and the added waiting time do not increase the probability of shortages to a very large extent.

Continuous inspection also applies to the SW in the NGiL model, i.e. replenishment orders from SW placed to CW are sent immediately. This is not true in reality but orders placed by SW are handled and shipped on the same day as they are placed (if the order passes the cut off). This means that the mean waiting time for an order is very short (0.5 days) and this does not constitute a problem for the assumptions of continuous inspection.

The waiting time for both dealer replenishments and SW replenishments from CW are taken into account when calculating the lead times for these order by adding the average waiting time to the “pure” lead time. This means that the NGiL model will take this waiting time into consideration when optimizing the reorder points.

The historical demand data from VP is on a periodical (once a month) basis. This makes the approximation that the daily demand is normally distributed hard to validate since only discrete data with a month apart is available. Also, the historical demand data available is only for the last 12 months which makes the calculation of mean and standard deviation less reliable. The data available is the sales data and not the real demand, which means that there may be a discrepancy between this data and reality since any possible lost sales are not seen.

The normal approximation of the demand at the dealers also makes it harder to calculate an exact demand distribution to SW from the dealers. In the model the demand to SW from each dealer is calculated as the fraction of demand that theoretically is not satisfied by the dealer  $(1 - a_i)$  multiplied by the dealer demand  $\mu_i$ , i.e.  $(1 - a_i)\mu_i$ , and hence is not based on any actual real demand seen at SW. VP policy states that not all types of parts are to be stocked at the SW and by calculating the demand in this way there is no distinction about the type

of the part and possibly all types of parts could be stocked at the SW according to the model. This can be seen as a disadvantage of the model but we believe that it is to be seen as an advantage since this new approach means that the model can be used to decide which types of parts that should be stocked at SW.

### **6.1.3 Service level measurement discrepancies**

The service index (KPI 1) at VP is measured as the percentage of parts with more than one week of forecasted demand in stock and measured on a dealer level only (see Appendix 3). Also, the performance indicators at VP are not measured on part level, and target levels are set for markets as a whole (KPI1) or dealer levels (PIs). The VP approach is therefore to control towards a goal for the average service rate fulfillment, whereas the model controls each part individually against a given service level threshold on a per part level. For these reasons the target fill rates entered as constraints to the NGiL model optimization are just experience based guesses from VP personnel (see Chapter 5). Since the definition of service is different between VP reality and the model it is difficult to determine the validity of these guesses.

We can however conclude from discussions with NGiL researchers that if the total lead time is exactly one week, the VP service index and the fill rate definition are identical. This is due to the fact that, in the case of a stock that is less than one week of forecasted demand when measuring service index, it will always be possible to place an order at the same time of the measurement. This order will then arrive to replenish the stock precisely one week later and thus the stock will always be large enough to handle one week of forecasted demand and service index will in calculations always be 100%. This also means that the stock will always be positive under the same conditions and all forecasted demand can immediately be satisfied, giving a fill rate of 100%. Any differences between the real demand and the forecasted demand will affect service index and fill rate to the same extent. And since the total lead time for all dealers in Spain (except the Canary dealers) is 7 days or less, this should, at least on an aggregated market level, give somewhat more strength to the validity of the experienced guesses approach.

## **6.2 Parameter determinations**

The inventory holding cost, lead times and shortage cost were not readily available from VP systems. Therefore, these needed to be determined using data found in VP systems.

### **6.2.1 Cost parameters**

The inventory holding cost was previously determined at VP in a master thesis in 2003. The components included in the inventory holding costs were thoroughly investigated and are believed to still be valid and VP currently uses these in calculations. Since the components could be separated even better control of the included costs could be achieved and together with the expertise from NGiL researchers only the relevant costs were included.

The lead time determination included an investigation of the structure of the order flows in VP supply chain. Through recurrent analyses, discussions with VP personnel and documents provided by VP the components in the lead time were identified and validated throughout the course of the investigation (see Chapter 5). The calculation of these components were made exclusively using data found in VP systems and are therefore believed to be valid to the highest possible extent limited by the information at hand.

The shortage cost determination proved to be a particularly challenging task, both in the sense that no such cost was found in VP systems and that no predetermined route on how to determine this was available. Also, the term “shortage” implied for VP employees that this cost applied to lost sales to a customer that had already occurred which was not the case and discussions on explaining the workings of the model and the shortage cost were often needed.

After identifying the components of this cost, which included handling and transport, it was found that VP most often defined costs related to orders using the “order line” concept which involves an order of an arbitrary number of units. This constituted a problem since the model worked on a per unit basis. The “order line” based costs therefore needed to be converted to a per unit basis.

Another complicating issue is the fact that the delivery of an order to a dealer is consolidated with other orders to the dealer in question and to other dealers on the market. For the transportation components this did not constitute a large problem since these could be found on a per kilogram basis. Data on

these costs were also readily available in the transportation budget figures for 2009 which was the actual costs VP would pay their transportation and hence these costs are believed to be very valid, at least for 2009. The handling costs, however, proved more difficult to determine. Firstly the handling costs at different locations were not something VP readily measured and secondly the size of an order line was not easily determined. Through discussion with VP personnel earlier projects were found from which these could be extracted. The problem here was that this data was not current and that the source of the data could not be found and it was therefore impossible to verify or validate the, thus we were forced to rely on the results stated in the projects. However, if one looks at the sizes of the costs in the total shortage cost shown in Appendix 8 it can be seen that the handling costs is the minor component and discrepancies or pure errors on these do not affect the total shortage cost to a very large extent.

Since the shortage cost is on a per kilogram basis alone there is the risk that parts on different sides of the weight spectrum get unreasonably low or high shortage costs that could impact the optimization of the model in unexpected ways. We did not find any way of dealing with this problem and the results of the pilot study have to show if this will have to be taken into consideration.

There is of course also the risk that components that should be included in these cost components have been unintentionally omitted which could impact the shortage cost. We do however believe that this risk is rather small since the shortage costs have been extensively discussed with all parties involved.

### **6.2.2 Order quantities and other quantities**

The model assumes that all parameters are entered on a per unit base and performs optimization on single units of demand and refill quantities throughout the supply chain. I.e. all demand, costs and order quantities are on a per stock keeping unit base in the NGiL model. This is not necessarily true in the VP supply chain – there are several “fixed” order quantities that the system takes into consideration (see Appendix 2), such as quantities that are most economical to ship from the CW and from the SW to the dealers, e.g. parts that are delivered to the dealers in “bulk packs” but sold in single units, or parts that always are sold in a fixed amount of units. The main impact of this is on inventory holding and transportation costs where the calculated “per unit”

cost not necessarily reflects the reality of storing or transporting a package (bulk pack) of the part.

The model also expects the ordering quantities (Q) to be close to the economic ordering quantity (EOQ) as defined by the Wilson formula (see e.g. Axsäter 2006). When this situation was analyzed in the VP data (using ordering costs provided by Volvo) it turned out that the Q used was often not close to EOQ and even varied between dealers for the same part. The main reason for this is believed to be the roughness of the table based control method used by VP and that other factors that the Wilson formula do not take into consideration may exist, such as e.g. the different ordering quantities. An attempt to recalculate the ordering quantities according to the Wilson formula was made but accurate ordering costs proved to be hard to find and validate. Therefore it was decided to use the ordering quantities currently set in VP systems.

### **6.3 Cost saving and capital reduction potential**

Although some parameters are hard to extract and calculate exactly in the form that the NGiL model needs them, and that some discrepancies between the model and VP supply chain reality are discovered, the overall conclusion made by us is that the model is a good representation of the VP supply chain. We see no reason why the pilot study could not be performed with the assumptions and approximations used by the model and the part selection and data extraction methods we have described.

The simulation study is thus performed on some of the selected parts on the Spanish market in order to compare the current inventory control in use by VP with the optimized scenario delivered by the NGiL model, in order to get a picture of what to expect in terms of cost savings, stock reduction and stock balancing. These preliminary results look promising – the optimization seems to work well for the majority of the parts resulting in significant reductions of costs and tied up capital while maintaining target service levels to end customers.

If these results (that are said to be valid for our 100 selected parts could be extendable to at least half of all parts sold at the Spanish market (10000 of 20000 pcs), the reduction of inventory holding and backordering costs of 15000 SEK per month thus becomes 1.5 million SEK per month and the reductions in tied up capital of 940000 SEK becomes 94 million SEK. And

even though these numbers have to be taken as very rough approximations they still show the great potential that coordinated inventory control has in the supply chain of VP. This should be enough motivation to implement the pilot study in the real world and to further investigate what could be potential drawbacks and disadvantage of the model that have not yet been discovered.

The simulation also does not find any easily distinguishable correlation or patterns between part characteristics and cost reductions or balancing of stock towards SW or dealers. This indicates that the decisions on which parts are to be stocked where in the supply chain are, from a coordinated perspective, not trivial and an advanced tool, such as the NGiL model, is needed in order to perform them. Hopefully the pilot study, or a more comprehensive simulation study, will show some consistent connections or patterns in these areas.

Since there are structural similarities between the Spanish market and the other European support warehouse markets there is potential to perform studies or even implementations on other SWs and markets by using the same tools and methods that we have described. And even though the model is created based on the structures and routines in the VP supply chain, there is no reason why it with minor changes not could be used in other companies and supply chains.

#### **6.4 Risks with the pilot study**

The pilot study is to be carried out for the duration of 6 months, during which the control parameters (R and Q) are not to be adjusted, or at least just checked up a couple of times during the study. This is mostly due to the fact that the NGiL model calculations are performed completely separated from the current VP systems, and thus there is no way to automatically recalculate and implement the updated control parameters automatically during the study.

This leads to several risks during the study, possibly resulting in wrong results and conclusions but potentially even lowering service to customers or raising costs if not handled correctly. Some of these issues have to be monitored and checked up on a continuous basis during the study and some that can be evaluated after the study is performed in order to determine and eliminate their impact on the models' work.

#### **6.4.1 Changes in part characteristics**

We believe that one of the most probable risks is with changes in demand patterns, although care has been taken to design the trend, seasonality and product lifecycle filters (see Appendix 5) in such matter as to minimize this possibility. However it is probable that at least a couple of the parts will have such changes in overall demand size, seasonality effects or in their life cycles that they will have to be excluded from the study. Some alarms have been proposed (Appendix 10) to be implement in order to pick up these changes automatically or give a decision tool that enables manual exclusion from the study.

It is our recommendation to look at the trend and seasonality characteristics of each parts demand pattern in the same way as our definition (see Appendix 6) and exclude parts that fall out of  $\pm 10\%$  change between months or rolling 6 period average for instance. Also when a part is getting close to the end of its life cycle and is about to be superseded (see Appendix 2) it is reasonable to guess that the demand patterns will be changing. For this reason we believe that parts should be extracted from the study as soon as a preliminary supersession is made.

Although the controllable quota threshold is set very high it is only based on last year's order data, and there is no guarantee that the demand distribution between controllable and non-controllable dealers will be constant during the study. There is potential risk that the amount of demand from non-controllable dealers on a particular part becomes significant and thus the part needs to be excluded from the study in order not to lower service to end customers.

#### **6.4.2 Financial crisis related**

The current state of the world economy has had a major impact on the automotive industry and the world at large. It is impossible to say for how much longer and what consequences these downturn will have, although today (Q1 2009) the impacts are already enormous. The financial crisis thus poses risks in two main areas during the pilot study – availability of spare parts from VP's suppliers, and demand pattern changes from customers.

Historically, according to VP personnel, the main reason that shortages in VP's CW have occurred is that new production always has been prioritized over the

after sales market. Now when production is severely limited the suppliers can focus on the aftermarket, but on the other hand there is a larger risk that suppliers will lower capacity or even go out of business.

From the dealers' point of view the financial crisis affects their customers' buying patterns. On the one hand the general vehicle fleet is getting older and needs more spare parts; on the other hand there is less transportation work to be done. We believe that both these effects in some extent cancel each other out, and general trends will have to be further analyzed in the follow up work of the pilot study.

### **6.4.3 Psychological factors**

We believe that there is a significant risk with dealers working "against" (not necessarily consciously) the new parameters set by the NGiL model. For instance by manually ordering part that are included in the study when seeing that inventory levels are lowered, or getting scared and trying to block parts from automatic refill when the model balances parts that previously were stored at SW towards their inventories. These problems can probably be somewhat reduced by providing the dealers with information on the purpose of the study and information about the involved parts but could still pose a threat to unbiased analysis of results and comparison of scenarios.

Another risk is with creating trust and confidence for this new way of thinking, especially since the method in which the model measures service level achievement differs from the current definition of KPIs used at VP. Thus the model can optimize the inventories for a part in such a way that the current service level measurement (KPI1) will be lowered. This is especially true for parts that are balanced towards the SW and creates a risk for misinterpretation of results or lack of enthusiasm for the project if all definitions are not explained properly when communicating between theorists and practitioners.

## 6.5 Conclusion

The purpose of this thesis was to prepare for the pilot study which aims to investigate and validate the assumptions and theory of the NGiL model as well as the applicability of such a model in real world inventory system. Volvo Parts also wanted to see if the model could be applied in today's and future system and also what potential improvements and cost savings it could provide.

We conclude that a pilot study is possible to implement in Volvo Parts' systems provided some minor problems with setting the parameters are resolved. The identification and extraction of information from Volvo Parts systems in order to obtain and calculate the parameters needed for the part selection and the parameters used by the model is achievable. We do believe that the proposed determination and calculations of the cost parameters are valid to a large extent but only a pilot study can answer this for sure.

The selection and parameter extraction was performed for 100 spare parts and accessories on the Spanish market. Several criteria on the included parts were enforced, which included part characteristics, demand patterns, availability and controllability, to ensure a good selection. These criteria were successively fine tuned to arrive at the final selection. The selection was also investigated using the dimensions of price, market demand, number of dealers and variance-to-mean ratio of demand between dealers to ensure to the highest extent possible that the selection also is a representation of the whole parts range.

The potential of the model was investigated with a small simulation study for 20 spare parts and accessories that best represented the 100 selected ones in all dimensions. In this study the current situation (with the control parameters used today by VP) was compared to situation where the control parameters were determined by the NGiL model. This study shows a significant cost savings potential as well as reductions in tied up capital, which should in our opinion, provide motivation behind the implementation of the pilot study in a near future. Although limited in scope and scale the simulation study also shows that there are no clear patterns and correlations between the workings of the model and parts characteristics, which further increase the value of the pilot study.

## 6.6 Final thoughts

The table based control approach currently in used by VP is due to the fact that there are so many spare parts and accessories to manage (>20000 pcs just in Spain). This makes it impossible to control each part individually and was, according to VP personnel, a really big issue a few years ago when the systems were designed and the cost of electronic information exchange was high.

Apart from being easier to implement and minimizing the amount of data that needs to be sent between systems the current control approach has one more advantage according to VP personnel – it is easier to communicate to dealers. This is probably a big issue when convincing dealers to “sign up” for the LPA concept with its centralization of control and inventory management decisions.

By having the LPA/VMI concept VP shows that they are interested in centralizing the inventory management and a further development towards coordinated control is seen as a natural development. VP is also currently in a process of exchanging its’ systems portfolio with a more standardized and generalized solution. This solution will probably provide more visibility between all steps and actors in the supply chain and a possibility to implement a more detailed control of the parts in this new of system.

From this perspective this study can be seen as showcasing the potential and possibilities with coordinated control and we hope that the decision to perform the pilot study will soon be taken and that the technological obstacles will be eliminated. The pilot study will hopefully highlight some areas of interest that we have not found and maybe some relationships and patterns that the simulation study failed to detect.

As mentioned before this way of thinking is in no way limited to markets with a SW structure or even VP itself. However, VP as a major actor on the automotive aftermarket here has an opportunity to gain advantages towards its competitors and be an early adopter of this new way of inventory control and supply chain management which will almost certainly lead to lowered costs and reductions in tied up capital as well as less transportation work and lower emissions.



## 7 REFERENCES

### LITTERATURE

AB, V. P. (2008). *Årsredovisning 2007*. Stockholm: Affärsdata.

Andersson, J., Axsäter, S., Howard, C., & Marklund, J. (2008). Benefits of Coordinated Control of Multi-Stage Inventory Systems - A Case Study at Volvo Parts AB. *PLANs Tillämpnings och Forskningskonferens 2009*. Göteborg: PLAN.

Atkinson, P., & Hammersley, M. (1994). Ethnography and participant observation. In *Handbook of Qualitative Research* (pp. 248-261). London: Sage Publications.

Axsäter, S. (2006). *Inventory Control* (2nd Edition uppl.). New York: Springer.

Axsäter, S. (1991). *Lagerstyrning*. Lund: Studentlitteratur.

Axsäter, S., Howard, C., & Marklund, J. (2009). *A Distribution Inventory Model with Transshipments from a Support Warehouse*. Lund: Lund University.

Axsäter, S., Howard, C., & Marklund, J. (2008). *A distribution inventory model with transshipments from a support warehouse, Working paper*. Lund: Lund University.

Axsäter, S., Howard, C., Marklund, J., Svensson, G., & Twedmark, A. (2009). Coordinated Control of Multi-Stage Inventory Systems at Volvo Parts – The use of Quick Response Stocks. *PLANs Forsknings- och Tillämpningskonferens 2009*. Växjö: PLAN.

Bell, J. (2006). *Introduktion till forskningsmetodik*. Lund: Studentlitteratur.

Björklund, M., & Paulsson, U. (2003). *Seminarieboken: att skriva, presentera och opponera*. Lund: Studentlitteratur.

Blom, G. (2005). *Sannolikhets teori och Statistikteori med Tillämpningar*. Lund: Studentlitteratur.

- Brodin, P., & Sandberg, E. (2003). *Master thesis: Economic consequences in the logistic system*. Linköping: Dept. of Management and Economics, Linköping Institute of Technology.
- Hüliier, F. S., & Lieberman, G. J. (2005). *Introduction to operations research*. Boston: McGraw-Hill.
- Holme, I. M., & Solvang, B. K. (1997). *Forskningsmetodik: om kvalitativa och kvantitativa metoder*. Lund: Studentlitteratur.
- Höst, M., Regnell, B., & Runeson, P. (2006). *Att genomföra examensarbete*. Lund: Studentlitteratur.
- Inflation in Sweden 1831-2008*. (2009). Retrieved 02 17, 2009, from Statistiska Centralbyrån: [http://www.scb.se/Pages/TableAndChart\\_\\_\\_\\_33832.aspx](http://www.scb.se/Pages/TableAndChart____33832.aspx)
- Laguna, M., & Marklund, J. (2005). *Business process modeling, simulation, and design*. Upper Saddle River: Pearson/Prentice Hall.
- Lekvall, P., Wahlbin, C., & Frankelius, P. (2001). *Information för marknadsföringsbeslut*. Göteborg: IHM Förlag AB.
- Lundahl, U., & Skärvad, P. (1999). *Utredningsmetodik för samhällsvetare och ekonomer*. Lund: Studentlitteratur.
- Marklund, J. (2008). *Evaluation and use of extended information in integrated supply chains, Final Report NGIL project F4A 06-007*. Lund: NGIL, Lund University.
- Marklund, J., & Axsäter, S. (2008). *Coordinated inventory control at Volvo Parts, Project description NGIL Project F4A 08-009*. Lund: NGIL, Lund University.
- Meredith, J. (1998). Building operations management theory through case and field research. *Journal of Operations Management Vol. 16* , 441-454.
- NGiL. (2008). Retrieved 12 11, 2008, from Next Generation Innovative Logistics: <http://www.ngil.se>
- Näslund, D. (2002). Logistics Needs Qualitative Research – Especially Action Research. *International Journal of Physical Distribution & Logistics Management, Vol.32, No.5* , 321-338.

Oskarsson, B., Aronsson, H., & Bengt, E. (2006). *Modern Logistik*. Stockholm: Liber.

Patel, R., & Davidsson, B. (2003). *Forskningsmetodikens grunder*. Lund: Studentlitteratur.

Rosling, K. (2002). *The (r, Q) Inventory Model with Lost Sales*. Växjö: Växjö Universitet.

Svensson, G., Claesson, C., Twedmark, A., Kåreby, E., Svartborn, F., & Mellström, J. (n.d.). Respondent Group Gothenburg. (P. Borowiec, & C.-J. Liedberg, Interviewers)

Wallén, G. (1996). *Vetenskapsteori och forskningsmetodik*. Lund: Studentlitteratur.

VINNOVA. (2009). *Excellence Center*. Retrieved 01 21, 2009, from VINNOVA: <http://www.vinnova.se/Verksamhet/Starka-forsknings--och-innovationsmiljoer/VINN-Excellence-Center/>

Voss, C., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. *International Journal of Operations and Production Management, Vol.22, No.2*, 195-219.

Yan, J., Blackwell, A., Anderson, R., & Grant, A. (2000). *The memorability and security of passwords - some empirical results*. Cambridge University.

Yin, R. K. (2003). *Case Study Research: design and methods*. Thousand Oakes: Sage.

## **SCIENTIFIC REPORTS, PAPERS AND PUBLICATIONS**

Andersson, J., Axsäter, S., Howard, C., & Marklund, J. (2008). Benefits of Coordinated Control of Multi-Stage Inventory Systems - A Case Study at Volvo Parts AB. *PLANs Tillämpnings och Forskningskonferens 2009*. Göteborg: PLAN.

Axsäter, S., Howard, C., & Marklund, J. (2009). *A Distribution Inventory Model with Transshipments from a Support Warehouse*. Lund: Lund University.

Axsäter, S., Howard, C., & Marklund, J. (2008). *A distribution inventory model with transshipments from a support warehouse, Working paper*. Lund: Lund University.

- Axsäter, S., Howard, C., Marklund, J., Svensson, G., & Twedmark, A. (2009). Coordinated Control of Multi-Stage Inventory Systems at Volvo Parts – The use of Quick Response Stocks. *PLANs Forsknings- och Tillämpningskonferens 2009*. Växjö: PLAN.
- Brodin, P., & Sandberg, E. (2003). *Master thesis: Economic consequences in the logistic system*. Linköping: Dept. of Management and Economics, Linköping Institute of Technology.
- Marklund, J. (2008). *Evaluation and use of extended information in integrated supply chains, Final Report NGIL project F4A 06-007*. Lund: NGIL, Lund University.
- Marklund, J., & Axsäter, S. (2008). *Coordinated inventory control at Volvo Parts, Project description NGIL Project F4A 08-009*. Lund: NGIL, Lund University.
- Meredith, J. (1998). Building operations management theory through case and field research. *Journal of Operations Management Vol. 16* , 441-454.
- Näslund, D. (2002). Logistics Needs Qualitative Research – Especially Action Research. *International Journal of Physical Distribution & Logistics Management, Vol.32, No.5* , 321-338.
- Rosling, K. (2002). *The (r, Q) Inventory Model with Lost Sales*. Växjö: Växjö Universitet.
- Voss, C., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. *International Journal of Operations and Production Management, Vol.22, No.2* , 195-219.

## **ELECTRONIC SOURCES**

- Inflation in Sweden 1831-2008*. (2009). Retrieved 2009-02-17, from Statistiska Centralbyrån: [http://www.scb.se/Pages/TableAndChart\\_\\_\\_\\_33832.aspx](http://www.scb.se/Pages/TableAndChart____33832.aspx)
- NGiL. (2008). Retrieved 2008-12-11, from Next Generation Innovative Logistics: <http://www.ngil.se>

VINNOVA. (2009). *Excellence Center*. Retrieved 2009-01-21, from VINNOVA: <http://www.vinnova.se/Verksamhet/Starka-forsknings--och-innovationsmiljoer/VINN-Excellence-Center/>

## **INTERVIEWS**

### **Respondent Group 1, NGiL Researchers, 2008-10 to 2009-06**

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### **Respondent Group 2, Volvo Parts AB Gothenburg, 2008-11 to 2009-06**

Svensson, G., Claesson, C., Lennerstad, A., Prissberg, B., Twedmark, A., Andersson, J., Kåreby, E., Svartborn, Överås, G., F., Hallin, A., Mellström, J., Sjögren, D., Svård, L. G., Wennerholm, K., Du Pont, R., Kinnander, J., Svensson, P., Kjellberg, M. & Brodin, P.

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## **8 APPENDICES**

This chapter contains the appendices of the report.

### **The included appendices are:**

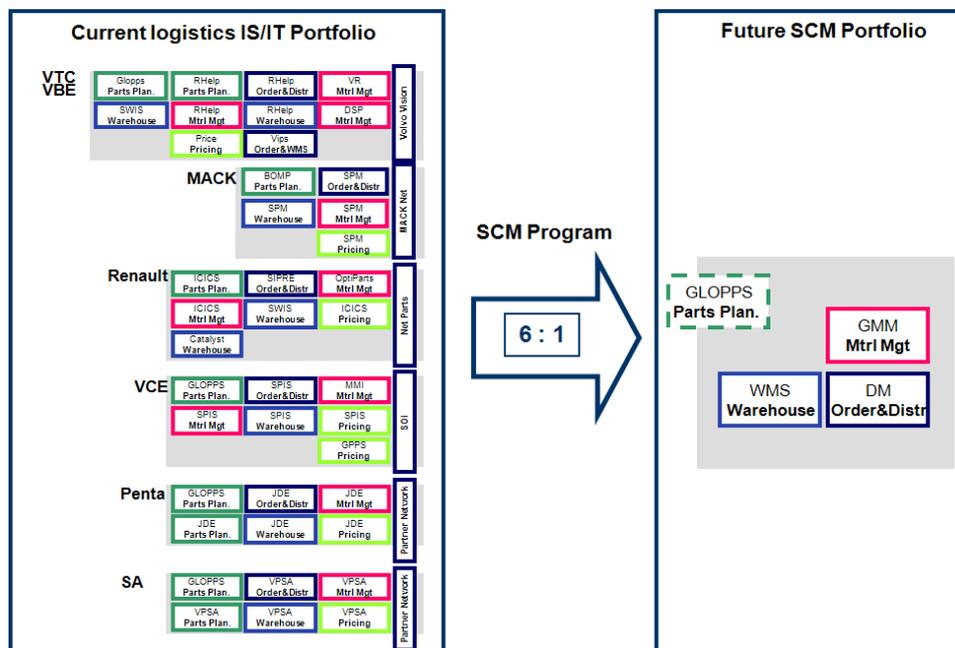
- Appendix 1 Systems
- Appendix 2 Spare part specific information
- Appendix 3 Key performance indicators
- Appendix 4 The SQL database
- Appendix 5 Selection of parts
- Appendix 6 The disparity of the selected parts
- Appendix 7 Lead times
- Appendix 8 Shortage cost
- Appendix 9 Simulation study
- Appendix 10 Initiation of the pilot study

## Appendix 1 Systems

This appendix contains information about the information and IT systems used by Volvo Parts.

Volvo was the first engineering company in Sweden to use computers for all administrative data management. The first mainframes were installed in 1961 and the Parts department (the precursor to Volvo Parts) was the first department to be computerized (in 1962). Since then a lot of new systems have been introduced and many modifications of some of the old systems have been performed, leading to a large portfolio of different information and management systems being used within different areas of the organization.

There is currently a large ongoing Supply Chain Management project with the goal to increase information visibility and service efficiency on a global scale. One of its objectives is to reduce the complexity of the systems portfolio, of which many are near the end of their life cycle, with one totally integrated system.



In the following sections there will be a short description of the main systems used in the processes at the Logistics & Customer Support function. The systems which are of special interest for this thesis – those that govern the

order processes in the areas of the supply chain where the pilot study is to be performed and systems from which data is extracted and used for analysis are described in more detail.

### **RHelp**

RHelp is a planning, material management, warehouse management, ordering and distribution system. It is run on a mainframe computer and commands are issued through a terminal application.

It is used many of the major activities at Volvo Parts, mainly in the procurement and refill processes for VTC/VBC. The other Business Areas such as Penta and Construction Equipment have their own tools for planning, ordering, refill and warehousing operations.

### **Business Objects**

Data from the RHelp system is accessed from a data warehouse in the client software Business Objects. It is a data mining and report generation tool that can extract information from all the databases used by the RHelp system and allows the user to perform spreadsheet operations such as summing, calculating averages, counting, pivoting and generating charts.

This data warehouse is used throughout the Logistics & Customer Support function and has many predefined reports, but also offers the users the ability to create their own customized queries and even to simulate data.

The data is categorized in universes (one for each Business Area) and then by modules corresponding to the department or process needs.

### **DSP**

DSP (Dealer Stock Control Package) is an information system for control and administration of stock replenishments at the dealer level.

It is mainly used by the LPA Process and holds information about sales history, forecasts, current stock situation for each dealer. The system also generates purchase orders and purchase proposals based on this information and conditions set by the LPA team. It offers an extensive set of parameters and control functions and can be tailored to conform to each specific situation that may arise in the dealers' sales and marketing strategies.

## **PAST**

PAST (Parts Analysis Segmentation Tool) is mainly a reporting tool and data warehouse for the DSP system, but some control can be issued from PAST such as parts range segmentation.

It is used by members of the LPA team for detailed inventory control and follow-up on the performance of dealers and parts at the final stages of the supply in order to ensure high local availability. It collects its data from the DSP system and the older VR system.

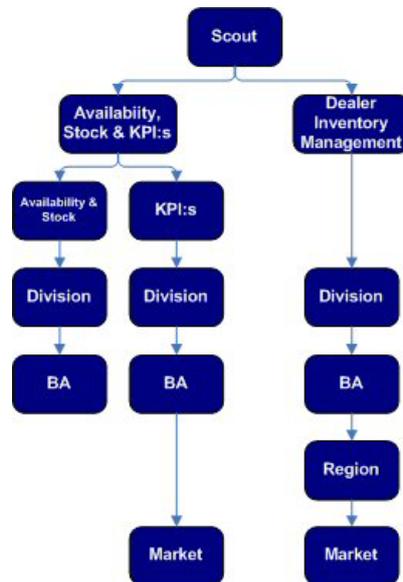
PAST has a web interface where analysis can be performed on an aggregated level (for the dealer) in a price/frequency class matrix, for parts from a specific class or for just one specific part. This analysis can include KPI development, sales volumes, stock value or turnover rate as well as many other measures that are used to evaluate the performance of the individual dealers. Summarized dealer statistics and reports can be created and sent by e-mail (to the dealer).

The system can also perform simulation in order to analyze service index and stock value.

## **Scout**

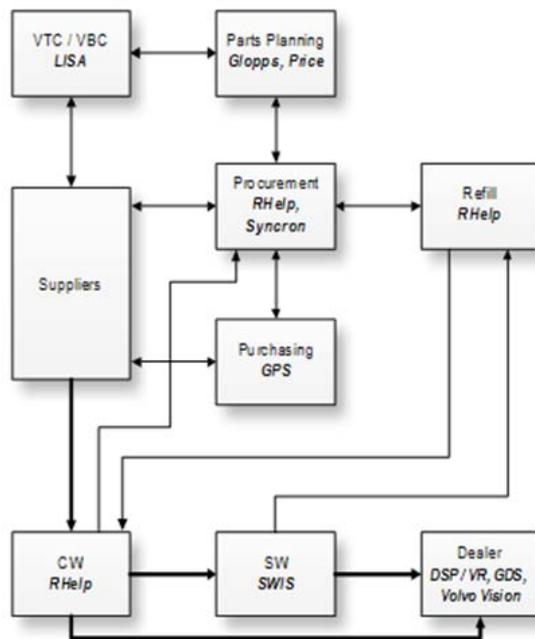
Scout is a web-based reporting tool for information about parts availability, stock information and key performance indicators on aggregated levels. It is used by management for strategic decisions and can be used for planning and follow-up on a global, regional or national scale.

The information in Scout is organized by geographical division and Business Area (e.g. VTC, VBC). Reports on key performance indicators can be shown on an aggregated level, for regions (e.g. continents, Nordic, Eastern Europe, Benelux), nations, dealer focus groups (LPA/non-LPA dealers) down to individual dealers. The data can be summarized or broken down on weekly basis and exported in a variety of ways.



### Other systems and tools

The mentioned systems cooperate with each other and a number of other systems within the Volvo Parts supply chain. The following figure places the mentioned tools (RHelp and DSP) in this context and also introduces some other tools which are then described.



*VR* is an older dealer control system that is still used in some markets. It is the predecessor of DSP and has many of the same functions as DSP. DSP was developed as a “light” version of VR during the time that information exchange was expensive but is now the dominant dealer control system.

*GDS* is the Global Dealer System and is a system used by VTC dealers and thus not a Parts system. It communicates with the DSP system for dealers in the LPA concept.

*Volvo vision* is a tool for dealers to enter manual orders (as part of the Volvo Action Service) and to follow up order status and obtain specific information about parts.

*Glopps* is the global parts planning system used by the planning department.

*Price (POS)* is the price management tool that decides on the purchase price of parts at dealers.

*Synchron* is a forecasting tool used by procurement in order to calculate safety stock and its calculations are synchronized with the RHelp system each night. It has trend and seasonality functions and is used on a CW level.

*GPS* is the global purchasing system used by the purchasing department. It can be used to locate parts information, even those used between different Business Areas.

*SWIS* is the support warehouse information system that runs together with the warehouse management systems at the SW to handle orders.

*VIPS* – the Volvo Importer Purchasing System is used on the markets where an importer has a warehouse and performs ordering and warehouse management functions.

*Macros* are built in Excel/Visual Basic and used to eliminate repetitive tasks e.g. for refillers working with the DSP system.

*Extra databases* are used to store data older than 12 months and can be accessed for special purposes where the normal reporting tools are not sufficient.

*LISA* – tool used by VTC, VBC and Volvo Parts to create and maintain parts information.

## **Appendix 2 Part specific information**

Information on how specific or special spare parts or accessories are to be handled in certain circumstances is presented in the sections below as well as the units of measure, kit and price definitions of parts.

### **Supersessions**

Supersession is the routine of replacing or removing parts from the parts range due to new improved solutions, quality reasons, rationalizing or outdateding of the part in order to improve the customer satisfaction, improve the quality and reduce costs of Volvo's parts range.

This responsibility falls on the Exchange process of VP whose policy is to achieve high quality of all products through continuous development and improved efficiency.

When a part is considered to be superseded (which could be done when; an end customer informs Volvo about a quality issue, by development of improved products, or by rationalization of the parts range) the parts planning department of VP adds a supersession code to the part in question. This code consists of a status code, a consumption code, a structure code and, if applicable, technical information that will give information of the superseded part and how the supersession should be handled. This supersession code also includes a date when parts are set to "final" and are to be superseded due to quality and/or legal reasons. This date is updated by the parts planning department.

Concerning parts superseded for quality reasons, the due date is set to 30 days (90 days for dealers not connected online) after the part's status code has been set to "final". In order for the dealers to be refunded for the superseded parts, all scrapping must be reported to VP before this date.

*The Status Code* is for internal use only and external systems are only notified about supersessions when the status code has turned to “final”.

- |   |             |   |
|---|-------------|---|
| P | Preliminary | The part is to be phased out at VP, meaning that the supersession has been fully processed by the parts planning department.<br>The system now awaits introduction week and availability of the, if applicable, superseding part and also, when it is “use up” coded, for the inventory at CW to be depleted. |
| F | Final       | When the code is set from “P” to “F”, no more deliveries from suppliers are to be expected and the part is to be used up or scrapped at the central/regional/support warehouse and/or dealer depending on the consumption code assigned.  |

*The Consumption code* defines the way in which the superseded part should be handled by internal and external systems.

- |   |           |   |
|---|-----------|---|
| 1 | Use Up    | The part is to be used up i.e. no more deliveries from suppliers and the part could still be used until the inventories are replaced by the superseding part(s), if applicable.   |
| 2 | Quality   | The part is superseded for quality reason and the part is to be scrapped as soon as the status code is set to “final”. From this date the part is not allowed to be used, sold or mounted at any Volvo facility affected by the supersession. |
| 3 | Pre. Prod | Preproduction part code is for internal use only and appears when the part is superseded in pre-production.   |
| 0 | (blank)   | If the part is not labeled with the consumption code 1,2 or 3, it is set to 0, i.e. the part is not to be superseded.   |

*The Structure Code* defines the replacement structure of the superseded part and is used in all external and internal systems.

- |   |          |   |
|---|----------|---|
| S | Single   | The superseded part is replaced by one superseding part   |
| M | Multiple | The superseded part is replaced by at least two superseding parts   |
| V | Variable | The superseded part is replaced by a variable amount of superseding parts depending on: type of vehicle, variant and/or function or location on the vehicle |
| 0 | Expired  | No structure exists, due to either new technical solution or a VP stock holding policy  |
| - | (blank)  | The part is not to be superseded. No structure exists   |

### **Exception parts**

Certain spare parts or accessories are to be excluded from normal routines and procedures due to the nature of the part or other exceptional events. These parts are labeled with an internal exception code in VP systems as follows:

- A All time buy - The supplier will seize production of the part in the near future. An offer is made to Volvo to make one last buy. The quantity in this buy is probably much larger than normal. The procurer flags the part with this exception code which notifies that it is allowed for this larger quantity in this case.
- P Passive - The part is set to passive by the parts planning which means that the part is not to be stocked until the exception code is changed.
- L Alarm - Same consequences as the Passive code but are set and controlled by a procurer.
- M Military - The part is specially built for military purpose and vehicles and is only to be sold to the military.
- S Special - Customer specific or market specific part that is not to be stocked.

### **Exchange parts**

In order to handle the flows of remanufactured parts from the remanufacturing plant as well as the reverse flows of parts from the dealers to the plant an exchange code is used.

This code consists of two characters; one identifying the type of the exception and the other presents the properties of the part. The part identifier can be blank, which means that it is an ordinary part that is not exchanged. It can also be either "Exchange part" E or "Radio" R. A radio part is exchanged since radios are custom build for Volvo vehicles and no other radios can be used or fitted in a Volvo vehicle.

The properties of the parts have the following presentation:

- Blank. Ordinary spare part or accessory
- X Exchange. Part that has exchange connection with other part
- Y Previous exchange. Exchange part previously existed to this part, but now only a new part is offered.
- C Core part. This part is sent to renovation when arriving when returned and replaced by an exchange part.
- R Remanufactured part. The part has been remanufactured at one of VP remanufacturing plants

The combination of these two characters gives e.g. “E R”, which then is interpreted as an exchange part that has been remanufactured or “R R” for remanufactured radios.

### **Hazardous parts**

Certain parts are to be treated as hazardous material and have limitations and regulations with respect to e.g. packaging, transportation and handling, which needs to be followed. Parts are therefore labeled with a Hazardous Code, or HazCode, that determines how the parts should be treated. The codes are as follows:

- 1 New spare part or accessory, not yet classified.
- 2 Part under investigation to be classified.
- 3 Normal part, not hazardous.
- 4 Part has transportation restrictions.
- 5 Part contains asbestos.
- 6 Part contains chemicals that do not have any restrictions.
- 7 Non existing code.
- 8 Part contains sealed asbestos, not under any restrictions.
- 9 No asbestos exists in the part.

### **Blocking codes**

Parts that are blocked from automatic orders at dealer inventories are flagged with a “Purchase code” different from 0 in DSP.

- 0 Part automatically ordered to supplier (no blocking)
- 1 Temporarily manual part, blocked by the systems.
- 2 Manual part, which means that the part is set to manual by the parameter limits and will remain manual until the National Inventory Manager manually changes the parameters.
- 3-9 Part manually blocked by the dealer.

Parts that are blocked from refill to the SW have a similar blocking possibility in the RHelp system. A code called “Refill part” decides if a part is to be refilled to SW or not.

### **Units of Measures and Kits**

UOM refers to the way in which the quantity of the part is measured and is noted as the UOM code. Several different codes may exist for the same type of measurement.

Parts can be sold separately or together with other parts into kits. These kits do have a unique part number and is treated as a single part. Some types of parts are only sold as a constituent in a kit but more common is that a part can be sold both separately and as a constituent.

Constituent parts are received from suppliers and are assembled and packed into kits at one of VP warehouses, typically at CW.

The different UOM codes are as follows:

EA.	Piece.
ST.	Piece.
PC.	Piece.
SA.	Kit.
KT.	Kit.
M.	Meter, running length.
F.	Feet, running length.
L.	Liter.
GA.	Gallon.
KG.	Kilograms.
SW.	Software.

### ***Quantity measures***

Demand, forecast and price is always calculated and stored for single entities in the unit of measure throughout VP systems.

However some orders and deliveries are performed in aggregated quantities in order to minimize workload and costs. Some of these quantities are listed below:

Q0	Quantity in box by supplier or pre-packer.
Q1	Sales quantity to dealers (“bulk pack”).
Service quantity	The quantity generally needed to perform a repair or installation of a part.

Order quantities of refill orders to the CW or SW are always rounded up to Q0 if it exists. This is the quantity in which the part is delivered from the supplier or pre-packer.

Q1 is the quantity that is delivered from CW or SW to dealers. It is only broken by the dealers (who sell in single units) or when VOR orders are dispatched from CW or SW. Refill order quantities are rounded up to Q1 if Q0 does not exist. Deliveries to dealers are always in multiples of Q1.

Dealer stock levels are always rounded up to multiples of the service quantity. This is to ensure that a sufficient amount of the part needed to perform the repair or installation is always stocked, e.g. both brake drums on a truck or bus are always replaced simultaneously, yielding a service quantity of 2.

### ***Price definitions***

Prices are stored in the VP systems in SEK and local currency (where applicable). The prices used are:

Standard price	Base price, includes all costs until the part is stored at CW.
Repurchase price	Standard price plus surcharges for transports, inventory holding and gross profit of the Business Area (VTC, VBC).
Retail price	The price set by dealers for end customers. Based on repurchase price and surcharges such as dealer gross profit.

The standard price is updated once a year by the financial department. Value-volume classes at SW are based on the standard price, however at the dealer level it is the repurchase price that decides the value class. The repurchase price is also the price used when VP buys back parts from dealers in the LPA concept.

### **Appendix 3 Key Performance Indicators**

Volvo Parts measures the performance of markets and dealers using key performance indicators (KPI). These KPIs are aggregated on a total level, market level or down to dealer level on a weekly or monthly basis. All KPI calculations are done automatically in the SCOUT-system (see Appendix 1).

- KPI1 *Dealer service index or over the counter fill.* This performance indicator measures the parts availability to the end customers at the dealers.
- KPI2 *Parts availability, all order classes and warehouses.* This performance indicator measures the availability to the dealers, i.e. if the dealer got the quantity ordered.
- KPI3 *Parts availability, day orders, all warehouses.* As KPI2 this performance indicator measures the availability to the dealers with the distinction that it only includes day orders.
- KPI4 *Price development.* Measures the price development of purchased materials.
- KPI5 *Freight cost* as a percentage of the transported volume, based on the standard value of the transported goods. Both inbound and outbound transports.
- KPI6 *Capital tied up in inventory.* Measures the capital turnover rate (ToR) to control the efficiency of the utilization of capital.
- KPI7 *Logistic operating expenses by volume.* Measures the cost efficiency of the logistics operations.
- KPI8 *Backorder recovery.* Measures the recovery on backorders for day orders.

For this thesis, the relevant KPIs to measure are KPI1, KPI2, KPI3 and KPI6. The definitions of these are therefore described in detail.

#### ***KPI1***

This KPI measures performance of all VTC and VBC parts supplied by VP of dealers connected to one of VP stock management systems (DSP, VR or LPA) on all levels weekly. Excluded from the measurements are finally replaced parts, parts without any forecast, parts without sales for the last half a year, parts that only have sold once, any sales reported as category 2 (cat2) sales (not affecting forecast) and software. It is the only KPI that measures services to end customers. It is defined as the percentage of parts that have more than one week of forecasted demand in stock compared to all parts with a forecast as

$$\frac{\sum \text{all parts} > 1 \text{ week demand, cat1 \& cat2 sales last 12 periods}}{\sum \text{all parts, cat1 \& cat2 sales last 12 periods}}.$$

### ***KPI2 and KPI3***

KPI2 measures the performance on all Business Areas, all warehouses, all order classes and fully and partly delivered orders on European, North- and South American market on a weekly basis. Excluded from the measurements are blocked parts, passive parts and orders labeled as scrapped, kits, packing material direct deliveries and special orders. It measures the service experienced by the dealers from Volvo Parts warehouses.

The KPI is calculated as a percentage of the gross (allocated) or net (delivered) quantity of the ordered quantity on an average order line as

$$\text{On gross level : } \sum \left( \frac{\text{allocated quantity}}{\text{ordered quantity}} \right) / \sum \text{order lines}$$

$$\text{On net level : } \sum \left( \frac{\text{delivered quantity}}{\text{ordered quantity}} \right) / \sum \text{order lines}.$$

### ***KPI5***

This KPI is measured and calculated in an analogue way but only considers day orders.

### ***KPI6***

The KPI measures the performance on all Business Areas on company level and distribution area for all markets on a monthly basis. The KPI measures on all parts from the point the parts delivery is advised from supplier to the point the parts are invoiced to a dealer. This KPI is also divided on automatic, manual and total orders. The turnover rate (*ToR*) is based on the outgoing deliveries and stock value calculated over the last 12 periods and based on previous week's values. This gives

$$\text{ToR} = \frac{\text{Outgoing deliveries last 12 periods}}{\text{Average stock last 12 periods}}.$$

## **Other Performance indicators**

Besides the KPIs described in the previous section VP also measures other performance indicators (PI) on markets on total market level or down on dealer level. These performance indicators are also available in SCOUT on dealers that regularly provide VP with stock and sales information.

### *Sales and stock value*

This PI measures the stock and sales value (in monetary value) on market or dealer level on a weekly basis. The stock value is divided into manually and automatically refilled stock and sales value is based on 12 period total sales.

### *Stock health*

The purpose of this PI is to see how healthy the stock is, i.e. the fractional distribution of the different characteristics of stocked parts and is measured weekly. Three stock types are defined; healthy stock, over stock and dead stock. Healthy stock is stocked parts that have a good turnover rate and a forecasted demand. Over stocked parts also has a forecasted demand, but low turnover rates due to having too large stock, more specifically, the stocked parts have not sold for at least one month. Finally, dead stock is defined as stocked parts older than one year, no forecasted demand and that have not sold for a long period of time. The dead stock is also divided into manually and automatically ordered dead stock.

### *Stock values*

This PI measures, on a weekly basis, the fractional distribution of the three different stock types (as described above) based on the monetary value of these types. The PI is illustrated on three levels; total stock, automatically refilled stock and manually refilled stock.

### *Day/Stock order development*

The PI measures the fractional distribution of day- and VOR orders compared to stock orders and the total number of order lines for the different order types on a weekly basis.

### *Share automatic orders*

The fraction of automatically refilled orders of the total number of orders is calculated on both an order line and value basis every month.

### *Sales not affecting forecast*

The KPI shows the fraction of the value of sales not affecting forecast compared to total sales, and the forecast quality, i.e. how good the forecast was compared to the actual outcome. This is calculated on a monthly basis.

### *Share of picks blocked parts*

This PI calculates the fraction of parts that are blocked from either automatic or manual refill. The PI is calculated on a monthly basis.

## **Appendix 4 The SQL database**

Since data for this study has to be extracted from a number of different VP systems and also due to the strict security policy (making data extraction impossible from non-VP workstations) an SQL database is created and filled with data extracted from the VP systems. The sheer amount of data extracted called for a solution outside of a classic spreadsheet software based approach in order to facilitate detailed analysis.

### **Data extraction and database creation**

The data necessary for the selection and classification of parts for the pilot study is extracted from the following VP systems or given from the following sources:

- List of all dealers in the selected Spanish market
  - From the Scout system
- Demand data on a per dealer and part basis
  - From the Past system, exportable to one Excel-sheet per dealer
- Data unique for a given part at a given dealer (such as reorder points and order quantities)
  - From the Past system
- General part characteristics
  - From the RHelp Data Warehouse
  - Exportable to Excel-sheets
- CW orders and backorders
  - From the RHelp Data Warehouse
- SW order and backorders
  - From personnel in the Refill process, in raw text format
- Cost parameters
  - From Excel sheets emailed from transportation and inventory management

The decision to construct a customized database for the project has the following benefits:

- Consolidation of data from different VP systems and other sources

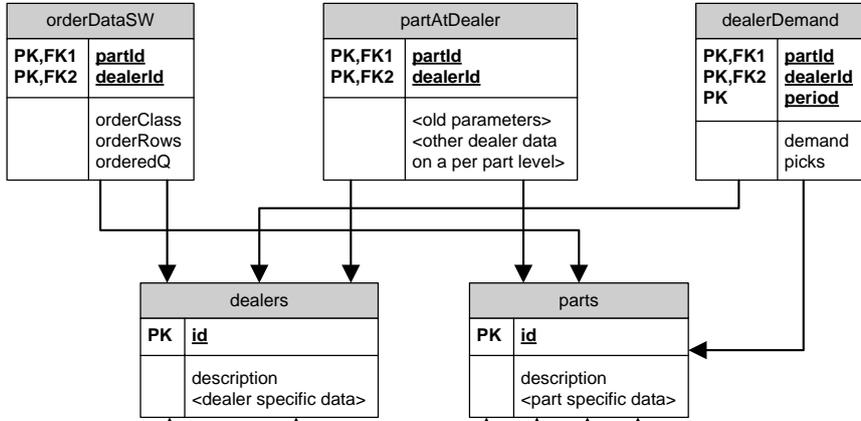
- Possibility to perform snapshots of data in time (beneficial for calculating own performance measures to be compared with post-study performance measures)
- Calculation of aggregate statistical measures for a large number of parts and the ability to reuse them without having to recalculate
- Experimentation with different selection criteria levels without wasting VP computational resources, which also saves time

### ***Database structure***

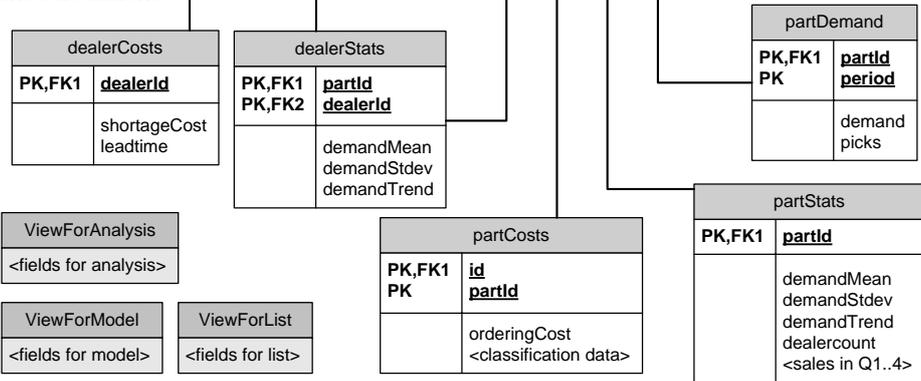
The database is roughly divided into data extracted from the above mentioned VP systems (“Data from Volvo systems”) and data generated and calculated outside these systems (“Own calculations”). For example the number of picks and sales on a dealer level are stored on a per period level in the “demandDealer” table in the “Volvo” section, whereas the calculated sums of demand for the market as a whole are stored in “demandPart” in the “calculated” section. Statistics for these sales such as sums, averages and standard deviations are stored in the “statsDealer” table or “statsPart” table in the “calculated” section. Likewise the number of CW order hits and CW backorders are stored per article in the “part” table, whereas the calculated service level is stored in “statsPart” table.

Several database views are created in order to easily extract data about articles for a given purpose such as: further analysis in Excel (viewForAnalysis), creation of lists for VP personnel (viewForLists) or the implementation of the analytical model (viewForModel). In each view the relevant data fields for each purpose are included from the different tables.

### Data from Volvo Systems



### Own Calculations



### ***Statistics calculation***

The demand (sales affecting forecast) is extracted from the Past system and stored in the database in this raw format (in the table “dealerDemand”). This demand data consists of monthly picks and sales in both categories – both normal and category 2 (no history) sales (see 4.2.3) for each part at each dealer. In order to speed up calculations and experimentation with different filtering levels the demand is summed for each article (in “partDemand”) and a couple of aggregate statistics (sum, average, standard deviation, trend and seasonality) are calculated.

Means and standard averages of these demand data (sales) are calculated using the normal statistical methods both on dealer level (in the table “dealerStats”) and on the market level (in “partStats”).

Trend is calculated by using normal linear regression, and normalized by dividing with the period average in order to get a value not in units of change but in percentage of change. The absolute value of this normalized value is referred to as ANT (absolute value of normalized trend) and is calculated both on a dealer level and on a market level for each part.

Seasonality is calculated on a market level by summing the demand of each quarter (“partDemand” table). This allows for a comparison of total market demand between each quarter for each article.

## Appendix 5 Selection of parts

This appendix contains the selected parts and information on these. The first table contains information about the selected parts obtained from VP systems while the second table contains information calculated and constructed in this thesis.

Number	Description	Function group	Product Group	Bulk-pack	Weight	Volume	Standard Price	SW VVCL	SW forecast
244328	BALL	1315	43	0	15	97	XX	5A	0.2
244815	GASKET KIT	5634	43	0	16	112	XX	5F	10.8
341717	ROLLER	5119	53	0	328	83.3	XXX	6C	1.6
477928	SLEEVE	2119	42	0	81	200	XX	4F	12.9
976489	V-BELT	1223	43	0	125	637.8	XX	4B	0.9
980573	PLUG	4609	42	0	66	18.7	XX	4E	6.8
981281	MAGNETIC	1515	43	0	63	17	XX	4E	4.6
1075723	BOLT	7213	43	0	975	208	XX	5E	5.5
1081328	DRAINING	5633	43	0	50	22	XX	4A	0.1
1089552	SEALING	7735	43	0	165	512	XX	5G	18
1128640	ANTENNA	3952	46	0	90	50	XX	4B	0.7
1161246	GREASE	1831	48	12	52	115	XX	6A	0
1161315	GREASE	1831	48	50	1100	2021	XX	7A	0
1161932	TRANSMISSIO	1833	48	4	4775	9327	XXX	7A	0
1161936	TRANSMISSIO	1834	48	4	4825	7524	XXX	7A	0
1161995	TRANSMISSIO	1833	48	4	4600	6897	XX	6A	0.1
1573081	WHEEL STUD	7734	43	0	405	116.4	XX	4F	13.1
1593924	LAMP	3526	43	0	300	3225.7	XX	5C	1.3
1605182	RUBBER	7629	43	0	255	778.6	XX	5E	5.2
1614798	DIAPHRAGM	5129	43	0	150	1231.2	XX	5B	0.5
1629193	AIR BELLOWS	7261	43	0	1740	24863	XXX	6F	13.6
1638052	SEALING	2539	42	0	20	912	XX	5D	3.6
1668822	FORK	4135	42	0	190	68	XX	5D	3.4
3090483	LOCK	8342	43	0	112	200	XX	5D	3.6
3090948	BULB SOCKET	3529	43	0	30	135.1	XX	4D	3.5
3092472	BALL JOINT,	6432	43	0	1490	900	XXX	6E	4.3
3092602	HEAT	5921	43	0	17000	22287	XXXX	9E	4.3
3944785	AIR CLEANER	5619	43	0	188	810	XX	4E	5.9
3978768	INLET VALVE	2141	42	0	143	581.3	XX	5F	9.2
3981594	HEADLAMP	3522	43	0	1917	17982	XXX	6E	7.1
3981782	LENS	3534	43	0	434	2762	XX	5C	2.2
6645225	REPAIR KIT	5615	43	0	5	752.6	XX	5C	1.5
8112354	COOLANT	2621	54	0	14210	20800	XXXX	8B	0.8
8112556	UNIT	2374	44	0	2240	2035.8	XXXX	8F	9.3
8112598	PRESSURE	4112	44	1	40500	48276	XXX	7C	1.9
8112818	UNIT	2374	44	0	1878	2352	XXXX	8B	0.9
8113121	TURBOCHARG	2551	44	0	19000	23115.4	XXXX	8C	1.9
8113286	UNIT	2374	44	0	1985	2035.8	XXXX	8E	4.3
8113893	INJECTOR,	2371	44	0	325	226.6	XXX	6E	4.8

8132024	ELECTRIC	2759	42	0	1084	8887.6	XXXX	8C	2
8140318	ADJUSTING	3522	43	0	15	7	XX	4C	1.6
8152010	AIR FILTER	5619	43	0	300	1134	XX	4C	1.8
8155731	CLAMP	9229	43	0	320	384	XX	4G	20.1
8156383	NIPPLE	3869	43	0	1	1	XX	4A	0
8191145	FLASH LAMP	3526	43	0	280	3703.1	XX	5B	1.1
9516524	BUSHING	7629	43	0	525	827	XX	4E	7.4
9520435	THERMOSTAT	3821	53	0	45	0	XX	5C	2.4
20382312	PRESSURE	5633	43	0	395	539	XX	5F	16
20390840	BUSHING	8181	43	0	900	567	XXX	6E	8
20398386	BEZEL	3523	43	0	3888	105000	XXX	7D	3
20398708	BUMPER	8611	43	0	2910	15750	XXX	6E	4.3
20424901	REGULATOR	5615	43	0	869	1560	XXX	7E	5.7
20452889	COVER	3522	43	0	992	49392	XX	5D	3
20453677	SPACER	8619	43	0	161	3025	XXX	6E	5.3
20453900	REAR FENDER	8251	43	0	3330	85600	XX	5C	2.5
20456806	SPOILER	8915	43	0	355	5800	XX	5C	2.1
20467442	UNDERRUN	8639	43	0	92000	1071000	XXXX	8E	5.3
20467950	CONNECTOR	3769	43	0	253	2212	XXX	6D	3.5
20516776	FRONT PANEL	8231	43	0	3068	117730	XXX	7D	3.4
20520130	COVER	8913	43	0	21	108	XX	4E	4.4
20527429	HOSE	5739	43	0	430	6292	XX	5E	4.5
20527443	SUN VISOR	8913	43	0	3000	4275	XXX	7D	3
20535877	AIR SPRING	7251	53	0	4250	10500	XXX	6B	0.7
20538793	SEALING	2116	42	0	295	1587	XX	5F	12.6
20568711	BRAKE PAD	5115	43	0	10720	4125	XXX	7G	24.4
20571928	RELEASE	4121	42	0	2660	8804	XXX	7D	2.8
20572012	PISTON	2145	42	0	135	40	XXX	6E	5.7
20582209	AIR SPRING	7261	43	0	6300	24768	XXX	7G	16.8
20583477	PULSE	3865	43	0	106	200	XXX	6F	16.2
20589788	MIRROR	8463	43	0	936	3960	XX	5E	5.8
20589817	WIDE VIEW	8465	43	0	575	5287.5	XX	5D	3.4
20755936	STUD	1126	43	0	190	34	XX	4B	0.8
20779040	SERVICE KIT,	4919	42	0	95	1056	XX	5G	22.9
20816210	PAPER	3835	43	0	96	262.5	XX	4D	2.6
20817742	GASKET	2152	42	0	47	726	XX	4E	5
20826227	LAMP BODY	3526	43	0	62	812.5	XX	4F	13.4
20826231	LAMP BODY	3526	43	0	62	812.5	XX	4F	11.3
20847116	KIT	4315	42	0	58	152	XX	4C	2.1
20854576	MIRROR	8463	43	0	728	1210	XX	5B	0.8
20879812	FUEL FILTER	2335	42	6	784	1936	XX	7F	81.6
20882320	AIR FILTER	2562	42	0	4300	98838	XXX	6D	3.5
20892199	CABLE	2849	42	0	3000	55755	XXX	7C	1.8
20894627	CLAMP	7621	43	0	190	114.4	XX	4E	5.4
20910229	SPARE PARTS	3531	43	0	360	3496.5	XX	5E	6.3
20917957	LAMP	3522	43	0	3980	100100	XXX	6F	11.5
20946393	CABLE	3769	43	0	1230	7020	XXX	6B	0.9
20972915	FILTER	5618	43	0	2675	3890	XXX	6G	22.3
21001663	HEADLAMP	3521	43	0	6703	39512.5	XXX	7E	5.1
21001668	HEADLAMP	3521	43	0	6703	39512.5	XXX	7E	5.2
21058175	CHARGE	3221	43	0	71	289	XXX	6F	9.5

85000064	COMPRESSOR,	5611	44	0	22000	28560	XXXX	8D	3.7
85000186	STARTER	3311	44	0	19120	17179	XXX	7E	5.5
85000194	COMPRESSOR,	5611	54	0	22000	28560	XXXX	8B	0.7
85000238	DRIVEN	4117	44	0	10500	13747	XXX	7E	7.6
85000265	CLUTCH KIT,	4111	44	0	72000	48276	XXXX	8C	2.5
85000483	CHARGE AIR	2651	44	0	56500	681390	XXXX	8E	4.4
85105029	ADAPTER	3711	43	0	55	160	XX	5E	6.8
85107093	BULB SOCKET	3522	43	0	4	10	XX	4C	2.4
85108900	COOLANT	1841	48	0	5510	7875	XX	5A	0
85108913	COOLANT	1841	48	4	5510	7875	XX	6A	0

Number	Description	CW SERV	Dealer count	Demand total on market	Demand average per dealer	VMR	classP	classF	classD	classV
244328	BALL	100%	15	11	0.73	1.41	M	L	L	M
244815	GASKET KIT	98%	34	112.83	3.32	2.13	M	H	L	H
341717	ROLLER	99%	6	8	1.33	5.74	M	L	L	H
477928	SLEEVE	99%	38	43.58	1.15	4.62	L	M	M	H
976489	V-BELT	97%	52	38.58	0.74	1.41	L	M	H	M
980573	PLUG	100%	58	59.58	1.03	1.98	L	H	H	M
981281	MAGNETIC	98%	58	44.5	0.77	1.74	L	M	H	M
1075723	BOLT	93%	38	27.08	0.71	1.72	M	M	M	M
1081328	DRAINING	98%	42	28.25	0.67	1.54	L	M	M	M
1089552	SEALING	100%	58	95.17	1.64	1.60	M	H	H	M
1128640	ANTENNA	100%	15	7.58	0.51	1.03	L	L	L	L
1161246	GREASE	100%	12	11.25	0.94	1.29	L	L	L	M
1161315	GREASE	100%	7	75.58	10.8	5.76	L	H	L	H
1161932	TRANSMISSI	96%	8	6.92	0.86	2.20	H	L	L	H
1161936	TRANSMISSI	100%	6	6.42	1.07	3.27	H	L	L	H
1161995	TRANSMISSI	98%	31	124.25	4.01	2.96	M	H	L	H
1573081	WHEEL	100%	39	30.83	0.79	4.30	L	M	M	H
1593924	LAMP	93%	51	28.58	0.56	1.12	M	M	H	L
1605182	RUBBER	100%	46	34	0.74	2.17	L	M	M	H
1614798	DIAPHRAG	99%	36	21.08	0.59	1.25	M	L	M	M
1629193	AIR	100%	51	56.25	1.1	2.29	H	H	H	H
1638052	SEALING	97%	30	15.33	0.51	1.16	M	L	L	L
1668822	FORK	99%	51	33.83	0.66	1.25	M	M	H	M
3090483	LOCK	100%	46	23.25	0.51	1.00	M	L	M	L
3090948	BULB	100%	48	43.75	0.91	1.64	L	M	M	M
3092472	BALL JOINT,	100%	46	24.5	0.53	1.20	H	L	M	L
3092602	HEAT	100%	32	12.33	0.39	1.00				
3944785	AIR	100%	60	284.5	4.74	1.59	L	H	H	M
3978768	INLET	98%	12	8.58	0.72	5.31	M	L	L	H
3981594	HEADLAMP	100%	57	60.75	1.07	1.26	H	H	H	M
3981782	LENS	100%	59	53.92	0.91	1.13	M	M	H	L
6645225	REPAIR KIT	100%	27	15.92	0.59	1.00	M	L	L	L
8112354	COOLANT	96%	10	2.92	0.29	1.11				
8112556	UNIT	100%	46	22.92	0.5	3.97				
8112598	PRESSURE	97%	38	15.5	0.41	1.04				

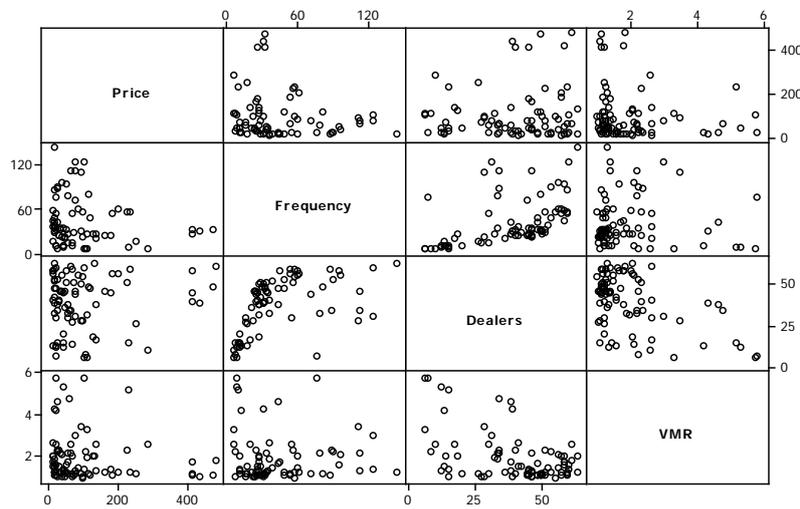
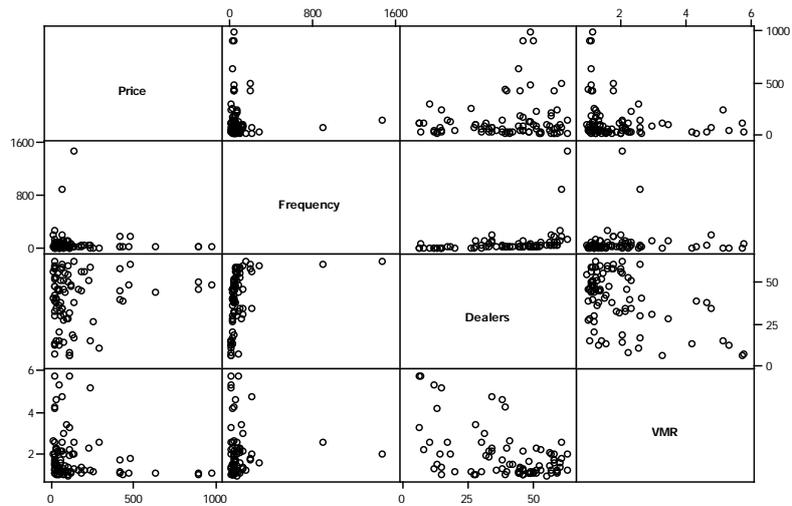
8112818	UNIT	96%	27	9.42	0.35	2.54					
8113121	TURBOCHA	92%	32	8.5	0.27	1.00					
8113286	UNIT	98%	24	6.58	0.27	1.81					
8113893	INJECTOR,	98%	15	9.17	0.61	5.15	H	L	L	H	
8132024	ELECTRIC	100%	25	7.08	0.28	0.96					
8140318	ADJUSTING	100%	53	89.58	1.69	2.20	L	H	H	H	
8152010	AIR FILTER	97%	48	32.08	0.67	1.10	L	M	M	L	
8155731	CLAMP	100%	57	201.92	3.54	2.01	L	H	H	H	
8156383	NIPPLE	100%	13	17.67	1.36	1.54	L	L	L	M	
8191145	FLASH LAMP	99%	45	34.17	0.76	1.29	M	M	M	M	
9516524	BUSHING	97%	40	25.08	0.63	2.28	L	L	M	H	
9520435	THERMOST	97%	14	10.83	0.77	2.04	M	L	L	H	
20382312	PRESSURE	96%	60	123.92	2.07	1.35	M	H	H	M	
20390840	BUSHING	94%	32	27.08	0.85	1.93	H	M	L	M	
20398386	BEZEL	86%	45	26.5	0.59	1.08	H	L	M	L	
20398708	BUMPER	100%	38	27.25	0.72	1.28	H	M	M	M	
20424901	REGULATO	99%	39	30.5	0.78	1.01	H	M	M	L	
20452889	COVER	87%	28	22.75	0.81	1.03	M	L	L	L	
20453677	SPACER	95%	48	48.33	1.01	1.11	H	M	M	L	
20453900	REAR	100%	50	31.17	0.62	1.15	M	M	H	L	
20456806	SPOILER	99%	20	11.42	0.57	1.18	M	L	L	L	
20467442	UNDERRUN	100%	51	24.92	0.49	1.09					
20467950	CONNECTO	100%	18	27	1.5	2.03	H	M	L	H	
20516776	FRONT	100%	44	25.08	0.57	1.06	H	L	M	L	
20520130	COVER	86%	41	36.5	0.89	2.62	L	M	M	H	
20527429	HOSE	100%	46	112.33	2.44	1.33	M	H	M	M	
20527443	SUN VISOR	98%	40	32	0.8	1.14	H	M	M	L	
20535877	AIR SPRING	97%	10	6.17	0.62	2.56	H	L	L	H	
20538793	SEALING	89%	44	71.67	1.63	1.19	M	H	M	L	
20568711	BRAKE PAD	89%	61	190.75	3.13	1.77	H	H	H	M	
20571928	RELEASE	96%	49	32.42	0.66	1.08	H	M	M	L	
20572012	PISTON	100%	17	20	1.18	2.60	H	L	L	H	
20582209	AIR SPRING	100%	58	187.75	3.24	1.75	H	H	H	M	
20583477	PULSE	99%	59	56.92	0.96	1.23	H	H	H	M	
20589788	MIRROR	91%	55	57.5	1.05	0.96	M	H	H	L	
20589817	WIDE VIEW	99%	46	33	0.72	1.22	L	M	M	M	
20755936	STUD	100%	13	11.75	0.9	4.18	L	L	L	H	
20779040	SERVICE	100%	33	78.92	2.39	2.15	M	H	L	H	
20816210	PAPER	98%	34	88.5	2.6	2.32	L	H	L	H	
20817742	GASKET	99%	53	48.67	0.92	1.20	L	M	H	L	
20826227	LAMP BODY	100%	59	87.17	1.48	1.08	L	H	H	L	
20826231	LAMP BODY	100%	63	143.5	2.28	1.23	L	H	H	M	
20847116	KIT	90%	41	25.5	0.62	1.51	L	L	M	M	
20854576	MIRROR	100%	46	23.67	0.51	1.04	L	L	M	L	
20879812	FUEL	93%	61	889	14.57	2.59	M	H	H	H	
20882320	AIR FILTER	100%	45	25.83	0.57	1.35	H	L	M	M	
20892199	CABLE	99%	13	4.75	0.37	1.03					
20894627	CLAMP	100%	30	54.83	1.83	2.59	L	M	L	H	
20910229	SPARE	100%	56	59.83	1.07	1.43	M	H	H	M	
20917957	LAMP	100%	57	54	0.95	1.10	H	M	H	L	
20946393	CABLE	100%	26	17.58	0.68	1.17	H	L	L	L	

20972915	FILTER	100%	63	1477	23.44	2.03	H	H	H	H
21001663	HEADLAMP	100%	46	24	0.52	1.01	H	L	M	L
21001668	HEADLAMP	100%	50	26.67	0.53	1.07	H	L	H	L
21058175	CHARGE	95%	49	80.58	1.64	1.17	H	H	M	L
85000064	COMPRESSO	91%	46	22	0.48	0.93				
85000186	STARTER	98%	49	30.25	0.62	1.12	H	M	M	L
85000194	COMPRESSO	89%	11	3.25	0.3	1.06				
85000238	DRIVEN	60%	44	21.17	0.48	1.11				
85000265	CLUTCH	62%	22	9.33	0.42	1.04				
85000483	CHARGE	100%	50	39.08	0.78	1.10				
85105029	ADAPTER	94%	56	96.08	1.72	2.04	L	H	H	H
85107093	BULB	90%	33	35.75	1.08	1.85	L	M	L	M
85108900	COOLANT	87%	28	111	3.96	3.44	M	H	L	H
85108913	COOLANT	99%	34	201.5	5.93	4.75	M	H	L	H

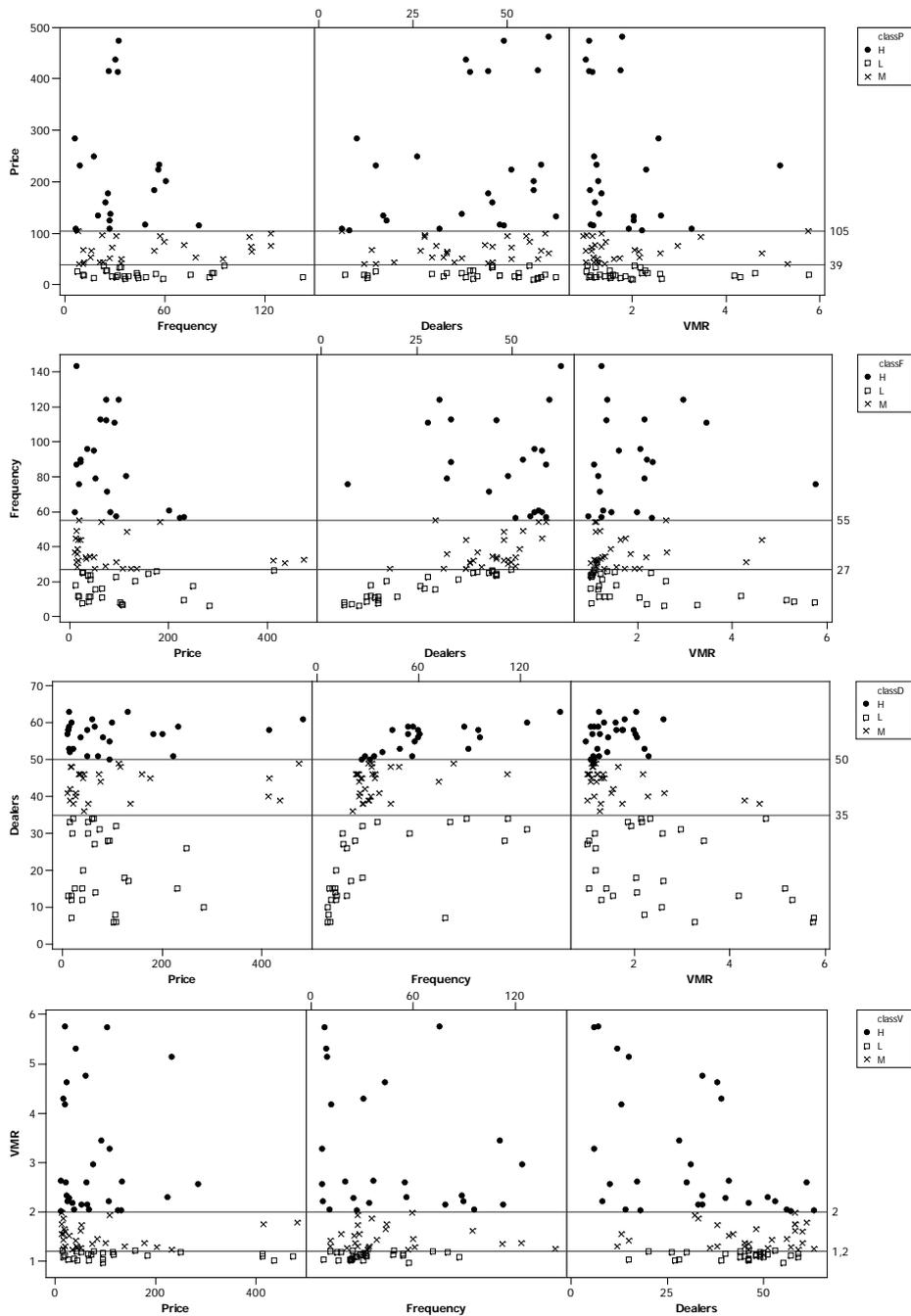
## Appendix 6 The disparity of the selected parts

The first matrix of scatter plots shows the full range of parts' characteristics in the four defined dimensions (price, frequency, number of dealers, and variance-to-mean ratio of dealers' demand).

Since the price and frequency dimensions are somewhat biased towards the low end a second matrix plot is provided with these dimensions zoomed in (price range 0-500 SEK, frequency range 0-150 units annually).



These four series of scatter plots show the spread in each dimension with respect to the other three. Horizontal lines are added where class limits are drawn and symbols vary with class.



## Appendix 7 Lead times

This appendix includes a complete list of the lead times (in working days) for all dealers and order classes in Spain.

Dealer Id	# Call offs per week	Mean waiting time	Handling time at CW	Transportation time CW to SW	Transportation time SW to Dealer	Total Lead time
<b>Lead time stock orders</b>						
<i>Peninsula</i>						
27	3	1	1,5	1,5	1	5
28	3	1	1,5	1,5	1	5
71	3	1	1,5	1,5	1	5
72	3	1	1,5	1,5	1	5
73	3	1	1,5	1,5	1	5
74	2	1,5	1,5	1,5	1	5,5
75	3	1	1,5	1,5	1	5
1277	2	1,5	1,5	1,5	1	5,5
1325	3	1	1,5	1,5	1	5
1327	3	1	1,5	1,5	1	5
15923	3	1	1,5	1,5	1	5
15924	2	1,5	1,5	1,5	1	5,5
15935	2	1,5	1,5	1,5	1	5,5
15940	3	1	1,5	1,5	1	5
30088	3	1	1,5	1,5	1	5
30165	3	1	1,5	1,5	1	5
30460	3	1	1,5	1,5	1	5
31811	3	1	1,5	1,5	1	5
31822	3	1	1,5	1,5	1	5
31823	3	1	1,5	1,5	1	5
31986	3	1	1,5	1,5	1	5
32409	2	1,5	1,5	1,5	1	5,5
184939	2	1,5	1,5	1,5	1	5,5
185027	2	1,5	1,5	1,5	1	5,5
185028	2	1,5	1,5	1,5	1	5,5
185067	2	1,5	1,5	1,5	1	5,5
185621	3	1	1,5	1,5	1	5
185771	3	1	1,5	1,5	1	5
186257	2	1,5	1,5	1,5	1	5,5
186500	2	1,5	1,5	1,5	1	5,5
186501	3	1	1,5	1,5	1	5
186503	2	1,5	1,5	1,5	1	5,5
187126	2	1,5	1,5	1,5	1	5,5
187128	3	1	1,5	1,5	1	5
187135	2	1,5	1,5	1,5	1	5,5
187137	2	1,5	1,5	1,5	1	5,5
187138	2	1,5	1,5	1,5	1	5,5
187142	2	1,5	1,5	1,5	1	5,5
291158	3	1	1,5	1,5	1	5

291622	3	1	1,5	1,5	1	5
295568	3	1	1,5	1,5	1	5
295571	2	1,5	1,5	1,5	1	5,5
297239	1	3	1,5	1,5	1	7
319426	3	1	1,5	1,5	1	5
386717	3	1	1,5	1,5	1	5
398614	1	3	1,5	1,5	1	7
412748	2	1,5	1,5	1,5	1	5,5
413426	2	1,5	1,5	1,5	1	5,5
436843	3	1	1,5	1,5	1	5
446227	2	1,5	1,5	1,5	1	5,5
482924	2	1,5	1,5	1,5	1	5,5
482925	3	1	1,5	1,5	1	5
482926	2	1,5	1,5	1,5	1	5,5
500623	2	1,5	1,5	1,5	1	5,5
563272	3	1	1,5	1,5	1	5
601733	1	3	1,5	1,5	1	7
606866	3	1	1,5	1,5	1	5
610304	2	1,5	1,5	1,5	1	5,5
618310	2	1,5	1,5	1,5	1	5,5
704642	2	1,5	1,5	1,5	1	5,5
<b><i>Balearic Islands</i></b>						
185965	2	1,5	1,5	1,5	2	6,5
<b><i>Canary Islands</i></b>						
548949	1	3	1,5	1,5	9	15
548954	1	3	1,5	1,5	9	15
SW Madrid	6	0,5	0,5	1,5	-	2,5
Madrid 1st cut off	6	-	-	-	0,5	0,5
Madrid 2nd cut off	6	-	-	-	1	1
Other dealers	6	0,5	-	-	1	1,5

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## Appendix 8 Shortage cost

The appendix shows all data and costs used to calculate the shortage cost.

### Transportation costs Spanish market from 2009 transportation budget

Origin	Destination	info	Total Cost (EUR)	Total Weight (Kg)	EUR/Kg
<b>Stock orders</b>					
Ghent	SW Madrid		XXX XXX	X XXX XXX	0,168
SW Madrid	Dealers Peninsula		XXX XXX	X XXX XXX	0,168
SW Madrid	Dealers Balearic Islands		XX XXX	XX XXX	0,444
SW Madrid	Dealers Canary Islands		XX XXX	XX XXX	0,800
SW Madrid	Dealers Canary Islands	Customs	X XXX	XX XXX	0,067
<b>Refill orders SW</b>					
Ghent	SW Madrid		-	-	0,168
<b>Day orders</b>					
SW Madrid	Dealers Peninsula		XXX XXX	XXX XXX	0,646
SW Madrid	Dealers Peninsula	2nd Cutoff	XX XXX	XX XXX	0,895
SW Madrid	Dealers Peninsula	Saturday deliveries	XXX XXX	XXX XXX	1,087
SW Madrid	Dealers Peninsula	Saturday pick ups	XX XXX	XX XXX	1,741
SW Madrid	Dealers Madrid	Daily	XX XXX	XX XXX	0,229
SW Madrid	<i>Weighted average Peninsula</i>				0,740
SW Madrid	Dealers Balearic Islands	AIR	XX XXX	XX XXX	2,000
SW Madrid	Dealers Canary Islands	Mon-Fri AIR	XXX XXX	XX XXX	4,063
SW Madrid	Dealers Canary Islands	Customs	X XXX	XX XXX	0,219

### Summary Transportation cost per kg (SEK/kg) (1 EUR = 9,25 SEK)

Dealer location	Stock orders	Refill orders SW	Day orders
Peninsula	3,11	1,56	6,84
Balearic Islands	5,67	1,56	18,50
Canary Islands	9,57	1,56	39,60

### Handling costs

Location	Handling cost (SEK) per order line	Mean weight (Kg) per order line	Cost per kg (SEK/kg)
Inbound SW	X,XX	XX,XX	0,46
Outbound SW	X,XX	X,XX	1,67

### Shortage costs

Dealer Location	Handling costs		Transportation Costs			Totals
	Inbound SW	Outbound SW	Refill orders SW	Day orders	Stock orders	Shortage cost
Peninsula	0,46	1,67	1,56	6,84	-3,11	7,43
Balearic Islands	0,46	1,67	1,56	18,50	-5,67	16,52
Canary Islands	0,46	1,67	1,56	39,60	-9,57	33,72

## Appendix 9 Simulation study

This appendix shows characteristics and results for the 20 parts included in the simulation study.

**Table 1** The 20 parts selected for simulation study and their characteristics (Classes: P = price, F = frequency, D = dealers, V = VMR)

PART CHARACTERISTICS								CLASS				
#	Part	Weight	Volume	Price	Market demand	Dealer demand	Nbr of dealers	VMR	P	F	D	V
2	244328	15	97	XX	11.00	0.73	15	1.41	M	L	L	M
1	244815	16	112	XX	112.83	3.32	34	2.13	M	H	L	H
20	341717	328	83.3	XXX	8.00	1.33	6	5.74	M	L	L	H
10	477928	81	200	XX	43.58	1.15	38	4.62	L	M	M	H
14	976489	125	637.8	XX	38.58	0.74	52	1.41	L	M	H	M
4	980573	66	18.7	XX	59.58	1.03	58	1.98	L	H	H	M
12	1075723	975	208	XX	27.08	0.71	38	1.72	M	M	M	M
19	1161932	4775	9327	XXX	6.92	0.86	8	2.20	H	L	L	H
18	1161936	4825	7524	XXX	6.42	1.07	6	3.27	H	L	L	H
15	1605182	255	778.6	XX	34.00	0.74	46	2.17	L	M	M	H
13	3092602	17000	22287	XXXX	12.33	0.39	32	1.00				
9	3944785	188	810	XX	284.50	4.74	60	1.59	L	H	H	M
17	8112354	14210	20800	XXXX	2.92	0.29	10	1.11				
6	8112556	2240	2035.8	XXXX	22.92	0.50	46	3.97				
7	8112598	40500	48276	XXX	15.50	0.41	38	1.04				
3	8112818	1878	2352	XXXX	9.42	0.35	27	2.54				
16	8113121	19000	23115.4	XXXX	8.50	0.27	32	1.00				
5	20467442	92000	1071000	XXXX	24.92	0.49	51	1.09				
11	20879812	784	1936	XX	889.00	14.57	61	2.59	M	H	H	H
8	20972915	2675	3890	XXX	1477.00	23.44	63	2.03	H	H	H	H

**Table 2** Results of the simulation study, costs and service calculations (NOW = current situation, OPT = optimized scenario)

#	Part	SIMULATION		COSTS		SERVICE				
		Total Cost NOW	Total cost OPT	Fill rate NOW	Fill rate OPT	Total Cost save	% Total Cost save	Target fill rate	Fill rate diff NOW	Fill rate diff OPT
2	244328	12.78	3.26	99%	94%	9.52	74%	92%	7%	2%
1	244815	122.35	23.51	100%	96%	98.84	81%	95%	5%	1%
20	341717	21.14	21.14	85%	76%	0.00	0%	93%	-8%	-16%
10	477928	38.08	29.26	100%	81%	8.82	23%	92%	8%	-10%
14	976489	19.52	16.20	100%	91%	3.32	17%	89%	10%	2%
4	980573	33.53	21.14	100%	91%	12.39	37%	94%	6%	-2%
12	1075723	79.26	62.80	100%	87%	16.46	21%	90%	10%	-3%
19	1161932	51.06	50.79	98%	91%	0.27	1%	93%	6%	-2%
18	1161936	57.37	54.40	95%	86%	2.97	5%	93%	2%	-7%
15	1605182	44.98	38.80	100%	85%	6.17	14%	91%	9%	-6%
13	3092602	1727.71	1411.83	99%	98%	315.88	18%	79%	20%	19%
9	3944785	90.33	63.56	100%	97%	26.77	30%	95%	5%	1%
17	8112354	189.18	178.53	98%	92%	10.66	6%	78%	20%	14%
6	8112556	778.92	527.47	87%	85%	251.45	32%	80%	6%	5%
7	8112598	1018.70	693.60	99%	98%	325.10	32%	78%	22%	21%
3	8112818	459.87	243.50	68%	83%	216.37	47%	78%	-10%	5%
16	8113121	883.17	764.78	100%	97%	118.39	13%	77%	23%	20%
5	20467442	3389.62	2273.45	100%	97%	1116.17	33%	81%	18%	16%
11	20879812	643.03	498.04	100%	97%	144.99	23%	96%	4%	1%
8	20972915	2020.14	1405.30	100%	99%	614.84	30%	96%	4%	3%

**Table 3** Results of the simulation study, inventory level and movement calculations.  
(TuC = standard price \* average inventory level)

#	Part	INVENTORY LEVELS				MOVEMENT			
		IL Now	IL Opt	Diff	Tied Up Capital	SW stock	D stock	Raw Mvmt	W. Mvmt
2	244328	29.96	5.40	-24.56	-XXX	1.24	-25.80	27.04	2.46
1	244815	179.63	14.69	-164.94	-XXXXX	-1.42	-163.51	162.09	1.44
20	341717	12.29	13.76	1.47	XXX	-3.28	4.75	-8.04	-1.00
10	477928	122.73	70.09	-52.63	-XXXX	-28.10	-24.53	-3.57	-0.08
14	976489	105.07	71.13	-33.94	-XXX	-4.25	-29.69	25.43	0.66
4	980573	260.35	138.14	-122.21	-XXXX	-22.53	-99.68	77.14	1.29
12	1075723	58.30	61.90	3.60	XXX	-9.89	13.49	-23.38	-0.86
19	1161932	30.87	25.74	-5.13	-XXX	-2.33	-2.79	0.46	0.07
18	1161936	24.08	21.18	-2.91	-XXX	-2.37	-0.54	-1.83	-0.29
15	1605182	93.96	66.35	-27.60	-XXX	-8.96	-18.64	9.68	0.28
13	3092602	31.78	21.90	-9.88	-XXXXX	-0.10	-9.78	9.68	0.79
9	3944785	423.22	238.05	-185.17	-XXXX	-19.63	-165.54	145.90	0.51
17	8112354	10.39	11.39	1.00	XXXX	-0.96	1.96	-2.92	-1.00
6	8112556	48.18	20.72	-27.46	-XXXXX	0.47	-27.92	28.39	1.24
7	8112598	38.60	57.00	18.40	XXXXX	-2.31	20.71	-23.02	-1.48
3	8112818	28.81	8.98	-19.82	-XXXXX	2.54	-22.36	24.90	2.64
16	8113121	32.38	24.45	-7.93	-XXXXX	-1.03	-6.90	5.87	0.69
5	20467442	56.43	77.29	20.86	XXXXX	-4.69	25.54	-30.23	-1.21
11	20879812	917.58	516.21	-401.36	-XXXXX	-62.47	-338.89	276.42	0.31
8	20972915	1396.11	729.50	-666.62	-XXXXX	-19.88	-646.74	626.86	0.42

## **Appendix 10 Initiation of the pilot study**

The implementation of the NGiL model in the VP systems is not performed as part of this study. In this Appendix some preparations that have been made for the implementation are listed. These are of interest for the project that will implement and initiate the pilot study, and some information (such as performance indicators and alarms) is of value during the observation and follow-up phases.

Information about the systems can be found in Appendix 1 and part specific information in Appendix 2.

### **Implementation technicalities**

The new reorder points are to be implemented in the RHelp system as well as the DSP system (if the pilot study is to be performed on the Spanish, British or Finnish market) and/or the VR system (for e.g. the Swedish or Portuguese market).

In RHelp the reorder point for the SW are implemented. This is easily done by utilizing the “Manual ROP” and “Manual EOQ” functions together with the corresponding fields for expiration dates for the manual overrides.

In DSP there is no manual override for the control parameters. Instead tables have to be constructed for each pair of control parameters (R, Q) and then the selected parts have to be connected to these tables by using “infocodes”. This work is to be performed by VP personnel in cooperation with Volvo IT given the correct sets of parameters.

It is also important to have control over the “purchaseCode” parameter. It can currently be set to 0 for parts that today are stocked at a dealer but according to the NGiL model should only be stocked at the SW (and thus the parameter needs to be updated to 1) or vice versa – currently set to 1 for parts that today are not stocked but should be according to the model. The parameter also has to be excluded from automatic updates by the system.

### **Alarms during simulation study**

Since some parts will almost certainly have changed in the real world that will make them unsuitable for the pilot study (for details about these criteria, please see Chapter 5) it is necessary to observe all the parts and then pull out if certain changes occur. This observation should preferably be carried out

manually by key personnel (e.g. the RIM) or defined as alarms in the system (for automatic or manual comparison).

- The demand is drastically changed (e.g. by looking at the trend between months).
- The parts is flagged as preliminary supersession.
- Exchange code or hazCode is changed to “forbidden” values.
- Part is manually blocked (purchaseCode) for other reasons.

This list is only a preliminary suggestion and further work and the exact levels of the demand trend alarm have to be performed in cooperation with VP personnel. Also by providing a list of the selected parts to the dealers and the RIM awareness can be created about which parts are included in the pilot study and need extra attention and fast reporting of abnormalities.

### ***Performance indicators***

The performance indicators should give a picture of the current situation of the selected spare parts and accessories as well as to enable a comparison between the current situation and the new situation after performing the pilot study. Both performance indicators readily available in VP systems and performance indicators designed especially for the pilot study are used for this comparison.

### ***Performance indicators defined in Volvo Parts systems***

The SCOUT system enables aggregated performance indicators on total, market or dealer level. For the pilot study KPI1, KPI2, KPI3 and KPI6 could provide comparisons between the situation before and after the pilot study. The performance indicators that are also relevant to use as the comparison between the two situations are: Sales and stock value, stock health, stock values, day/stock order development and share automatic orders.

Since the parts selected for the pilot study will have its own “infocodes” it will be possible to use SCOUT to perform KPI and PI calculations aggregated on only these parts.

### ***Definitions of additional performance indicators***

To get a picture of the cost savings potential the NGiL model approach could provide measurements of the stock level, the holding costs and the tied up capital is to be performed.

### **Average stock level**

By having access to the initial stock levels and real order data it is possible to get an exact value of the average stock level, as well as the negative inventory level (i.e. backorders).

It is however important to note that a certain “transient phase” will be experienced during the simulation study, since all the inventories start with the “old” stock (i.e. using the old VP control parameters). Calculations of average inventory levels should thus not start immediately after the initiation of the pilot study.

### **Holding costs**

The inventory holding cost is defined for keeping one unit in inventory and is calculated on a period basis. It is now interesting to calculate the holding costs for either the SW or for all the dealers. This could be done one part at a time or for all parts simultaneously. The holding costs at an inventory can, as Chapter 3 describes, be expressed as

$$C = bE(IL)^+ = bE(IL) + bE(IL)^-$$

Since the selected parts have stable demand, i.e. low trends, the expected inventory level  $IL$  can be modeled by the average stock level described above. Data on the number of backorders  $E(IL)^-$ , interpreted as the number of day orders  $DO$  placed to SW, are readily available from VP systems on an order basis for dealers. The number of backorders at the SW  $BO$  is modeled using the number of orders forwarded to CW when the SW cannot satisfy the demand from the dealers. This is also available from VP systems. Using the average stock level  $SL$  and denoting a part as  $k$  the inventory holding cost  $HC$  at the SW and all the dealers respectively is

$$HC_{SW,k} = b \cdot SL_{SW,k} + b \cdot BO_{SW} =$$
$$HC_{Dealers,k} = b \cdot \overline{SL}_k + b \cdot \sum_i^n (DO_{i,k}) = b \sum_{i=1}^n \left( \frac{SL_{i,k}}{n} + DO_{i,k} \right)$$

where  $b = i_b \cdot p$ . This could also be expressed on a total level for all 100 parts. Denoting the parts as  $[k_1, k_2, \dots, k_{100}]$  the total holding cost  $THC$  is

$$THC_{SW} = \sum_{k=k_1}^{k_{100}} HC_{SW,k} = \sum_{k=k_1}^{k_{100}} (b \cdot SL_{SW,k} + b \cdot BO_{SW})$$

$$THC_{Dealers} = \sum_{k=k_1}^{k_{100}} (HC_{Dealers,k}) = \sum_{k=k_1}^{k_{100}} \left( b \sum_{i=1}^n \left( \frac{SL_{i,k}}{n} + DO_{i,k} \right) \right)$$

### **Tied up Capital**

It is also relevant to measure the amount of capital tied up  $TUC$  by the parts every period. Using the same assumptions as for the holding cost calculation the tied up capital is

$$TUC_{SW,k} = p \cdot SL_{SW,k} + p \cdot BO_{SW} =$$

$$TUC_{Dealers,k} = p \cdot \overline{SL}_k + p \cdot \sum_i^n (DO_{i,k}) = p \sum_{i=1}^n \left( \frac{SL_{i,k}}{n} + DO_{i,k} \right)$$

where  $p$  is the standard price of the part. The total tied up capital  $TTUC$  for the 100 parts then is

$$TTUC_{SW} = \sum_{k=k_1}^{k_{100}} TUC_{SW,k} = \sum_{k=k_1}^{k_{100}} (p \cdot SL_{SW,k} + b \cdot BO_{SW})$$

$$TTUC_{Dealers} = \sum_{k=k_1}^{k_{100}} (TUC_{Dealers,k}) = \sum_{k=k_1}^{k_{100}} \left( p \sum_{i=1}^n \left( \frac{SL_{i,k}}{n} + DO_{i,k} \right) \right)$$

### **Total costs**

To be able to compare the current situation of the total costs for the selected parts this cost is modeled in analogy with that of the NGiL model) using information gathered from VP systems instead of probability distributions for the number of day orders and backorders. According to the NGiL model the total costs  $TC$  on a period basis per part  $k$  and a total market level, respectively, can be expressed as

$$TC_k = C_{SW,k} + \sum_{i=1}^n C_{i,k} = HC_{SW,k} + HC_{Dealers,k} + \sum_i^n (DO_{i,k} \cdot b_{i,k})$$

$$TC_{market} = \sum_{k=k_1}^{k_{100}} TC_k$$

where  $b$  is the shortage cost.