LUND UNIVERSITY

VOLVO PENTA

Master of Science Thesis

MIOM05 Degree Project in Production Management

Global Service Level Targets and Stock Requirements in the Distribution System of a Manufacturer of Industrial Goods

Faculty of Engineering LTH
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Abstract

Title: Global service level targets and stock requirements in the distribution system of a manufacturer of industrial goods

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Background: Volvo Penta is facing challenges in inventory management of marine engines in remote markets. Currently, a Make-To-Stock (MTS) strategy is used for specific engines to serve customers within the required lead times. These engines are referred to as Authorised Stock Engines (ASE). However, inventory levels are not balanced and are set by old practices that are not aligned with theory, leading to high holding costs and unsatisfied customers.

Purpose: Establish customer lead time and service level requirements for different types of engines in selected markets, suggest which engines to select as ASEs, and provide a method for determining Service Level Targets (SLT).

Research Questions:

I. How should Volvo Penta define its service level, and how does it compare with theoretical perspectives?
II. What are the required service levels and acceptable lead times for Marine customers for different engines?
III. Which engines should the stock consist of?
IV. How much safety stock is required, and what will the inventory holding cost be to close the gap between the desired and actual service levels?

Methodology: The methodology follows an Operations Research framework and approaches the problem from different angles by using a triangulation approach, which includes four methods: interviews to establish market requirements, inventory segmentation, service level performance, and an analytical model for comparing trade-offs between SLTs and the Cost of Tied-up Capital (CTC).

Conclusions: Volvo Penta should implement fill rate as a service level definition and include a time-based approach based on the customer's acceptable waiting time. The ASE list should be updated annually using the ABC-XYZ-VED model in collaboration with sales representatives. SLTs should be updated simultaneously by surveying customer lead time requirements and including these in the analysis, monitoring service level performance, and making trade-offs between SLTs and the CTC.

Keywords: Service level target, inventory control, inventory segmentation, supply chain management, distribution system.

Preface

This project marks the end of the authors' studies in Mechanical Engineering within the master's program Logistics and Production Management at the Faculty of Engineering LTH, Lund University. During this five-year period, we have gained valuable knowledge and friends, for which we are deeply grateful.

We would like to express our gratitude to the people who have made this thesis possible. First of all, we would like to thank Volvo Penta and our supervisor, Lisa Thorsell, for the opportunity to write this thesis, for guidance, and for helping us connect with people within the company. We would also like to thank our supervisor, Professor Johan Marklund, for excellent advice and feedback along the way.

Lund, May 2024
Nils Holmqvist & Hugo Lundholm

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Abbreviations

APD	Acceptable Promised Delay
ASE	Authorised Stock Engine
AWT	Acceptable Waiting Time
CODP	Customer Order Decoupling Point
CTC	Cost of Tied-up Capital
CV	Coefficient of Variation
DRP	Distribution Requirement Planning
ERP	Enterprise Resource Planning
GAS	Gasoline
KPI	Key Performance Indicator
MRP	Material Requirement Planning
MTO	Make-To-Order
MTS	Make-To-Stock
OEM	Original Equipment Manufacturer
OPR	Orders Promised to Request
OTS	On Time Shipments
SKU	Stock Keeping Unit
SL	Service Level
SLT	Service Level Target
SS	Safety Stock

1 Introduction

This section is an introduction to the master thesis. Section 1.1 provides a general background, section 1.2 describes the case company, and sections 1.3-1.6 state the problem, purpose, research questions, and delimitations.

1.1 Background

Supply chain management is crucial for the success of all companies that produce a product. It involves managing the product, information, and financial flow. Managing these flows is closely connected to the company's overall performance (Chopra & Meindl, 2015). Therefore, companies should consider this essential to ensure adequate supply chain flows.

Supply chain decisions can be divided into three phases: supply chain strategy and design, supply chain planning, and supply chain operation (Chopra & Meindl, 2015). Supply chain strategy involves decisions that concern the supply chain structure for the next several years. Decisions can, for example, be to decide whether products should be stored at various locations. Given the constraints set during the strategy phase, supply chain planning decisions should be made to maximise the supply chain surplus. Determining how an inventory policy should be developed is an example of a planning decision. The timeframe for planning decisions is usually a quarter to a year. Lastly, the supply chain operation phase is about day-to-day operations, which involves placing orders within the fixed constraints and policies.

Volvo Penta is facing challenges in inventory management and distribution. Inventory management has become a crucial segment for modern companies, which need constant monitoring and improvement to meet customer demands with as low Cost of Tied-up Capital (CTC) as possible (Stojanović & Regodić, 2017). The challenge concerns achieving a target service level and efficient lead time for marine engines. Therefore, decisions involve setting appropriate service levels and lead time targets and achieving these by selecting which marine engines to Make-To-Stock (MTS). These decisions should be made on a strategic level where the constraints can be followed by updating planning and operation decisions.

1.2 Case Company

Volvo Penta is one of ten business areas in Volvo Group, see Figure 1. Volvo Penta's net sales in 2023 were 21,006 MSEK (Volvo Group, 2024a). While the truck segment had the largest share of Volvo Group's net sales, 67% in 2023, Volvo Penta had 4% in 2023. Further, Volvo Penta is a multinational supplier of marine and industrial engines that focuses on Make-To-Order (MTO) engines but maintains stocks for some remote markets. The company refers to these engines as Authorised Stock Engines (ASE). The ASEs are used to offer these markets acceptable lead times and service levels that are in line with customer expectations. While inventory cost reduction is an essential target for the company, customer expectations cannot be compromised. Due to internal restructuring, the ownership of the ASE inventory is changed between departments. Consequently, the ASE stock has emerged as a focal point influencing the company's tied-up capital and ensuring customer satisfaction.

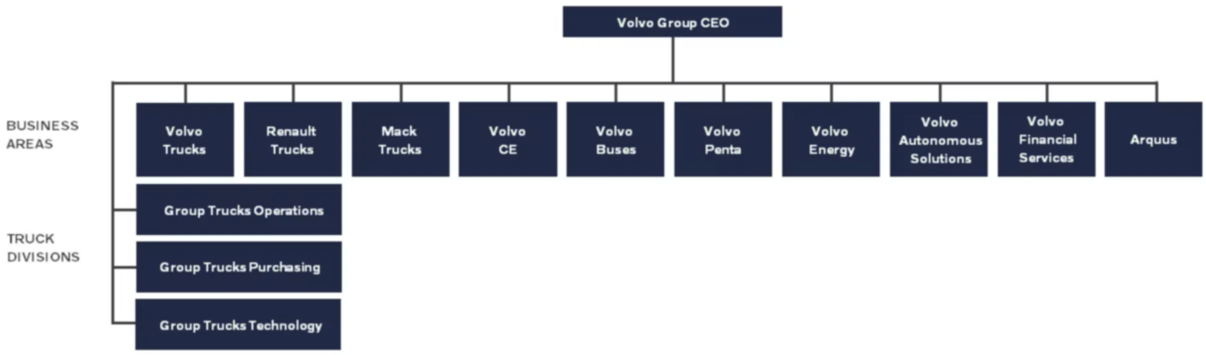

Figure 1: Volvo Group's organisational *structure (Volvo Group, 2024b).*

1.3 Problem statement

The ASE stock meets customer expectations by reducing the lead times that arise from the engines being sold and produced in different parts of the world. The decision to have ASE inventory in certain places was made because the production lead time, combined with the transportation lead time, was considered longer than customers could accept. Not having available stock sufficiently close to the customers could lead to dissatisfied customers and lost sales. Therefore, inventory is viewed as an important tool to increase sales and prevent losing customers to competitors.

However, the exact requirements for service levels and lead times for different customers are unknown. Also, service level is not measured for the stock locations. Choosing ASE levels has, in the past, been done by a top-down approach, calculating average demand daily with a few weeks' buffers. This creates problems for the company since it is difficult to know if engines are over or under-stocked and if customer requirements are met with set ASE levels. The stock consists of many engine types, and the demand can vary greatly, making some units sold less frequently than in the previous forecasting period. Thus, a portion of the stock can shift from a high- to low inventory turnover, which implies unnecessary holding costs. However, increasing turnover by lowering stock could negatively impact service levels in future periods. Therefore, it is important to establish correct targets so the stock can be efficiently used without negatively impacting customer relationships.

1.4 Purpose

The project aims to establish customer lead time and service level requirements for different types of engines in selected markets, suggest which engines to select as ASE, and provide a method for determining Service Level Targets (SLT).

1.5 Research Questions

I. How should Volvo Penta define its service level, and how does it compare with theoretical perspectives?
II. What are the required service levels and acceptable lead times for Marine customers for different engines?
III. Which engines should the stock consist of?
IV. How much safety stock is required, and what will the inventory holding cost be to close the gap between the desired and actual service levels?

1.6 Delimitations

The project focuses on marine engines sold in the geographical markets Oceania, Brazil and Vara GAS (Gasoline). The market Vara GAS is restricted to gasoline engines that are mainly sold to European customers, while Oceania and Brazil not only include gasoline engines but also diesel engines, which drives the sales. Besides the European customers, Vara GAS includes South Africa and Importer Business. The delimitation of selecting these three markets was made because Volvo Penta was most interested in these markets. Due to the current state of high stock, lead times, and sales in the Oceanian and Brazilian markets, these were selected to investigate. Vara GAS was also selected due to similar reasons. The delimitations are based on the priority list that was developed in collaboration with Volvo Penta, see Table 1. This was done to guarantee that the most important parts of the problem were solved within the project's timeframe. According to Table 1, the project proceeded to consist of the three markets with the highest priority.

Table 1: List of priorities of the markets to include in the project.

Priority	Market	Motivation
1	Oceania	High stock, high sales and long lead times
2	Brazil	High stock, high sales and long lead times
3	Vara GAS	High stock and long lead times
4	China	No current stock
5	Southeast Asia	Stock but no ASE, long lead times

1.7 Disposition

This section describes the disposition and structure of this report to provide the reader an easy way to navigate through it.

Chapter 1: Introduction
This section introduces the reader to the project by providing background on the case company and stating the problem, purpose, research questions, and delimitations.

Chapter 2: Current distribution network and inventory control system
This section describes the distribution of marine engines to the selected markets and the inventory control system which includes descriptions of ASEs, ordering process and forecasting.

Chapter 3: Research methodology
This section describes and motivate the applied methodology.

Chapter 4: Theory
This section presents relevant theory that was used in the project. It also describes the applied inventory segmentation model that was based on a literature review which also is included in this section.

Chapter 5: Numerical study
This section describes the steps that was done to achieve the results.

Chapter 6: Analysis and result
This section presents the analysis and results including the proposed ASE lists with SLTs, safety stock targets and inventory holding costs are included. Lastly, the proposed ASE lists are benchmarked against previous ASE lists.

Chapter 7: Conclusion
This section concludes the report by answering the research questions and summarises the insights from the study.

2 Current Distribution Network and Inventory Control System

This section provides an overview of Volvo Penta's current distribution network and inventory control system. The descriptions of the systems are based on interviews with Volvo Penta employees; see interview guides in Appendix A-B.

2.1 Distribution Network

Volvo Penta sells and distributes marine engines globally, and in this project, the focus will be on the remote marine markets in Oceania, Brazil, and Vara GAS see Figure 2. The Oceanian market mainly consists of customers from Australia and New Zealand and includes both gasoline and diesel engines. The Brazilian market consists of Brazilian customers and includes both gasoline and diesel engines. Lastly, Vara GAS primarily serves European customers and includes only gasoline engines. Gasoline engines are produced in Lexington, US, which is why Vara GAS is considered a remote market. The lead times to the three markets are long because the production and global distribution centre of marine engines is in Vara, Sweden, and for gasoline engines, it is in the US. All engines to these markets are shipped by boat, with some exceptions of express orders via air freight. Maritime shipping results in longer lead times and higher tied-up capital but is a cost-efficient mode of transporting heavy goods. Since the transportation time is extended, Volvo Penta has decided to keep ASE for specific engines at these locations to reduce the lead times and ensure satisfied customers.

Figure 2: Volvo Penta's marine distribution network with a focus on the markets inside the project's scope.

The engines are shipped in containers, so it is preferable to ship Full Container Loads (FCL) from an ordering cost perspective. However, always ordering FCL will mean higher inventory holding costs due to shipping more engines than is demanded. Since the engines are expensive products, the Supply Chain Planners do not plan the ordering after exact FCL sizes[1]. Planning the shipments is instead done by Delivery Coordinators in a later step. One of the tasks for a Delivery Coordinator is to mix different products into FCL[2]. Since mixed containers are used for shipments, it becomes less important to order in FCL.

2.2 Inventory Control System

2.2.1 Authorised Stock Engines

Authorised stock engines (ASE) are engines that have been decided to keep as stock. The selection process of which engines should be ASEs can be seen in Figure 3. If the customer demand can be fulfilled during the lead time, ASE is unnecessary, and the engines can be produced MTO. However, engines with a lead time demand that is not met, can be selected to be stocked as ASE. Then, the decision depends on the number of configurations. Engines with fixed and low configurations are MTS and selected as ASE. Lastly, if the number of configurations is high, engines are sub-assembled or produced locally.

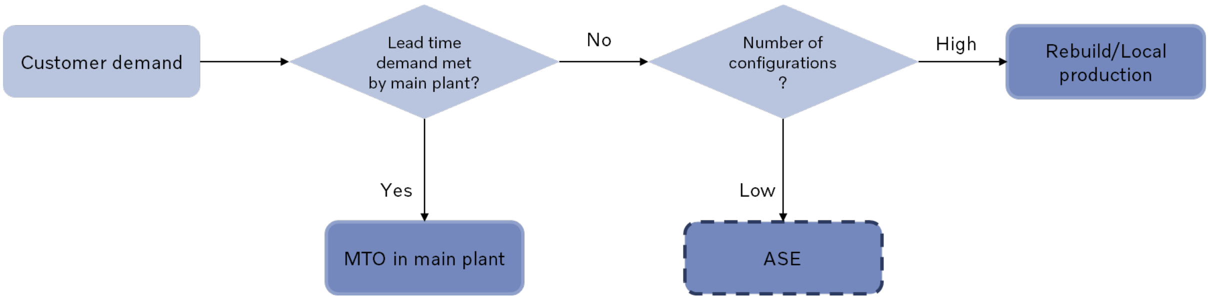

Figure 3: Volvo Penta's MTO/MTS strategy, with actions marked in darker colors and a focus on the ASE action. Rebuild refers to sub-assembly or up-fit.

2.2.2 Ordering System

At Volvo Penta, Distribution Requirement Planning (DRP) is in place to replenish the ASE inventory. The stock is reviewed manually via the software Rapid Response. A Supply Chain Planning Manager (SCPM) reviews the stock weekly to accommodate newly placed orders. Orders are sent to production every week. For each ASE, there is a safety stock target. DRP should fulfil the safety stock target for the coming periods. This implies that the stock balance should equal the safety stock target for each period after planned orders and forecasted demand are subtracted. Furthermore, there is no fixed order quantity for ASEs, as they can be ordered one for one. The system has a frozen period (when an item enters the production plan, and no further changes can be made) of around 1-3 weeks, but it varies slightly between order types.[3]

At Volvo Penta, the inventory control policy in use is not clear. However, despite having a DRP system, their policy resembles a periodic (s, S)-policy described in Axsäter (2006). To describe the inventory policy, s is the reorder point, and when the inventory position is below, a new order is placed in the system. The inventory position includes stock on hand, outstanding orders and backorders, see section 4.2. Then, an order is placed to order up the inventory position to S. S is equal to the safety stock target plus forecasted demand plus outstanding orders during the planned periods. s is equal to S-1 in this case. Further explanation of the (s, S) policy and how to derive its parameters from Material Requirements

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[1] Supply Chain Planning Manager 1 (interview 5 February 2024), Volvo Penta Operation and Logistics
[2] Supply Chain Planning Manager 2 (interview 6 February 2024), Volvo Penta Operation and Logistics
[3] Supply Chain Planning Manager 2 (interview 6 February 2024), Volvo Penta Operation and Logistics

Planning (MRP) parameters (similar to those parameters in Volvo Pentas DRP) can be found in sections 4.6 and section 4.9.1.

Moreover, the inventory control system at Volvo Penta can be seen as several independent single-stage (or single-echelon) systems. Volvo Penta has one global distribution centre linked to production in Vara; see Figure 2. The global distribution centre supplies all regional distribution centres. This could be mistaken for a multi-echelon system. However, orders are designated for a specific market before they are produced, so a replenishment for a region will not impact the stock for another area. After an engine has been produced, it is immediately linked to that specific order and the regional distribution centre[4]. Therefore, the inventory control system can be treated as single-echelon systems with a replenishment lead time.

2.2.3 Forecasting

The system that is used for forecasting at Volvo Penta is Rapid Response[5]. Rapid Response inserts the forecast data into sheets, and the SCPM makes order decisions based on forecasts, customer orders, and safety stock targets. The SCPM can choose whether to confirm the suggested orders from Rapid Response or adjust them if the data does not seem accurate. The forecasts are updated monthly, but a new forecast can be requested if the demand changes quickly. The Demand Planner makes the forecasts in Rapid Response. Therefore, it is essential that communication between the demand planner and the supply chain planners is frequent to ensure that the actual demand is met. The inventory control process is displayed in Figure 4.

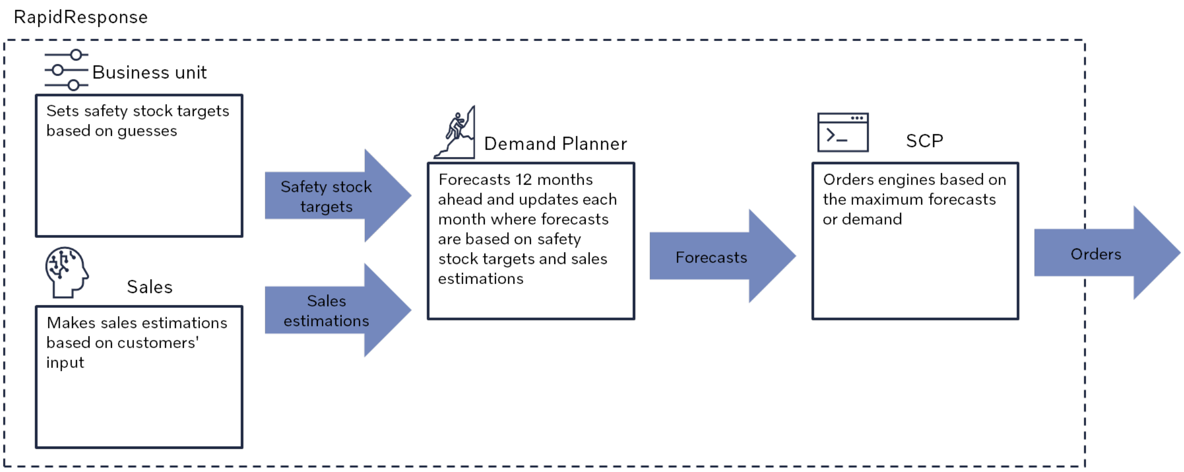

Figure 4: Inventory control process in Rapid Response.

2.2.4 Customer Order Process

When a customer places an order, it appears in Volvo Penta's Enterprise Resource Planning (ERP) system. A customer order enters the ERP system with a request for a specified quantity and delivery date which Volvo Penta either confirms or a new promised delivery date is negotiated according to Figure 5. Then the customer can choose to accept the proposed delivery date or cancel the order. Important to note is that it happens that customers first accept and later cancel an order before arrival. This costs a lot as it happens that engines are being shipped even if the customer does not want them in the end. One way to mitigate this

[4] Supply Chain Planning Manager 1 (interview 5 February 2024), Volvo Penta Operation and Logistics
[5] Demand Planner 1 (interview 8 February 2024), Volvo Penta Operation and Logistics

risk is to have the engine in stock and available for immediate shipment. Then, the customer will not have time to regret their purchase.

Figure 5: Overview of Volvo Pentas customer order process.

From the customer order process in Figure 5, dates can later be monitored in the ERP system. The dates of interest for this project are order entry, requested shipment, promised shipment and actual shipment, see Figure 6. Noteworthy is that the shipment date refers to the shipment from the regional distribution centres. Therefore, these dates are often equal or close to the delivery date which is not possible to monitor.

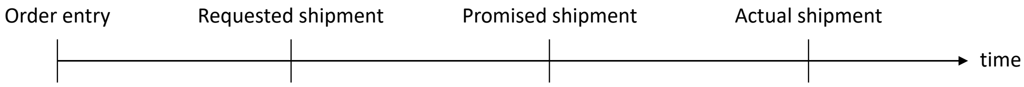

Figure 6: Dates timeline in Volvo Pentas customer order process.

3 Research Methodology

This section describes the methodology used to achieve the thesis's purpose. First, the Operations Research (OR) framework is defined in section 3.1 as the research method that will be used in this project. This is followed by how it is applied step by step in section 3.2.

3.1 An Operations Research Framework

The project's research method follows the steps of an Operations Research (OR) study. Since the field of OR deals with mathematical modelling of decision problems it was considered to be a suitable approach for this project.

Hillier and Lieberman (2010) list the following six major phases that are usually included in an OR study:

1. *Defining the problem and gathering data*
   To give relevant recommendations to management, it is essential to define the decision-maker's problem accurately at the start. Otherwise, the project might not solve the actual problem. Also, the importance of gathering relevant data should not be underestimated. Today, companies usually have several IT systems with much data. Therefore, a project must identify the data that is useful for the specific problem.

2. *Formulating a mathematical model*
   To solve the problem, a mathematical model including decision variables, objective functions, constraints, and parameters should be used. The mathematical model aims to achieve an optimal objective function (usually a maximum or minimum value) by choosing decision variables within defined constraints. The parameters are fixed values based on the gathered data and rough estimations.

3. *Deriving solutions from the model*
   When the mathematical model is established, the next step is to find a procedure to derive solutions from the model. This procedure is generally computer-based.

4. *Testing the model*
   Testing the model is crucial since the first version often contains flaws. Therefore, it must be tested and corrected several times before implementing the solution.

5. *Preparing to apply the model*
   If a model becomes accepted and should be used repeatedly, it must be maintained. In this case, documentation of how to use the model and how to update it becomes vital.

6. *Implementing*
   The last step is to implement the model.

Steps 5 and 6 were assessed as outside the current project's scope and are therefore not applied in this study.

3.2 Method Applied

The first step in the applied OR methodology includes interviews and a literature review in the data gathering part. Exploratory interviews were conducted with Volvo Penta employees to understand the current inventory control system. Structured interviews were conducted with sales representatives at the selected markets' to get input on the customers' lead time and service level requirements. Secondly, the literature review of relevant research in inventory control and related topics will expand our knowledge and provide the basis for relevant improvement possibilities. Axsäter's (2006) book *Inventory Control* will form the inventory modelling part of the thesis. The literature review aimed to find theories that could be applied to the Volvo Penta case. Lastly, relevant data was collected, and the current performance of the ASE inventory distribution system was analysed quantitatively to evaluate suggested inventory improvements and changes to the current system.

After all data had been collected, we proceeded to formulate the model. Since Service Level Targets (SLT) and Authorised Stock Engine (ASE) requirements are not easily measured or understood, a triangulation approach was used to ensure validity and credibility, see Figure 8. By approaching the problem from four different angles, and deriving solutions and testing the model, the project succeeded to find a combined method for setting SLTs and stock requirements.

3.2.1 Step 1: Defining the problem and gathering data

To achieve good recommendations, relevant quantitative and qualitative data to collect was suggested for each market. The data was structured into six categories to ensure not missing anything important, see Table 2. It was expected that some of the suggested data may not be available. However, in *step 2, Formulating the model,* the applied model will be adjusted to the available information. A combination of different data sources was used to gather the data for the studied markets. This combination was databases, literature, interviews, and observations.

Table 2: Data gathering process divided into categories.

Category	Data
Distribution	• Network structure • Lead times • Transport modes
Order	• Description of the ordering process • Ordering Policy • Review system
Service level	• Service level definition • Measurement of service level
Inventory	• Stock keeping units • ASE inventory levels: current and historical
Demand	• Demand data • Forecast methods • Sales revenue per item

Exploratory interviews

The exploratory interviews were conducted with employees from Volvo Penta's headquarters to understand their way of working, especially regarding service levels, lead times, and inventory control. First, an initial interview with open structure was conducted with Volvo Penta's Vice President of the Marine Business Unit, to get a strategic view of inventory control and how Volvo Penta defines service level on a strategic level. This interview lasted approximately 30 minutes and took place via Teams on the 8th of February. To capture the interviewee's full view of the problem, the interview was conducted by letting the interviewee speak freely but with focus on the specific areas: service level and lead time, inventory control, and customers. Therefore, the choice of having an open structure was deemed appropriate. Höst et al. (2006) also confirm that this is a good choice for exploratory interviews when the purpose is to get the interviewee's experience of a phenomenon.

To learn how Volvo Penta employees work and understand the inventory control system, one demand planner and two Supply Chain Planning Managers were also interviewed. The interviews aimed to identify different parameters found in Table 2. Since there was a clear goal of identifying parameters, these interviews were more structured. However, to ensure not missing anything important the interviews were semi-structured (Bryman & Bell, 2005). The discussion areas were fixed but the interviews also allowed the interviewees' to speak freely around the discussion areas according to interview guides, see Appendix A-C. During these interviews, their way of working was also observed via screen sharing in Teams. These interviews lasted approximately one hour and were held on Teams. The interviews took place throughout the month of February.

Structured interviews

To identify the customer's service level and lead time requirements, market research was performed according to the steps in Figure 7. Due to the current external relations, it was not possible to interview customers. The best alternative was to interview sales representatives as they should have a good understanding about different customers' requirements. Before conducting the first of these interviews, the already available data had to be investigated. The parameters from Table 2, that were not possible to find in Volvo Penta's systems, needed to be collected from these interviews. Before the interview, a structured interview guide was developed, see Appendix C, to ensure that all parameters could be identified. The interview guide was developed carefully to ensure that relevant and accurate data could be applied to the numerical analysis. Since the data gathering was both quantitative and qualitative, we used structured interviews (Bryman & Bell, 2005).

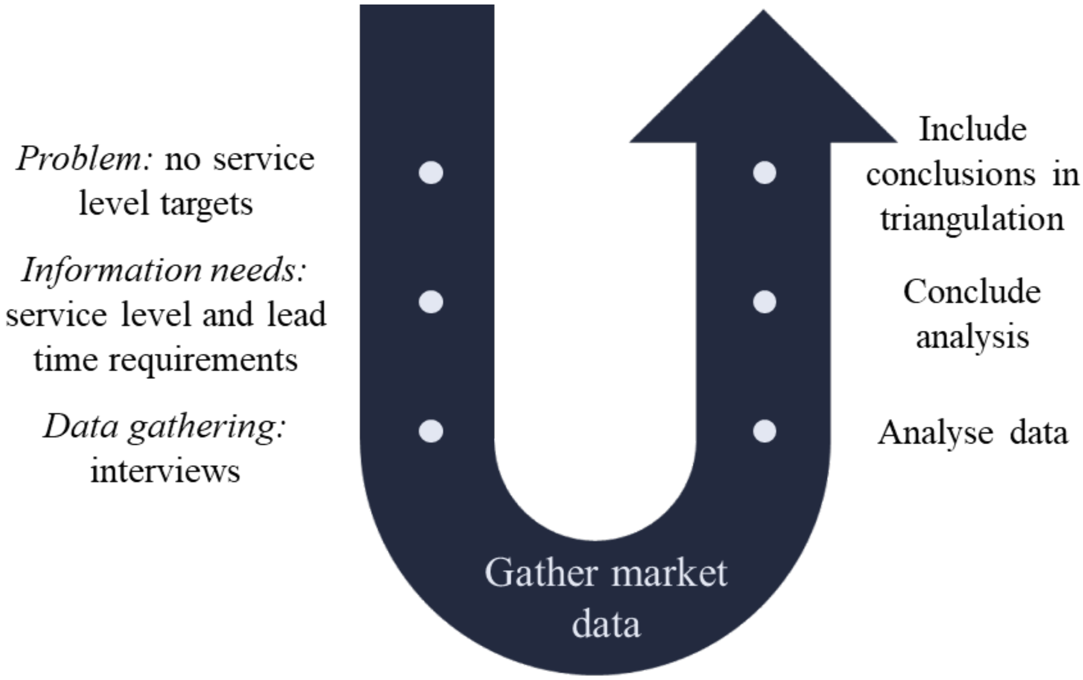

Figure 7: Market research process based on Lekvall and Wahlbin (2007).

Literature review
Gathering reliable and valid data was a crucial part of the project. Without ensuring these two criteria, the quality of the project would be compromised. A literature review was conducted according to the approach in Höst et al. (2006). The approach is divided into three steps: search broad, select and search deep. In the first step, LubSearch, which is the search engine of Lund University Libraries, was identified as a reliable search engine for accessing articles and books. The keywords used in the broad search were service level, lead time, inventory control system, distribution control system, ordering policy, segmentation, and customer order decoupling point. Then, the most relevant and credible articles were selected to dive deep into.

3.2.2 Step 2: Formulating the Model

As seen in Figure 8, a triangulation approach was used to formulate the model. The triangulation combined market requirements identified from interviews with sales representatives, an inventory segmentation model, a service level performance analysis, and an analysis of analytically calculated service levels and Cost of Tied-up Capital (CTC), see Figure 8. The ABC-XYZ-VED model was selected to segment Volvo Penta's engines to determine which engines to select as Authorised Stock Engines (ASE) and Service Level Target (SLT) guidelines for different engines according to section 4.13. Service level performance and the analytical model for comparing SLTs and CTC were applied according to sections 5.2.2 and 5.2.3. Based on the accessible data in Volvo Penta's ERP system and interviews with Volvo Penta employees, it was identified that Volvo Penta uses a DRP ordering policy with periodic reviews. To calculate the SLTs, Volvo Penta's ordering policy was estimated as an (S-1, S)-policy according to Anderson and Lagodimos (1989) and Axsäter (2006) (See sections 4.9.1 and 4.10). The combination of these four analyses was then used to indicate appropriate SLTs and decide which engines should be ASEs. By using triangulation, the project will approach the problem from different angles to achieve the purpose of the thesis.

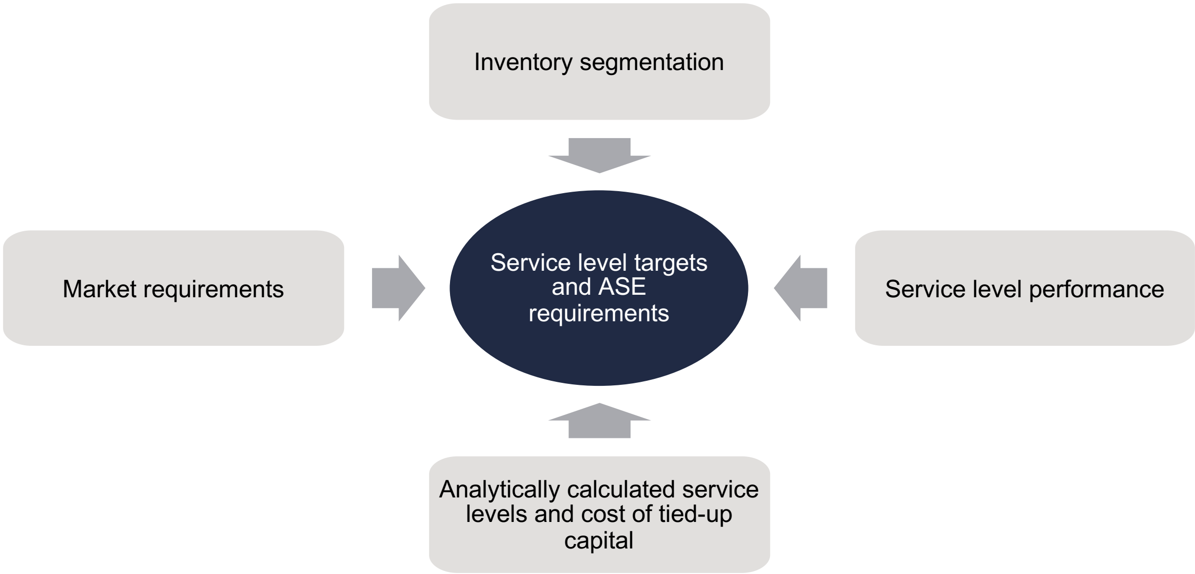

Figure 8: Illustration of the triangulation method, with the different methods at the edges and the objective they aim to achieve in the middle.

3.2.3 Step 3: Deriving solutions from the model

The solution for the problem was developed using Microsoft Excel, so adjustments to the model could easily be made with new or updated input data. It was created so that the results could be replicated and extended to other markets and business areas outside of the scope of this thesis that utilises ASE stock. By Hillier and Lieberman (2010), a solution should aim to produce a satisfactory result. Hence, the goal of the solution was to find a “good enough” solution where trade-offs between SLTs and CTC have to be made. Striving for an optimal or perfect solution for SLTs was identified as a potential pitfall since this may become too difficult or time-consuming.

3.2.4 Step 4: Testing The Model

Microsoft Excel contains the Visual Basics (VBA) extension which was a helpful tool to make the model dynamic and adaptable to change the input data. Programming is a requirement for implementing VBA projects, which requires testing and debugging. Time was allocated for model validation where the model was tested and validated using cases and examples from Axsäter (2006).

4 Theory

This section provides an overview of the relevant inventory control theory used to achieve the result. The main theoretical framework for this thesis is based on Axsäter (2006) and research articles on related topics.

4.1 Overview of a Single-Echelon System

The single-echelon system is characterised by an independent stock that is directly replenished from the production or a supplier, see Figure 9. The assumption is that SKUs are controlled independently and are stocked at a single location. However, it is common for items to have a central warehouse when distributing over larger regions. This is considered a multi-echelon system, which makes the system more complex to analyse. A difference between multi-echelon and single-echelon is that the availability of stock in each installation is affected by an upstream stock, which is affected by demand from multiple markets for the multi-echelon system. (Axsäter, 2006)

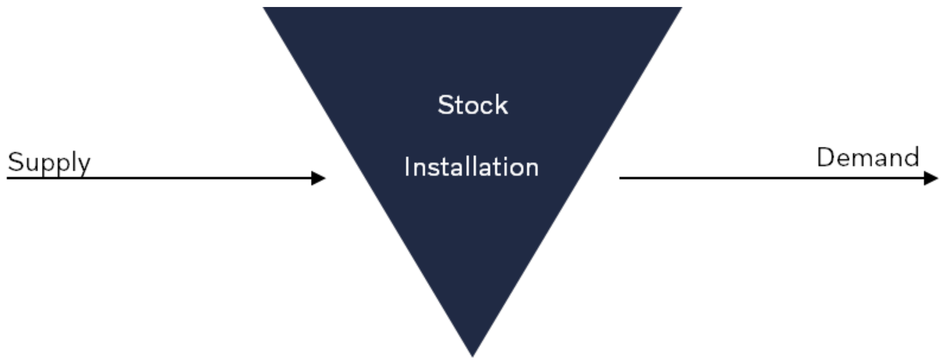

Figure 9: Illustration of a single-echelon inventory system.

As mentioned in section 2.2.2, a central warehouse structure is not always considered a multi-echelon system from a theoretical perspective. In the central distribution centre at Volvo Penta, items are not stored for the long term to replenish the local stock but are sent as soon as possible. The stock can be viewed as a transit stock between production and final storage. Also, products of the same type are controlled as independent SKUs depending on which market they are ordered for. Therefore, the regional stock at Volvo Penta can be viewed as a single-echelon system (according to the theory of Axsäter (2006)). This is, however, not true for some items (Item$_{O}$ 14, 15, 16, 17), which are centrally stored in Vara and distributed to local stock in different markets. This would be defined as a multi-echelon system. To limit the scope of the thesis, it is assumed that these items are part of a single-echelon system. This assumption would be equivalent to saying that the supply of Item$_{O}$ 14, 15, 16, 17 and at Vara is high enough that no stockouts will occur.

4.2 Inventory Level and Inventory Position

Inventory control systems aim to determine when and how much to order (Axsäter, 2006). These decisions are generally based on the inventory position, see (1). However, the holding costs and service levels will depend on the inventory level since outstanding orders are not available directly when an order is received, see (2). Without lead times, the inventory position would be equal to the inventory level, but this is usually not the case. Another important relationship can be seen in (3) when the system is in a steady state and the replenishment lead time is assumed constant (Axsäter, 2006). For Volvo Penta, the production facilities and the customers are located on different continents, which means long lead times, therefore, the inventory position and the inventory level can differ a lot.

$$Inventory\ position = outstanding\ orders + stock\ on\ hand - backorders \quad (1)$$
$$Inventory\ level = stock\ on\ hand - backorders \quad (2)$$
$$Inventory\ level = Inventory\ position - Lead\ time\ demand \quad (3)$$

4.3 Safety Stock and Reorder Point

Safety stock is a mechanism to deal with uncertainty, such as varying demand and lead times in an inventory system. In inventory control theory, the safety stock plus lead time demand is equivalent to the reorder point R= $s+\mu L$ (Axsätter, 2006). The reorder point triggers replenishment of the stock when the inventory position reaches this point or declines below. In a deterministic case, the reorder point should be set equal to the demand during the lead time (Axsätter, 2006). However, several factors impact an optimal reorder point in a stochastic environment. These are SLTs, lead time demand variation, order policy, component commonality and holding cost (Gonçalves et al., 2020). This complicates the determination of the reorder point in an inventory system. Different analytical models can be used for this task depending on which inventory policy is used. Generally speaking, an optimal reorder point should strike a balance between costs such as holding-, backorder- and ordering costs while ensuring the fulfilment of demand and service level expectations timely (Gonçalves et al., 2020). The case of this study will require an assessment of all the factors impacting the reorder point to determine a target service level and corresponding reorder point.

4.4 Service Level

Service levels are often considered important Key Performance Indicators (KPIs) for a business, but they can have several different definitions within a company. The required service level is the minimum service level that needs to be exceeded for a supply chain (Zijm et al., 2019). Therefore, Volvo Penta needs to measure and know whether it achieves the required service level. Otherwise, it can lead to a loss of sales due to customers turning to competitors or penalty costs to compensate for lost goodwill due to delays. However, the service level should not be too high since it costs to provide a higher service level. The costs are often in terms of inventory holding costs and ordering costs (Zijm et al., 2019). Backordering costs can also be included, but this is often difficult to estimate and is usually replaced with a service level constraint that is often perceived as easier to set. The goal should be to minimise inventory holding and ordering costs until a particular service level is fulfilled. The target service level should be decided by considering the trade-off between cutting costs and the consequences of shortages (Willemain, 2018). Setting the target service level is a strategic decision and should be decided in collaboration between the operations, finance, and sales departments. Therefore, Volvo Penta must set a target service level and implement a definition for the service level that is interpreted equally within the company to manage the trade-off between inventory costs and stock availability.

4.4.1 Definitions

Service levels are often used to set a suitable safety stock and reorder point. Axsäter (2006) describes three definitions for service levels, see Table 3. The probability of no stockout per order cycle (S_1) is still often used in practice as it is easy to use, but is not considered the preferred method from a theoretical perspective. One disadvantage of S_1 is that it does not consider the order quantity. As a result, problems can arise if order quantities are high, and then S_1 can be low even if there is plenty of stock. Both the fill rate (S_2) and the ready rate (S_3) take the order quantity into account and are therefore preferred measures to use. However, they are usually more complex to calculate. The most used definition is the fill rate, but the optimal definition depends on the item (Teunter et al., 2017). The trade-off between reducing costs and providing high service depends on the item (Axsäter, 2006). For products with long lead times and varying demand, it is more expensive to provide high service levels than for products with short lead times and stable demand. Therefore, setting the service level suitably for the stock included in this project is crucial.

Table 3: Service level definitions.

S_1	Probability of no stockout per order cycle
S_2 (Fill rate)	Fraction of demand that can be satisfied immediately from stock on hand
S_3 (Ready rate)	Fraction of time with positive stock on hand

It is important to note that service can be defined in other ways than probability. In some cases, it can be more beneficial to have a time-based approach to measuring service (Axsäter, 2006). One example is setting an average customer waiting time that orders should not exceed. Time-based approaches set a desired time window within which an order should be delivered. This time window is the maximum waiting time allowed, which is the difference between the maximum delivery time and the agreed delivery time, see Figure 10 (Ahmadi et al., 2020). Then, a probability rate can be set to guarantee that orders should be delivered within this time window. For example, if the maximum waiting time is set to three days, an SLT can be to deliver 95% of the orders within this time window. These kinds of service measurements can also apply to a company using a preorder strategy, meaning customers order in advance of production (Ahmadi et al., 2020). A time-based approach to measuring service is relevant to Volvo Penta since the customer lead times are long, and it can be assumed that customers generally accept some delay. Then, it can be more important to identify the customer's acceptable waiting time and satisfy the demand within this time window.

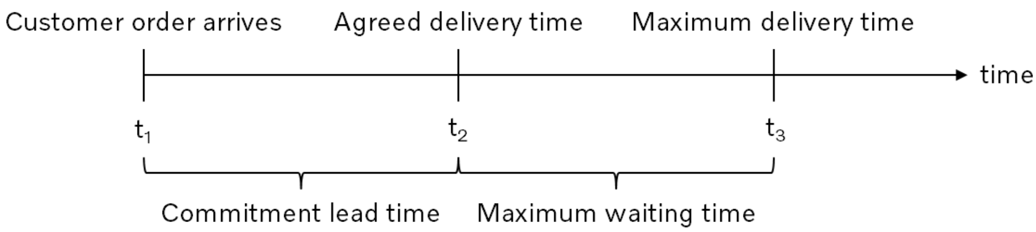

Figure 10: Illustration of customer waiting time (adapted from Ahmadi et al., 2020).

4.4.2 Service Performance Measurements

It is crucial for companies to select performance measurements aligned with the overall strategy (Stadtler et al., 2008). The risk of not achieving the targets increases significantly if they are not aligned. SCOR is a model for performance measurements and a framework to use when deciding strategic and diagnostic metrics regarding supply chain performance

(ASCM, 2024). Based on the available data on requested, promised, and actual shipment dates according to section 2.2.4, the supply chain performance measurements in Table 4 were of importance for this project. Service level performance can be tracked by evaluating the fill rate, which is one of the service level definitions mentioned in section 4.4.1. The fill rate is a metric that measures a company's ability to meet customer demand from available inventory. According to the SCOR model, the fill rate can be expressed as a percentage of the number of items shipped on or before the requested date, compared with the total number of items shipped during a specific period (see Table 4). In this way, a fill rate that is analytically determined can be followed up to ensure that the actual performance is as expected.

Table 4: Supply chain performance measurements with corresponding definitions (ASCM, 2024). The definitions are based on ASCM (2024) but adjusted to suit Volvo Penta.

S_2 (Fill rate)%	$\frac{Number\ of\ items\ shipped\ on\ or\ before\ the\ requested\ date}{Total\ number\ of\ items\ shipped}$
On Time Shipments (OTS)%	$\frac{Number\ of\ orders\ shipped\ on\ or\ before\ the\ promised\ date}{Total\ number\ of\ orders\ shipped}$
Orders Promised to Request (OPR)%	$\frac{Number\ of\ order\ requests\ accepted\ without\ negotiating\ a\ new\ commit\ date}{Total\ number\ of\ requests}$

Other relevant measurements of delivery performance are the percentage of On Time Shipments (OTS) and the percentage of Orders Promised to Request (OPR) (ASCM, 2024). OTS can be defined as the percentage of orders that were shipped on or before the promised ship date, see Table 4. This imply that an order is considered to be shipped on-time if the waiting time is equal to or below zero, see Figure 11. OTS is a measurement of how well a company fulfils its commitments, regardless of when the request was made. OPR can be defined as the percentage of order requests that were accepted without negotiating a new commit date, see Table 4. This implies that an order is considered to be promised to request if the promised delay is equal to or below zero, see Figure 11. OPR can be a good measurement of customer satisfaction. Integrating these two metrics with the fill rate allows for a more comprehensive analysis of service and delivery performance. Figure 11 illustrates the differences between the metrics regarding which dates are compared. The combination of metrics provides indications about the service level performance and the ability to meet customer expectations. It is essential to synchronise the metrics. For example, if the order promises are made optimistically, it will increase the performance on OPR but result in poor OTS due to infeasible promises. However, if OTS are high and OPR are low, OPR could be set more optimistically. Therefore, it is vital to balance these metrics to optimise customer satisfaction.

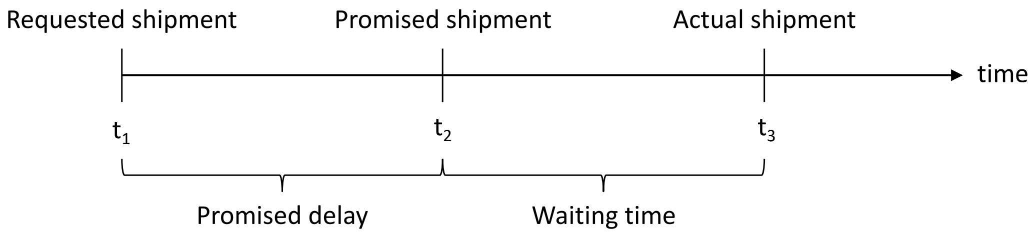

Figure 11: Ilustration of the differences between the performance measurement. Orders Promised to Request (OPR) is measured on promised delay, On Time Shipments (OTS) is measured on waiting time, and fill rate is measured total difference between actual and requested shipment.

4.5 Backorders and Lost Sales

In cases where a demand occurs and cannot be delivered due to shortages, costs will occur. This happens when the stock on hand reaches zero and customers arrive. Depending on the situation, the costs can be of different character. If the customer is willing to wait and the order is backlogged, the inventory level becomes negative, and the costs could be defined as backorder costs, which might involve price discounts due to late deliveries. In the other case where the customer instead is lost, the inventory level never gets below zero, and the costs are defined as lost sales. Lost sales costs are often difficult to estimate since they usually mean a loss in goodwill, which may result in lower sales in the future. Due to the difficulties in calculating shortage costs, they are often replaced by a service level constraint, which is easier to determine in most practical situations (Axsäter 2006).

4.6 Ordering Policies

Ordering policies are a set of rules determining when an order should be made and what quantity should be ordered. Different ordering policies can be more or less appropriate depending on the situation. The most common ordering policies in literature are (R, Q) and (s, S) policies (Axsäter, 2006). In many cases, these policies can be equivalent, but in some cases, they are not. Another policy that is also frequently used is the (S-1, S)-policy. This means that an order is placed directly when a demand occurs (Axsäter, 2006).

In an (R, Q)-policy, orders are made in batches of Q when the inventory position reaches R, but in an (s, S)-policy, orders are always ordered up to a specific inventory position S when the inventory position reaches s (Noblesse et al., 2014). However, both policies use the same reorder points, denoted R and s. Therefore, in cases of continuous review and continuous demand, these two policies are equal, s=R and S=R+Q (Axsäter, 2006). However, in cases where the inventory position can be lower than the reordering point, the equivalence does not hold. From an economic and sustainable aspect, a (R, Q) policy is usually preferred since shipments with fixed batches are often easier to consolidate into full truckloads or containers, while a (s, S) policy does not consider this. A disadvantage of ordering in batches, whether they are of the same size or not, is that it contributes to the bullwhip effect since the batch ordering amplifies the demand variability when moving upstream in the supply chain. Thus, upstream suppliers will have difficulties forecasting the demand, which will eventually have a negative impact on the whole supply chain (Noblesse et al., 2014). Also, ordering in batches will increase the amount of inventories stored and, as a result, the inventory holding cost will also increase. Therefore, a trade-off between these aspects should considered when selecting an appropriate ordering policy.

Moreover, the (S-1, S) policy is a special case of the (R, Q) policy where R=S-1 and Q=1. This policy is also called a one-for-one policy because a new order is placed immediately when demand occurs (Axsäter, 2006). Expressing the (S-1, S) policy as an (R, Q) policy is useful since models formulated for the (R, Q) case can be used.

4.7 Review Policies

In inventory control, there are two main types of review policies. These are continuous and periodic review. In both cases, an order is triggered when the inventory position is at or below the reorder point. The difference between the two is that in periodic review orders can be placed only in connection to the review process, while for continuous review a replenishment order can be placed at any time. The policy used by a company is often a result of its IT system where periodic review fits a traditional approach of manual ordering while continuous review requires automatic ordering systems to reach its full potential. (Axsäter, 2006)

The review policy will impact the service level of the inventory system. This implies that different analytical models have to be used depending on which review policy is used (Axsäter, 2006). Therefore, it is important to understand the inventory control system at the case company fully to determine the correct service level measure.

For continuous review, the inventory control system is set up so that the inventory position is monitored at all times. A replenishment is triggered immediately when the inventory position reaches the reorder point. The advantage of this method is that it reduces the need for safety stock. (Axsäter, 2006)

The periodic review system evaluates inventory position only at predetermined points in time. With this policy, the uncertainty period, which consists of the lead time and time between the reviews, becomes more significant. Hence, the periodic review system can require more stock. In Figure 12, the review time starts at *t.* Orders can be placed at *t, t+T...* where *T* is the constant review period. Deliveries can arrive at *t+L, t+L+T...* where *L* is the replenishment lead time. The fill rate is dependent on the interval between two deliveries. (Axsäter, 2006)

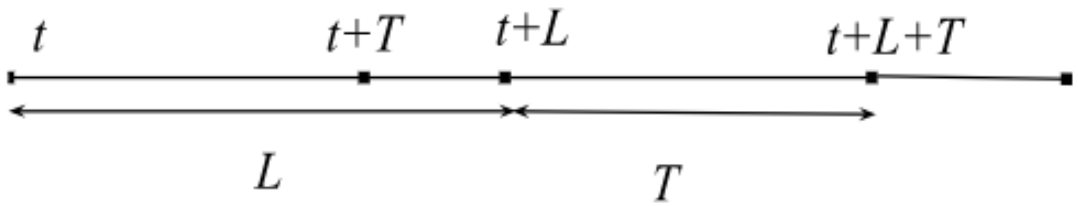

Figure 12: Periodic Review.

There are only minor differences between continuous and periodic review policies when the review period is short. In these cases, the continuous review system which is easier to analyse analytically can be used as an approximation (Axsäter, 2006). In practice, it is common to approximate a periodic system with methods used for continuous systems by replacing the lead time with *L+T/2.*

4.8 Inventory Holding Cost

Inventory holding costs are an essential decision parameter when modelling an inventory control system (Axsäter, 2006). Traditionally, in literature, the cost of capital has been used as inventory carrying cost, but this is only a part of the total cost. The total cost of holding inventory consists of four main components. First, the cost of capital contributes to inventory cost, interest due to missed returns on alternative investments sacrificed due to holding inventory. Second, an inventory service cost exists. This cost can, for example, include tax and insurance. Third, storage space cost contributes. This can include rent, staff, etc. if there is an alternative use for the facility. Fourth, inventory risk cost is a contributor to the inventory holding cost, which should include costs such as depreciation and obsolescence. The inventory risk cost can sometimes be the most significant part of the inventory holding cost. (Berling, 2005)

Furthermore, determining the entire inventory holding cost is not straightforward. It includes using methods such as activity-based cost analysis and risk-adjusted valuation. Axsäter (2006) asserts that the cost of capital typically constitutes a significant share of the inventory holding cost. In coherence with Volvo Penta's current approach, the cost of capital is employed to approximate the holding cost in this report. This cost is expressed as an interest rate for the opportunity cost of holding inventory.

4.9 Material Requirements Planning

Material Requirements Planning (MRP) is a system that can be compared to Volvo Penta's DRP system, see section 2.2.2, and is usually used for inventory control (Axsäter, 2006). The process identifies the demand, stock on hand, and scheduled receipts to plan new orders. Such a system can be used both in the supply, production and distribution of materials. MRP can be seen as a reorder point system where the reorder points are updated continuously concerning known requirements. This is the difference between implementing MRP and not just an ordering policy from section 4.6. In a traditional ordering policy, the reorder points are fixed over a fixed periodicity, which results in poor performance in cases with considerable changes in demand. MRP is not necessarily done in software but can also be done by hand.

To successfully use the MRP method, it is crucial to accurately determine the safety stock and lead time parameters, where the safety stock should be determined by the service level parameter (Jonsson & Mattsson, 2008). Other important conditions to increase the performance of MRP are integration between the MRP and ERP system, knowledge level of the planners making the orders, and inventory accuracy.

4.9.1 Inventory policy in an MRP system

A single-stage MRP environment can be generalised to a periodic review (s, S)-policy with a periodic review (Anderson and Lagodimos, 1989). In this model, it is assumed that the gross requirement is constant for each period i.e., $G_i(j)$. Gross requirement refers to the total demand for an item in period j before considering existing inventory or planned receipts. It is the total quantity needed to satisfy demand without considering current stock levels. This implies that the forecasted demand does not vary across the periods. The generalisation of an MRP ordering system as an (s, S)-policy can be used to apply the theory from Axätter (2006) when determining Volvo Penta's inventory control service levels. The (S-1, S)-policy is also a special case of the (s, S)-policy. A derivation of (4) and (5) can be seen in Appendix D.

The (S-1, S) policy can be expressed through equations (4) and (5), where l is lead time, including safety lead time if this is used, u_s is the planned safety stock, *c* gross requirement, and *p* number of planning periods covered by a new order. S is the order up-to-level and s is the reorder point. See section 4.6 for a more thorough explanation of the (S-1, S) policy.

$$S = u_s + (l + p)c \quad (4)$$
$$s = S - 1 \quad (5)$$

4.10 Modelling of The Inventory Control System

This section contains the theory used to create a mathematical model for the inventory control system deployed at Volvo Penta (described in section 2.2). Section 4.9.1 is also an essential part of the modelling to generalise the DRP system that Volvo Penta uses so that the main framework of Axsäter (2006) can be applied.

4.10.1 Compound Poisson Demand

In cases where the demand is reasonably low and infrequent, using a discrete demand model such as Poisson distributed demand is advantageous. If the demand is high and frequent, using a continuous demand model such as normally distributed demand is typical. A rule of thumb when considering the Poisson distributed demand is when the variance-to-mean ratio $\frac{\sigma^2}{\mu} \approx 1$. When $\frac{\sigma^2}{\mu} > 1.1$ negative binomial distributed demand is the preferred option, which is the compound Poisson demand with a logarithmic compounding distribution (Axsäter, 2006).

In Volvo Penta's case for marine engines, the demand is relatively low and infrequent and fulfils the criteria of $\frac{\sigma^2}{\mu} > 1$. Therefore, a discrete demand model such as a compound Poisson demand should be used. This model assumes that the total demand for a product can be represented as a non-decreasing stochastic process, where changes in demand are random but do not follow a specific pattern over time and do not influence each other. It is a model that is made up of smaller, independent random events that add up to the total demand. In practical scenarios, especially when products have low and unpredictable demand, assuming compound Poisson demand can be helpful. Stenius et al. (2016) used this model in a similar project, where the case company produced both Make-To-Order (MTO) and Make-To-Stock (MTS) for the construction industry. In both their case and this project, the customer demand can be characterised by randomness in several orders that arrive and the individual order sizes.

A compound Poisson process means that the customers arrive according to a Poisson process with an arrival intensity λ. The time between arrivals is exponentially distributed with a mean of $1/\lambda$, and customer demand is an independent discrete stochastic variable. The probability distribution function for Poisson demand is defined by (6). To get the probability distribution for compound Poisson demand, (6) has to be combined with (7). In (7), f_j^k is the probability that *k* customers demand *j* units. (7) uses f_j , the probability that a customer demands *j* units. Finally, (6) and (7) are combined into (8), which is the probability of a demand of *j* units during *t* time units where $D(t)$ is stochastic demand during *t*. (Axsäter, 2006)

$$P(k) = \frac{(\lambda t)^k}{k!} e^{-\lambda t} \quad (6)$$

$$f_j^k = \sum_{i=k-1}^{j-1} f_i^{k-1} f_{j-i} \quad (7)$$

$$P(D(t) = j) = \sum_{k=0}^{\infty} \frac{(\lambda t)^k}{k!} e^{-\lambda t} f_j^k \quad (8)$$

$D(t)$ = stochastic demand in the time interval *t*

f_j^k = probability that *k* customers give the total demand *j*

f_j = probability that a customer gives the total demand *j*

The average demand per unit of time, μ, and the variation of the demand per unit of time, σ^2, can be calculated according to (9) and (10) (Axsäter, 2006). (9) can be used to determine the parameter λ used in (8) if μ and f_j is known.

$$\mu = \lambda \sum_{j=1}^{\infty} j f_j \quad (9)$$

$$\sigma^2 = \lambda \sum_{j=1}^{\infty} j^2 f_j \quad (10)$$

Moreover, f_j is the probability that a customer demands *j* units. This can be estimated using different methods. The approach used in this project is to determine f_j empirically with available data as relative frequences. Hence, each element in the f_j vector is determined by the number of orders consisting of *j* units divided by the total number of orders.

4.10.2 Service Level for a Periodic review (R, Q)-policy

For a periodic review system, the inventory position is reviewed at each inspection interval. Therefore, there is a significant difference with the continuous models for determining the fill rate when the inspection interval is long. The fill rate for a (R, Q) policy can be obtained from (11).

$$S_2 = 1 - \frac{E(IL")^- - E(IL')^-}{\mu T} \quad (11)$$

$E(IL')^-$is the expected backorders at t+L just after delivery and $E(IL'')^-$ is the expected number of backordered units at t+L+T just before the next delivery. The difference between $E(IL'')^- - E(IL')^-$ corresponds to the expected demand occurring in [t+L, t+L+T] that cannot be met.

The expected backorders can be calculated using the following equations. The expected backorders are calculated by (12), and average inventory levels (13) and (14). The probability distribution for IL'' and IL' are expressed in equation (15) and (16). These can be used to calculate $E(IL)^+$, which is described in section 4.10.3 by (19). (Axsäter, 2006)

$$E(IL)^- = E(IL)^+ - E(IL) \quad (12)$$

$$E(IL'') = R + (Q+1)/2 - \mu(L+T) \quad (13)$$

$$E(IL') = R + (Q+1)/2 - \mu L \quad (14)$$

$$P(IL' = j) = \frac{1}{Q} \sum_{k=max\{r+1,j\}}^{R+Q} P(D(L) = k - j) \quad j \le R + Q \quad (15)$$

$$P(IL'' = j) = \frac{1}{Q} \sum_{k=max\{r+1,j\}}^{R+Q} P(D(L+T) = k - j) \quad j \le R + Q \quad (16)$$

By using (12)-(16) and (19), equation (11) can be rewritten as (17).

$$S_2 = \frac{\sum_{j=1}^{R+Q} j\, P(IL' = j) - \sum_{j=1}^{R+Q} j\, P(IL'' = j)}{\mu T} \quad (17)$$

4.10.3 Comparing the Cost of Tied-up Capital and Service Level

In section 4.8, it was argued that cost of capital should be used as an estimate for the inventory holding cost. The Cost of Tied-up Capital (CTC) for a given inventory policy can be calculated and then compared to the service level (fill rate) of the same policy by the results of (20) and (17). This comparison allows for a direct assessment of the relationship between fill rate and CTC for an item and is an essential part of the analysis in section 6.4. First, to calculate the average stock on hand $E(IL^{+})$ in (19), the probability distribution of inventory level $P(IL = j)$ has to be determined by (18). This is achieved by using the estimate for periodic review, replacing the lead time with a lead time of L+T/2 (section 4.7), and using the compound Poisson demand (8). Then, the average stock on hand that a reorder point of R and order quantity of Q would give is computed by (19). Finally, the CTC can be calculated by multiplying the interest rate for the cost of capital (*r)* with capital tied up in material and production (*c)* in (20).

$$P(IL = j) = \frac{1}{Q}\sum_{k=max\{r+1,j\}}^{R+Q} P(D(L + T/2) = k - j) \quad j \leq R + Q \tag{18}$$

$$E(IL^{+}) = \sum_{j=1}^{R+Q} j\, P(IL = j) \tag{19}$$

$$CTC = r * c * E\left(IL^{+}\right) \tag{20}$$

Moreover, a reorder point of R will correspond to a mean lead time demand and safety stock, *ss* i.e., $R = ss + \mu L$, thereby enabling the determination of a corresponding fill rate and CTC for each item by varying the safety stock component *ss* of the reorder point in (20) and (12) to get the service level and corresponding CTC. Also, (18) and (19) are also applicable for the special case of the order-up to policy (S-1, 1) corresponding to an (R,Q) policy with *Q= 1* and R=S-1, which is used in this study. The S parameter is defined in section 4.9.1.

4.11 Customer Order Decoupling Point

Customer Order Decoupling Point (CODP) is defined as the point in the value chain where the product gets linked to a specific customer order (Olhager, 2010). The most frequently used CODPs are Make-To-Order (MTO) and Make-To-Stock (MTS). MTO means that a product goes into production when a customer order is received. In an MTS system, the product is produced in advance, and the production rate is based on forecasts. The CODP divides the material flow into forecast-driven activities upstream of the CODP and customer-driven activities downstream of the CODP, which should be managed differently, see Figure 13. The two other kinds of CODPs are Assemble-To-Order (ATO) and Engineer-To-Order (ETO). Choosing an optimal CODP for each product and managing them accordingly is crucial for companies (Olhager, 2010). Volvo Penta has engines that are both produced according to MTO and MTS. Choosing which engines should be produced MTS as Authorised Stock Engines (ASE) is a strategic decision since it will affect the delivery times and service levels. Additionally, the stock levels at the CODP should be determined by the service level and lead time requirements downstream of the CODP to ensure satisfied customers.

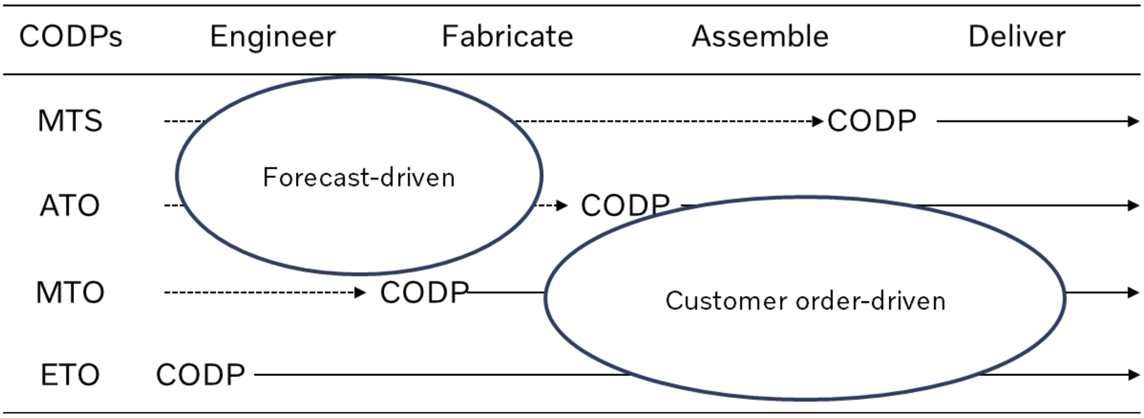

Figure 13: Illustration of different CODPs (adapted from Olhager, 2010).

There should be several determinants of the CODP. Some business characteristics that should influence managers' decisions regarding the position of the CODP are illustrated in Figure 14. Olhager and Van Donk (2024) highlight lead times as a key characteristic when evaluating CODP options. The customer's requirements determine restrictions. If the customer demands immediate deliveries, an MTS strategy should be used, but an MTO strategy can be possible if the customer is willing to wait. For a customer who requests an order longer ahead of the cumulative lead time, the MTO strategy can be applied since it is possible to fulfil the customer's requirement without stocking expensive items. In this way, the customer dictates the optimal position of the CODP.

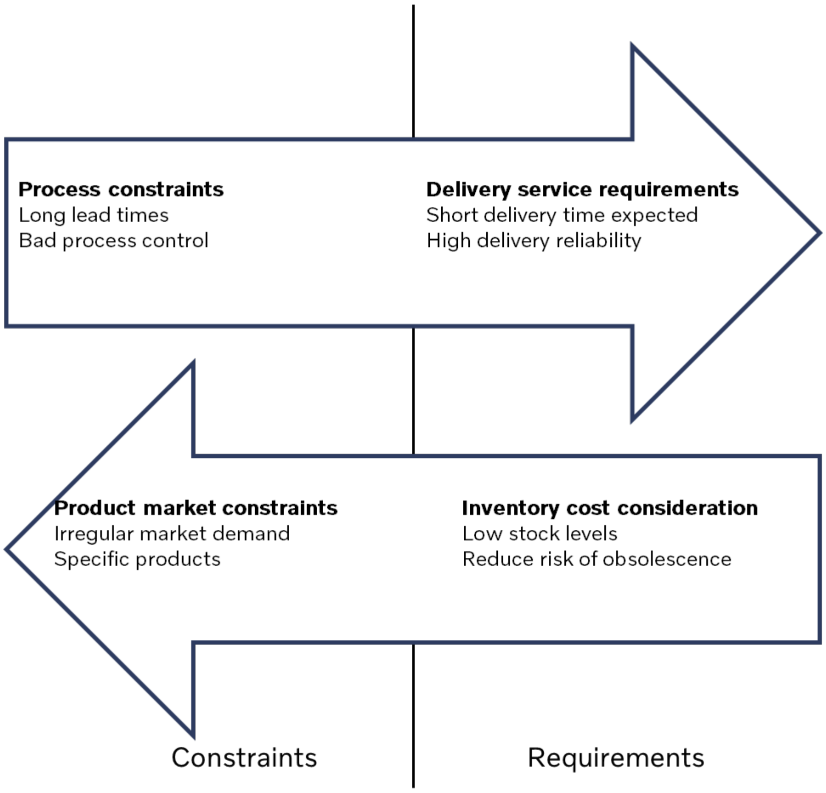

Figure 14: Business characteristics and their influence on the CODP, based on van Donk (2001). The right direction arrow characteristics influence the CODP towards downstream activities. The opposite applies to the left direction arrow.

4.12 Inventory Segmentation Models

This section presents a literature review of different methods to segment inventory. To be able to set reasonable Service Level Targets (SLT) and safety stocks, it is crucial to evaluate different methods to identify a suitable approach.

The most common tool for segmenting inventory is the ABC model, which has been used in the discipline of inventory management for a long time (Flores & Whybark, 1988). It is based on the Italian economist Pareto's principle. In inventory management, it means that 20% of the inventory items comprise roughly 80% of the total inventory value. The ABC model classifies SKUs into segments based on their sales volume. Teunter et al. (2010) state that the ABC model is also widely used in practice. They apply the model to three large real cases where they set different SLTs based on the classification. Inventories in segment A were assigned the highest SLTs, and inventories in C were assigned the lowest. However, their research found that the ABC model performed poorly compared to a model that also included criteria with criticality. Even if the ABC model is well known it also has some limitations. Silver et al. (1998) mean that the ABC model only takes one criterion into account and risks missing out on other crucial criteria. They recommend that the ABC analysis should be complemented with other dimensions. Flores et al. (1992) also criticise the ABC model for the same reason. By adding more dimensions to the analysis, other important factors beyond sales volume can be taken into account.

One example of this is the ABC-XYZ analysis which Stojanović and Regodić (2017) suggest. The XYZ model classifies products by demand variability. Greene (2021) also confirms that an ABC model benefits greatly by adding the XYZ model to the analysis in his article about combining an ABC with an XYZ model. Without taking the demand variability into account, Greene (2021) means that an ABC model risks performing poorly since it usually multiplies the selling price with the sold amount, meaning that the most expensive items risk being stored for a long time, which would result in extensive holding costs. By including demand variability in the analysis, this risk can be mitigated. Scholz-Reiter et al. (2012) and Stoll et al. (2015) are other examples of articles that include an XYZ model in their inventory segmentation analysis.

Another way to include demand characteristics in an inventory segmentation analysis can be to use an ABC-FMR analysis (Lukinskiy et al., 2019; Lukinskiy et al., 2020; Ongkicyntia & Rahardjo, 2017). This model has been used to segment items into Make-To-Order (MTO) and Make-To-Stock (MTS) products by the global electrical equipment manufacturer Schneider Electric (Oberlé, 2012). The FMR part segments the inventory based on the demand frequency compared to the demand variability in the XYZ model. However, since the FMR does not account for variability, the model risks storing items that have one large order and otherwise few orders.

An original ABC-XYZ model considers two dimensions, but decisions concerning how different products should be managed are more complex in reality. Flores and Whybark (1988) mean that two dimensions are not enough to analyse inventory. They believe that other dimensions, like lead time, criticality, and others, can also be important to include. Depending on the demand pattern, product characteristics, supply chain, and data availability, the dimensions become differently easy to analyse.

Stojanović and Regodić (2017) mitigate this by an extended ABC-XYZ analysis, which includes sales volume, lead time, and criticality as parameters in the ABC part. Stoll et al. (2015) evaluated spare parts and presented another way to include multiple criteria. The model is called ABC-XYZ-VED, where VED assesses the items', criticality using multiple criteria analysis. The main model or criteria is broken down into sub-criteria in both Stojanović and Regodić (2017) and Stoll et al. (2015). This is done using the Analytical Hierarchy Process (AHP) approach, which is an efficient way to break down problems and, in this case, a criterion based on multiple sub-criteria (Saaty, 1990). In Stojanović and Regodić (2017), the ABC is broken down into the following sub-criteria: sales volume, lead time and criticality. Instead, Stoll et al. (2015) keep the ABC as the original, which only involves sales volume, and extend the analysis with a third dimension where multi-criteria related to criticality are handled. Important to notice is that the weights for the criteria in an AHP are subjectively chosen by using expert judgment (Stojanović & Regodić, 2017).

Overall, in articles, the ABC model is almost always used when segmenting inventory items, sometimes independently but often in combination with at least one more model. In more recent papers, the ABC model is usually complemented with the XYZ model. Many authors are then satisfied with the combination of these two, but many authors also include other models or criteria. How this is done varies a lot in literature, but criticality is a criterion that, in general, appears when other criteria are included in the analysis.

4.13 Applied Inventory Segmentation Model

This section will delve into the ABC-XYZ-VED model, the inventory segmentation model chosen for the Volvo Penat case. Its selection was based on a literature review in section 4.12, which concluded that this three-dimensional model is the most suitable for our context.

Each component of the ABC-XYZ-VED model will be described and how they are integrated. This combined method will help decide which engines to produce MTS and offer a practical rule of thumb for setting SLTs and ensuring inventory levels are reasonable compared to other SKUs and different high-impact and low-impact SKUs.

This combination was chosen because the aim was to use a model that was as holistic and objective as possible. From the start of the literature review, it became clear that a model combining ABC and XYZ should be used. This combination is frequently used in inventory management literature to segment items. It considers the sales volume and demand variability, which Greene (2021) highlights as crucial for the analysis's performance. Additionally, several authors conclude that more criteria should be added to a segmentation analysis, specifically criticality criteria (Flores & Whybark, 1988; Teunter et al., 2010; Stojanović & Regodić, 2017; Stoll et al., 2015). Therefore, a VED part was included in the model, which takes a criticality criterion into account. However, since the aim was an objective model, the VED analysis was based on the available data. It did not include an AHP with multi-criteria since it includes subjectively chosen weights.

4.13.1 ABC Classification

The ABC classification can identify useful inventories that contribute to a business's performance and distinguish these from inventories that are mostly a cost for a company. The classification is based on the vital few and the trivial many rules, which says that 20% of the articles contribute to 80% of the sales. This is not always strictly true, but it is not uncommon that a minor part of the SKUs contributes to a more significant part of the sales in a company.

The cumulative sales revenue is used to classify the products according to Table 5. (Stojanović & Regodić, 2017)

Table 5: Cumulative revenue (ABC) upper and lower bounds.

Category	cumulative sales revenue lower bound	cumulative sales revenue upper bound
A	0%	<80%
B	80%	<95%
C	95%	100%

The revenue of the SKUs can be calculated by the items' annual usage (see equation 21). Then, the cumulative revenue can be calculated, and the ABC category can be determined according to the classification in Table 5. The traditional ABC method that only analyses the annual usage is easy to implement and requires limited managerial time (Flores et al., 1992).

$$GV_i = c_i \times x_i \tag{21}$$

where c_i = the unit price and x_i = the volume of demand

4.13.2 XYZ Classification

For the XYZ classification, the demand for the product is assessed. Demand can vary between different SKUs, so this analysis provides a segmentation based on the consumption of the articles. Group X consists of items of continuous demand, or at least have low variability and high forecast accuracy; Group Y have higher demand volatility and less forecast accuracy; Group Z have high variability, which makes forecasting difficult (Stojanović & Regodić, 2017). These categories are determined by the coefficient of variation (CV) (23), which is the standard deviation of the demand (22) divided by the average demand (Stojanović & Regodić, 2017). This indicates the demand variability.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x}_i)^2} \tag{22}$$

$$CV = \frac{\sigma}{\bar{x}} \tag{23}$$

The classification thresholds based on CV values are divided in the literature. For example, Stojanović and Regodić (2017) propose that items with a coefficient of variation of 0-0,1 should be classified as group X, coefficient of variation of 0,1-0,25 as Y, and coefficient of variation higher than 0,25 as Z. However, Scholz-Reiter et al. (2012) suggest 0-0,5 for X, 0,5-1 for Y, and higher than 1 for Z. The conclusion is that the chosen thresholds depend on which kind of items are evaluated. Higher thresholds can be necessary if all items experience low demand, which is often the case for spare parts and components for machinery and equipment industries. An example is Stoll et al. (2015), which evaluated spare parts management. They used the thresholds according to Table 6. Since the demand for Volvo Penta's engines is subject to similar demand patterns as spare parts, these thresholds were also used in this project.

Table 6: Coefficient of Variation (CV) upper and lower bounds that were used in this project.

Category	CV lower bound	CV upper bound
X	0	1,5
Y	1,5	3
Z	3	-

4.13.3 VED classification

Stoll et al. (2015) present a three-dimensional classification approach, including the standard ABC-XYZ analysis. The third dimension, VED, which stands for "vital", "essential", and "desirable", analyses criticality, which contains several criteria that are connected to criticality. These are, for example, lead time, installation time and equipment availability. "Vital" items are the items that result in significant consequences if they are unavailable. "Essential" items are not critical but can still cause severe consequences and be controlled and corrected. Lastly, "desirable" items can be substituted and, therefore, least critical; however, since Stoll et al. (2015) analyse spare parts, the VED analysis needs to be adjusted to become suitable for the Volvo Penta case, and other criteria are needed.

As described in section 4.11, the lead time is crucial to analyse when choosing the position of the Customer Order Decoupling Point (CODP) and is also a criterion connected to criticality in Stoll et al. (2015). Analysing lead time is especially applicable to this project since sometimes customers request orders ahead of the total lead time. In these cases, an MTS strategy is often not needed since the customer will get the order in time with the assumption of no disruptions. Therefore, this project's VED analysis will be based on the share of orders that will not be delivered on time if an MTO strategy is used, according to (24). Orders that cannot be delivered on time with an MTO strategy will be referred to as "critical" (25), and orders that will be delivered on time are "non-critical". Dekker et al. (1998) are examples of other authors who analyse spare parts in terms of criticality. They separate orders similarly, "critical" and "non-critical" demand.

$$criticality = \frac{number\ of\ critical\ orders}{number\ of\ total\ orders} \tag{24}$$

$$critical\ order = requested\ delivery\ date - order\ entry\ date < total\ lead\ time \tag{25}$$

Applied thresholds can be seen in Table 7. Note that these differ from the thresholds in Stoll et al. (2015) because the VED analysis will not include multi-criteria. Criticality was defined as the share of orders that cannot be delivered on time with an MTO strategy instead of multi-criteria because of its simplicity in practice and the available data which makes it possible to calculate. Compared to subjective multi-criteria approaches found in literature, which would require more work to apply the model and needs additional data.

Table 7: Criticality lower and upper bounds that were applied in this project.

Category	Criticality lower bound	Criticality upper bound
V	70%	100%
E	40%	70%
D	0%	40%

4.13.4 Combined ABC-XYZ-VED analysis

By combining the ABC-XYZ-VED, 27 different segments for SKUs are identified; see Figures 15 and 16. This three-dimensional analysis is based on Stoll et al. (2015), who used the same combination of analyses.

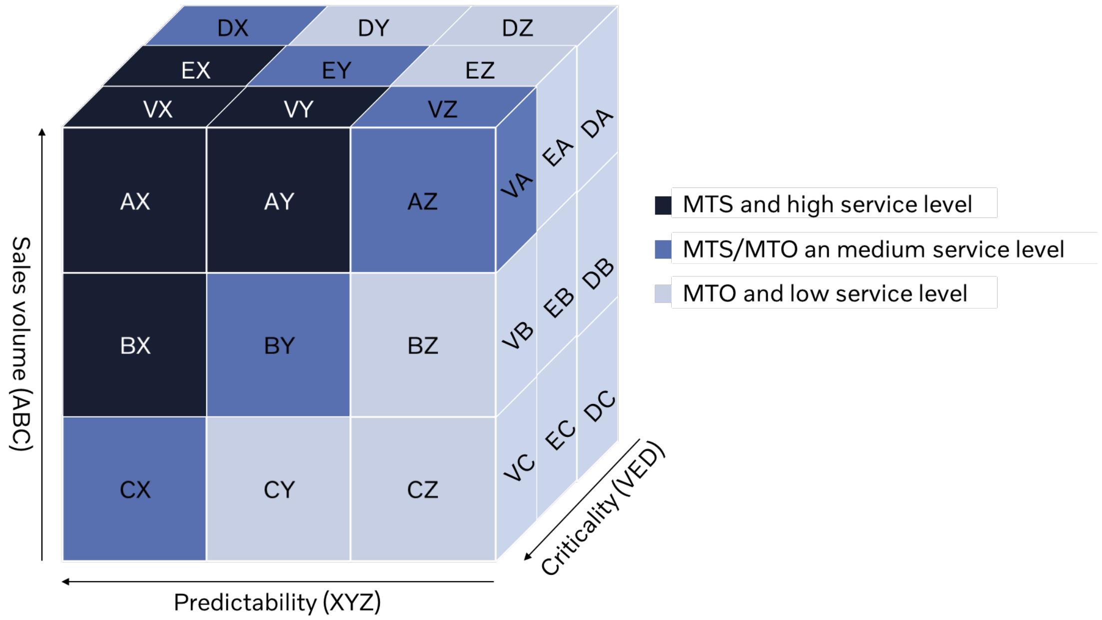

Figure 15: ABC-XYZ-VED model with inventory and service level strategy assigned to each segment.

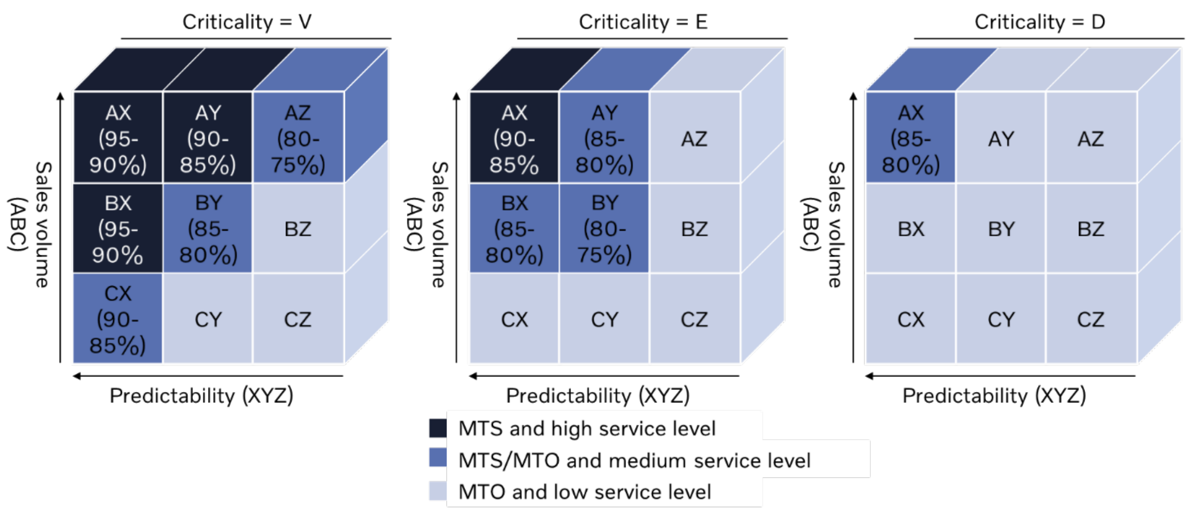

Figure 16: ABC-XYZ-VED model divided into cross-sections with fixed criticality. Guidelines for Sevice Level Targets (SLT) for each segment are noted within the parenthesis.

This segmentation is useful for assessing stock levels and service levels for SKUs. For each of the 27 segments, there is a preferred inventory strategy and service level strategy. The choice of MTS or MTO adjusts the actual service level, which needs to be aligned with the SLT. To provide higher service levels, an MTS strategy can be used, where the safety stock ensures increased service.

The strategies that should be used for each segment are based on three things. Firstly, it is more important for Volvo Penta to ensure a high service level on highly sold engines and not risk loss of high-value sales. Secondly, it is less costly to provide high service levels on engines that are easier to predict since they require lower inventory levels. Lastly, the higher the share of orders MTO cannot meet, the more critical it is to have items in stock. Items that, instead, often can be met by MTO would have less impact on customer satisfaction and mainly drive costs if they are being MTS. Therefore, the conclusion is that higher SLTs and MTS strategy should be set for engines with high sales value, predictability, and criticality.

5 Numerical Study

This section includes a detailed description of the numerical study. Section 5.1 provides an overview of the numerical study, including objectives. Section 5.2 focus on the data collection, and section 5.3 describes the analytical models used in the triangulation approach.

5.1 Overview

The numerical study was performed with three objectives: (i) investigate which engines should be Authorised Stock Engines (ASE) and provide guidelines for setting Service Level Targets (SLTs), (ii) provide historical performance of service levels for each item and market, (iii) illustrate the trade-offs between SLTs and Cost of Tied-up Capital (CTC) in a dynamic environment which can be used to set future SLTs for ASEs.

Based on insights from the numerical study, the research questions could be addressed in the result section. The study was performed in the prioritised markets: Oceania, Brazil, and Vara GAS. Figure 17 provides an overview of the numerical study, with input and output variables for each part stated.

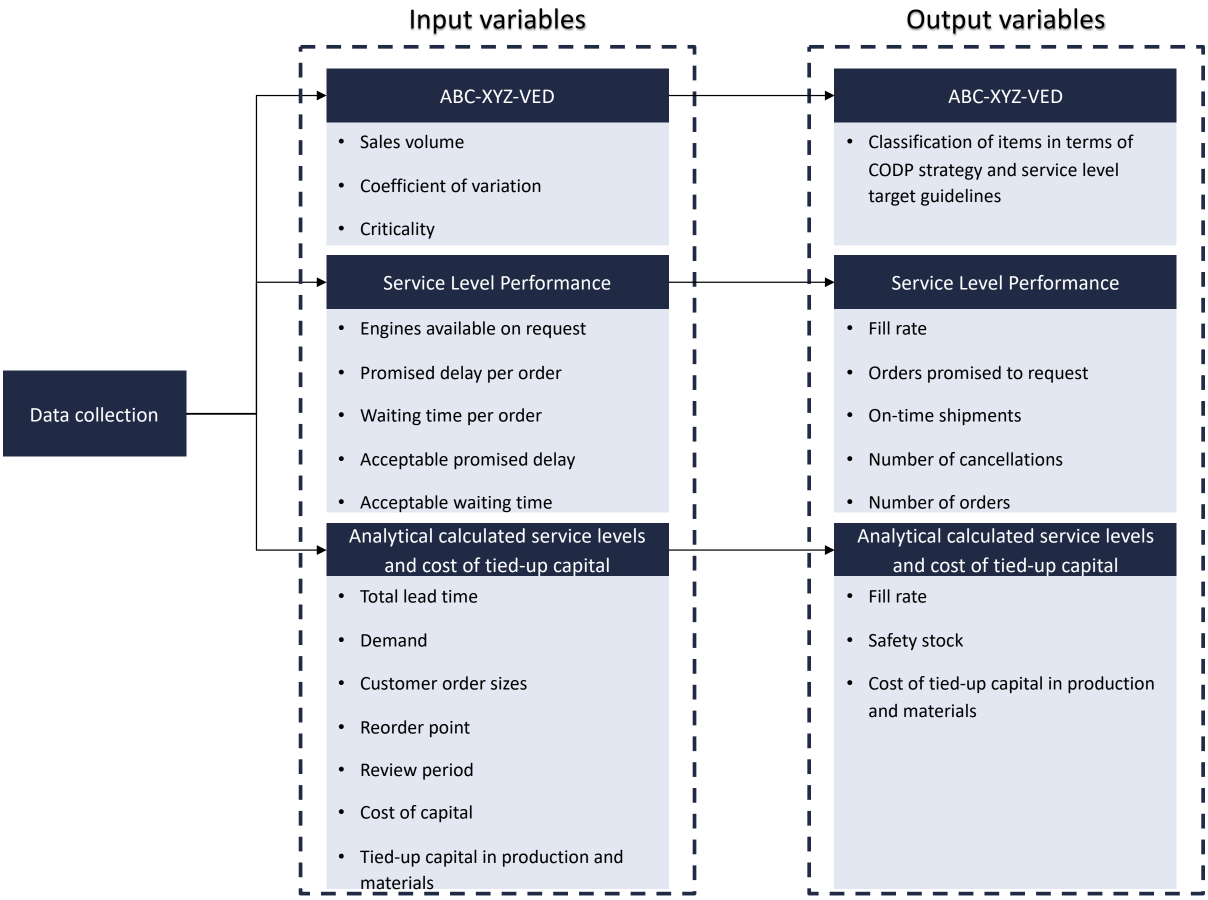

Figure 17: Overview of the numerical study.

In order to ensure that no classified internal information is published, the engines were anonymised. This was done by adding a subscript after “Item” which indicates which market an engine is sold to. $Item_O$ is sold to Oceania, $Item_B$ is sold to Brazil, and $Item_V$ is sold to Vara GAS.

5.2 Data Collection

This section describes how data was collected. All data in the numerical study was extracted from Volvo Penta's ERP system, with a few exceptions where interviews complemented the data. Filters concerning market area, product segment, and sales order type were applied to extract relevant data for specific markets and product segments. Based on a discussion with Volvo Penta and ensuring that appropriate data were collected, data was filtered on dates for one year.

5.2.1 ABC-XYZ-VED

Data was collected to perform the ABC-XYZ-VED model, considering each engine's sales volume, demand variability, and criticality, as defined in section 4.13. Data for each parameter can be seen in Table 8. It is important to note that data was collected on item description 1 level since data on item number could be misrepresentative. The reason for this is that item numbers update frequently. This decision prevents engine types from ending up in the wrong segment of total sales (ABC). For example, an ASE is replaced with a new item number; its predecessor might have belonged to segment A, but the new item number could end up in segment C if few sales have been placed.

Table 8: Data was collected for each input variable for ABC-XYZ-VED . Total lead time includes production, pick-and-pack, and transport lead time.

Input variables	Collected data
Sales volume	Invoiced sales
Coefficient of variation	Ordered engines per month
Criticality	Requested delivery date, order entry date, and total lead time

5.2.2 Service Level Performance

Data was collected to analyse time-based service levels to measure service level performance defined in section 4.4.2, i.e., On Time Shipments (OTS), Orders Promised to Request (OPR), and fill rate. This data was based on the input variables and corresponding data in Table 9. It is important to note that data regarding the acceptable promised delay and waiting time were collected from interviews with sales representatives; see the interview guide in Appendix C.

Table 9: Data collected for each input variable of service level performance.

Input variables	**Collected data**
Engines available on the requested date	Number of engines per order, actual and requested ship date
Promised delay per order	Promised and requested ship date per order
Waiting time per order	Actual and promised ship date per order
Acceptable promised delay	Requirement based on interviews with sales representatives
Acceptable waiting time	Requirement based on interviews with sales representatives

5.2.3 Analytically Calculated Service Level and Cost of Tied-up Capital

Table 10 shows the data collected to calculate the probability-based service level, i.e., fill rate and corresponding CTC and safety stock. The review period and reorder point were unavailable in the ERP system, so they were collected from interviews with SCPM (see Appendix A).

Table 10. Data was *collected for each input variable for analytical calculated service level and Cost of Tied-up Capital (CTC). Total lead time includes production,* pick-and-pack*, and transport lead time.*

Input variables	**Collected data**
Total lead time	Production, pick-and-pack and transport lead time
Demand	Ordered engines per month
Demand size	Sales order history
Reorder point	Interviews with Volvo Penta employees
Review period	Interviews with Volvo Penta employees
Cost of capital	Volvo Group Cost of Capital Rate
Tied-up capital in production and materials	Inventory History

5.3 Description of Analytical Models

This section describes the numerical study's analytical modelling. It is divided into the ABC-XYZ-VED model, service level performance, and analytically calculated service level and Cost of Tied-up Capital (CTC). With the triangulation approach, conclusions could be made considering ASE requirements and SLTs.

5.3.1 ABC-XYZ-VED Model

The data collected in section 5.2.1 were analysed to provide insights into the objectives. These were to recommend which engines should be ASE and have high service levels. First, the ABC model was performed according to section 4.13.1, where the sales volume for each engine type was calculated by (21). Next, the XYZ model was executed according to section 4.13.2, where the coefficient of variation for each engine type was calculated according to (22-23) based on the number of ordered engines per month. Then, the VED model was performed according to section 4.13.3, where criticality was defined as the share of orders that cannot be delivered on time with an MTO strategy and calculated according to (24-25). Lastly, the three models were combined into the complete ABC-XYZ-VED model, which outputs items in terms of Customer Order Decoupling Point (CODP) strategy and SLT guidelines according to section 4.13.4.

5.3.2 Service Level Performance

The data from section 5.2.2 were analysed to provide historical service level performance for each item. Time-based service levels were calculated based on historical data from the company's ERP system and input from interviews with sales representatives on acceptable waiting times and promised delays.

The metrics of On Time Shipments (OTS) and Orders Promised to Request (OPR) were calculated based on the total amount of orders fulfilling the specific market requirements. The fill rate was calculated for each stock engine. First, OTS and OPR were measured without the market-specific requirement that no delays are allowed. Then, the same procedure was executed, and the metrics were calculated concerning acceptable waiting time and promised delay for each market. This approach enabled identifying the share of orders, achieving the highest potential and acceptable service. It was decided to include input from the markets regarding acceptable waiting time and promised delays to identify when customers become unsatisfied and risk choosing a competitor in the long run. Then, it can be more critical for Volvo Penta to ensure a high service level of acceptable delivery performance than on-time deliveries.

Moreover, the metric OPR could be calculated for all orders. OTS and fill rates will have a smaller sample since these metrics excludes cancellations and orders that have not arrived yet. Therefore, the number of cancellations, orders, and orders that had not yet arrived were included in the result to visualize the different sample sizes. Comparing the two could indicate if there is a difference between OTS and OPR. If the metrics are not synchronised, it can depend on too optimistic promises, resulting in high OPR but poor OTS or many cancellations due to lateness. In such a case, Volvo Penta should evaluate the order promising process and may increase the promised delay overall.

The fill rate indicates the stock availability since it compares the date requested by the customer to the date each ASE was shipped. A five-day delay is allowed for this measurement, as it is an internal diagnostic measurement of availability. This depends on a short delay of five days and can depend on other aspects like internal logistics and not the availability of the specific engine. Therefore, allowing a delay of five days on the fill rate metric should be more accurate. One flaw of the measurement is that cancelled orders are excluded. Whether a cancellation depends on the customer regretting their purchase or the order being out of stock cannot be identified. Therefore, cancellations are left out of the calculation. However, if there are many cancellations and the fill rate is high, it might result from low availability. Moreover, acceptable promised delays and waiting times were often given as a range during the sales representative interviews. Subsequently, the acceptable promised delays and waiting times were set to the average values within the given ranges.

5.3.3 Analytically Calculated Service Level and Cost of Tied-up Capital

To illustrate the trade-offs between Sevice Level Targets (SLT) and the Cost of Tied-up Capital (CTC) in a dynamic environment, the data collected in section 5.2.3 were included in a model created in the Visual Basics application for Microsoft Excel. This program was chosen because Volvo Penta uses Excel for various purposes, which would significantly ease the implementation of the model.

In the model, a probability-based fill rate was calculated based on Axsäter's (2006) model for single-echelon periodic review (R, Q) system following Compound Poisson Demand (12)-(20). The input parameters of demand and lead times were extracted from Volvo Penta's ERP system. Demand input was based on order entry for each month per item one year back. To determine the probability of a customer ordering j units (i.e., f_j vector), empirical distributions were formulated utilizing the historical sales order data. This process involved quantifying the frequency with which a customer orders j units for a particular item and subsequently dividing it by the total count of orders placed for that item. This procedure was applied to each element of the f_j vector to establish its respective probability distribution for an item. Another input that can be inserted into the model is the net requirements from Rapid Response. Gross requirements refer to the quantity of an item that needs to be produced to fulfil demand while not taking into account existing inventory levels, incoming shipments from production, and outstanding orders. This can be used to determine corresponding reorder point (s) and order up to level (S) according to (4) and (5). However, in computations for the thesis, it is assumed that gross requirements follow average demand.

The same calculations were carried out on the three markets considered in this project: Oceania, Brazil, and Vara GAS. In total, the fill rate was calculated for 40 different SKUs. The model also outputs a service level graph against CTC/safety stock for each market and engine. New gross requirements can be input once the current parameters are outdated and the safety stock can be adjusted to get the corresponding fill rate.

The following assumptions were made to implement the model.

- Gross requirements are estimated with mean demand for the investigated items. Because the demand forecast was inconsistent and was not done for all items, the average mean demand was used as an input parameter instead of actual gross requirements.
- Demand that is not satisfied during the order cycle will be backordered and fulfilled in later order cycles. Hence, no sales will be lost.
- The model refers to the historical fill rate and can be updated with forecasted net requirements to predict the fill rate for future periods.

6 Analysis and Result

This section presents the project's results. In section 6.1, the result of sales representative interviews is summarised, with a focus on service level and lead time requirements. Section 6.2 presents the result of the ABC-XYZ-VED segmentation analysis. Section 6.3 presents the service level performance. Section 6.4 compares Service Level Targets (SLT) for current Authorised Stock Engines (ASE) with corresponding tied-up capital and safety stock. Section 6.5 contains a combined analysis based on the triangulation method described in section 3.2.3. Section 6.6 includes a benchmark of the suggested stock compared to a previous ordering policy.

6.1 Service Level and Lead Time Requirements

This section presents the results of the interviews with sales representatives, see interview guide in Appendix C. Data was collected for three markets: Oceania, Brazil, and Vara GAS. Some of the information collected will be left out of this section because it is outside the scope and relevance of the thesis. First, the aspects that apply for all markets are presented and then the aspects that differentiate the markets are presented in sections 6.1.1 to 6.1.3.

Based on the interviews, there are commonalities between the three markets. Generally, the primary customer types to consider are Original Equipment Manufacturers (OEM), importers and dealers. OEM customers have their own production and purchase higher volumes. In some cases, their boats are designed for Volvo Penta's engines and cannot be changed in a short-term perspective. Therefore, a late order will not result in lost sales, but it can deteriorate the relationship and impact future sales. OEMs often give their forecast to Volvo Penta so demand can be better planned. The time notice ahead of an OEM wanting an engine will vary. To clarify, the time notice is the time between a customer order enters and the customer's requested delivery date. Often, some notice is given, but it depends on how well the OEM's production plans are and last-minute orders from their customers. Most often, OEMs will place an order longer in advance than a dealer. The amount of buffer stock the OEMs have will vary. OEMs with a small buffer will have a higher demand on availability and lead time and will be more sensitive to delays.

Dealers sell the engines off-shelf to customers. For this customer segment, re-powering of old boats exists, which means replacing the engine with a new one. Depending on the boat model, the end customer could choose another brand if the engine cannot be supplied on time. Hence, a missed opportunity cost from lost sales would exist in these cases. Generally, dealers keep no stock or very low stock. Therefore, high availability is vital not to lose sales to the end-customer in this segment. Dealers often sell the smaller types of engines.

Importers are customers who have the right to distribute Volvo Pentas products in a country or region. Relations are close with these customers. Importers often keep safety stocks, so delays are generally less critical than for a dealer.

According to the interviews, there are usually no direct penalty costs for backorders. In a few instances, discounts have been given to the affected customer, and air freight has also been used. The large volume of late orders does not incur any backorder penalty cost. Of

urse, Volvo Penta's goodwill will deteriorate with many large orders, but this is not quantified in a cost.

The interviews confirm that lead time and availability are viewed as essential to competing in all three markets. Having an engine available and offering a proper lead time are necessary to qualify for an order. Other attributes such as price, technical aspects, and service may be more critical to winning the order from competitors. However, lead time and availability will impact customer satisfaction if they are lower than customers' expectations.

6.1.1 Oceania

Table 11 summarises some essential aspects of the market. Oceania has the most significant lead time of all the studied markets. The lead time is generally much longer than customers are willing to wait. Therefore, stock is vital to be able to sell an engine. The largest Original Equipment Manufacturer (OEM) customer would like to enter an order shorter before needing it than they currently do. Other customers can request a very short time before requiring the engine, for example, marine commercial customers that have had a breakdown. Generally, the customer wants Volvo Penta to hold stock and deliver within X days. This can be compared to four times the total lead time, making MTO impossible for most orders.

There are a few large OEM customers and one large importer and dealers. Customer relationships are fragile due to production and quality issues, as well as price increases. According to the respondents, respondent availability and pricing are the main reasons for losing a customer.

Table 11: Key aspects and answers from Oceanian sales representatives. To ensure that no classified information is published, "X" was used instead of the actual Acceptable Promised Delay and Acceptable Waiting Time.

Aspects	Answers
Acceptable promised delay	X weeks on average. For critical MC customers and high-volume OEMs it is lower
Acceptable waiting time	Depending on the type of customers, X days or less for critical customers
Customer satisfaction regarding delivery performance	Could be improved
Input on current stock	Engines Item$_O$ 19 and Item$_O$ 18 should be stocked as ASE

6.1.2 Brazil

The Brazilian market consists of many small customers (fleet owners, dealers, and Original Equipment Manufacturers (OEM)) and a few larger OEMs. Majority of total sales are to OEM customers. According to the interviews, stock is essential for most dealers since many are small companies and can often not afford their own safety stock. OEM customers generally have a close relationship with Volvo Penta, and forecasts for the year are shared. Companies purchasing Inboard Performance System (IPS) engines are locked to Penta in a long-term perspective. On the other hand, shaft engines can be changed to a competitor on a short-term basis.

Moreover, according to the interviews' orders are often placed in advance to be on the safe side when the OEMs need the engines. Dealers find it challenging to plan orders ahead of time. They give a shorter notice, and stock is required to win the sale. To avoid losing the sale, an engine swap with an OEM customer is possible if there is no current stock on hand. A dealer could wait around one week, but it can be different case-to-case. OEMs could often wait longer before the sales are lost. However, a late order impacts their operations and can come with a penalty cost (of some sort) depending on its lateness, where both discounts and air freights have been used in these cases.

Availability and lead times are essential to competing in this market. Marine commercial customers are interested in availability since they need the engines on short notice. For other customers, this aspect might not be as critical as price and technology, but it is important for the customer's overall satisfaction.

Table 12 summarises customers' delivery expectations and requirements for the Brazilian market. Customers are generally satisfied. Acceptable promised delay and waiting time will vary depending on the customer. Promised delay is expected to be relatively short for some OMEs with a strict production schedule. For other customers with less tight schedules, higher promised delays could be accepted. There is a shorter acceptable promised delay for dealers and well-planned OEMs. For other OEMs that build bigger boats or have a less strict production schedule, a longer acceptable promised delay could be tolerated since their operations would not be as heavily impacted. However, it should be noted that the Brazilian market has many customers, making these generalisations difficult.

Table 12: Key aspects and answers from Brazilian sales representatives. To ensure that no classified information is published, "X" was used instead of the actual Acceptable Promised Delay and Acceptable Waiting Time.

Aspects	Answers
Acceptable promised delay	x weeks on average, depending on how well-organised the OEM is
Acceptable waiting time	x days for dealers, some OEMs are very sensitive to but less organised OEMs and customers of larger engines could tolerate longer waiting time
Customer satisfaction regarding delivery performance	Generally satisfied
Input on current stock	The market doesn't have any specific ASEs to suggest; all orders should be on time.

6.1.3 Vara GAS

In Vara, Sweden, an ASE stock for gasoline engines is placed. The production facility is located in Lexington, US. The stock is meant to reduce the lead time for orders of gasoline engines sold to Europe and international markets. The market areas using the Vara stock can be viewed in Table 13. The importer business, Italy, Central Europe, and Nordic countries were interviewed. The interviewed markets have approximately 80% of the net sales of the GAS ASEs placed in Vara. The remaining markets were contacted but we could not get an interview within a feasible time frame for this thesis project.

Table 13: Markets using Vara GAS stock.

Market Area Name	*Net Sales*
IMPORTER BUSINESS	1,1%
MARKET BENELUX	1,6%
MARKET CENTRAL EUROPE	20,1%
MARKET FRANCE	5,2%
MARKET ITALY	46,3%
MARKET NORDIC	12,2%
MARKET SOUTH AFRICA	1,7%
MARKET SPAIN	6,0%
MARKET TURKEY	1,5%
MARKET UK	4,2%
Grand Total	**100%**

A summary of important aspects is displayed in Table 14. For the markets using the GAS ASEs, these engines have a relatively small share of their total sales. The customers are dealers, Original Equipment Manufacturers (OEM) and Importers. However, importers purchase only a small share of the total ASEs. OEMs in Central Europe can order a long time before they need the items. In general, OEMs in Italy orders items with a shorter notice than the OEMs in Central Europe. Dealers give shorter notice than OEMs for all markets, especially when repowering. Customer demand is also cyclic for this market, with more repowering customers before summer, which requires a higher availability in these seasons. In the wintertime, the availability can be lower.

Generally, customers in the Nordic countries are not so sensitive to delays, but OEM customers in Central Europe and Italy are more sensitive to delays. One reason is that the OEM production line will be stopped if engines are not delivered on time. Even a short delay could be a problem for some customers.

Price, service, and speed of delivery are ways to compete in the GAS segment. In the past, customers have been lost due to price, and sales can be lost due to lead time and availability in the GAS segment. Engines of this type are easy to change to a competing brand if they cannot be supplied on time. Therefore, one strategy to solve the unavailability of a particular engine is to offer a similar one, for example, discount an older model or offer them a model with more horsepower for the same price.

Generally, the customers are satisfied with the current delivery performance, but a few have experienced out-of-the-ordinary delays. Customers have accepted some degree of lateness and longer lead time moving out of COVID, but the customer's expectations are getting back to normal levels.

According to the sales representatives, one issue with the current ASE stock is the frequent updates of configurations, which can cause discounts when selling the old configurations. Engines with electronic steering were requested for the Vara stock since these must be ordered from Lexington.

Table 14: Key aspects and answers from Vara GAS representatives. To ensure that no classified information is published, "X" was used instead of the actual Acceptable Promised Delay and Acceptable Waiting Time.

Aspects	Answers
Acceptable promised delay	X days is tolerated as total delay. However, a short delay could be a problem for large-volume OMEs and dealers that need the engine as soon as possible.
Acceptable waiting time	For example, OEMs with production lines are very sensitive to delays; on the other hand, low-volume customers, customers building larger boats, or customers with stock could wait longer.
Customer satisfaction regarding delivery performance	Generally satisfied, a few delays out of the ordinary have been recorded.
Input on current stock	Stock Item$_V$ 2 and engines with electronic steering "ready to use"; Difficult to explain to customers with frequent updates to configurations

6.2 ABC-XYZ-VED

This section presents the result of the ABC-XYZ-VED analysis, and changes regarding the Authorised Stock Engine (ASE) lists are addressed for each market in sections 6.2.1-6.2.3. Inputs on current stock from section 6.1 were included to take the market requirements into account. For example, if a market suggests that a specific engine should be added to the list and the ABC-XYZ-VED analysis confirms this, there are more incentives to add an engine to the list. Moreover, engines that belong to a segment that should have a Make-To-Stock (MTS) strategy (according to the ABC-XYZ-VED analysis) have almost always been selected for the list. It is the engines in the grey area between MTS and Make-To-Order (MTO) that need incentives to be added or removed from the list. Other incentives for adding an engine can be high criticality and high predictability. Incentives for removing engines can be low sales frequency, and high CTC, see section 6.4. A pattern that can be seen for Oceania and Brazil is that some complex engines are suggested to be stocked over simpler engines. This depends, in general, on higher criticality and a higher contribution to total sales. A complex engine requires higher production lead time than a simpler engine, which means a longer waiting time for the customer if it is produced MTO.

6.2.1 Oceania

The data for the Oceanian market includes 49 different engine types. The result is summarised in Figure 18. It shows that ten different engine types should be MTS, and 14 may be MTS. Data on at least one of the three dimensions was not possible to identify for 11 of the engine types, and the other 19 engine types should be MTO.

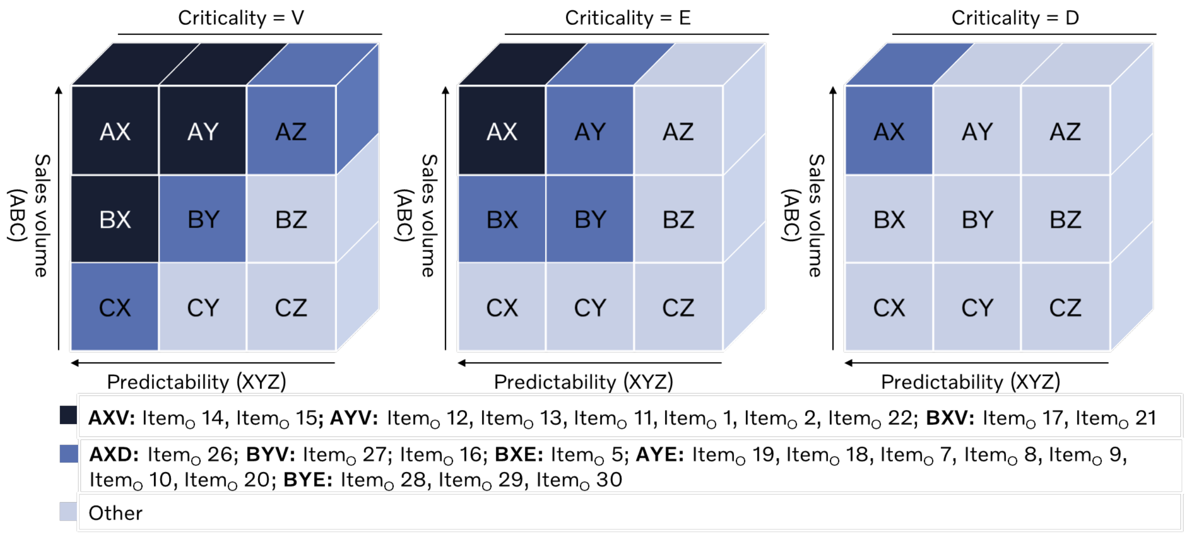

Figure 18: The inventory segmentation result for Oceania. The engine types in the darkest fields should be Make-To-Stock (MTS), the medium dark fields may be MTS, and the light fields should be Make-To-Order (MTO).

The result for Oceania in Figure 18 shows that many of the engines have high criticality, meaning that few orders can be delivered on time if an MTO strategy is used. The reason for this depends mainly on the long transportation lead time. For diesel engines that are transported from Vara, it is approximately 60 days; for gasoline engines that are transported from Lexington, it is approximately 52 days. When adding the production and pick and pack lead time, the total lead time is often higher than 100 days. This means that the customer needs to order an engine many days ahead of the requested date to be able to use an MTO strategy. Otherwise, the customer's request cannot be fulfilled on time, leading to dissatisfied customers who eventually may look at alternatives from competitors. However, based on section 6.1, this seldom happens in the short term for huge OEM customers since their boats are often customised to fit a specific engine, but in the long run, it can harm the relationship. Another thing to notice is that most engines in the market have medium predictability. This means it is possible to stock engines without significant safety stock.

The result becomes interesting since the findings are not aligned with the current ASE list Volvo Penta uses for Oceania. According to the results in Figure 18, the changes in Table 15 should be considered. Notable is that both configurations of Item$_O$ 8 and 10 were proposed to be removed, while Item$_O$ 18 and 19 were suggested to be added instead. All require a high CTC to be stocked, as seen in section 6.4, and may, therefore, be avoided to stock. However, the combination of the market suggested that Item$_O$ 18 and 19 should be in stock, see section 6.1.1, and a high contribution to the total sales resulted in it being added to the proposed list. Only one more sold unit can make a notable change in the total sales due to its high sales value per engine. Since the demand for these engines has been notably higher than the actual sales, it is possible that having stock can increase sales. Also, section 6.3.1 shows low performance on OPR, which means that customers do not get these engines when they want them. The significant number of cancellations on Item$_O$ 18 also implies that this could have caused lost sales.

Another change that should be considered is the removal of Item$_O$ 7 and Item$_O$ 9. Both engines had no demand data, but since the criticality is only "D", they should be removed anyway. Most of the gasoline engines should be removed from stock since they contribute less to the total sales and are often not highly critical due to shorter transportation lead times from Lexington than from Vara. The only gasoline engine that should be kept in stock is the Item$_{O}$ 5 since it contributes to the total sales and has predictable demand, which requires less safety stock. Item$_{O}$ 3 should also be removed due to low contribution to total sales. Instead, Item$_{O}$ 20 21 and 22 should be added to stock due to high sales and criticality.

Table 15: Changes to consider from the current ASE list for Oceania.

Item	ABC-XYZ-VED	Comment
Item$_{O}$ 3	CYV	Remove
Item$_{O}$ 4	CXD	Remove
Item$_{O}$ 6	CYE	Remove
Item$_{O}$ 7	B-D	Remove
Item$_{O}$ 9	B-D	Remove
Item$_{O}$ 8	AYE	Remove
Item$_{O}$ 10	AYE	Remove
Item$_{O}$ 22	AYV	Add
Item$_{O}$ 21	BXV	Add
Item$_{O}$ 18	AYE	Add
Item$_{O}$ 19	AYE	Add
Item$_{O}$ 20	AYE	Add

6.2.2 Brazil

The data for the Brazilian market includes 36 different engine types. The result is summarised in Figure 19. It shows that five different engine types should be MTS, and 20 engine types may be MTS. Data on at least one of the three dimensions was not possible to identify for four of the engine types, and the other 12 engine types should be MTO.

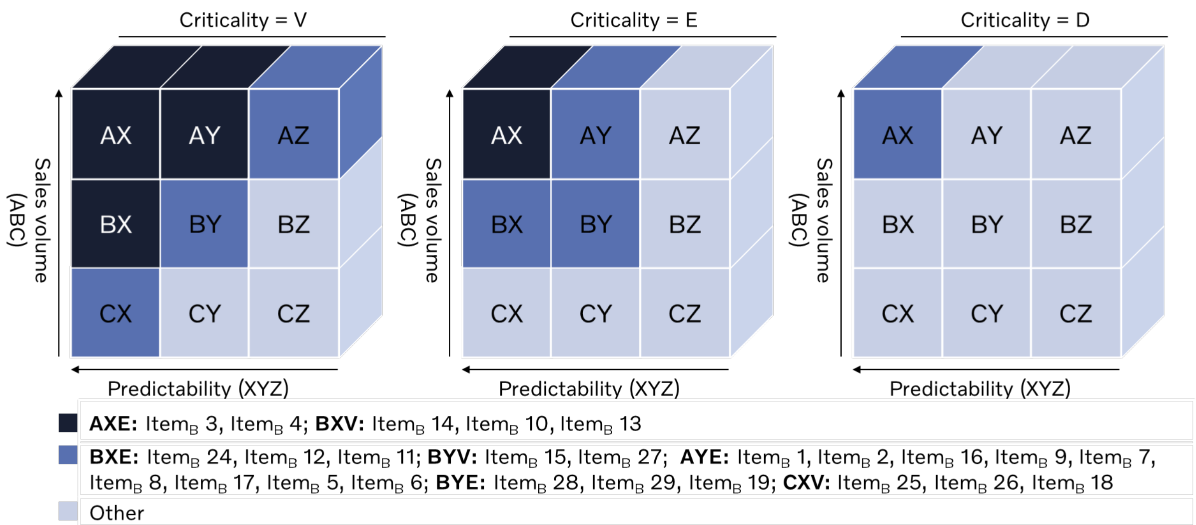

Figure 19: The inventory segmentation result for Brazil. The engine types that belong to the darkest fields should be Make-To-Stock (MTS), the medium dark fields may be MTS, and the light fields should be Make-To-Order (MTO).

For the engines in the Brazilian market, the criticality is generally medium with high predictability; see Figure 19. The transportation lead time for diesel engines from Vara to this market is approximately 32 days and 26 days for gasoline engines from Lexington. Compared to the transportation lead times to Oceania, the time to Brazil is roughly half of this. This is one reason why many engines sold to the Brazilian market are less critical than engines sold to Oceania. A larger share of the orders can be shipped on time with an MTO strategy. Therefore, fewer engine types should be ASEs in Brazil than in Oceania. However, the higher predictability makes it simpler to stock, and therefore, some engines should be stocked anyhow.

According to Figure 19 results, many engines are in the grey area. Four engines should be added to the ASE list, but only one engine should be removed due to low contribution to total sales, see Table 16. Item$_B$ 24 should be stocked in Brazil due to high values on all three dimensions. Other engines that should be added to the stock are Item$_B$ 15, 16 and 17, due to high sales, and relatively high predictability and criticality. The engine that should be removed is Item$_B$ 26 since it does not contribute much to the total sales. However, gasoline engines generally contribute more to total sales in Brazil than in Oceania, so most gasoline engines should be kept in stock. Common for the kept gasoline engines are that they have a very predictable demand, making them easy to achieve high service levels with low costs.

Table 16: Changes to consider from the current ASE list for Brazil.

Item	ABC-XYZ-VED	Comments
Item$_B$ 26	CXV	Remove
Item$_B$ 14	BXV	Add
Item$_B$ 15	BYV	Add
Item$_B$ 16	AYE	Add
Item$_B$ 17	AYE	Add

6.2.3 Vara GAS

The data for the Vara GAS market includes 15 different engine types. In Figure 20, the result is summarised. It shows that seven different engine types should be MTS, and five engine types may be MTS. The other three engine types should be MTO. For this market, it was possible to find data for all three dimensions.

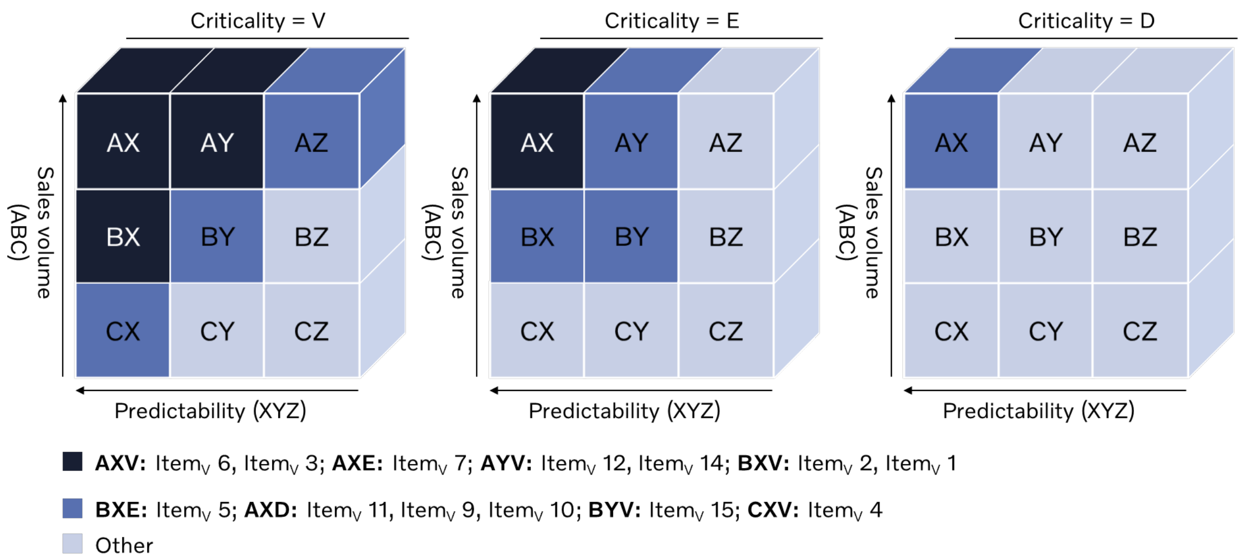

Figure 20: This inventory segmentation result for Vara GAS. The engine types that belong to the darkest fields should be Make-To-Stock (MTS), the medium dark fields may be MTS, and the light fields should be Make-To-Order (MTO).

The Vara GAS market is quite different to the Oceanian and Brazilian markets. Here, the gasoline engines are shipped from Lexington to Vara, which are later shipped to a large part of the European market. This means a transportation time of 43 days. An important assumption was that all gasoline engines sold through Vara are treated as the same market. All diesel engines were removed from the analysis since they are produced in Vara and, therefore, can be shipped on time using an MTO strategy. If all engines were included in the study, the gasoline engines would only constitute a small part of the total sales volume for this market.

Criticality and predictability for Vara GAS are high, especially predictability. These two outcomes mean that many engines can be stocked. This depends on the fact that engines can often not be shipped on time with an MTO strategy, and high service levels can be fulfilled with low safety stock levels, meaning fewer holding costs. According to Figure 20, one engine type should be added to the ASE list, and two should be removed, see Table 17. Although the market stated that CE engines should be stocked, as seen in section 6.1, the Item$_V$ 8 should be removed due to the low contribution to total sales. However, the other CE engines are suggested to be stocked; therefore, there are similar alternatives in stock with higher or lower horsepower. Item$_V$ 4 also has a low contribution to the total sales and should be removed. Instead, should Item$_V$ 12 be added since it contributes much more to sales and has high criticality. Engine Item$_V$ 16 was not included, even if it belongs to segment AYV; see Figure 20. This deviation from the guidelines depends on its special demand, where it was ordered in many units simultaneously from the same customer during the investigated time period.

Table 17: Changes to consider from the current ASE list for Vara GAS.

Item	ABC-XYZ-VED	Comments
Item$_V$ 8	CYE	Remove
Item$_V$ 4	CXV	Remove
Item$_V$ 12	AYV	Add

6.3 Service level performance

In this section, the analysis relies on the historical performance of service levels for the engines on the current ASE lists and those suggested for addition in section 6.2. The measurements of On Time Shipments (OTS), Orders Promised to Request (OPR), and fill rates were evaluated for Oceania, Brazil, and Vara GAS. These measures are defined in section 4.4.2. Furthermore, the metrics of OTS and OPR are compared with the inputs received from interviews with sales representatives in section 6.1. These inputs, such as Acceptable Waiting Time (AWT) and Promised Delay (APD), are grounded in sales representatives' expertise.

It is important to bear in mind that the measurements of OPR can be calculated for all orders, but fill rate and OTS have their limitations. These metrics cannot be measured on orders that have not yet arrived or were cancelled, as they lack an actual ship date required for calculation. This leads to a difference in the sampling populations between the metrics. Therefore, on items with many cancellations or orders that have not arrived yet, the OPR are not directly comparable to the fill rate and OTS. Fill rate and OTS, on the other hand, can always be compared as they share the same sample populations. Moreover, the fill rate is calculated per engine, while On-time shipment and OPR are calculated per order. This is important for some since an order can contain many engines.

6.3.1 Oceania

Table 18 displays Oceania's service level performance. The metrics could not be calculated for two items because no orders were placed for the evaluated time period. There were a significant number of cancellations. Some reasons may be overbooking due to capacity constraints, stockouts, or customers changing their minds. However, it is difficult to evaluate its main contributors and whether a higher service level would have reduced cancellations. Either way, cancellations may indicate low availability when the customer demands the item.

Furthermore, the metric Orders Promised to Request (OPR) within Acceptable Promised Delay (APD) is high for the current ASEs. This shows that most orders are within what is adequate for the customer. However, APD is rather generous compared to the other markets. This indicates that the market has difficulties meeting customer requests, which could be a reason for cancellations for specific engine types. Moreover, the fill rate for the market is low. This would indicate that stock availability could be higher in the market, and a significant fraction of the demand cannot be satisfied by stock when the customer requests it. A significant fraction of the orders is considered as On Time Shipments (OTS) when adding the Acceptable Waiting Time (AWT). As a result, Volvo Penta delivers a significant fraction of orders within the acceptable waiting time of the customer, but still a fraction cloud not be delivered in time. Generally, more stock is needed to improve the fill rate; this could improve OTS and OPR because these metrics depend on availability.

Table 18: Performance on On time Shipments (OTS), Orders Promised to Request (OPR), and fill rate per ASE for Oceania. The performances on OTS and OPR when adding the Acceptable Waiting Time (AWT) respectively Acceptable Promised Delay (APD) are also presented in the table. Sample sizes for OPR, and OTS and fill rate are included.

Item	OTS	OTS (AWT)	OPR	OPR (APD)	Fill rate	Sample size OPR	Sample size OTS, Fill rate
$Item_O$ 1	Low	Medium	Medium	High	Low	45	13
$Item_O$ 2	Low	Medium	Medium	High	Low	45	13
$Item_O$ 3	Low	Low	High	High	Low	2	1
$Item_O$ 4	High	High	High	High	High	5	5
$Item_O$ 5	Low	Low	Low	Low	Low	1	1
$Item_O$ 6	High	High	Low	Low	Medium	4	3
$Item_O$ 7	No data	No data	No data	No data	No data	No data	No data
$Item_O$ 8	High	High	Medium	High	High	17	2
$Item_O$ 9	No data	No data	No data	No data	No data	No data	No data
$Item_O$ 10	High	High	Medium	High	High	17	2
$Item_O$ 11	Low	High	Medium	High	Low	67	35
$Item_O$ 12	Low	High	Medium	High	Low	99	65
$Item_O$ 13	Low	High	Medium	High	Low	98	66
$Item_O$ 14	Low	Medium	Medium	High	Medium	31	18
$Item_O$ 15	No data	Medium	Low	Medium	Low	14	8
$Item_O$ 16	Low	Medium	Low	Low	Low	15	11
$Item_O$ 17	Medium	Medium	Low	Medium	Medium	10	6
Total	**Low**	**Medium**	**Medium**	**High**	**Low**	**469**	**248**

Table 19 contains the historical service performance of the suggested stock from section 6.2.1. Most items have a low fill rate, as could be expected since they are MTO. OPR is low, even within Acceptable Promised Delay. This would indicate difficulties meeting customer demand. $Item_0$ 22 has a high performance, but this is explained by the item being MTS during the period but not currently stocked.

Table 19: *Performance on On time Shipments (OTS), Orders Promised to Request (OPR), and fill rate per suggested ASE additions for Oceania. The performances on OTS and OPR when adding the Acceptable Waiting Time (AWT) respectively Acceptable Promised Delay (APD) are also presented in the table. Sample sizes for OPR, and OTS and fill rate are included.*

Item	OTS	OTS (AWT)	OPR	OPR (APD)	Fill rate	Sample size OPR	Sample size OTS, Fill rate
Item0 18	Low	Medium	Low	Low	Low	31	8
Item0 19	Low	Low	Low	Low	Low	15	9
Item0 20	Low	Low	Medium	Medium	Low	10	4
Item0 21	Low	Low	Medium	High	Low	9	4
Item0 22	Medium	High	Medium	High	High	4	4

6.3.2 Brazil

Table 20 contains the service level performance calculated for the Brazilian market. On Time Shipments (OTS) within Acceptable Waiting Time (AWT) was high. Although this shows that the promised date is held in most cases, the market has difficulties meeting customers' requests since Orders Promised to Request (OPR) is medium. Cancellations are also significant compared to the number of orders, which could indicate that customers are not satisfied with availability. The fill rate is high, except for two items. As expected, these items have a lower OTS than the rest. Higher stock availability on these would likely improve the fill rate and OTS. The fill rate is generally high compared to the Vara GAS and Oceanian markets. This could indicate that Brazil has high stock availability, which is in line with interviews with sales representatives. The customers are generally satisfied with the availability and lead times, so it can be assumed that the current levels are reasonable. However, it is difficult to draw any conclusions about the fill rate since cancellations are not included in this sample size.

Table 20: Performance on On time Shipments (OTS), Orders Promised to Request (OPR), and fill rate per ASE for Brazil. The performances on OTS and OPR when adding the Acceptable Waiting Time (AWT) respectively Acceptable Promised Delay (APD) are also presented in the table. Sample sizes for OPR, and OTS and fill rate are included.

Item	OTS	OTS (AWT)	OPR	OPR (APD)	Fill rate	Sample size OPR	Sample size OTS, Fill rate
Item$_B$ 1	High	High	Medium	High	Medium	43	27
Item$_B$ 2	High	High	Medium	High	Medium	41	26
Item$_B$ 3	High	High	Medium	Medium	High	47	23
Item$_B$ 4	High	High	Medium	Medium	High	46	23
Item$_B$ 5	High	High	Medium	Medium	High	21	5
Item$_B$ 6	High	High	Medium	Medium	High	21	5
Item$_B$ 7	High	High	High	High	High	73	33
Item$_B$ 8	High	High	High	High	High	70	32
Item$_B$ 9	High	High	Medium	High	High	31	15
Item$_B$ 10	High	High	Medium	Medium	High	35	18
Item$_B$ 11	High	High	Medium	Medium	High	30	14
Item$_B$ 12	High	High	Medium	Medium	High	27	8
Item$_B$ 13	High	High	Medium	High	High	10	5
Total	**High**	**High**	**Medium**	**High**	**High**	**495**	**234**

Table 21 contains the new suggestions for MTS from section 6.2.2. Generally, these engines have a lower OPR within Acceptable Promised Delay (APD) than the total average in Table 20. This could indicate that availability is low and customer expectations are not met. The fill rate is relatively high, but it should be noted that cancellations are not included, so the actual fill rate could be lower since there are a significant number of cancellations on each engine. The OPR could be improved by stocking these items, and the number of cancellations could decrease due to higher availability.

Table 21: Performance on On time Shipments (OTS), Orders Promised to Request (OPR), and fill rate per suggested ASE additions for Brazil. The performances on OTS and OPR when adding the Acceptable Waiting Time (AWT) respectively Acceptable Promised Delay (APD) are also presented in the table. Sample sizes for OPR, and OTS and fill rate are included.

Item	OTS	OTS (AWT)	OPR	OPR (APD)	Fill rate	Sample size OPR	Sample size OTS, Fill rate
Item$_B$ 14	High	High	Medium	Medium	Medium	33	6
Item$_B$ 15	High	High	Low	Medium	High	10	4
Item$_B$ 16	High	High	Medium	Medium	High	52	14
Item$_B$ 17	High	High	Medium	Medium	Medium	8	3

6.3.3 Vara GAS

The results for Vara GAS can be viewed in Table 22. The fill rate for all items combined is Medium. Therefore, stock levels may be increased more for some of the items. Orders Promised to Request (OPR) within Acceptable Promised Delay (APD) were Medium, indicating that meeting customers' requests within a week is difficult. The On Time Shipments (OTS) within Acceptable Waiting Time (AWT) is High. However, this number does not include cancellations and orders not arrived. Hence, cancellations due to lateness are not accounted for. Knowing why orders were cancelled are challenging, but some cancellations may arise from a lack of available ASEs. It is also interesting that OPR is lower than OTS. A high deviation between promised and requested can be problematic for some customer types since they have a strict production plan or need the engine for repowering. This could lead to cancellations and lost sales since customers could choose a competitor. Higher availability could reduce the number of cancellations in this market since it is many times possible for the customer to choose a competitor if the engine cannot be supplied.

Table 22: Performance on On time Shipments (OTS), Orders Promised to Request (OPR), and fill rate per ASE for Vara GAS. The performances on OTS and OPR when adding the Acceptable Waiting Time (AWT) respectively Acceptable Promised Delay (APD) are also presented in the table. Sample sizes for OPR, and OTS and fill rate are included.

Item	OTS	OTS (AWT)	OPR	OPR (APD)	Fill rate	Sample size OPR	Sample size OTS, Fill rate
$Item_V$ 1	Medium	High	Low	Low	Medium	25	10
$Item_V$ 2	Medium	High	Low	Low	Low	33	16
$Item_V$ 3	Low	High	Low	Medium	Medium	33	19
$Item_V$ 4	Medium	High	Low	Medium	Medium	29	15
$Item_V$ 5	Medium	Medium	Low	Medium	Medium	24	17
$Item_V$ 6	Medium	High	Low	Medium	Medium	20	7
$Item_V$ 7	Medium	High	Medium	High	Medium	31	20
$Item_V$ 8	High	High	Medium	Medium	High	7	4
$Item_V$ 9	Medium	High	High	High	Medium	32	20
$Item_V$ 10	No data	No data	Low	Low	Low	5	2
$Item_V$ 11	Low	Medium	Medium	Medium	Low	203	44
Total	**Medium**	**High**	**Medium**	**Medium**	**Medium**	**442**	**174**

Table 23 contains the suggested stock for Vara GAS. OPR within Acceptable Promised Delay (APD), and the fill rate is below the average from Table 22. Each order of $Item_V$ 12 contains several engines, sometimes 8-10. So, stocking this item could improve the fill rate.

Table 23: Performance on On time Shipments (OTS), Orders Promised to Request (OPR), and fill rate per suggested ASE additions for Vara GAS. The performances on OTS and OPR when adding the Acceptable Waiting Time (AWT) respectively Acceptable Promised Delay (APD) are also presented in the table. Sample sizes for OPR, and OTS and fill rate are included.

Item	OTS	OTS (AWT)	OPR	OPR (APD)	Fill rate	Sample size OPR	Sample size OTS, Fill rate
Item$_V$ 12	High	High	No data	Medium	Medium	4	2

6.4 Analytical Calculated Service Levels and Cost of Tied-up Capital

This section presents analytically calculated service levels and the respective Cost of Tied-up Capital (CTC) and safety stock for Oceania in section 6.4.1, Brazil in section 6.4.2 and Vara GAS in section 6.4.3.

In Figures 21, 24, and 27, safety stock is plotted against the fill rate. From these graphs, it is possible to see that an amount of stock will yield different fill rates for each item. The curves' steepness can be interesting from a managerial perspective because achieving a high Service Level Target (SLT) will be different. For an item with a steep curve, gaining a high service level is possible without keeping a significant safety stock. The items that have a more gradual increase would require more stock to achieve the same service level. The graphs can be used to reason if a specific SLT is appropriate for an item or if the necessary safety stock would become too large.

The curves' steepness can be explained by items having a lower demand and variation, so a few units will cover a more significant part of the demand and provide a higher service. Also, demand frequency and order size will impact the fill rate. For example, an engine where orders always are for two units will generally require a little more safety stock for the same fill rate compared to an engine where customer orders are for a single unit if everything else is the same. Moreover, varying SLTs according to the individual item's variation aligns with the ABC-XYZ-VED service level guidelines in Figure 16. Generally, an item with more demand variation for XYZ will have a more gradual curve in Figures 21, 24 and 27. Therefore, it is reasonable that an item in category X (steepest curve) has a higher SLT, and items with a gradual curve category Y/Z have a lower curve.

The Cost of Tied-up Capital (CTC) is also essential when determining SLTs since there are significant differences in the cost of materials and production between engine types. The CTC is plotted against fill rate in Figures 22, 25, and 28. The CTC is based on the average units on hand that a given fill rate would result in. These figures are important from a decision-making perspective because it is possible to determine the effects on the CTC with the increased fill rate. The graphs compare all items in a market, making it possible to see that some items will have a significantly higher CTC to achieve a given fill rate.

On the other hand, using the CTC for SLTs can be partly contradictory to the ABC-XYZ-VED service level guidelines in Figure 16. An item that contributes more to total sales (A-segment) will generally have a higher average inventory, which can make the CTC greater, so lowering an item based on the CTC could go against the guidelines where service level increases with more contribution to sales. However, the CTC effectively compares whether the guidelines are reasonable for a specific item and determines where an item should end up in the guideline range. Once again, the steepness of the graph can aid in determining if an item should end up in the higher or lower part of the range. Furthermore, it should be noted that the fill rate increases in discrete increments. Hence, achieving a specific range is impossible if the fill rate increases more than 5% per increased safety stock. In these cases, the cost of tied-up capital is a helpful tool to determine if the SLT should be placed over or under the guideline range.

6.4.1 Oceania

Figure 21 demonstrates the fill rate plotted against safety stock for the Oceanian market of the current stock. It is worth noting that two items, Item$_O$ 7 and 9 are excluded due to the absence of demand data needed for visualisation. As discussed in section 6.4, the slopes of the curves differ, indicating that varying stock quantities would be required to achieve a specific fill rate for the entire market. To illustrate, achieving a 95% fill rate requires a minimal safety stock for Item$_O$ 3, while extensive safety stock is necessary for Item$_O$ 11 to reach a 90% fill rate.

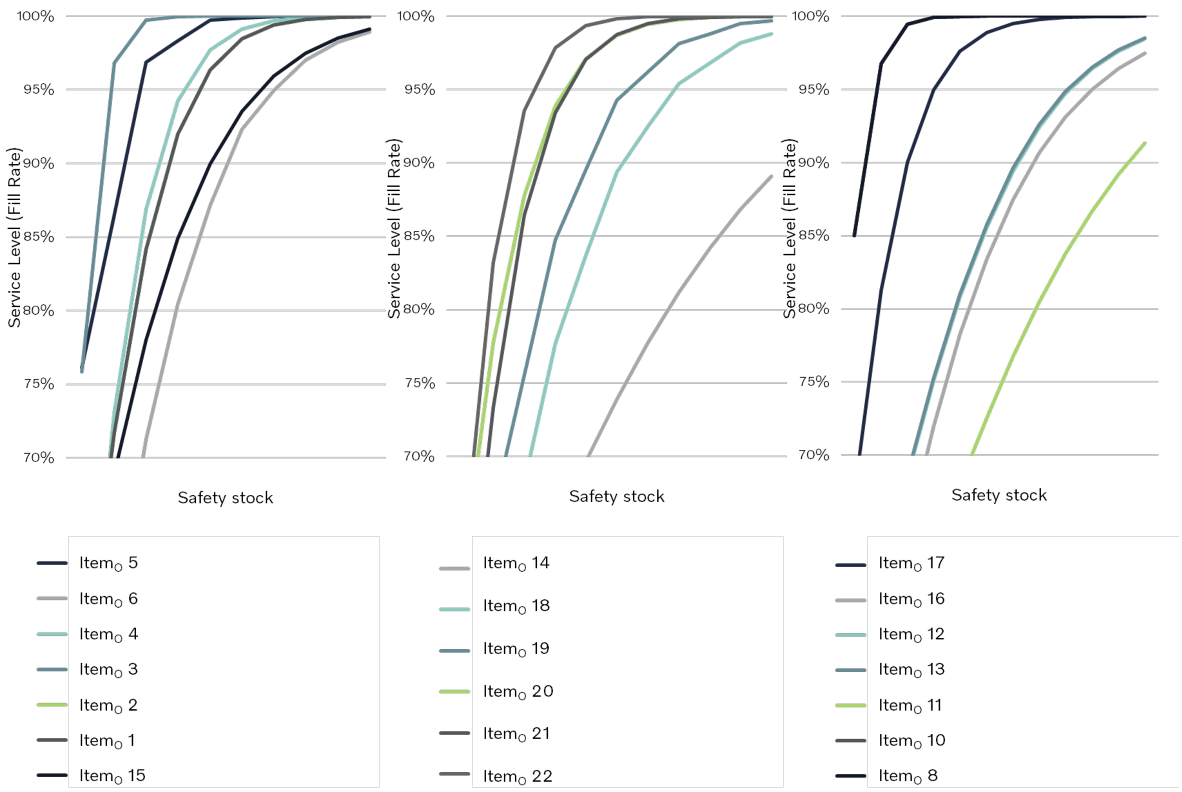

Figure 21: Fill rate and safety stock for Oceania. To ensure that no classified information is published, the scale for Safety stock was removed.

Figure 22 displays the CTC plotted against the fill rate for Oceania. Eight engines have a higher price compared to the rest of the items. The high-cost items are showcased in Figure 23. More precautions must be taken for these items when determining SLTs since these will most impact the total CTC. For low-cost items, it is possible to see, when comparing them to all items (Figure 22), that achieving a high fill rate will require a relatively low CTC in comparison to the high-cost items. Figure 23 contains the same graphs as Figure 22 but is divided between the low, medium and high CTC.

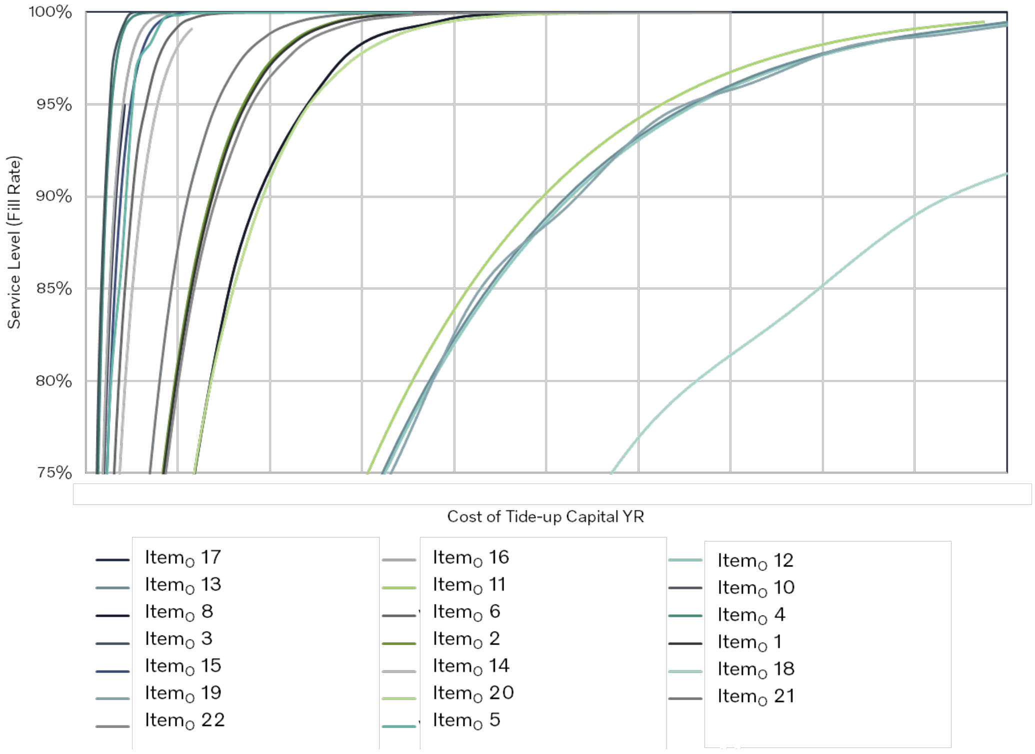

Figure 22: Comparison of Cost of Tied-up Capital (CTC) and fill rate for suggested and current stock in Oceania. To ensure that no classified information is published, the scale for Cost of Tied-up Capital YR was removed.

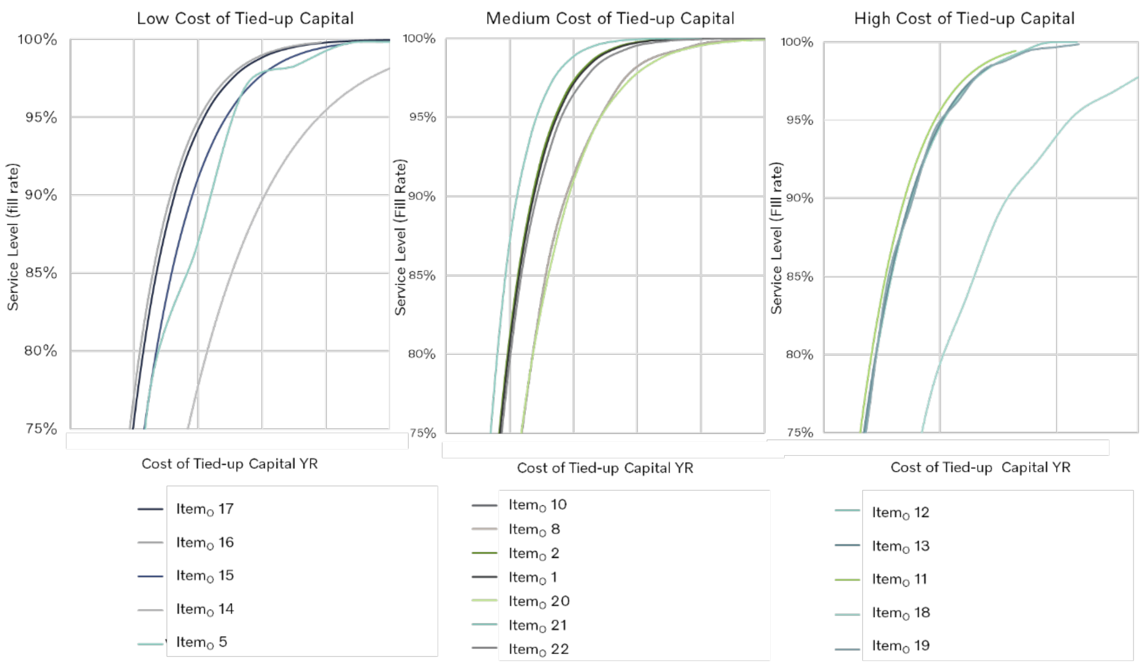

Figure 23: Comparison of Cost of Tied-up Capital (CTC) and fill rate, Oceania. To ensure that no classified information is published, the scale for Cost of Tied-up Capital YR was removed.

6.4.2 Brazil

Figure 24 displays the fill rate plotted against safety stock for Brazil. The same reasoning as section 6.4.1 can be applicable here. Item_B 9 will require more stock to achieve the same fill rate compared to the rest of the engines. This is because the engine has the largest demand

and relatively high variation. In comparison, Item$_B$ 15 only need a low safety stock to achieve a 95% fill rate. Therefore, it is apparent that different stocking strategies should be used in accordance the ABC-XYZ-VED guidelines for SLTs are in Figure 16.

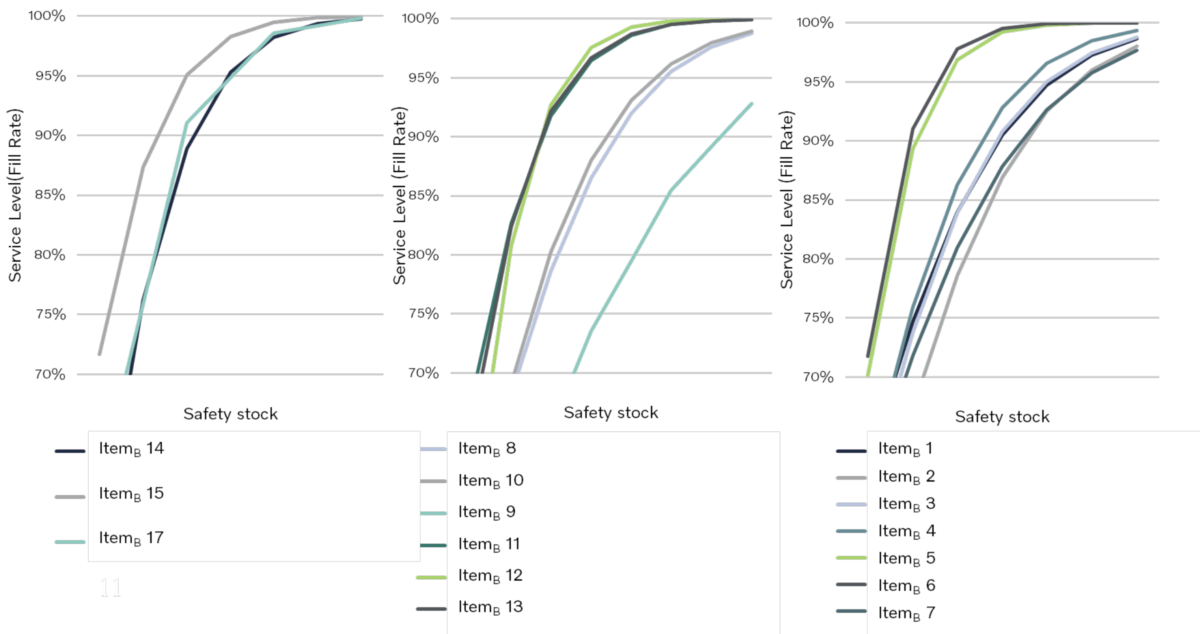

Figure 24: Fill rate and safety stock for Brazil. To ensure that no classified information is published, the scale for Safety stock was removed.

Figure 25 showcases the CTC for the Brazilian market. There is a significant difference in the cost of achieving a given fill rate. This has multiple explanations, as discussed in section 6.4, such as different costs of material and production and demand characteristics. Figure 26 contains the same graphs as Figure 25 but is divided between the low, medium and high CTC.

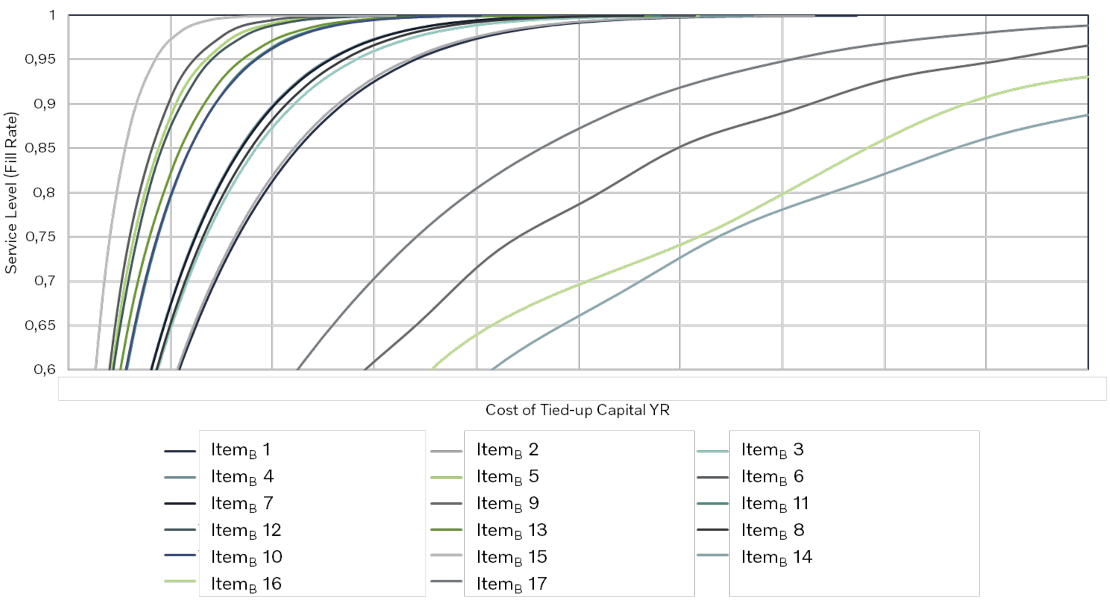

Figure 25: Comparison of Cost of Tied-up Capital (CTC) and fill rate for suggested and current stock in Brazil. To ensure that no classified information is published, the scale for Cost of Tied-up Capital YR was removed.

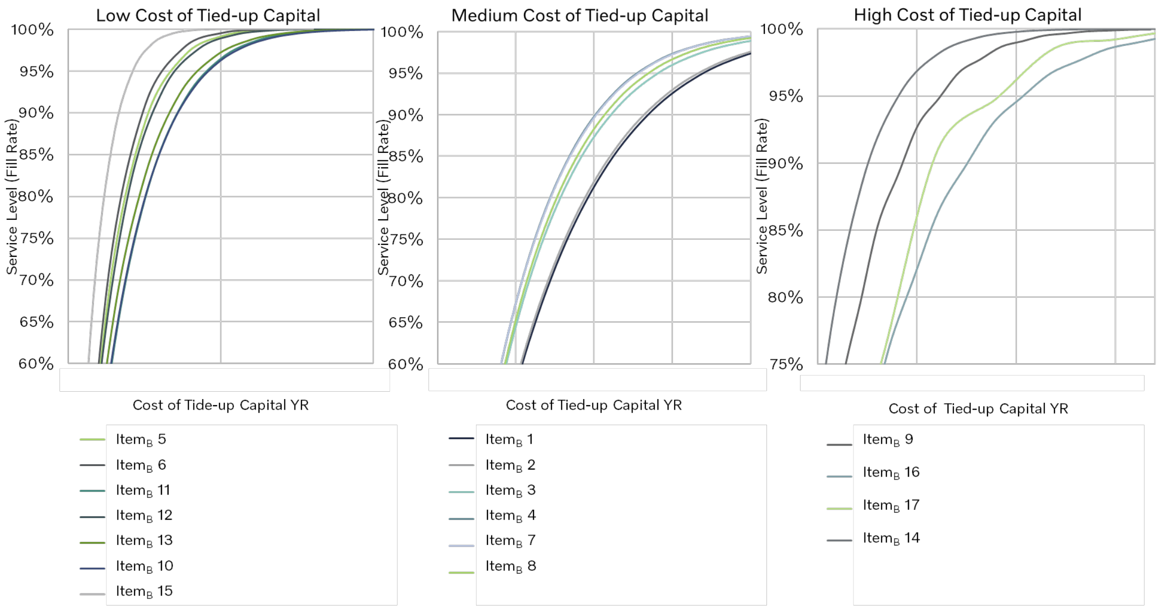

Figure 26: Comparison of Cost of Tied-up Capital (CTC) and fill rate, Brazil. To ensure that no classified information is published, the scale for Cost of Tied-up Capital YR was removed.

6.4.3 Vara GAS

Figure 27 displays the current stock and suggestions for Vara GAS. In Figure 27 below, some items have a more gradual fill rate increase than others. Item$_V$ 11 and 12 have a more gradual curve. These two items will require the highest safety stock to reach the same fill rate as the other items. The reason for the Item$_V$ 12 is that the demand always comes in large batches. Usually, eight or ten items are ordered. Item$_V$ 11 has the largest demand and requires a more extensive stock.

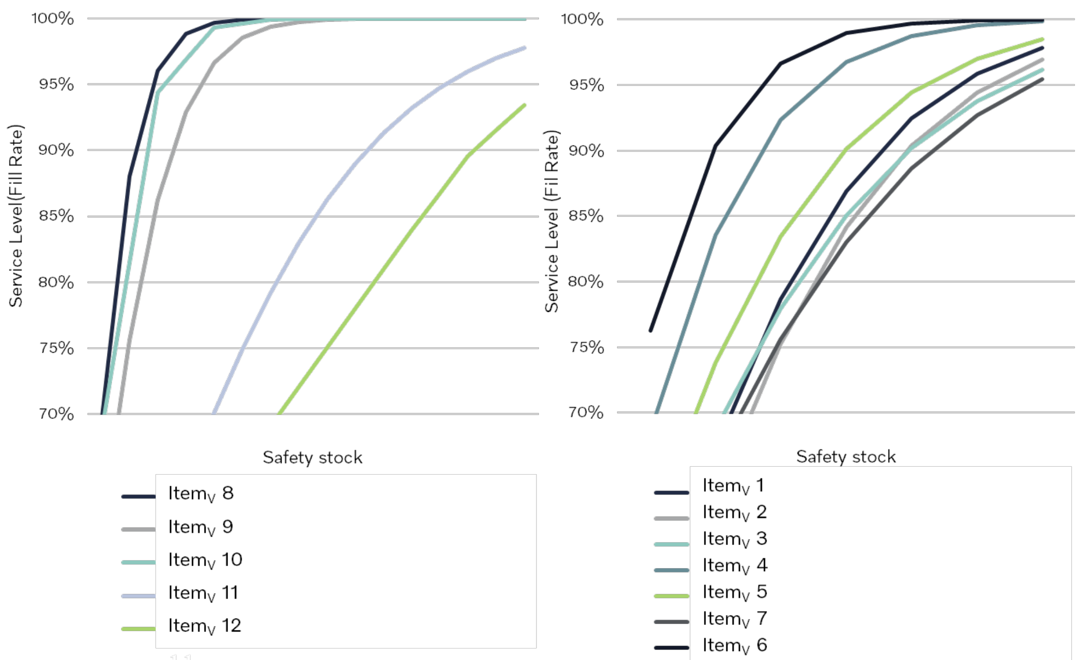

Figure 27: Fill rate and safety stock for Vara GAS. To ensure that no classified information is published, the scale for Safety stock was removed.

Figure 28 compares the CTC and fill rate. Some items will cost more to achieve a certain fill rate. The reasons are discussed in section 6.5. From this perspective, SLTs for the respective items may be set at different levels to reduce the CTC. Some items will have a higher impact on the total CTC. These items (Item$_V$ 11 and 12) require greater caution when determining an SLT because they will significantly contribute to the total CTC.

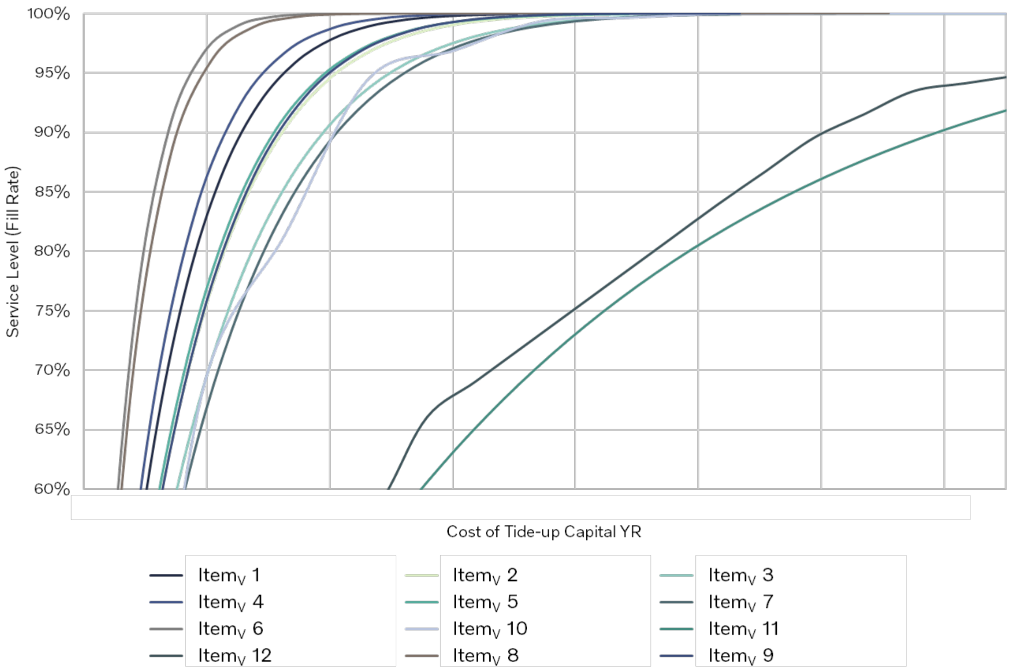

Figure 28: Comparison of Cost of Tied-up Capital (CTC) and fill rate for suggested and current stock in Vara. To ensure that no classified information is published, the scale for Cost of Tied-up Capital YR was removed.

6.5 Combined analysis

This section combines the results from sections 6.1-6.4 in a triangulation approach. The main outcome from the combined analysis is the proposed Sevice Level Targets (SLT) with corresponding safety stock targets for each market. However, overall targets regarding On Time Shipments (OTS) and Orders Promised to Request (OPR) are also included based on interview inputs from section 6.1. First, section 6.5.1 describes how the different results are analysed in combination with set SLTs. Then, the proposed Authorised Stock Engine (ASE) list with SLTs and corresponding safety stock targets for each market is presented in sections 6.5.2-6.5.4.

6.5.1 Introduction to the Analysis

To set optimal SLTs, insights and results from sections 6.1-6.4 were combined. Before evaluating SLTs, the proposed ASE list had to be determined. This step was based on the result in 6.2. After the engines to stock are identified, accurate SLTs could be analysed for all these engines. This was done by analysing the results in section 6.1-6.4. First, the ABC-XYZ-VED analysis provided SLT guidelines in Figure 16; see section 4.13.4. Other insights that were used to determine SLTs were customer satisfaction and engine type requirements from section 6.1. Such insights are that the Oceanian customer satisfaction level can be improved while both Brazil and Vara GAS have relatively good customer satisfaction levels. Also, sales of GAS and smaller engines often require shorter lead times, which the VED analysis should capture and confirm. Finally, an example of the triangulation analysis applied to determine SLTs and ASE requirements can be viewed in Figure 29.

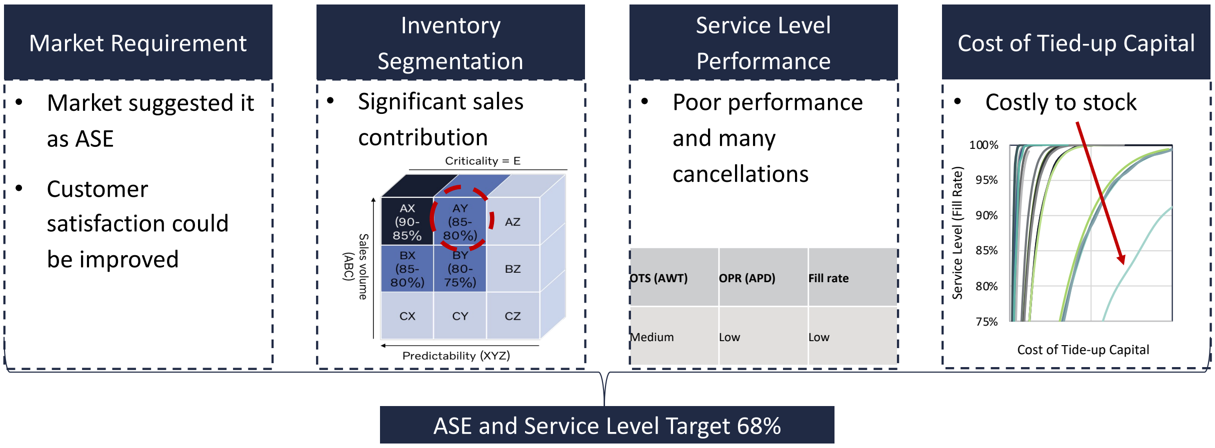

Figure 29: Visualization of the triangulation method used to determine Service Level Target (SLT) and ASE requirement. The example is based on Item$_O$ 18 for Oceania.

In section 6.3, the service level performances were used to visualise the relationship between achieved fill rates, OTS, and OPR. Targets for OTS and OPR were set to 95% within the market's acceptable delays from section 6.1. The reason why 95% was used is because input from the interviews shows that if deliveries frequently exceed the acceptable promised delay or waiting time, it can lead to lost sales in the long term, which should be avoided. To achieve this, the Oceanian market needs to significantly increase the achieved fill rate, which incentivises increased safety stock targets. The other markets also need some improvements regarding fill rate performance to achieve the requirements, but not as high adjustments are needed.

Lastly, section 6.4 had a strong influence on setting SLTs. Since the analytical calculated service level analysis illustrates the trade-offs between SLTs and Cost of Tied-up Capital (CTC)/safety stock, it can indicate whether a target should be equal to, higher, or lower than the interval guidelines from the ABC-XYZ-VED analysis. Important to note is that safety stock only allows integers. Therefore, the SLTs and CTC have discrete increases.

6.5.2 Oceania

In Table 24, the proposed ASE list for Oceania can be seen. The list includes proposed Service Level Targets (SLT) and corresponding safety stock targets per engine. The overall targets regarding On Time Shipments (OTS) and Orders Promised to Request (OPR) should be 95% within Acceptable Waiting Time (AWT), respectively, Acceptable Promised Delay (APD). Engines that are on the list have been selected since they either are in segments that should have an MTS strategy or if they are in the grey area and there are incentives to include them in the list, see section 6.2.

Notable from the list is that most engines require an SLT above 80%, see table 24, which, in combination with the long lead time to the market, results in high safety stock targets and CTC. The highest fill rates were assigned to Item$_O$ 17 and 15 since they are in the AXV segment with the highest SLT guidelines. High predictability and low costs per engine make it possible to achieve high SLTs without high CTC. The suggested engines to add to the list were instead assigned lower SLTs. One reason for this is a precaution, start with low-safety stock and monitor the performance before making huge changes. Another reason is that most of them require high CTC, and the fill rate increases slightly for each unit added to safety stock, see figures in section 6.4.

Table 24: Proposed market targets and ASE list for Oceania. On Time Shipments (OTS) and Orders Promised to Request (OPR) are set generally for the entire market, while Service Level Targets (SLT) and Safety Stock (SS) targets are set per engine. Note that the engines below the marked line are engines that are proposed to be added to the list, and the engines above the line are the ones that are proposed to be kept on the list. Also, SL (AWT days) and SL (30 days) show the corresponding service level when allowing the Acceptable Waiting Time (AWT) or 30 days, respectively. Cost of Tied-up Capital (CTC) for each item is calculated yearly, and both SS-target and CTC are calculated as a percentage of the total for the list.

On Time Shipments			**Orders Promised to Request**		
95% within Acceptable Waiting Time			95% within Acceptable Promised Delay		
Item	SLT	SL (AWT days)	SL (30 days)	SS-target	CTC
Item$_O$ 17	95%	96%	98%	5,36%	1,42%
Item$_O$ 16	78%	81%	89%	7,14%	0,71%
Item$_O$ 12	86%	92%	99%	8,93%	15,16%
Item$_O$ 13	86%	92%	99%	8,93%	15,16%
Item$_O$ 11	84%	89%	97%	14,29%	13,50%
Item$_O$ 2	92%	94%	98%	5,36%	4,97%
Item$_O$ 1	92%	94%	98%	5,36%	5,04%
Item$_O$ 15	96%	97%	99%	10,71%	1,76%
Item$_O$ 14	89%	92%	97%	17,86%	2,00%
Item$_O$ 5	86%	88%	91%	1,79%	1,32%
Item$_O$ 18	68%	72%	82%	3,57%	16,27%
Item$_O$ 19	76%	79%	86%	3,57%	11,37%
Item$_O$ 20	78%	80%	86%	1,79%	4,30%
Item$_O$ 21	86%	88%	91%	3,57%	3,28%
Item$_O$ 22	83%	86%	92%	1,79%	3,76%

6.5.3 Brazil

In Table 25, the proposed Authorised Stock Engine (ASE) list for Brazil can be seen. The list includes proposed Service Level Targets (SLT) and corresponding safety stock targets per engine. The overall targets regarding On Time Shipments (OTS) and Orders Promised to Request (OPR) should be 95% within Acceptable Waiting Time (AWT), respectively, Acceptable Promised Delay (APD). OTS is already fulfilled. However, the OPR performs poorer, which can be a reason why OTS are fulfilled because promises are set to pessimistic.

Notable from the list is that some adjustments from the ABC-XYZ-VED analysis guidelines have been made. First, engine Item$_B$ 6 is set to 91% SLT even though it belongs to segment AYE, which has the suggested interval of 80-85%. This decision depends on the fact that the fill rate increases significantly with only a small increase in safety stock. Additionally, Item$_B$ 12 deviates from the guidelines for the same reason. Also, important to keep in mind is that most of the engines in the proposed ASE list are in the grey area between MTS and MTO.

Therefore, some can be better removed from the list if good reasons for this are available. Fewer engines in the most important segment also led to the SLTs being set generally smaller than for the Oceanian market.

Another reason for lower SLTs is the higher interest rate, which makes it more expensive to stock in Brazil than in Oceania. However, the significantly shorter lead times to the market make achieving relatively high SLTs with fewer safety stock targets possible. Examples of low-set SLTs can be seen in Table 25 amongst the proposed engines to be added. Both Item$_B$ 14 and Item$_B$ 14 were assigned approximately 60% SLTs, which means safety stock targets zero. A zero percentage safety stock target means that orders are replenished according to forecasts but without any safety stock.

Table 25: Proposed market targets and ASE list for Brazil. On Time Shipments (OTS) and Orders Promised to Request (OPR) are set generally for the entire market, while Service Level Targets (SLT) and Safety Stock (SS) targets are set per engine. Note that the engines below the marked line are proposed to be added to the list, and the engines above the line are proposed to be kept on the list. Also, SL (AWT days) and SL (30 days) show the corresponding service level when allowing the Acceptable Waiting Time (AWT) or 30 days, respectively. Cost of Tied-up Capital (CTC) for each item is calculated yearly, and both SS-target and CTC are calculated as a percentage of the total for the list.

On Time Shipments			**Orders Promised to Request**		
95% within Acceptable Waiting Time			95% within Acceptable Promised Delay		
Item	SLT	SL (AWT days)	SL (30 days)	SS-target	CTC
Item$_B$ 1	84%	86%	96%	6,25%	6,03%
Item$_B$ 2	87%	88%	97%	9,38%	6,56%
Item$_B$ 3	91%	92%	98%	9,38%	6,34%
Item$_B$ 4	93%	94%	99%	9,38%	6,34%
Item$_B$ 5	89%	90%	95%	3,13%	2,86%
Item$_B$ 6	91%	92%	96%	3,13%	2,83%
Item$_B$ 7	81%	83%	97%	6,25%	4,14%
Item$_B$ 8	79%	81%	96%	6,25%	4,06%
Item$_B$ 9	89%	91%	98%	9,38%	3,83%
Item$_B$ 10	80%	81%	94%	12,50%	14,28%
Item$_B$ 11	83%	85%	97%	3,13%	3,08%
Item$_B$ 12	93%	94%	99%	6,25%	3,45%
Item$_B$ 13	92%	93%	97%	6,25%	4,06%
Item$_B$ 14	55%	56%	67%	0,00%	5,36%
Item$_B$ 15	87%	88%	94%	3,13%	1,67%
Item$_B$ 16	69%	71%	86%	6,25%	15,03%
Item$_B$ 17	60%	62%	72%	0,00%	10,09%

6.5.4 Vara GAS

Table 26 shows the proposed Authorised Stock Engine (ASE) list for Vara GAS. The list includes proposed Service Level Targets (SLT) and corresponding safety stock targets per engine. The overall targets regarding On Time Shipments (OTS) and Orders Promised to Request (OPR) should be 95%. That is the same as for the Brazilian market Acceptable Waiting Time (AWT) and Acceptable Promised Delay (APD), which is reasonable since the lead times are closer to the ones for Brazil than Oceania, and GAS engines often have shorter lead time requirements.

Notable from the list is that engine Item$_V$ 11 requires a high safety stock target to achieve 79% SLT. However, if a waiting time is included, the SLT increases rapidly. Another reason why its SLTs only was set to 79% was its low criticality, see section 6.2. The only engine added to the list was also given a lower SLT, 66%. As for the Item$_V$ 12, the engine is expensive to stock compared to other gasoline engines. However, both engines contribute heavily to the total sales of gasoline engines, and therefore, some safety stock should be used. Seen to how many gasoline engines Volvo Penta sells, there is a high number of engines that are on the list, 10 out of 15 engines. A reason for this is the shorter lead time requirement from customers, which leads to many engines being positioned as highly critical to stock in the VED analysis.

Table 26: Proposed market targets and ASE list for Vara GAS. On time Shipments (OTS) and Orders Promised to Request (OPR) are set generally for the entire market, while Service Level Targets (SLT) and Safety Stock (SS) targets are set per engine. Note that the engines below the marked line are proposed to be added to the list, and the engines above the line are proposed to be kept on the list. Also, SL (AWT days) and SL (30 days) show the corresponding service level when allowing the Acceptable Waiting Time (AWT) or 30 days, respectively. Cost of Tied-up Capital (CTC) for each item is calculated yearly, and both SS-target and CTC are calculated as a percentage of the total for the list.

On Time Shipments			**Orders Promised to Request**		
95% within Acceptable Waiting Time			95% within Acceptable Promised Delay		
Item	SLT	SL (AWT days)	SL (30 days)	SS-target	CTC
Item$_V$ 1	93%	94%	99%	12,12%	7,16%
Item$_V$ 2	90%	91%	98%	12,12%	8,55%
Item$_V$ 3	94%	97%	99%	15,15%	11,32%
Item$_V$ 5	84%	86%	97%	6,06%	5,77%
Item$_V$ 6	90%	91%	97%	3,03%	4,85%
Item$_V$ 7	88%	89%	98%	9,09%	7,39%
Item$_V$ 9	86%	88%	98%	6,06%	9,70%
Item$_V$ 10	81%	82%	87%	3,03%	7,62%
Item$_V$ 11	79%	83%	99%	18,18%	22,17%
Item$_V$ 12	66%	67%	77%	15,15%	15,47%

6.6 Benchmarking

In this section, the results of a benchmark of yearly Cost of Tied-up Capital (CTC) can be found. The proposed MTS engines from section 6.5 are compared to the stock of April 2023.

It should be noted that the comparison is not based on historical financial data on tied-up capital because it is not a fair comparison because CTC in ASE lists in section 6.5 are calculated in idealized condition. To make the comparison fairer, the target safety stock of April 2023 was imputed to the analytical model used for determining service levels, see Section 5.3.3. Safety stock targets was before changed on a monthly basis, however, for this benchmark it is assumed that the safety stock targets of April 2023 were kept constant, and the forecast followed average demand. Hence, same demand is used to model the April 2023 safety stock targets against the new suggestions.

6.6.1 Oceania

The results of the benchmark for Oceania can be viewed in Table 27. The proposed stocks will result in a 20% decrease in total safety stock and a 37% decrease in total yearly CTC compared to April 2023. The decrease in cost is explained by a significant reduction of $Item_O$ 12 and 13 in stock and the removal of $Item_O$ 7, 8, 9 and 10 from the list. A reduction of the CTC could be made, although some expensive items like $Item_O$ 18 and 19 were added. Otherwise, most service level and safety stock targets for the kept ASEs are increased in the proposed list due to poor service level performance, see section 6.3, and customer satisfaction can be improved in the market according to section 6.1.

Table 27: Benchmark Proposed ASE list and ASE list 2023-04 for Oceania. Note that Cost of Tied-up Capital (CTC) is calculated yearly. Service Level Targets (SLT) and Safety Stock (SS) targets are also included. SS-target and CTC are shown as percentage increases to ensure that no classified information is published.

Item	SLT (Proposed ASE list)	SLT (Benchmark ASE list 2023-04)	SS-target (Difference)	CTC (Difference)
$Item_O$ 17	95%	95%	0%	0%
$Item_O$ 16	78%	56%	300%	110%
$Item_O$ 12	86%	100%	-67%	-61%
$Item_O$ 13	86%	100%	-67%	-61%
$Item_O$ 11	84%	87%	-11%	-9%
$Item_O$ 2	92%	92%	0%	0%
$Item_O$ 1	92%	92%	0%	0%
$Item_O$ 15	96%	94%	20%	16%
$Item_O$ 14	89%	70%	150%	84%
$Item_O$ 5	86%	86%	0%	0%
$Item_O$ 18	68%	-	-	-
$Item_O$ 19	76%	-	-	-
$Item_O$ 20	78%	-	-	-
$Item_O$ 21	86%	73%	100%	45%
$Item_O$ 22	83%	62%	-	85%
$Item_O$ 8	-	97%	-	-
$Item_O$ 10	-	97%	-	-
$Item_O$ 3	-	76%	-	-
$Item_O$ 4	-	87%	-	-
$Item_O$ 6	-	58%	-	-
$Item_O$ 25	-	68%	-	-
$Item_O$ 7	-	100%	-	-
$Item_O$ 9	-	100%	-	-
$Item_O$ 23	-	85%	-	-
$Item_O$ 24	-	85%	-	-
Total			-20%	-37%

6.6.2 Brazil

Table 28 contains a benchmark for the proposed Authorised Stock Engine (ASE) list compared to the list of 2023-04. For the proposal, the total amount of safety stock decreased by 41% compared to April 2023. Most of the engines' new SLTs are lower than the expected service level from 2023-04. Consequently, the safety stock is lower in the new list. Yearly CTC increased by 3% despite lowering safety stock on most of the current items. The increase in cost is mainly explained by the new stock suggestions. Some expensive items, such as $Item_B$ 14, 16 and 17, were added.

Table 28: Benchmark Proposed ASE List and ASE list 2023-04 for Brazil. Note that Cost of Tied-up Capital (CTC) is calculated yearly. Service Level Targets (SLT) and Safety Stock (SS) targets are also included. SS-target and CTC are shown as percentage increases to ensure that no classified information is published.

Item	SLT (Proposed ASE list)	SLT (Benchmark ASE list 2023-04)	SS-target (Difference)	CTC (Difference)
$Item_B$ 1	84%	95%	-50%	-35%
$Item_B$ 2	87%	93%	-25%	-20%
$Item_B$ 3	91%	84%	50%	29%
$Item_B$ 4	93%	86%	50%	30%
$Item_B$ 5	89%	97%	-50%	-33%
$Item_B$ 6	91%	98%	-50%	-33%
$Item_B$ 7	81%	93%	-50%	-35%
$Item_B$ 8	79%	92%	-50%	-37%
$Item_B$ 9	89%	0%	-	-
$Item_B$ 10	80%	89%	-33%	-27%
$Item_B$ 11	83%	99%	-75%	-55%
$Item_B$ 12	93%	98%	-33%	-27%
$Item_B$ 13	92%	82%	100%	45%
$Item_B$ 14	55%	0%	-	-
$Item_B$ 15	87%	99%	-75%	-56%
$Item_B$ 16	69%	-	-	-
$Item_B$ 17	60%	-	-	-
$Item_B$ 18	-	86%	-	-
$Item_B$ 19	-	92%	-	-
$Item_B$ 20	-	71%	-	-
$Item_B$ 21	-	53%	-	-100%
$Item_B$ 22	-	No Data	-	-
$Item_B$ 23	-	No Data	-	-
$Item_B$ 24	-	94%	-	-
$Item_B$ 25	-	No Data	-	-
$Item_B$ 26	-	83%	-	-
Total			-41%	**3%**

6.6.3 Vara GAS

The benchmark of the 2023-04 ASE list and the proposed ASE list for Vara GAS can be viewed in Table 29. The proposed list will result in a total decrease in safety stock of 57% compared to the 2023-04 list. Generally, safety stock levels were adjusted down in the proposed list. Some items were previously overstocked and would reach a 100% service level by a high margin, for example $Item_V$ 7, 9, 11. With the proposal the yearly CTC will decrease by 40% compared to the 2023-04 list. As mentioned, this decrease is explained by the previous overstocking of some items and removing 2 ASEs from the current list.

Table 29: Benchmark Proposed ASE list and ASE list 2023-04 for Vara GAS. Note that Cost of Tied-up Capital (CTC) is calculated yearly. Service Level Targets (SLT) and Safety Stock (SS) targets are also included. SS-target and CTC are shown as percentage increases to ensure that no classified information is published.

Item	**SLT (Proposed ASE list)**	**SLT (Benchmark ASE list 2023-04)**	**SS-target (Difference)**	**CTC (Difference)**
Item$_V$ 1	93%	79%	100%	65%
Item$_V$ 2	90%	64%	300%	136%
Item$_V$ 3	94%	98%	-29%	-23%
Item$_V$ 5	84%	100%	-78%	-68%
Item$_V$ 6	90%	97%	-50%	-26%
Item$_V$ 7	88%	100%	-70%	-65%
Item$_V$ 11	79%	100%	-81%	-69%
Item$_V$ 9	86%	100%	-67%	-55%
Item$_V$ 10	81%	81%	0%	0%
Item$_V$ 12	66%	-	-	-
Item$_V$ 8	-	99%	-	-
Item$_V$ 4	-	92%	-	-
Item$_V$ 13	-	No Data	-	-
Total			-57%	-40%

7 Conclusions

This section concludes the thesis by answering the research questions in section 7.1 and stating future research areas in section 7.2.

The thesis has developed an approach to determine stock requirements and Service Level Targets (SLT) by combining four different methods: *market requirements from interviews, inventory segmentation model, service level performance, and an analytical model comparing SLTs and, Cost of Tied-up Capital (CTC) and safety stock*. Current requirements and inventory have been analysed in the thesis but in order to keep the Authorised Stock Engine (ASE) stock efficient in the future, the requirements and ASE lists should be updated on an annual basis according to Figure 30.

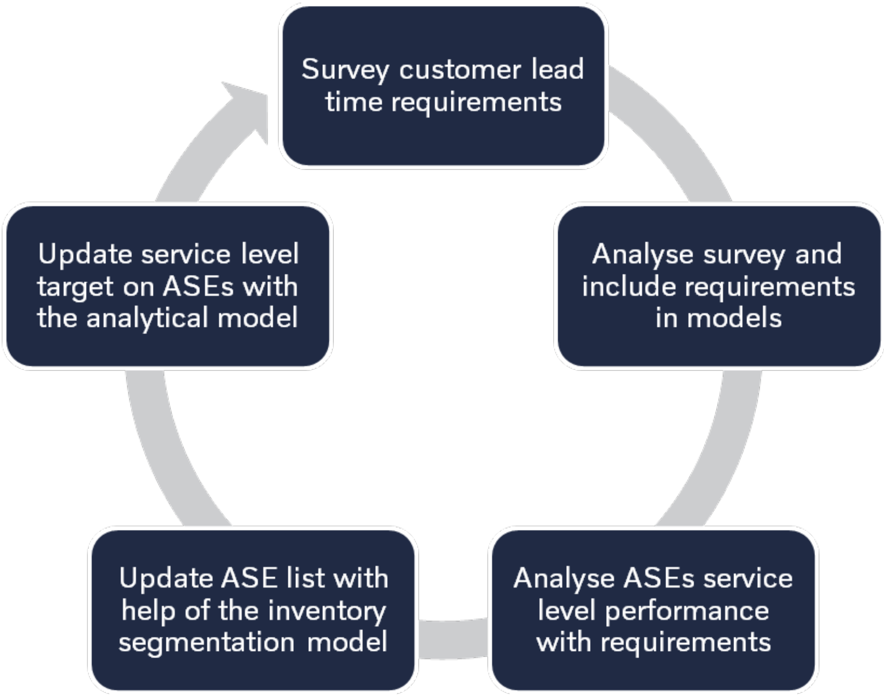

Figure 30: Method to determine Service Level Targets (SLT) and Make-To-Stock (MTS) decisions on an annual basis.

7.1 Research Questions

The thesis focused on answering the four research questions to answer the problem statement in section 1.3.

I. How should Volvo Penta define its service level, and how does it compare with theoretical perspectives?
II. What are the required service levels and acceptable customer lead times for Marine customers?
III. Which engines should the stock consist of?
IV. How much safety stock is required, and what will the inventory holding cost be to close the gap between the desired and actual service levels?

The project successfully answers the first research question, providing a practical suggestion for Volvo Penta. By implementing the fill rate as a service level definition, Volvo Penta can effectively track internal stock availability and adjust the SLT to enhance customer experience, such as On Time Shipments (OTS) and Orders Promised to Request (OPR), to desired levels.

The second research question can be answered to some extent. Service level requirements were set for each engine based on the combined analysis and are included in the proposed ASE lists, see section 6.5. Sales representatives gave lead time requirements regarding waiting time and promised delays at each of the three markets. However, since this information was not from actual customers, the data might deviate from the customer's actual requirement. Therefore, a recommendation is to include the questions regarding acceptable waiting time and promised delay in a yearly customer satisfaction survey, see the interview guide in Appendix C. By doing this, Volvo Penta can adjust the SLTs to fit the customer requirements per this study and monitor the performance yearly. Some examples of questions that would be interesting to answer are as follows:

- *How important is it for customers that orders arrive on the agreed date?*
- *How important is it for customers that the requested delivery date is met by Volvo Penta's promised delivery date?*
- *How long of a deviation (in days) can be acceptable regarding the two previous questions?*

The thesis answers the third research question by the engines the stock should consist of; see tables in section 6.5. The ASE lists are mainly based on the ABC-XYZ-VED analysis and the interviews with the sales representatives. One conclusion from the lists is that most changes regarding the ASE list should be done in Oceania. For this market, it seems that according to the segmentation, the wrong engines are stocked and should be replaced by others of higher priority in the analysis. Another conclusion is that Brazil has many engines within the grey area of the segmentation analysis, meaning that some still on the list may be removed. However, almost all gasoline engines can be considered for stock for Vara GAS due to their high criticality and short lead time requirements. 67% of all gasoline engine types were proposed to stock for the market.

The final research question is also answered where the inventory holding costs are approximated with Cost of Tied-up Capital (CTC) according to section 4.8. In the Authorised Stock Engine (ASE) lists in section 6.5, SLTs are stated with corresponding safety stock targets and CTC. For some engines, the CTC increases significantly when adding an extra unit in safety stock, and in these cases, it can be accepted to lower the SLTs. A general conclusion is that the longer the lead times are, the more it costs to provide high fill rates. This is because of the demand for lead time, and uncertainty increases with longer lead times. Due to the insufficient service level performance and the need to improve customer satisfaction in Oceania, it is recommended that safety stock be increased according to the set SLTs in Oceania. However, the proposed ASE list decreased by 37% in the CTC compared to the benchmarked safety stock targets due to the previously unnecessary high safety stock targets and the removal of other ASE engines, see Section 6.6.1. For Brazil, the service level and safety stock targets for the current ASEs were generally set lower than the benchmarked data in section 6.6.2. The reasons for this are the high CTC in Brazil, the current service level performance, and customer satisfaction, which are better than in other markets. Even if the safety stock targets are reduced, the CTC will increase by 3% yearly due to adding some crucial but expensive engines to the ASE list. Lastly, regarding Vara GAS, the service level and safety stock targets were reduced overall due to previous stock level targets not taking demand variations, leading to unnecessary high stock levels for some engines (and low stock levels for some). This proposed change resulted in a decrease of 40% in the yearly CTC. All proposed lists would result in a 21% decrease in annual CTC and a 40% decrease in safety stock compared to the inventory policy held in April 2023. High SLTs can be achieved on the most crucial engines for Volvo Penta, with high sales volume, low demand variability and high criticality.

7.2 Future research

While this study has provided insights into single-echelon inventory management and SLTs within the context of the Volvo Penta case, there are options for future projects that could further improve the company's understanding of inventory control systems.

One direction for future research is to extend the analysis from single-echelon to multi-echelon inventory management. Certain areas of Volvo Pentas inventory control could be considered multi-echelon. For example, $Item_O$ 14, 15, 16, 17 and accessories are stocked in Vara and then distributed for storage in a regional warehouse. By considering coordination between stock locations, such as suppliers, regional warehouses, and distribution centres, higher SLTs can be achieved while minimising excess inventory and decreasing overall CTC.

Another area for further improvement is developing and implementing time-based service level metrics. Fill rates provide probabilistic measurements of stock availability, but they may not fully capture customer expectations regarding delivery timing. In addition to focusing on delivery precision, Penta should consider incorporating customer-specific measures. Future projects could focus on establishing time-based service level metrics that align with customer requirements based on actual customer inputs. The organisation can enhance customer satisfaction without excessive inventory levels by adjusting fill rates to meet performance targets based on OTS and OPR.

Although tested on a small segment of items in this study, the ABC-XYZ-VED is promising for greater application in the context of accessories for marine engines. Future projects could explore implementing this model or similar approaches to classify and manage accessory inventory items based on their demand patterns, value contribution, and criticality. By segmenting accessories according to these criteria, Volvo Penta can improve its stocking decisions by resource allocation for both MTO and MTS. Moreover, inventory segmentation can be improved further by including more criteria. Some criteria Volvo Penta should consider are which engines are most crucial for the customer and could segment criticality between different customers. Altogether, this will give a more accurate picture of what is essential to stock and which customers to prioritise. Also, product life cycle and obsolescence are aspects that could be considered to avoid overstocking products that are soon phased.

In conclusion, future research should address the company's complexities of inventory management by investigating multi-echelon optimisation strategies, developing time-based service level metrics, incorporating customer-specific considerations, and applying inventory segmentation models to accessories. By improving these areas, Volvo Penta can enhance its competitiveness, customer satisfaction, and overall delivery performance in the industry.

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Appendix

Appendix A: Interview Guide SCPMs

Introduction

- Briefly introduce ourselves.
- Introduce the thesis project.

General

- Would you like to give a brief introduction about yourself?
- Can you describe your role and responsibilities?
    - Which markets and regions does it include?
    - Can you describe the supply chain for ASEs?

Inventory Control

- Can you describe the order process for ASEs?
- How far in advance is an order placed before it is produced?
- What inventory policy do you use?
    - When is a new order placed? (At what inventory level?)
    - Do you have fixed inventory quantities, or do you order up to a certain level?
- Is the same policy used for all inventories?
- Is there any restriction on order quantity (min, max)?
    - Can engines be ordered one for one?
    - Do you vary order quantities for the same type of engine?
- Is a replenishment order shipped in one shipment or can it be split?
- How often is the order policy updated?
    - Are safety stock levels for engines in the inventory changed?
- What happens when inventory runs out? Do you lose the customer or place a new order?
- Are orders placed automatically (continuous)? Or how often is inventory checked by a person? (periodic)
    - If periodic, what is the inspection period?
- What systems are used for inventory control?
- Do you optimise the inventory in any way, model/tool?
- What are your biggest challenges in the inventory control system?
- What is the reorder point for the inventory? At what level do you place orders?
- How often are orders placed?
    - Are they placed only at the beginning of the period when forecasts are received, or do you order directly when new orders are promised?
- What happens when inventory in the market runs out?
    - Do you lose customers, or do they wait until there is inventory?

Distribution

- For ASEs in Brazil, Australia and Vara do the engines go "directly" from production to regional warehouses?
- Are the engines (in a replenishment order) always reserved by the market?
- Are there other warehouses besides the regional ones where engines are not reserved?
- Can the warehouse located in Australia only be used by Australia?
- What does the regional distribution look like in your region?

- Do you have any priority for which market gets the most?
- Are the engines ready for sale as soon as they arrive in the market?
- What modes of transport are used?
- What are your biggest challenges in the distribution network?

Other

- Do you use service level as a KPI? If so, what is your definition of it? How do you measure it?
- Is there historical data about ASE levels, safety stock, and orders?
- What is your opinion on ASE stock? What do you think of ASEs' performance?
  - What problems do you see?

Appendix B: Interview Guide Demand Planner

Introduction

- Present ourselves briefly.
- Present the thesis.

General

- Can you describe your role and work task?
    - Are you towards all regions?
    - Can you describe the SC for ASEs?
    - How do you work with SCP?
    - Do you know how the order process works for ASE items?

Demand

- What characterizes the demand of marine engines?
    - Is demand categorized when forecasting,
    - slow, lumpy etc.?
    - Is segmentation used? How?
    - Are there some kind of cyclic trends or seasonalities?
- Which regions have the largest demand for engines?
- Are there differences in the engine types demanded in the regions?
- On which time-interval do you store demand data (e.g. weekly, monthly, daily)?
- Is lost sales accounted for in the demand Data?
    - Backorder?
    - if a customer asks for in item that can't be supplied is this tracked
    - Difference between sales and demand data
    - Is the data based on actual demand or sales?

Forecast

- What forecasting methods are used?
- How long is a forecasting period? When does it occur more often?
- How are the forecasts used and by who?
- How difficult are the markets to forecast, do they have high accuracy?
- How often are the forecasts updated?
- Are forecasts made on an aggregated level (e.g all typ) or done on each product type?
- Does forecasting impact the current safety stock levels?
    - When are they changed?

Open questions

- What is your opinion of ASE stock? What do you think about its performance?
    - What problems do you see?
- What are the greatest difficulties with forecasting the demand?
    - Which engines are most difficult and why?

Other

- How do we access demand data?
    - Is it the same data that we have available in GDW?
    - order-time, frequency?
    - Past inventory policy parameters?
- Do you know how it's formatted?
    - On which level are products aggregated?
    - Can a single order and time between orders be observed in the data?

Appendix C: Interview Guide Sales Personal

Introduction

- Present ourselves briefly
- Present the thesis

Customer

- Please give us an overview of your market e.g., the customers and their size.
  - What approximate percentage of sales do they contribute to?
- Are there competitors that customers can choose instead of Volvo Penta in this market?
  - Approximate Volvo Penta market share and positioning compared to competitors?
  - What is crucial to prevent customers from choosing a competitor?
- Do you sometimes loose an order/customer?
  - Before or after an order is placed?
  - For what reasons?
- How is the relationship with the customers?
  - Are they close, collaborative partnerships or more transactional relationships?
- How satisfied would you say customers are with Volvo Penta?
- How satisfied would you say customers are with Volvo Penta regarding delivery precision and availability?
- What is the difference between requirements for customer types e.g. dealers and OEMs?
  - Lead time?
  - How long ahead do the customers order from your market?

Inventory

- Which customers do you store ASEs for?
- Do you store ASEs in multiple regional warehouses for each market?
- What happens if the inventory runs out and you cannot supply the customer on time?
  - Do you lose the customer, or do they wait?
  - Are there any penalty costs? Possibilities for emergency orders?
- Should all current ASE configurations be kept in stock? Are there other configurations that should be included or removed from the ASE list?

Lead Time and Service Level

- Generally, in the market, what demands and expectations do customers have regarding availability, lead time and delivery precision?
- How important is it for customers that orders arrive on the agreed date?
  - How long of a deviation can be acceptable?
- How important is it for customers that the requested delivery date is met by Volvo Penta's promised delivery date ?
  - How long of a deviation can be acceptable?
- How long ahead in time do customers order before needing an engine?
- From your perspective, how do you view service level, lead time, and availability in order to compete in the market?
- How important is lead time for the customer?
- Would customers choose another option if the right lead time or availability cannot be provided?
  - How important is the brand for the customer in comparison?
- How do you suggest we contact customers to understand their service level and lead time requirements?

Appendix D: (s, S)-Policy Derived for MRP

The derivation of (4) and (5) is retrieved from Anderson and Lagodimos (1989). In this article, the steps in the derivation are described in more detail. Table A1 contains the notation used for the derivation.

The MRP system works by calculating the net requirements for each period and then placing an order to bring the inventory position up to the order-up-to-level. The order quantity is equal to the sum of the net requirements for the current period and all future periods up to the lead time. Hence, the system can be generalized to a base stock or (S-1, S)-policy.

Gross requirements $G_i(j)$ refer to the total demand for an item in period j before considering existing inventory or planned receipts, which is the total quantity needed to satisfy demand without considering current stock levels. Usually this represents the forecast during the period. The net requirements $N_i(j)$ represent the quantity of an item needed in period j after accounting for net inventory $u\ (i)$, planed safety stock u_s, expected receipts from production $R_i(j)$, and gross requirements. In other words, it is the additional quantity required to meet demand during that period.

The (S-1, S)-policy can be expressed with (4) and (5), where l is lead time, including safety lead time (if this is used, otherwise the lead time L replaces l), u_s is the planned safety stock, c expected gross requirement per period, and p number of planning periods that are place an order for (i.e, $p \times c$ is the forecasted demand for a planning review of p periods that the order should cover). Orders are placed to reach the reorder point S-1. S is the order-up to level and s is the reorder point. In this model, it is assumed that the gross requirement $G_i(j) = c$, i.e., the gross requirement constant for each period.

$$S = u_s + (l + p)c \quad (4)$$
$$s = S - 1 \quad (5)$$

Table A1: Notations for the formulation of (s, S) inventory policy in a MRP environment.

$N_i(j)$	Net requirements in period *j* as calculated in period *i*
$G_i(j)$	Gross requirements in period *j* as calculated in period *i.*
$R_i(j)$	Expected receipts in period j as calculated in period *i*
I(i)	Inventory position
u_s	Planed safety stock
$u\ (i)$	Net inventory at the end of period *i*
l	Lead time including safety lead time
L $d(i)$	Lead time Demand in period *i*
p	The number of planning periods ordered for each replenishment.
$r_i\ (j)$	Total requirements up to period *j*, calculated in *i*

To derive (4) and (5), first the total requirements $r_i\ (j)$ must be defined. Then, an expression for the net requirements $N_i(j)$ can be formulated by using the total requirements $r_i\ (j)$. To clarify, period *i* is the current period and period *j* is a future period. The expression for $N_i(j)$ makes it possible to compute the amount ordered $O(i)$, in each period. The amount ordered is important since this can be used to formulate S the order up to level (4). $u\ (i)$ units of inventory at the end of period *i* must be determined to calculate the inventory position *I(i).* The inventory position will be useful to determine the reorder points.

The model assumes that planning occurs at the start of each period, with only the orders for the current period *i* being placed. Additionally, it is assumed that any unsatisfied demand is backlogged.

(1A) are the total requirements $r_i\ (j)$ up to period *j* as seen in period *i.* This is the amount needed to reach a projected inventory level of u_s ,the planned safety stock, in period *j*. The projected inventory at the end of the period should always be u_s. Therefore, the total requirements up to period *j* should at least be u_s. $r_i\ (j)$ considers the planned safety stock u_s, the sum of the differences between gross requirements $G_i(k)$ and expected receipts $R_i(k)$ for each period *k* from 1 to *j*, and subtracts the previous period's net inventory $u(i-1)$.

$$r_i\ (j) = u_s + \sum_{k=1}^{j} [G_i(k) - R_i(k)\ ] - u(i-1) \quad (1A)$$

Net requirements in the current period *i* calculated in the beginning of period *i* $N_i(i)$ is the same as $r_i\ (i)$, but cannot be negative, which results in (2A). (3A) defines the net requirements $N_i(j)$ in period *i* for a future period *j*>*i*, and calculates the difference between the total requirements $r_i\ (j)$ up to period *j* and the sum of net requirements $N_i(k)$for all periods *k* from *i* to *j-1*. The max [0, ...] ensures a non-negative value for net requirements.

$$N_i(i) = \max\{0, r_i\,(i)\} \quad (2A)$$
$$N_i(j) = \max\{0, r_i\,(j) - \sum_{k=i}^{j-1} N_i(k)\,\}\ j = i+1, i+2\,... \quad (3A)$$

By using (3A) and (2A) the net requirements $N_i(j)$ can be expressed by (4A). This means that the system will place an order in period *i* if the total requirements up to a time *l* ahead are positive. An order placed in time period *i* will arrive in time period *i+l.*

$$N_i(j)\ = max\{0, r_i\,(j)\ - max_{i\le k\le j}[r_i\,(k)]\}\ j > i \quad (4A)$$

The net inventory in period i $u\,(i)$ will depend on receipts $R_i\,(i)$ and demand $d(i)$ (6A). Note, $u\,(i)$ will be negative if there are backorders. This expression is needed to formulate the expression for inventory position (7A).

$$u\,(i) = u(i-1) + R_i\,(i) - d(i) \quad (6A)$$

In (7A), it is now assumed that gross requirements are held constant $G_i(j) = c$. By assuming this, the inventory position *I(i)* can be expressed. This is the sum of stock on hand in period *i* *(*$u\,(i)$*)* and total outstanding orders counting from *i* to *l-1*. $O(i)$ is the amount ordered in period *i*.

$$I(i) =\ u\,(i) + \sum_{k=0}^{L-1} O(i-k)\ \ ,$$

$$I(i) = I(i-1) + O(i) - d(i) \quad (7A)$$

The amount ordered $O(i)$ in period *i* for planning of p periods is expressed in (8A), which is the sum of net requirements from period *i* up to $l+\ p-1$ (if the total requirements for the lead time is larger than zero).

$$O(i) = \begin{cases} \sum_{k=0}^{l+\,p-1}\ N_i(i+k)\ \ for\ r_i\,(i+l) > 0 \\ 0\ \ \ otherwise \end{cases} \quad (8A)$$

If only orders larger than zero are considered, is it possible to rewrite (8A) with (9A) because net requirements are defined as the orders required to raise the cumulative net requirements to $r_i\,(j)$ in (4A). The order size will be $r_i\,(i+l+p-1)$ when gross requirements are constant. This is possible to see by using algebra to simplify the summation expression in (8A).

$$O(i) =\ u_s\ + (l+p)c - I(i-1) \quad (9A)$$

If no rescheduling at the beginning of period *i* is allowed, there will be no scheduled receipts after period *i+L-1*. Hence, an order placed at the start of period *i* is for the amount required to raise the inventory position from level *I(i-1)* to level S, expressed in (10A).

$$S =\ u_s + (l+p)c \quad (10A)$$

For the timing of when orders are placed, the condition $r_i\,(i+l) > 0$ in (3A) must be considered. With the same logic used to derive (10A) it is possible to express (11A). This means that that the inventory level for period i $I(i)$ will be less than *S*.

$$I(i) < u_s + (l + p)c \tag{11A}$$

This makes the system equivalent to a (S-1, S)-policy reorder point of $u_s + (l + 1)c$ and order up to-level $u_s + (l + p)c$. If $p=1$, from (7), then in period i the amount ordered will required to increase the net inventory to the order-up to level. This will be at inventory level *I(i)=S- d(i),* so that *I(i-1)=S- d(i-1),* which implies that an order of *d(i-1)* is placed each period which is a (*s, S)-policy*