Improving Service Level and Inventory Management

A Holistic Approach to Operational Enhancement

Master of Science in Supply Chain Management Program

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ABSTRACT

Growing competition and increasingly complex global supply chains have made businesses focus more on improving efficiency and effectiveness. In today's business landscape, merely possessing the right products is insufficient; instead, there is a growing emphasis on finding innovative strategies to improve supply chain effectiveness and enhance customer satisfaction. The present study addresses the challenges and opportunities in improving supply chain performance and reduces stockout or obsolete. As businesses face intensified competition and heightened supply chain complexities, there is a need to enhance efficiency in order to meet evolving customer demands.

This thesis investigates the specific areas of operations within a case company, aiming to identify inefficiencies and propose viable solutions for service level improvement of the final products. Through a comprehensive case study methodology, including semi-structured interviews, investigating through internal documents and analysis of data, the research uncovers potential areas for enhancing inventory management and improving service level. Key recommendations include investigating inventory management approaches and multi-criteria ABC classification of components based on their volume and value and assigning related service levels to each individually. Additionally, different sales orders are defined as different scenarios for testing the accountability of assigned service level.

Keywords: Supply Chain, Service Level, Inventory Management, Operational Efficiency, ABC Classification, Multi-criteria classification.

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Abbreviation

SL- Service Level

RR- RapidRespons

SS- Safety Stock

KPI- Key Performance Indicators

MRP- Material Requirement Planning

ERP- Enterprise Resource Planning

LT- Lead Time

EOQ- Economic Order Quantity

SO- Sales Order

ACCs- Accessories

DDMRP- Demand-Driven Material Requirements Planning

ROI- Rate of Investment

SLAs- service level agreements

MTS- Make to stock

MTO- Make to order

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1. Introduction

In this chapter, readers will be introduced to the study, delving into the background of the thesis which provides context about the field of study and introduces the case company. Additionally, the purpose of the study and the research questions are outlined with a brief explanation of the reason behind the questions. Furthermore, the scope of the study is justified, and an overview of the report's structure is presented to provide readers with a roadmap of what to expect.

1.1 Background

Nowadays, supply chains are getting more complicated and, at the same time, more prone to disruptions due to the constant market changes driven by technology and changing customer needs, which make demand less predictable for organizations (Cardoso et al 2015). Companies that employ a one-size-fits-all approach for their products often struggle to achieve success, as noted by Lee (2002). It's crucial for organizations to effectively address uncertainties in demand to retain customers, as emphasized by Gupta and Maranas (2003).

Inventory management plays an important role in meeting customer demands by ensuring adequate supply levels while minimizing excess inventory. This process involves the supervision of procurement, storage, and accessibility of items, striving to strike a balance between supply and demand. Inventory management functions as a link within the broader supply chain framework, facilitating the seamless flow of products and services from suppliers to customers and vice versa (Singha and Verma, 2018). To achieve effectiveness in inventory management, it is essential to pinpoint the root causes of discrepancies between sales and purchases. This can be accomplished through a thorough evaluation of inventory performance. When inventory performance is suboptimal, it leads to higher service levels than needed, increased logistics costs, and unnecessary tied up capital in inventory. This inefficiency arises from inadequate planning and control of inventory levels, as highlighted by Relph and Milner (2015).

According to Beutel and Minner 2012, forecasting demand poses a significant challenge in supply chain management. Inaccurate forecasts can lead to either excess inventory and subsequent markdowns or shortages, resulting in dissatisfied customers. To safeguard supply chain performance against forecast inaccuracies, an important measure is the implementation of safety stocks. The size of these safety stocks required to achieve a certain level of customer service depends on the degree of demand uncertainty and the corresponding forecast errors. Misleading demand specifications can have a significant impact on the entire supply chain, but the associated costs can be minimized by reducing forecast errors.

Introduction of case company

In the sector of marine and industrial engine manufacturing, Volvo Penta stands as a distinguished industry leader, renowned for its development, production, and marketing of world-leading engines and complete power systems with about 2419 employees worldwide. Penta operates under two primary business units, with an equal distribution of focus – 50% in the industrial sector and 50% in the marine sector. The industrial and marine engines and power solutions are produced across multiple global locations, each specializing in different aspects of the manufacturing process.

Volvo Penta's production sites are strategically located across the globe. The Vara plant in Sweden specializes in marine diesel engine production, while the Lexington plant in the USA focuses on industrial diesel and marine gasoline engine manufacturing. Other production sites in Skövde (Sweden), Lyon (France), Köping (Sweden), Curitiba (Brazil), and Pithampur (India) contribute to the production of both industrial and marine engines as the Volvo Group Production sites.

One of the prominent challenges faced by Volvo Penta revolves around the efficient management of non-engine components, commonly referred to as accessories. These accessories play a crucial role in the overall functioning and performance of marine and industrial engines. The company aims to optimize its inventory management processes to ensure a seamless supply chain for these critical components to increase Service level as one of the most Key Performance Indicators (KPIs) for the company.

To address the complexities of supply and demand planning, Volvo Penta has adopted RapidResponse, a comprehensive tool that integrates Sales and Operations Planning processes and Execution processes. The implementation of RapidResponse facilitates accurate demand forecasting, constraint management, and production leveling. The E1 Order Promise system ensures precise order commitments based on the availability of products, enhancing customer satisfaction.

1.2 Aim

The aim of this research is firstly, to conduct a thorough analysis of Volvo Penta's current inventory management practices, focusing on engine accessories, to identify areas for potential service level improvement and consequently cost reduction within the supply chain by examining the performance of different departments and historical sales; secondly, to propose efficient strategies to enhance current inventory management practices, aiming to improve overall supply chain effectiveness. By delving into factors like actual sales orders, lead times, demand variability and stock levels, the study aims to ensure timely accessory availability while maintaining an acceptable service level, aligning with Volvo Penta's commitment to customer satisfaction. This study will categorize different accessories with the aim of classifying them based on their importance which encompasses volume and value, hence each accessory would end up with a specific class and the related service level percentage which has been derived based on suggested methods.

Additionally, it seeks to determine optimal stock levels for consistent service level attainment across product offerings, offering insights applicable to similar challenges in the automotive industry and contributing to broader discussions on inventory management optimization.

1.3 Research questions

Based on above purpose, following research questions have been formulated:

- *RQ1: What methodology/logic can be implemented for accessories to ensure service level of the final product?*

- *RQ2: How do different methods of ABC analysis assist improving service level?*
- *RQ3: How can the proposed guideline be evaluated/supported in terms of generalizability and accuracy?*

1.4 Scope of the study

The scope of the study was intentionally restricted to ensure a comprehensive and effective examination that could directly address the research questions and contribute to enhancing Volvo Penta's operations. This narrowing down process was essential to optimize resources and efforts towards areas where the most significant improvements could be achieved.

We selected specific areas considered crucial for potential enhancement based on identified problems. This selection process prioritized those aspects believed to offer the greatest potential for improvement. Any other areas with improvement potential were left for future investigations, as the focus of this study was to delve deeply into inventory management within some particular warehouses of Volvo Penta.

While Volvo Penta operates across multiple warehouses and a complex supply chain network, it was neither feasible nor practical to conduct a comprehensive review of the entire supply chain in this study due to time constraints. Hence, we chose to examine some specific warehouses of Volvo Penta.

Furthermore, our study focused on engine accessories within the warehouses, despite the fact that Volvo Penta stocks various other products. The decision to focus solely on engine accessories stemmed from the recognition that this area required more attention and has the potential to be improved in order to increase the overall efficiency.

Moreover, we intentionally excluded an investigation into the customer side of operations, as it was irrelevant to the immediate objectives of enhancing inventory management. Instead, our primary goal was to identify and implement strategies to streamline inventory processes within the selected warehouses.

To facilitate our analysis, we conducted a thorough examination of a certain number of engines and their related accessories stored in the warehouses. This comprehensive approach allowed for detailed numerical analysis and provided valuable insights into areas for improvement within Volvo Penta's inventory management system.

2. Theoretical framework

The following section delves into the theoretical framework and models used in the study, which are collected from existing literature.

In today's ever-changing world, companies are constantly challenged by uncertainties, especially when it comes to managing their supply chains efficiently. Many businesses hesitate to make large investments in expanding their manufacturing capabilities without clear forecasts of future demand. This hesitation forces them to rethink their operational approaches. To tackle these challenges effectively, companies need a cohesive framework that integrates various functions within the supply chain, including marketing, distribution, planning, manufacturing, and procurement. Supply chain planning plays a crucial role in orchestrating these functions, ensuring a smooth flow from sourcing raw materials to delivering finished products to customers (Gupta and Maranas2003).

2.1 Cost management

The aim of supply chain management is to reduce uncertainty and risks within the supply chain while positively impacting inventory levels, cycle time, and processes to achieve desired levels of service for end customers (Goldbach, 2002). According to Suk Suh (2015), one of the essential tasks for the supply chain organization is to reduce the volume of inventory held, while minimizing the expenses associated with transportation cost of required inventories in a way that meets the customer service level. The relationship between inventory, cost and service level can be seen in Figure 1.

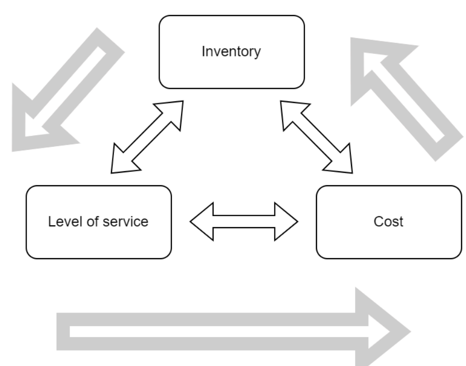

Figure 1. Relation between inventory, service level and cost (Suk Suh, 2015)

When companies reduce inventory level to save costs, it often leads to a drop in service levels due to increased stockouts. To mitigate this, expedited shipping is used, raising transportation costs. This cycle prompts a need for a quantitative framework to optimize inventory, service, and costs effectively. By analyzing inventory types, implementing reduction strategies, and considering relevant cost elements, companies can identify optimal inventory levels to minimize total corporate costs in the supply chain (Suk Suh, 2015). According to Goldbach (2002), successful inventory management is considered as a core element affecting both margin and capital turnover of the Rate of Investment (ROI), therefore there are cost-cutting opportunities by optimizing inventory finance within the supply chain.

As stated by Ramos et al. 2020, the critical importance of service level in supply chain management is also prominent. Effective service levels positively impact consumers' purchasing decisions and loyalty, ultimately influencing demand. Organizations must establish optimized service levels to ensure product availability that satisfies customers. This level of service acts as a target percentage below which all orders can be fulfilled with existing inventory. Given the uncertainty of demand, statistical methods are employed to calculate safety inventory levels necessary to meet the desired service level. Organizations must bear the cost of physical flow,warehousing, stock maintenance, and other costs if they want to ensure a high customer service level which also potentially raises the level of safety stock (Kot et al, 2011).

2.2 Demand forecasting

In today's competitive market, maintaining a flexible and efficient supply chain is vital for success. However, uncertainties, such as fluctuating customer demands, pose significant challenges. Failing to forecast and address these uncertainties can result in missed opportunities for growth or excessive inventory costs, both of which can harm a company's bottom line (Gupta and Maranas2003). According to (Gupta and Maranas2003), there are two types of uncertainties which can be categorized into short-term and long-term uncertainties. Short-term uncertainties encompass day-to-day operational fluctuations like processing variations, sudden order changes, and equipment failures, necessitating immediate adjustments to maintain operational efficiency. In contrast, long-term uncertainties, containing extended periods, include factors such as raw material price fluctuations and seasonal demand shifts, demanding strategic planning and adaptation to changing market dynamics. Neglecting to address either type of uncertainty can lead to adverse consequences, from customer dissatisfaction to inefficient resource allocation.

Demand forecasting serves as the foundation of effective inventory planning, enabling organizations to anticipate future demand patterns and adjust inventory levels accordingly. Utilizing historical sales data, market trends, and advanced forecasting techniques such as time series analysis and machine learning algorithms, organizations can improve forecast accuracy and reduce uncertainty. Accurate demand forecasting is essential for maintaining optimal inventory levels and meeting customer demand promptly, thus contributing to achieving desired service level targets (Lapide, 2005). Additionally, the implementation of Demand-Driven Material Requirements Planning (DDMRP) methodologies allows for dynamic adjustments to inventory levels based on real-time demand signals, ensuring optimal inventory management (Murray, 2017).

Bullwhip effects

The bullwhip effect, a notable phenomenon in supply chain dynamics, describes the amplification of order variability as it moves upstream along the supply chain, starting from consumer demand.This effect is a significant concern for supply chain participants due to its detrimental impacts on inventory management, resource utilization, and ultimately, customer service and profitability. There are four possible factors that contribute to the bullwhip effect. Firstly, demand forecast updating plays a role as orders are transmitted along the supply chain, leading to the buildup of safety stocks to account for uncertainties and long lead times. Secondly, periodic order batching, driven by material requirements planning or transportation economics, creates surges in demand followed by periods of low or no orders, exacerbating demand variability. Additionally, price fluctuations from discounts or promotions can distort buying patterns, resulting in larger demand variability. Finally, rationing and shortage gaming occur when demand exceeds supply, leading to manufacturers rationing products and customers placing larger, more frequent orders in anticipation of shortages (Paik and Bagchi, 2007).

Measuring the bullwhip effect in supply chains involves evaluating how demand variability amplifies as it moves upstream. This phenomenon initially arises due to delays in sharing demand information and product movement along the chain. One proposed method is comparing demand variability at different chain points. Understanding its causes, as emphasized by Lee et al. (1997), is vital for effective measurement and mitigation. This study identified four primary factors: changes in demand forecasts, order batching practices, price fluctuations, and responses to supply shortages. Solutions to mitigate it include direct demand data sharing and reassessing order handling procedures. However, measuring the bullwhip effect presents challenges, such as determining data aggregation and analysis methods and identifying significant contributing factors. Overcoming these challenges is crucial for enhancing supply chain efficiency and performance, necessitating stakeholder collaboration to implement strategies that reduce demand variability and enhance information sharing across the supply chain.

2.3 Inventory management

Inventory management is a critical aspect of organizational operations, involving the continuous process of planning, organizing, and controlling inventory to optimize investments while maintaining a balance between supply and demand (Nallusamy et al, 2017). According to Mor et al. (2021), inventories should be maintained to ensure the organization operates smoothly, maintaining service levels and customer satisfaction despite fluctuations in demand due to factors like seasonality, new product launches, and market trends. Hence, the primary goal of inventory management is to achieve the desired level of customer service, optimize operational costs, and minimize the investment in inventory.

The inventory management system serves as a crucial tool for monitoring items within a company's operations. By addressing the complexities inherent in accessory inventory management, businesses can enhance quality control, optimize supply chain efficiency, and minimize operational costs. The system also tackles common challenges associated with manual inventory management, such as labor-intensive processes, slow processing times, and susceptibility to errors. Moreover, by automating inventory tracking and management processes, the system improves accuracy and reliability, facilitating better decision-making by providing timely insights into stock levels and trends (Magallanes et al, 2021). In this regard, maintaining high stock levels can help organizations to minimize shortage costs and enhance service levels, although there is a significant risk of obsolescence associated with excess inventory. This risk is amplified with higher stock levels, leading to increased holding costs for companies (Hasni et al., 2019).

Crum and Palmatier (2003) suggests that for organizations seeking to minimize inventory levels, the utilization of planning systems for scheduling and determining order quantities is crucial. These systems not only facilitate decision-making but also enable future demand scheduling, fostering organizational cohesion. It's essential for companies to harmonize operational strategies across departments to avoid misunderstandings, as discrepancies often result in avoidable costs.

Effectively managing inventory involves understanding the variance between sales and purchases. One approach to addressing this is by evaluating inventory performance, which includes factors like the accuracy of sales forecasts, delivery reliability, lead time, and inventory balance accuracy. Failure to manage these aspects effectively can lead to increased service costs, tied-up capital in inventory, and unnecessary logistics expenses due to inadequate planning and control. Inventory levels are adjusted based on various product characteristics such as service level, batch sizes, lead times, suppliers per item, and demand variations (Relph and Milner, 2015).

2.3.1 ABC inventory classification

Based on the article by Teunter et al (2010), ABC inventory classification is a method used by businesses to categorize inventory items into three classes - A, B, and C - based on their importance, typically determined by criteria like annual volume value or demand volume. The primary goal is to efficiently manage large inventories by prioritizing efforts and resources where they are most needed. Service levels, which measure the ability to fulfill customer demand, are crucial in inventory control, often set by assigning the same level to all items within a class.

In ABC classification class A represents a relatively small portion of items, approximately 10% of the total inventory, yet they hold significant importance, contributing substantially to the total inventory value. These items require more control due to their critical role in the organization's operations. In contrast, Class B encompasses around 20% of items, also important but necessitating less control efforts compared to Class A. The majority of inventory, around 70%, falls into Class C, comprising items of lesser criticality and allowing for more flexible control measures. In further detail, Class A items constitute the top 70-80% of the annual consumption value, despite their smaller volumes, typically accounting for only 10-20% of total inventory items. Class B items, intermediate in value, encompass approximately 15-25% of the annual consumption value and 30% of total inventory items. Conversely, Class C items, while numerous in volume, contribute minimally to consumption value, comprising the lower 5% of the annual consumption value yet constituting 50% of total inventory items (Nallusamy et al., 2017).

The traditional method of using ABC analysis has been widely adopted in warehousing industries for a long time. Originally, the classification of items into A, B, and C categories was based on a single criterion, as intended by Pareto when he introduced the method (Flores and Whybark, 1987). However, relying solely on this traditional approach can sometimes be misleading in determining how to manage different products, as it focuses on only one aspect (Flores et al., 1992).

The execution of ABC analysis involves several steps: initially classifying items based on expected usage and unit price, then calculating the total value by multiplying expected units with unit price, followed by ranking items according to total value. Subsequently, ratios are computed to assess the relative importance of each item, aiding in the formation of the three categories. This strategic categorization enables organizations to prioritize resources efficiently, directing focus towards managing high-value items more closely while optimizing inventory control efforts. This approach enhances overall operational efficiency and reduces costs in supply chain management (Nallusamy et al., 2017). As stated by Jonsson and Mattsson (2009),the most economic way of allocating safety stock and safety lead time against the production disturbances is to have larger quantities and longer lead times for low value items.

In companies, there is a wide range of product demands, each with varying costs, service needs, and levels of demand (Syntetos and Boylan, 2008). By dividing these products into segments, it's possible to provide better service for some parts over others (Naylor, 1996). Items can be classified based on their criticality as low, medium, or high, which indicates how their potential unavailability impacts costs, process quality, and other factors (Dekker and Bayindir, 2004).

According to Syntetos (2009), this type of categorization offers more flexibility in setting service levels by category, considering different factors to achieve overall targets while minimizing costs. Relying solely on one category may overlook other important perspectives, leading to suboptimal outcomes. However, a drawback of using a multi-criteria approach is that it can make the classification system more complex to manage and optimize. According to Nielsen and Steger-Jensen (2007), conducting a multi-criteria ABC analysis that considers factors like resources (such as capacity), similarity, and material perspectives (volume, cost, seasonality) is essential for establishing a robust method.

While the most common criterion for inventory items has been their volume value, which is calculated by multiplying their value with annual usage, other factors may also be important considerations for management. Some of these alternative criteria may even carry more weight than volume value (Flores and Whybark, 1987).

To devise combinations of different categories, companies employ various approaches. In a study by Flores and Whybark (1987), two main methods were utilized. The primary distinction between these methods lay in the incorporation of management policies; only one of them employed such policies. Both methods begin with an initial classification of items drawn from a large pool of inventory data. Subsequently, ABC categorization is applied based on the chosen criterion, such as the commonly used dollar-usage value. Following this, management reviews the classification to decide whether it necessitates reclassification or if it remains satisfactory. Should managers opt for reclassification, an additional categorization is conducted, which is then compared to the initial one. The manager's categorization is based on criteria different from the initial one and is determined by criticality. This additional step assesses the items' criticality for the company from the manager's perspective, rather than solely from the perspective of dollar usage.

In the study, managers were tasked with considering all factors they deemed crucial in defining an item's criticality. These factors might include the impact of an outage, ease of replacement, and similar aspects. If an item was deemed critical, it was classified as "I," whereas if it was clearly non-critical, it was classified as "III." Subsequently, the initial classification was compared to the managers' classification, and a new combined classification was formulated, incorporating more criteria than just dollar usage. In cases like this, where two different criteria are involved, each combination generates nine different possibilities. For each of these combinations, various management policies could be developed, leading to complexity; therefore, the combinations need to be streamlined (Flores and Whybark, 1987).

Based on Flores and Whybark, 1987, there are nine potential combinations, each of which might require different management strategies. To simplify the situation and make it more manageable, the number of categories needs to be reduced. However, this reduction necessitates figuring out how to blend the various criteria. A straightforward mechanical process was utilized to merge classifications for both organizations, resulting in three initial item categories: AA, BB, and CC. These categories provided a starting point for management to review and reconsider the classifications of items. The procedure involved assigning every item in certain categories - such as AI, AII, and BI - to category AA; every item in categories like AIII, CI, and BII to BB; and every item in categories BIII, CII, and CIII to CC.

2.3.2 Service level

Service level, according to Lambert et al. (1998), represents how well a company aims to satisfy its customers' needs and desires. In the automotive industry, where timely availability of components is critical, achieving and sustaining a high service level is indispensable for fostering customer loyalty and maintaining competitive advantage (Mentzer et al., 2001).

Mattsson (2003) defines service level as the likelihood of delivering directly from stock during an inventory cycle, expressed as:

Service level in percent=1− total number of inventory cycles/number of inventory cycle shortages ×100

Knod and Schonberger (2001), argue that addressing stock outs for C items is not a worthwhile endeavor due to their relatively low value and impact. Consequently, it is suggested that C items should be assigned the highest service levels to minimize the resources spent on managing their availability. This perspective hinges on the idea that ensuring constant availability of C items, despite their lower individual value, can streamline operations and reduce the complexity and costs associated with frequent restocking and potential disruptions. By maintaining high service levels for these low-impact items, organizations can simplify inventory management processes and ensure a smoother overall workflow. Figure 2 based on Jonsson and Mattsson (2009) is also supporting the same assessment.

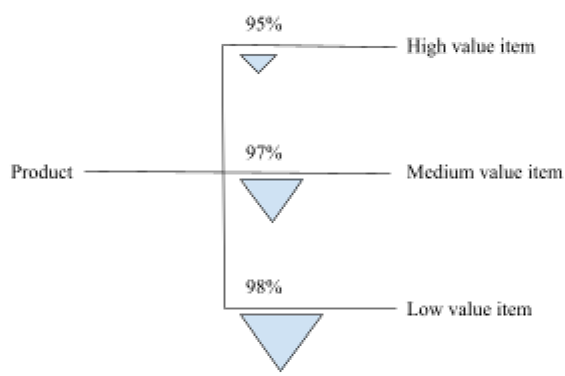

Figure 2- Differentiating service level based on item value (Jonsson and Mattsson., 2009)

Several factors intricately influence service level performance in inventory management. Demand variability, lead times, and ordering costs emerge as primary determinants, as elucidated by Silver et al, (1998). The Bullwhip Effect, posited by Forrester (1958), exacerbates demand variability's impact, necessitating proactive strategies to mitigate its repercussions. Additionally, service level agreements (SLAs) play an important role in defining and measuring expected service levels, fostering collaboration and accountability across supply chain partners (Lambert and Cooper, 2000).

2.3.3 Safety Stock

Safety stock management plays an important role in ensuring uninterrupted supply chain operations by mitigating the risks associated with demand variability and supply disruptions (Christopher, 2016). Safety stock, also known as buffer stock, serves as a cushion against uncertainties in demand and supply, thereby enhancing service levels and customer satisfaction (Simchi-Levi et al., 2015). By maintaining an appropriate level of safety stock, companies can reduce the likelihood of stockouts and backorders, thereby minimizing the risk of lost sales and potential revenue loss (Chopra & Meindl, 2020).
Several factors influence the determination of safety stock levels, including demand variability, lead time variability, and desired service levels (Snyder & Shen, 2017). Demand variability refers to the fluctuations in customer demand over a specific period, while lead time variability represents the uncertainty associated with the time it takes for suppliers to deliver goods (Gavirneni et al., 2016). Additionally, companies must consider their desired service levels, which reflect the level of customer satisfaction they aim to achieve through adequate product availability (Ivanov & Dolgui, 2021). Balancing these factors is crucial in determining the optimal level of safety stock that strikes a balance between inventory holding costs and the risk of stockouts (Kiesmüller et al., 2017).

The classic Newsvendor Model, formulated as:

$$SS = Z\alpha \cdot \sigma_D$$

Where:
SS = safety stock.
$Z\alpha$= z-score corresponding to the desired service level.
σ_D = standard deviation of demand. (Praka et al., 2017)

And σ_D is formulated as below:

$$\sigma_D = \sqrt{\frac{1}{M-1} \sum_{k=N-M+1}^{N} (Y_K - Y_N)^2}$$

Where:

- M =the number of past observations used for the estimation.
- N= the total number of observations.
- Y_K = represents the demand observation at time k
- Y_N = the corresponding Simple Moving Average (SMA) estimator of the mean demand

The two most common dimensioning targets, as outlined by Jonsson and Mattsson (2009), are: the ability to deliver from stock during an inventory cycle (Serv2) and the portion of demand that can be met directly from stock. An inventory cycle refers to the time between inventory replacements. Balancing between backlog and excessive inventory is crucial to controlling costs, with the service level set according to item importance and value. In this study Serve 2 has been applied for all the relevant calculations.

The relationship between service level and safety stock is pivotal in supply chain management, where the aim is to strike a balance between meeting customer demands and managing inventory costs efficiently. Service level, often synonymous with customer satisfaction, reflects a company's ability to fulfill customer orders promptly and reliably. Safety stock, on the other hand, serves as a buffer against uncertainties in demand or supply chain disruptions. By holding extra inventory, a company can mitigate the risk of stockouts during periods of high demand or unforeseen delays in supply (Junget al, 2004).

However, the decision to increase service level by holding more safety stock comes with cost implications. While higher safety stock levels enhance the likelihood of meeting customer demands, they also entail additional inventory holding costs. This trade-off between service level and inventory costs necessitates a strategic approach to inventory management. Holding too much safety stock can tie up capital and increase storage expenses unnecessarily, impacting overall profitability (Junget al, 2004).

As it can be seen in figure 3, Junget al, 2004 discusses different operational scenarios based on the relationship between demand variability and production capacity. In situations where demand variability is low relative to production capacity, lower levels of safety stock may be adequate. Conversely, in scenarios characterized by moderate to high demand variability, higher safety stock levels may be necessary to manage fluctuations in demand effectively.

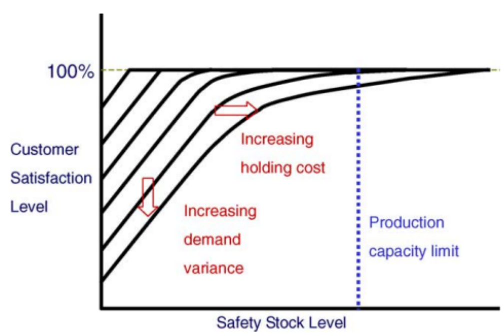

Figure 3. Relation between customer satisfaction level and safety stock level (Junget al, 2004).

2.2.4 Lead time variability

Variability in lead times can lead to inconsistencies in order fulfillment, causing delays or stockouts. If lead times fluctuate unpredictably, organizations may struggle to meet customer demand promptly, resulting in lower service levels and potentially impacting customer satisfaction. Customers rely on consistent and reliable order fulfillment times, and any variability in lead times can erode trust and loyalty (Chopra & Meindl, 2016).

Additionally, lead time variability can also impact production planning, inventory control decisions, and overall supply chain performance. Organizations may need to adjust their inventory management strategies, reorder points, and replenishment policies to account for lead time variability and mitigate its impact on service level (Simchi-Levi et al., 2008).

Lead time variability significantly impacts service level through its effect on safety stock levels, which are crucial for buffering against uncertainties in order fulfillment. The impact of lead time variability on service level can be analyzed using the reorder point formula, which considers both demand during lead time and safety stock requirements (Chopra & Meindl, 2016).
The reorder point formula can be expressed as:
Reorder Point (ROP) = (Demand During Lead Time)+(Safety Stock)

Where:
Demand During Lead Time = Average demand per unit of time multiplied by the lead time.
Safety Stock = Z-score * Standard Deviation of Demand During Lead Time

This formula demonstrates that as lead time variability increases, the standard deviation of demand during lead time also increases, leading to higher safety stock requirements. Consequently, organizations must hold more safety stock to achieve the same service level, as a greater level of variability increases the risk of stockouts and customer dissatisfaction.

3. Methodology

The section below outlines the methodology employed in this study. It consists of an explanation of the research method, followed by a review of relevant literature. Subsequently, it describes the data collection process and the methodology adopted for data analysis. Finally, it discusses the reliability and validity of the case study.

3.1. Research Approach

This study adopts a single case study approach and the primary objective is to address the research questions established at the project's outset. Bryman and Bell (2011) categorize research strategies into two main approaches which are quantitative and qualitative. Quantitative research aims to generalize theories from specific environment samples, making it effective for examining frequency and extent of phenomena. Conversely, qualitative research focuses on describing and interpreting individuals' experiences and perceptions. Creswell (2014) suggests that strategies often blend elements of both approaches, known as mixed methods research. In this study, a mixed method approach was chosen to comprehensively explore areas in the supply chain requiring improvement.

The study employs both quantitative and qualitative analyses to identify areas for supply chain enhancement. Interviews and interpretation of numerical data form the basis for understanding employees' perceptions of supply chain challenges and identifying opportunities for improvement. Data collection, utilizing multiple sources of information, enhances the robustness of findings. Empirical data primarily consists of qualitative interviews with company personnel. Interviews and qualitative data analysis were validated through respondent review to ensure accuracy. Theoretical frameworks provided foundational knowledge for understanding supply chain costs, optimizing inventory management, and structuring interviews.

The examination of the case company progressed through three separate stages, as illustrated in Figure 4. These phases ran parallel to each other throughout the study. The literature review and gathering of empirical data were iterative processes spanning a considerable period during the project. The delineation of these phases aims to clarify the project's progression for the reader and to indicate the methods emphasized during each phase.

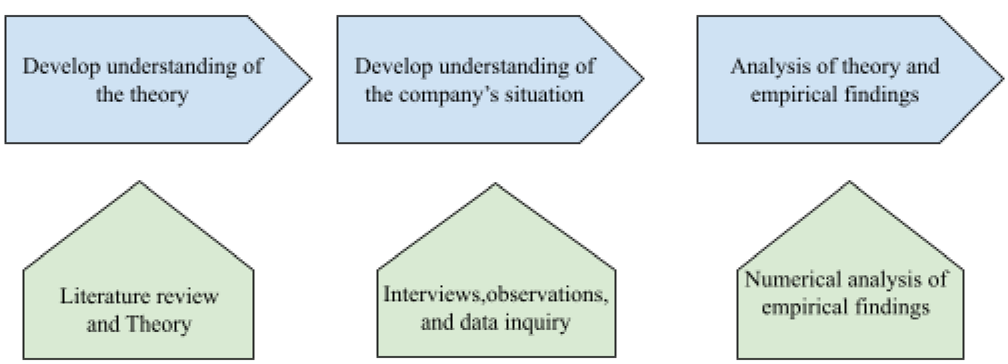

Figure 4- Methodology structure in the study

The first step in this study methodology involves multi-criteria classification and assigning service level, continuing with calculating the safety stock for each accessory in different sites. According to Silver et al., 1998, Safety stock serves as a buffer against variability in demand and lead time, ensuring sufficient inventory levels to meet customer demand while minimizing the risk of stockouts.

3.2 Literature review

To achieve the aims of this study, it was crucial to gather a substantial amount of pertinent data. This was necessary not only to propose suggestions and improvements but also to gain a deeper insight into the subject area. The literature was primarily sourced through searches in the Chalmers library database and Google Scholar. Access to the database was obtained via lib.chalmers.se, which offers access to scientific articles from various journals. Common keywords used in the literature search included "forecast", "ABC classification", "Service Level", "Safety Stock" and "Inventory management."

The literature review in this paper began with an overview and description of the studied area. The theoretical review was then focused on specific aspects chosen for emphasis in this study. This approach was adopted to provide the reader with a comprehensive understanding of the particular problem areas highlighted during the project.

3.3 Data collection

Gathering data was a significant aspect of this study. Initially, there was limited information available about the company and its operations, so a considerable amount of time was dedicated to understanding their situation and operational processes. This involved conducting interviews with different employees of different departments of the company, as well as analyzing numerical data from Volvo penta's RapidResponse and JDE E1 system. These interviews provided valuable insights into identifying supply chain issues and potential bottlenecks.

3.3.1 Interview structure

The empirical data was gathered through semi-structured interviews, although some interviews were conducted in an unstructured manner. An unstructured interview, as defined by Bryman and Bell (2011), involves the respondent being provided with a list of topics or issues, known as an interview guide, which they can address. Unlike structured interviews, where the interview guide must be strictly followed, unstructured interviews allow for flexibility, allowing additional questions to arise depending on the respondent's answers. Interviews are a potent method for accessing respondents' understanding and experiences regarding specific questions, problems, or issues, as they provide insights from diverse perspectives (Kvale, 2007).

The primary source of information for this project stems from interviews with various company employees. Interview guides were utilized for nearly all interview sessions (see Appendix A), with the guides tailored to the interviewee. All questions in the interview guides were open in a way which allowed respondents to provide detailed responses in their own words. Additionally, all interviews were recorded, and notes were taken during each session to ensure that no important information was overlooked and to gather as much data as possible.

In the initial phase of this project, interviews were conducted with various key personnel from different departments of the case company, including the Supply Planning Manager, Demand manager, Directors of S&OP and S&OE, Business process developer, and Director Order to Customer. Employees from these diverse departments were selected to ensure a comprehensive understanding of the situation and facilitate fruitful discussions. These initial interviews helped identify the initial problem areas and allowed the writers to gain a better grasp of the current state.

As indicated in Table 1, separate interviews were held with each department to delve deeper into their specific challenges. Follow-up meetings were held after each session to continuously address ongoing issues and brainstorm ideas. In the latter part of the project, idea meetings were held regularly to exchange ideas and gather additional perspectives from the writers. The initial interviews were aimed at understanding the current state and identifying both strengths and weaknesses. Appendix A provides details on how the interview questions were formulated to maximize the effectiveness of each session.

Department	Interviewee	Main Problem	Recommended Actions
Supply Planning	Manager	- Inventory Overstock - DCN process	- Improving input for RR - Selling phased out items to aftermarket
Demand Management	Manager	- Conflicting interests between different departments, - Inefficiency in forecasting	Review attach rate forecasting regularly
S&OP	Director	- Low Service Level, - Lack of Forecast Accuracy	-
S&OE	Manager	- Low Service Level, - Lack of Forecast Accuracy	-
Planning & Order Development	Developer	- Manual Processes of SS calculation and Lack of Automation -Delays or disturbances from suppliers	- Improving Monitoring inventory level - Automated Safety Stock Calculation
Finance & Business Support	Director	- Lack of communication between different units - Difficulty in managing planning for product replacements - DCN process	-Setting some guidelines for the replacement of orders - Training SCPMs regarding inventory management and obsolete items

Table 1. Interviews summary

3.3.2 Data analysis

In order to conduct a thorough numerical analysis, various datasets were gathered from local Volvo Penta software systems such as Rapid Response (RR) and JDE E1, accessible to all business units for analysis and forecasting purposes. To perform ABC analysis, determine safety stock, and explore different scenarios for enhanced reliability, historical data on actual orders, unit costs of accessories, lead times, lists of accessories bundled with engine packages, and the quantities used in each package were collected. This data was sourced from different workbooks in RR and covered a period of the past 6 months, ensuring relevance to the analysis. The actual orders have also been extracted from E1.

The extracted data was investigated and some lumpy demands were observed. According to Gutierreza et al., (2007), Lumpy demand refers to irregular demand patterns characterized by intermittent periods of no demand and sudden spikes in demand levels. Traditional forecasting methods, like exponential smoothing and regression analysis, often struggle to accurately predict such demand patterns. This can lead to inappropriate inventory levels and biased demand estimates. Hence, for better accuracy, we decided to put those demands aside to get better results. There were also components which had not been sold over the past 6 months, we excluded them as well since they would cause errors in our calculations.

Various methods were explored to optimize our results. Initially, calculations were initiated based on all accessories associated with a particular engine type, followed by an ABC analysis considering both volume and value of each accessory. Different service level percentages were then assigned based on their classification as earlier discussed in chapter 2.3.1. However, despite setting high service level percentages, it was observed that the overall service level of the entire engine package was low due to the many accessories multiplied together.

During weekly meetings with company supervisors, it was revealed that not all accessories are uniformly paired with each engine; rather, they are dependent on specific orders. On average, only 10 out of 70 different accessory types are included with an engine package. To enhance the reliability of our calculations, various scenarios were defined based on actual orders, randomly selected to reflect real-world variations in sales.

To address this challenge, we employed a Multi-criteria ABC method, yielding improved results. Initially, this method was applied to a single engine and its associated accessories. Each accessory was categorized as A, B, or C, and these classifications were tested across the actual order samples. Consequently, service levels were assigned based on these categories. The service level of each package was then computed by multiplying the service levels of all included accessories in a specific order sample, followed by calculating the average service level across all order samples. It is important to note that multiple service level configurations were experimented with to achieve an acceptable overall service level.

To enhance the generalizability and practicality of our findings, we introduced the concept of product groups. This involved categorizing engines with the most similar accessories into distinct groups. For instance, engines D13 and D16 for industrial and D4 and D6 for marine, which shared a significant number of accessories, were grouped together. By doing so, we aimed to streamline our analysis and draw more meaningful insights from the data.

Moving to the calculation of Safety Stock, we first extracted the service level factor (K) from the appendix B, which corresponded to each designated service level. Additionally, we computed the standard deviation of demand during Lead Time (σ_D) using a formula outlined in chapter 2.3.3. Lead times and historical demand data spanning the previous 6 months and subsequently utilized in the formula in 2.3.3. This comprehensive approach ensured that our Safety Stock calculations were based on robust and relevant data inputs, thereby enhancing the accuracy and reliability of our results.

3.4 Discussion of reliability and validity of results

According to Bryman and Bell (2011), for a research to be considered valid, it must effectively identify, measure, and observe the targeted areas. This evaluation involves considering internal and external validity. Internal validity relates to whether the theory aligns with the gathered data, while external validity assesses if the study's findings can be applied to different contexts beyond the specific case being studied. Reliability refers to the ability to replicate the study in various settings.

Bryman and Bell (2011) suggest that reliability can be assessed through internal reliability, the consistency of results despite changes in measurement, stability over time, and the consistency among different observers or researchers. Ensuring internal reliability involves examining if alterations in measurement affect the results. Stability refers to whether results remain consistent over time, while inter-observer consistency assesses if different observers reach the same conclusions consistently or if personal biases influence outcomes.

The reliability and validity of the study were assessed based on the above criteria. While there was a possibility of observer bias due to personal experiences during interviews, this risk was minimized as both researchers attended and transcribed the interviews together. Additionally, clarifying questions were posed to respondents to enhance understanding and minimize transcription errors. Standardized questionnaires were utilized to mitigate personal biases and enhance result robustness and validity. Despite being based on opinions from the case company's respondents, involving various departments improved result reliability.

Utilizing multiple data sources, as recommended by Creswell (2014), enhances study validity. This was achieved through interviews, observations, internal documents and literature review. Interviewing representatives from different company departments reduced the risk of personal bias and provided a comprehensive understanding. Incorporating various data sources and literature approaches increased result validity. Creswell (2014) also suggests conducting follow-up interviews to enhance validity, a practice implemented through ongoing discussions with employees. Employing a mixed-method approach, combining quantitative and qualitative methods, further strengthened result robustness and validity.

According to Voss et al, (2002), validity in case research is paramount, ensuring that the findings accurately represent the phenomena under investigation. Within this context, validity encompasses several dimensions, each crucial for establishing the credibility and trustworthiness of the study. One fundamental aspect is construct validity, which is super important because it makes sure measurements are right on target. It is like double-checking that the measurements used actually measures what is needed. This is done by making sure measurements line up with what's expected, using different kinds of evidence to back up findings, making sure not to accidentally measure something else, and using different methods to make conclusions stronger. To assess construct validity, researchers employ various strategies. Firstly, they examine whether predictions regarding relationships with other variables align with empirical evidence. Secondly, employing multiple sources of evidence, such as different data collection methods or perspectives, aids in corroborating findings, thereby demonstrating convergent validity. Thirdly, discriminant validity is established by differentiating the construct being measured from others. Lastly, triangulation, the use of multiple methods or data sources, strengthens construct validity by providing a more comprehensive understanding of the phenomenon.

Internal validity in case study research refers to how well cause-and-effect relationships between conditions can be established, ensuring that changes in one condition actually lead to changes in another, without being influenced by unrelated factors. It's about making sure findings accurately represent the true relationships studied, rather than being affected by random or external factors (Voss et al, 2002).

In the thesis, construct validity and internal validity was ensured by employing multiple data sources, including interviews, observations, local softwares and literature review, and by using standardized questionnaires to mitigate biases. The involvement of representatives from various departments minimized bias, while the utilization of a mixed-method approach strengthened the reliability and validity of the findings.

External validity, according to Voss et al. (2002), refers to the extent to which the findings of a study can be generalized beyond the specific case being studied. It is about knowing whether the conclusions drawn from the research can apply to other similar situations or contexts. External validity is crucial for ensuring that research has real-world relevance and practical implications beyond its immediate scope. The data was analyzed regardless

This study has considered diverse scenarios among different warehouses and for various engines which makes the study more generalizable and implementable for any industries producing products with subsets specially in marine or car industries which manufacture engines and all the belongings. It can be applied in the similar situation for better insight of the subsets' service levels and a better classification for any further operation in their industry.

4. Empirical findings

This section describes the empirical findings from the data collection. It starts by introducing the operation process and the product range and continues with their current strategies used to manage and control the inventory. A presentation of demand management and planning methods is thereafter introduced.

4.1 Operation processes and products

Volvo Penta, a renowned player in various industrial sectors including forestry, material handling, construction, agriculture, mining, leisure boating, and marine propulsion, boasts a diverse product range and assortment. This thesis delves into the empirical findings concerning Volvo Penta's product offerings across its distinct market segments. By examining its internal and external supplier network, manufacturing facilities, distribution channels, and customer delivery processes, this research sheds light on the intricate dynamics of Volvo Penta's product management strategy.

From heavy-duty industrial applications to leisure boating enthusiasts, Volvo Penta's product portfolio encompasses a wide array of engines and propulsion systems. However, this study aims to analyze the empirical findings related to limited products of Volvo Penta, since investigating through all of it would become out of scope.

Volvo Penta divides its operations into five primary segments: Marine, Marine Leisure Gas, Marine Leisure Diesel, Marine Commercial, Industrial Genset and Versatile. Each segment serves distinct customer needs, ranging from recreational boating to heavy-duty commercial applications. Understanding these segments is crucial for comprehending Volvo Penta's product strategy and market positioning.

Volvo Penta's production capabilities are supported by both internal and external suppliers. Internal production sites, such as the Vara and Lexington factories, play a pivotal role in manufacturing engines for various market segments. External suppliers, including Perkins factories, contribute components and engines to augment Volvo Penta's product offerings. By examining these production facilities, this research elucidates the integration of internal and external suppliers within Volvo Penta's supply chain. The diversity of Volvo Penta's product range is exemplified by its extensive lineup of engines and propulsion systems. From the high-performance diesel engines for marine leisure applications to heavy-duty engines for industrial use, Volvo Penta caters to a broad spectrum of customer requirements.

Volvo Penta is dealing with inventory management challenges, especially concerning accessories. To summarize Operation Process Overview, Volvo Penta operates two main processes: supply material and planning. The supply material process involves inbound material flow from suppliers to factories, while the planning process focuses on scheduling material for delivery to end customers and factories, a flowchart supply chain of one the sites can be seen in figure 5. Planning includes response during planning, managing finished goods item numbers, and coordinating supply networks. The company strives to align with customer delivery dates, although challenges arise due to varying product types and customer demands.

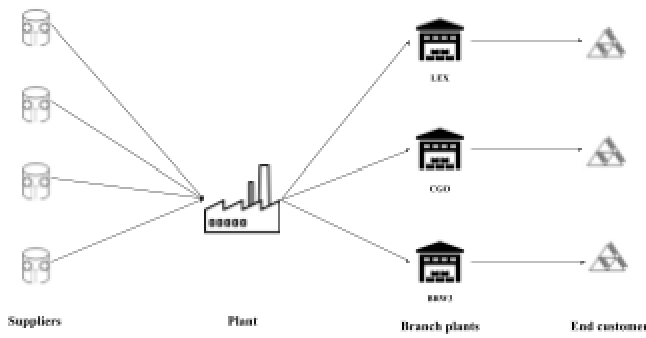

Figure 5- Sample Site Supply Chain Flowchart

4.2 Inventory management

In order to deliver a whole package to the customer, including the engine and its attached accessories, all the accessories need to be available in stock. Otherwise, the company would fail to deliver the package. This leads to a high level of inventory for the accessories to fulfill demand. High stock levels would lead to high inventory carrying costs, and in the long run the company faces some operational risks of scrapping obsolete items . Many employees express a significant concern regarding the excessive number of products stored in their warehouse, leading to considerable costs. Overall, the company lacks an effective strategy for managing products that have remained in inventory for extended periods. One notable reason identified for this issue was the management of the Design Change Notice (DCN) process, particularly concerning the replacement of old items with new ones. Inadequate planning during these transitions and inaccurate planning of phasing out processes often results in excess inventory of obsolete items. At the same time, there are still some orders that cannot be delivered because of the accessories shortage. This could be because of the inaccurate forecasting or inefficient inventory management strategy which results in shortage and the package service level would fall respectively. Additionally, one other identified factor involved in this issue is that the safety stock for different items has been calculated based on gut feeling, hence there is no systematic way for this calculation.

Volvo Penta has two different strategies of Make to stock (MTS) and Make to order (MTO) depending on the type of product. The lead time would vary depending on these two strategies. Make to stock products would have lower lead time compared to make to order products. According to the historical sales data, the company faced a shortage for some certain accessories such as propellers. The focus of this study is on the MTS orders of accessories since the Pareto analysis and safety stock calculation cannot be implemented for the items that are pulled from the customer's order.

4.3 Demand management

Based on empirical findings, in 2019, forecasting all accessories across different sites of Volvo Penta was a significant task, involving statistical methods and careful validation to ensure accuracy. It was a time-consuming process that required thorough checks to maintain precision. By 2021, they began using an attach rate for specific items like mufflers and drives, while the rest still relied on statistical forecasts. This approach expanded further with the introduction of attach rate for D4/D6, broadening the scope of accessories covered. In 2023, they extended the attach rate to include all accessories across all sites, streamlining forecasting efforts. Statistical forecasting now focuses solely on independent sales, capturing those accessories sold without an engine. Approximately 10% or less of accessory sales occur without an accompanying engine line on the sales order, identifying them as independent accessories.

The attach rate calculation considers sales data from the past six months, based on the request date on sales orders, reflecting actual customer demand. This method prioritizes customer needs, ensuring that forecasts align closely with sales patterns.,One major advantage of the attach rate is its alignment with the engine program. As engine demand fluctuates, accessory forecasts adjust accordingly, maintaining synchronization with overall demand trends. While attach rates primarily rely on historical data, they can be adjusted proactively if needed, allowing for flexibility and adaptation to changing market conditions.

The forecasting is being done by Rapid Response (RR) which is a customized software for demand planning at Volvo. To receive the forecasts, RR requires some main inputs which includes Lead Time, Safety Stock and Service Level. Manual processes for setting safety stock levels and Service Level for RR forecasting and insufficient monitoring of supplier delivery precision further complicate inventory management efforts and would affect forecast accuracy. Moreover, different statistical methods or data driven methods can be implemented to find the best forecasting solution. Additionally, for project-based or seasonal demand patterns, the historical data cannot be reliable since it would lead to inaccurate forecasts.

5. Analysis

This chapter includes an analysis of the empirical findings based on the theoretical framework. It starts by identification of the problem areas and continues with the inventory management strategies followed by the multi criteria approach and ends up with a chapter of how to improve planning of inventory management.

5.1 Current situation

As a weakness, there is no certain way of defining service level for the accessories. Additionally, when they want to deliver a product, if a single accessory is not delivered, the whole package needs to wait, leading to a drop in service level of the whole package.

Another issue stated by the interviewees is excessive inventory, likely stemming from inaccurate forecasting. Volvo Penta relies on statistical forecasting, utilizing historical sales data or attach rates—the ratio of specific accessories ordered with engines over a given period—to predict accessory demand. Yet, the accuracy of these methods remains a challenge, leading to inventory imbalances and operational inefficiencies, with certain items overstocked while others face shortages.

The primary focus of this analysis has been to examine and assess the determination of service levels for attached accessories, with the aim of enhancing the overall service level for engine packages. An engine package includes all components, such as propellers, drives, fuel filters, etc., that are sold alongside the engine. Any shortage in one of these components results in a delay in delivering the complete package, as regulations prohibit the delivery of incomplete sets. This underscores the interdependence of all assembled accessories on the associated engine, necessitating precise planning based on each engine's specifications. However, our investigation has revealed a lack of systematic methods for calculating safety stock and determining service levels for these components based on the engine’s demand. Presently, safety stock calculations are conducted manually by supply planning managers across different sites which is not an efficient way.

Forecasting is facilitated through Rapid Response (RR), a customized demand planning software at Volvo Penta’s operation process. Empirical evidence indicates that the primary issue lies in low service level, likely coming from inaccurate forecasting and independent demand planning for accessories separately from engines’ demand planning. The company relies on statistical forecasting, utilizing historical sales data or attach rates—the ratio of specific accessories ordered with engines over a given period—to predict accessory demand. Yet, the accuracy of these methods remains a challenge, leading to inventory imbalances and operational inefficiencies, with certain items overstocked while others face shortages.

The solutions and suggestions in Figure 6 of how to improve Penta’s current situation are further explained in the next coming sections, with focus on how to manage the inventory in a way that will improve SL, increase customer satisfaction and eliminate the problems Penta is facing.

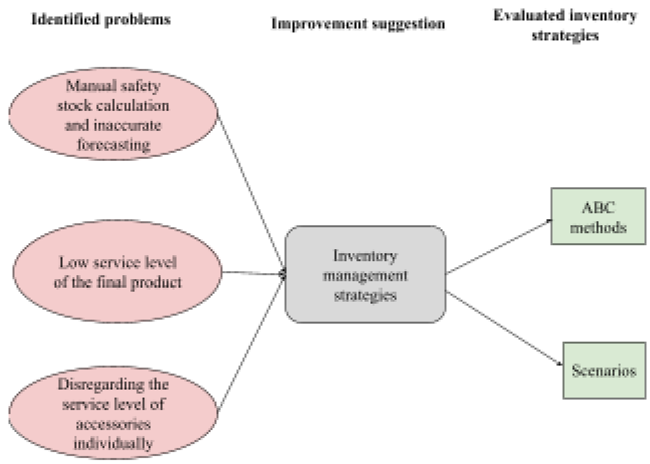

Figure 6- Discovered areas of improvements and suggestions in the study

Prioritizing inventory management performance is crucial for organizational success, ensuring a balance between purchased and sold items. Although Rapid Response automatically generates order replenishments, the output lacks reliability. Consequently, Volvo Penta planners rely on manual analysis to make decisions, without assessing the most optimal order replacement method for their current situation. This approach has resulted in instances of either obsolete items and excess inventory or the risk of stockouts. Planners consider various factors during the manual order replenishment process, such as current stock levels, future demand fluctuations, and the number of pending orders. However, the drawback lies in the inaccurate demand trend, leading to issues such as over-ordering or under-ordering, which can disrupt production.

Jonsson and Mattsson (2009) propose calculating the safety stock level to enhance control and manage inventory more efficiently. Upon analyzing the current state, it became evident that there is no proper method for managing orders and inventory levels. This has led to instances of stockouts and the risk of losing customers, as well as higher-than-needed inventory levels for some items. Both excessive and insufficient stock levels incur unnecessary costs for Volvo Penta. Managing inventory levels involves calculating safety stock levels to find the optimal level during various time periods that align with demand.

The current service level of the package stands at around 75%, which is adjusted with the new ABC classification. SS formula involves multiplying the standard deviation by the safety factor. When demand varies greatly, the standard deviation increases, leading to a higher level of safety stock. Conversely, if demand remains relatively stable, the safety stock level can be decreased as the standard deviation will be smaller. The safety factor, influenced by the service level, also determines the appropriate level of safety stock based on the item's value and sensitivity to stockouts.

5.2 ABC single-criteria classification

The traditional approach to ABC analysis has been extensively utilized across various business sectors to identify products with the greatest impact on a business's operations, thereby guiding focus and resource allocation. Originally, this analysis relied solely on one criterion, often the dollar value of items, as initially proposed by Flores and Whybark (1987). Despite its widespread application, relying on a single criterion can lead to misleading classifications and potentially overlook crucial insights that could be gained by considering multiple factors.

ABC classification based on a single criterion, such as sales volume, can result in a product with high sales volume being categorized as a C-class item without taking into account the value of its individual components. This approach might lead to an overemphasis on certain products that do not necessarily contribute the most to profitability or efficiency. For example, a product categorized as C-class due to high sales volume might occupy excessive warehouse space and receive undue attention compared to more valuable B or C items. By incorporating additional factors into the classification process, such risks can be minimized, leading to more accurate and effective guidelines for product targeting (Flores and Whybark, 1987).

To explore the implications of single-criteria ABC classification, this study initially focuses on one type of engine from a specific production site within the organization, along with its attached components sold over the past six months. The necessary data, including unit costs and sales volume for each component, were extracted to perform the ABC classification. In this classification, items with high value are categorized as A, medium-value items as B, and low-value items as C. Conversely, items with high volume are categorized as A, items with medium volume as B, and items with low volume as C. The data for attached accessories to each engine package were sourced from different workbooks in Rapid Response. This data included all the different types of components sold with the engine, their values, and the volume sold with different packages, without considering order-specific variations, meaning that in each package only a few ACCs sell with a package of an engine based on order specifications rather than all components types.

In table 2, split between categories and the ranges that are assigned to each category is mentioned. These ranges can be changed based on the company's preferences. In this table, products are classified based on their value and volume. Items with a value between 0 and 500 kr are categorized as C (low value), between 500 and 3000 kr as B (medium value), and above 3000 kr as A (high value). Similarly, items with a volume between 0 and 40 are classified as C (low frequency), between 40 and 100 as B (medium frequency), and above 100 as A (high frequency). This detailed classification allows for a more nuanced understanding of product importance, facilitating better decision-making in inventory management.

Value (kr)	Classification	Volume	Classification
+3000	A (High Value)	+100	A (High Frequency)
500 - 3000	B (Medium Value)	40 - 100	B (Medium Frequency)
0-500	C (Low Value)	0-40	C (Low Frequency)

Table 2-Classification Ranges for Value and Volume

Table 3 presents a single-criteria ABC classification analysis applied to two components, denoted as Component A and Component B, within a stock management context. Component A, characterized by a sales volume of 433 units over a 6-month period, showing a significant volume of transactions. However, its unit cost of 43,395.79 kr places it within the "A" category in terms of value classification, and its volume classification remains at "A." This discrepancy underscores the necessity of examining both volume and value metrics in isolation to derive comprehensive insights into inventory management strategies. Conversely, Component B, with a sales volume of 395 units, falls under the same volume classification as category "C." Nonetheless, its substantially lower total value of 507.95 kr situates it in the "B" category for value classification. This discrepancy between volume and value classifications emphasizes the nuanced nature of stock management decisions, which must account for both quantitative and qualitative factors.

Name	Volume	Value	Volume classification	Value classification
Component A	433	43,395.79 kr	A	A
Component B	395	507.95 kr	A	B

Table 3- Single-criteria ABC

Above ABC analysis, emphasizes the importance of considering both volume and value metrics for effective stock management strategies. By understanding this interplay, organizations can make informed decisions that align with their financial objectives. Items categorized as "A" in value and "C" in volume, for example, may initially seem less significant; however, their substantial value contribution underscores their critical role in the inventory portfolio.

5.3 Multiplied ABC classification

According to Teunter et al, (2010), one common method involves sorting items based on their annual dollar volume, calculated by multiplying the price per unit by the projected volume of sales or usage. This approach simplifies inventory control by prioritizing attention and resources according to the value and volume of items. Class A typically includes high-value items with significant sales volume, while class C comprises low-value, low-volume items. This method allows companies to allocate resources efficiently and optimize inventory levels based on the relative importance of items within each class.

In this method, volume and value are multiplied together to create a single composite criterion. The resulting numbers are then sorted in descending order. Following the Pareto principle, the top 20% of the highest numbers are designated as category A, the next 30% as category B, and the remaining numbers fall into category C. Unlike methods where volume and value are considered separately, this approach does not establish specific ranges based on each factor individually, necessitating the use of the Pareto principle for sorting. Category A encompasses items of high value and volume, while category C consists of items with relatively low value and volume.

5.4 Joint-criteria approach

What will be proposed to Penta's categorization is to introduce more factors to increase the accuracy of the categorisation. In this research, enhancing the ABC classification is crucial due to the challenges of excessive inventory levels and shortages of certain components that can lead to a lower delivery position for the final product. To address these issues and enhance inventory management, an approach to product categorization is suggested. Based on Flores and Whybark (1987), adopting a multi-criteria ABC classification system can help companies in reducing inventory and improving delivery schedules. These aspects, inventory reduction, and meeting delivery schedules, are particularly problematic areas identified within Volvo Penta.

Hence, another approach is adopted by considering multiple factors to enhance the accuracy of product categorization. Flores and Whybark (1987) advocate for a joint-criteria classification method. Joint Criteria ABC Classification is an inventory management approach that categorizes items based on a combination of two or more critical factors, such as dollar usage, volume, lead time, and obsolescence risk. This method enables a more effective prioritization of inventory by integrating multiple dimensions of importance, allowing for more precise management decisions, optimized resource allocation, and improved control over high-priority items while efficiently automating the handling of low-priority items. For Volvo Penta, sales volume and value of units are considered in the joint categorization of engine components to enhance service level since these two factors play a critical role in decision making. Value represents the financial impact of the parts, and volume indicates the frequency of usage in different packages. This combination helps prioritize high-value parts that are used frequently, ensuring their availability to prevent production delays, while also efficiently managing less critical, lower-value components, therefore, a parent file has been defined as the assessment of different scenarios which can be seen in appendix C.

By incorporating both usage frequency and value into the classification process, nine new categories have been established, as outlined in table 4. Flores and Whybark (1987) emphasize the importance of limiting these categories, as each combination may necessitate different management policies. Otherwise, the management of various policies and rules for different categories could become overly complex and challenging to navigate. The development of management principles varies widely among companies, sometimes resulting in vague or disorganized approaches. To enhance service level performance, a strategic decision has been made to conduct an ABC classification of accessories based on their significance. This involves testing various scenarios based on the parent file that will be discussed in chapter 5.4.

Inventory management is a critical aspect of organizational efficiency, with traditional ABC analysis serving as a foundational tool for prioritizing resources. However, recognizing the multifaceted nature of inventory management, this research advocates for an extended approach: the Multi-Criteria ABC Analysis framework. This framework proposes four distinct categories tailored to reflect varying levels of importance and management priority. The first and most critical category is named "Critical" in this study which can be seen in table 4. Items in this category are of utmost importance to the organization and require meticulous attention from management. Within the "Critical" category, items are further subdivided based on their value and volume metrics. Items classified as AA are both high in value and volume in this classification, indicating that they represent a substantial portion of the inventory and require proactive management strategies, hence these ACCs are categorized as critical.

<table>
<tr><td>Critical</td><td>AA</td><td>High value high volume</td></tr>
<tr><td rowspan="2">Important</td><td>AB</td><td>High value medium volume</td></tr>
<tr><td>BA</td><td>Medium value high volume</td></tr>
<tr><td rowspan="2">Intermediate</td><td>AC</td><td>High value low volume</td></tr>
<tr><td>BB</td><td>Medium value medium volume</td></tr>
<tr><td rowspan="3">Low Concern</td><td>CA</td><td>Low value high volume</td></tr>
<tr><td>BC</td><td>Medium value low volume</td></tr>
<tr><td>CB</td><td>Low value medium volume</td></tr>
<tr><td>Non-critical</td><td>CC</td><td>Low value low volume</td></tr>
</table>

Table 4 - Joint-ABC classification

Within the framework, the "Important" category holds significant items that are pivotal for organizational operations but do not reach the criticality of those in the top category. Within this category, two subcategories, AB and BA, are identified. These subcategories represent items that are pivotal for organizational operations due to their high value and high usage levels. While not reaching the criticality of items in the top category, AB and BA items demand significant management attention to ensure optimal inventory control and operational efficiency. Strategies for managing these items must strike a balance between ensuring availability and minimizing holding costs to maintain operational continuity and maximize organizational performance.

The "Intermediate" category occupies a crucial position, including items that hold moderate importance within organizational operations. This category comprises two distinct subcategories: AC (High value low volume) and BB (Medium value medium volume). Items classified under AC are characterized by their high value but low usage volume, representing a significant investment for the organization despite infrequent usage. These items necessitate meticulous management strategies to ensure their availability when needed while minimizing holding costs. BB items, on the other hand, exhibit moderate value and usage volume, requiring regular review and efficient inventory management practices to maintain optimal stock levels and operational continuity. The Intermediate category thus presents a diverse array of items that require tailored management approaches to strike a balance between availability and cost-effectiveness, thereby contributing to overall organizational performance.

Moving down the hierarchy, "Low Concern" category encompasses items that have a relatively minor impact on organizational operations and require minimal managerial oversight. This category includes BC (Medium value low volume) and CB (Low value medium volume) items and CA items. BC items, with their moderate value and low usage, do not demand frequent review but must be adequately stocked to avoid disruptions, ensuring availability without incurring high holding costs. Conversely, CB items, despite their low individual value, are used more frequently, necessitating efficient reorder practices to maintain a consistent supply without overstocking. Managing these items involves periodic reviews and setting appropriate reorder points, balancing operational efficiency and cost-effectiveness while ensuring necessary items are available as needed. Lastly, CA items, although low in value, exhibit high usage volume, collectively exerting a notable impact on operational efficiency and cost. Managing these items involves ensuring their availability while minimizing holding costs and the risk of stockouts. This streamlined approach allows organizations to allocate resources efficiently and maintain smooth operations without dedicating excessive attention to low-impact inventory and therefore, requires higher SL.

The last category is called "Non-critical or Minimal Priority" which comprises items that have the least impact on organizational operations and require minimal management attention. This category consists solely of the CC subcategory, which includes items of low value and low volume and have the relatively high SL (Table 5). These items are characterized by their negligible cost and infrequent usage, making them the least critical components in inventory management. The management strategy for CC items focuses on maintaining a sufficient stock level to prevent any interruptions in operations without tying up significant resources. These items typically do not justify frequent reviews or intensive oversight due to their low impact on overall costs and operations. By employing a simple, low-effort management approach, organizations can ensure that CC items are available when needed, maintaining operational continuity without unnecessary expenditure or resource allocation.

Implementing the multi-criteria categorization system at Volvo Penta allows for a more stable and robust foundation for classifying products. Since inventory management relies partly on this classification, the new approach could enhance the way of controlling inventory management. In the current method, forecasting for engine components is based on historical sales and employee gut feeling for replenishment, which may not provide sufficient grounds for accurate forecasts. However, with the proposed approach, these variables will still be utilized alongside additional information. This new method enables identification of items that generate the highest value per item and for the entire product group, rather than solely focusing on the highest sales volume from previous years.

		Volume		
		A	B	C
Value	A	AA =97.00%	AB =97.30%	AC= 98.00%
	B	BA= 97.30%	BB= 98.00%	BC =98.5%
	C	CA =98.50%	CB =98.50%	CC= 98.80%

Table 5 - Service level allocation to Join-ABC

5.5 Service Level

In inventory management, defining appropriate service levels is crucial for balancing product availability and cost efficiency. Service levels indicate the probability that a product will be in stock when needed, directly impacting customer satisfaction and operational performance. Establishing these levels involves segmenting inventory items based on specific criteria, such as their importance, demand frequency, and value. By systematically categorizing items and assigning tailored service levels, companies can optimize their inventory management processes, minimize stockouts, and ensure efficient use of resources. The following sections will explore the application of the Single ABC and Joint ABC methods for determining service levels in detail.

5.3.1 Single-Criteria ABC and Multiplied ABC

When implementing safety stock levels, it's crucial to segment items based on their characteristics, as suggested by Naylor (1996). Segmentation facilitates identifying items requiring higher safety stocks and those more sensitive to stockouts. The importance of an item and its sensitivity to stockouts determine the level of safety stock needed.

A practical approach for structuring service levels involves ranking items based on parameters like volume, price, or order frequency, then aligning categories with appropriate service levels. This not only reduces costs but also enhances warehouse control and forecasting accuracy. Moreover, it helps determine the necessary safety stock levels based on the required service levels for different categories. A higher proposed service level implies a greater safety factor and consequently, a higher safety stock level (Naylor 1996). The most economic way of allocating safety stock and safety lead time to tackle production disturbances is to have relatively larger quantities and longer lead time for low value items compared to high value items (Jonsson and Mattsson , 2009).

The targeted service level for Volvo Penta is 85% for the whole package. Hence for a package which includes an engine and different accessories, the final service level would be calculated through multiplying all the individual service levels of accessories together. The percentage would consequently become lower by each time multiplying. Based on the ABC classification in the previous section, each accessory would be assigned a service level depending on their importance. However, in order to reach the target for the whole package, a Trial and Error approach for the desired service level percentages for the final product has been conducted.

To assign service levels (SL) in a single ABC classification, either volume or value as the primary dimension for classification has been chosen. If value is selected as the main dimension, the highest service level is assigned to the lowest value items, since these less expensive components are easier to stock in larger quantities. Similarly, if volume is chosen as the main dimension, the highest service level is assigned to the highest volume items, as these are in high demand and must be readily available in the warehouse to prevent shortages. The relevant results of service level assigned to each scenario can be seen in chapter 5.

Moving to the multiplied method, according to chapter 2.3.2 , after the numbers are sorted, the highest service level had been assigned to C group and the lowest service level had been assigned to category A.

5.3.3 Joint-ABC

After categorizing the components into Critical, Important, Intermediate, Low Concern, and Non-critical groups, we assign service levels based on specific criteria. The highest service level is given to the Low Concern category, as these components require least monitoring and have low value, and low impact on the organization, requiring least attention from management. Conversely, the lowest service level is assigned to the Important category, which contains items with relatively high value and high volume. These components require close management monitoring.

The Important and Critical category, which include items with high value and high volume, is assigned the lowest service level. These items need careful management oversight. The service level for this category should be low from an economic perspective because maintaining a large inventory of expensive items would impose a significant cost on the company. The purpose of close monitoring is to minimize the stock of these items while ensuring there is enough to avoid shortages. The Important category includes AB, BA and AA components which are pivotal for operations and require significant management attention to balance availability and holding costs.

The Intermediate category consists of AC and BB items, each demanding tailored management approaches to ensure cost-effectiveness and availability. In the AC category, although the value is high, the volume is recognized as low. These expensive low-demand items still require close monitoring but it can be held relatively higher than the Important category since the demand is low to fulfill, however the service level is still lower than the Low-concern and Non-critical.

The Low Concern and Non-Critical category includes CA, BC, CB, and CC components, which require periodic reviews and efficient reorder practices to maintain operational efficiency without incurring high costs. These items should have higher service levels due to their moderate or low value, making it logical to assign them a higher service level and keep more in stock without causing significant economic issues for the company. Implementing this multi-criteria categorization system at Volvo Penta enables more precise management decisions, optimized resource allocation, and improved control over high-priority items, ultimately enhancing inventory management and delivery schedules.

5.4 Scenarios

In this chapter, the results of three different ABC categorization methods—value-based, volume-based, and multi-criteria (value and volume) based—applied to historical sales orders are analyzed (Appendix D). The goal is to determine the most effective method for achieving a reliable service level (SL) and efficient categorization of engine packages. This part of the study is defined to make the results more practical for the organization and also more generalizable for the future purposes. For a more reliable outcome, the product group has been defined. To enhance the reliability of the tests, products with similar components and functions were grouped together within the organization, a practice known as creating product groups. For instance, engines D13VE and D16VE share many similar components, making it more practical to analyze and classify their components collectively. Appendix F shows the result of marine engines D4/D6 for multi criteria ABC classification.

The value-based categorization method classifies components based on their monetary value. The results indicate different average sold components for packages across categories. High-value items, classified as A items, showed an average of 1 sold component per order. Medium-value items, classified as B items, had an average of 5 sold components per order. Low-value items, classified as C items, exhibited an average of 3 sold components per order. On average, 9 components are sold with a package of an engine, and the average SL is around 86%, which is the highest percentage among the other two ABC methods (table 6).

Value				
Scenario	Attached accessories per scenario	**A**	**B**	**C**
1	3	0	3	0
2	12	0	6	6
3	10	0	5	5
4	10	1	6	3
5	5	1	2	2
6	19	2	11	6
7	5	0	3	2
AVG sold components	**9**	**1**	**5**	**3**
AVG SL of the package	**86%**	**97.00%**	**98.00%**	**99.00%**

Table 6 - Value-based Categorization Results

The volume-based categorization method focuses on the number of units sold over the past 6 months. According to this method, high-volume items, classified as A items, had an average of 3 sold components per order. Medium-volume items, classified as B items, also had an average of 3 sold components per order, while low-volume items, classified as C items, exhibited an average of 3 sold components per order. This method differs from the value-based categorization by emphasizing the number of units sold rather than their monetary value. Despite this focus, the average SL (Service Level) for the package is 83.46%, which is lower than the value-based approach (table 7).

Volume				
Scenario	Attached accessories per order	**A**	**B**	**C**
1	3	1	0	2
2	12	6	3	3
3	10	1	3	6
4	10	2	6	2
5	5	2	2	1
6	19	10	4	5
7	5	2	0	3
AVG sold components	**9**	**3**	**3**	**3**
AVG SL of the package	**83.46%**	**97.00%**	**98.00%**	**99.00%**

Table 7- Volume-based Categorization Results

The multiplied method considers both the monetary value and the volume of units sold to classify components by multiplying these two factors together. This method aims to leverage the strengths of both value-based and volume-based methods. High-priority items, classified as A items, showed an average of 3 sold components per order. Medium-priority items, classified as B items, had an average of 3 sold components per order. Low-priority items, classified as C items, exhibited an average of 4 sold components per order. Please note that the averages have become rounded. This approach provides a balanced perspective, leading to an average SL of 84.03%, which is an improvement over the volume-based method but slightly lower than the value-based method (Table 8).

Multiplied (Volume*Value)				
Scenario	Attached accessories per order	**A**	**B**	**C**
1	3	2	1	0
2	12	3	4	5
3	10	3	3	4
4	10	5	3	2
5	5	1	2	2
6	19	4	6	9
7	5	2	0	3
AVG sold components	**9**	**3**	**2**	**4**
AVG SL of the package	**84.03%**	**97.00%**	**98.00%**	**99.00%**

Table 8- Multiplied Categorization Results

The multi-criteria categorization method, as illustrated in Table 9, combines both value and volume for a more comprehensive approach. Critical items, classified based on their significant impact and necessity, had an average of 9.14 sold components per order and an average SL of the whole product group is 85%. Critical components showed an average SL of 97.00% without any sold components in 7 tested scenarios. Through the Trial and Error, important items exhibited an average of 2 sold components per order and an average SL of 97.30%. Intermediate items had an average of 3 sold components per scenario and an average SL of 98.00%, similarly low concern items demonstrated an average of 3 sold components per order with an average SL of 98.50%. Non-critical ACCs in this multi-criteria categorization method received the average Service Level of 98.80%. This indicates that while these items are considered of lower priority or urgency, they still maintain a high level of service reliability in terms of delivery performance. This method achieves a more balanced categorization across all categories, particularly improving the focus on critical items, ensuring that items with the highest impact receive adequate attention and also ensuring that the SL for the package is desirable for the company.

Joint-ABC						
Scenario	**Attached accessories per order**	**Critical**	**Important**	**Intermediate**	**Low Concern**	**Non-critical**
1	3	0	1	0	2	0
2	12	0	3	5	2	2
3	10	0	1	1	5	3
4	10	0	2	5	2	1
5	5	0	1	2	1	1
6	19	0	2	7	9	1
7	5	0	2	1	1	1
AVG sold components	**9**	**0**	**2**	**3**	**3**	**1**
AVG SL of the package	**85%**	**97.00%**	**97.30%**	**98.00%**	**98.50%**	**98.80%**

Table 9- Joint-ABC Categorization Results

Upon analyzing the results from the three categorization methods, it becomes clear that each method offers unique advantages and limitations regarding service level (SL) and the efficiency of categorizing engine packages. The value-based method prioritizes components based on their monetary value, achieving the highest average SL of 86% for the package. This method ensures that high-value items receive the most attention, which is crucial for managing costs effectively. However, it may overlook the importance of frequently sold lower-value items, potentially impacting overall service efficiency and the availability of commonly needed components.

The volume-based method, on the other hand, focuses on the number of units sold, emphasizing items that are frequently ordered and achieving an average SL of 83%. This approach effectively addresses demand frequency but may under prioritize high-value items, leading to potential overstock or scrapping of expensive components. This could result in significant disruptions, especially when high-value items are essential for the operation or assembly of engine packages.

The multiplied method with the average of 84.03 has relatively low results since it cannot consider the difference between Volume and Value. Although it considers both volume and value for the classification, it may still cause some misleading results specially for the data with the huge difference between volume and value.

The multi-criteria method combines both value and volume for a more comprehensive approach, achieving an average SL of 85%. It ensures that both high-impact and high-frequency items are adequately managed, offering a more balanced and reliable categorization. This method's balanced consideration of both monetary value and sales volume is the key difference between this and other two methods, making it an acceptable approach for improving supply chain management and maintaining high service levels. Consequently, the multi-criteria method stands out as the superior choice for organizations aiming to achieve a reliable and efficient inventory management system. The comparison between different scenarios service level can be seen based on their categorization can be seen in figure 7.

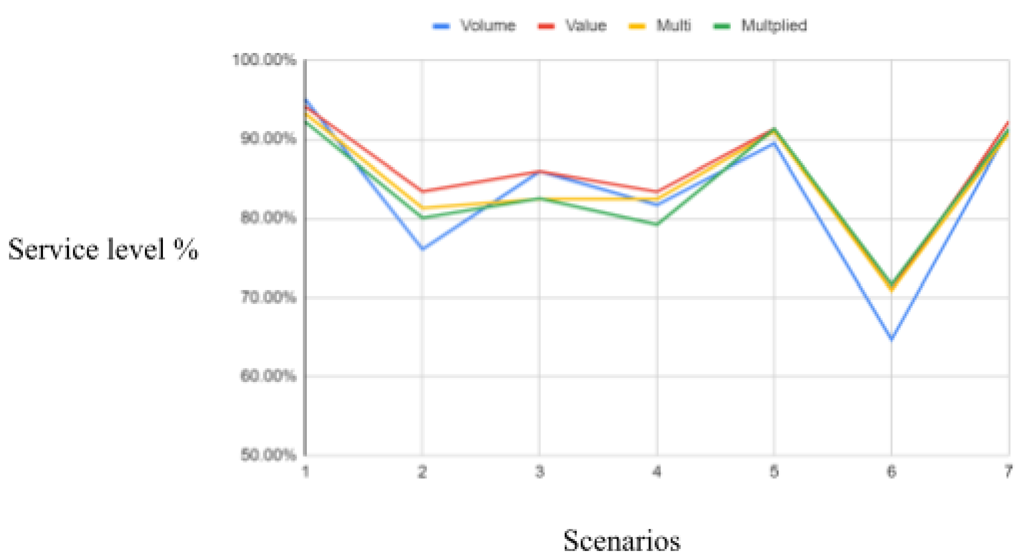

Figure 7- Comparison between the results of scenarios

5.5 Safety Stock

The analysis of the current situation revealed that there is no effective system for managing orders and inventory levels, relying instead on intuition for future order placements. This has led to stockouts and the potential loss of customers, as well as excess inventory for certain items. Both excessive and insufficient stock levels result in higher costs for Volvo Penta.

Inventory management involves calculating safety stock levels to determine the optimal amount needed during various periods, aligning with demand to minimize costs. Recent six-month demand data has been extracted from RR, and safety stock for each accessory has been computed using the formula in chapter

2.3.3. An increase in the service level necessitates higher safety stock, meaning that items with high service levels require more safety stock to meet the desired service level, the safety stock had been calculated for some components based on their categories and related service level which can be seen in appendix E.

Calculating the safety stock level for items using the formula outlined in section 2.3.3. This formula calculates safety stock (SS) as the product of the standard deviation and the safety factor. Greater demand fluctuations lead to a higher standard deviation, necessitating more safety stock. Conversely, if demand remains stable over a period, the safety stock can be lower due to a smaller standard deviation. The safety factor, which is based on the desired service level, also influences the safety stock size by considering the item's value and sensitivity to stockouts.

By determining the optimal safety stock levels that adjust in sync with seasonal demand fluctuations, more precise control over order placements can be achieved. This approach will help prevent backlogs and reduce the risk of excess capital being tied up in inventory, ultimately enhancing supply chain performance through improved inventory management.

5.6 Strengths and Weaknesses

Using multiple criteria for ABC classification aids in making more accurate management decisions. This multi-criteria approach provides a comprehensive view of inventory by considering various factors simultaneously, such as dollar usage, lead time, obsolescence risk, and criticality. By integrating these criteria, managers can develop more precise and effective inventory policies. This leads to better prioritization, ensuring that high-impact items receive appropriate attention and resources, while low-impact items are managed efficiently.

The traditional approach to ABC analysis has been widely utilized across various business sectors to identify products with the greatest impact on a business's operations, thereby guiding focus and resource allocation. This method, initially proposed by Flores and Whybark (1987), typically relies on a single criterion, such as the dollar value of items. Despite its simplicity and ease of implementation, which allows for rapid decision-making and straightforward understanding, relying on a single criterion can lead to misleading classifications and potentially overlook crucial insights that could be gained by considering multiple factors. For instance, ABC classification based solely on sales volume might result in a product with high sales volume being categorized as a C-class item, ignoring the value of its individual components. This could lead to an overemphasis on products that do not significantly contribute to profitability or efficiency, potentially resulting in inefficient resource allocation. Thus, while the single-criteria approach is easy to implement and understand, its oversimplification and potential for misalignment necessitate the consideration of more comprehensive methods.

In contrast, the multi-criteria ABC classification approach integrates multiple factors, such as value, volume, lead time, and obsolescence risk, to provide a more comprehensive understanding of inventory importance. This method, advocated by Flores and Whybark (1987), addresses the limitations of the single-criteria approach by allowing for more accurate prioritization of items that are critical to business operations. For organizations like Volvo Penta, which face challenges with excessive inventory levels and shortages of certain components, adopting a multi-criteria ABC classification can enhance inventory management by reducing inventory levels and improving delivery schedules. This approach enables better resource allocation, optimized management practices, and improved service levels.

However, the multi-criteria method is more complex and resource-intensive, requiring sophisticated analytical tools and systems for effective implementation. The need to manage different policies and rules for various categories can also present challenges, potentially leading to confusion or implementation issues if not handled properly. Despite these challenges, the multi-criteria approach's flexibility and adaptability make it a valuable tool for organizations seeking to improve their inventory management strategies.

The multiplied ABC classification method represents an approach to inventory management that combines the consideration of both volume and value for each inventory item. By multiplying the volume of items by their corresponding value, this method offers a more comprehensive evaluation of inventory importance compared to traditional single-criteria approaches. Its strengths lie in its ability to provide a balanced perspective on inventory significance, leading to improved prioritization and enhanced inventory control. However, the implementation of multiplied ABC may pose challenges due to its complexity and potential for implementation issues. It also would lead to misleading results when there is a huge gap between volume and value. Organizations considering adopting this method should carefully assess its benefits and drawbacks in relation to their specific needs and capabilities to make informed decisions about its suitability for their inventory management practices.

Tables 10 to 12 provide a clear illustration of the strengths and weaknesses of each method.

Single-Criteria ABC Classification

Strengths	Weaknesses
- Simplicity and ease of implementation	- Oversimplification of inventory complexities
- Quick decision-making process	- Potential misalignment of critical items
- Easy to understand for stakeholders	- Misleading prioritization of items

Table 10- Strengths and weaknesses of single-Criteria ABC Classification

Multiplied ABC Classification

Strengths	Weaknesses
- Comprehensive evaluation of inventory importance	- Not considering the gap between Volume and Value
- Easy to understand for stakeholders	- Complexity in implementation
- Improved prioritization of critical items	- Misleading prioritization of items

Table 11- Strengths and weaknesses of multiplied ABC Classification

Multi-Criteria ABC Classification

Strengths	Weaknesses
- Comprehensive evaluation of inventory importance	- Complexity in implementation and management
- Improved prioritization of critical items	- Resource-intensive and demanding more data
- Enhanced inventory control and optimized resource allocation	- Management challenges in handling various categories
- Flexibility and adaptability of criteria to tailor to specific organizational needs	- Potential for confusion or implementation issues

Table 12- Strengths and weaknesses of multi-Criteria ABC Classification

In comparing the strengths and weaknesses of single-criteria, multiplied, and multi-criteria ABC classification approaches, it becomes evident that each method offers distinct advantages and limitations. The single-criteria approach excels in simplicity and quick decision-making but lacks the depth needed for accurate inventory management. The multiplied ABC method strikes a balance by considering both volume and value, offering a more detailed analysis than the single-criteria approach while remaining simpler than the multi-criteria method. On the other hand, the multi-criteria approach provides a comprehensive understanding of inventory importance but requires greater resources and expertise for effective implementation. Ultimately, the choice between these approaches should be guided by the specific needs and capabilities of the organization, weighing the trade-offs between simplicity, comprehensiveness, and resource availability in inventory classification and management.

6. Conclusions

In conclusion, our analysis has shed light on several critical aspects of inventory management and service level determination within Volvo Penta's operations. The current situation reveals challenges related to defining service levels for accessories, managing inventory effectively, and accurately forecasting demand. These challenges contribute to operational inefficiencies, excess inventory, and compromised service levels. The lack of systematic methods for determining service levels and managing inventory has resulted in instances of material shortages, delays in product delivery, and excessive inventory levels. Volvo Penta relies on statistical forecasting methods and manual order replenishment processes, which have proven inadequate in ensuring optimal inventory levels and service performance.

To address these challenges, we have proposed several strategies for improving inventory management and service level determination. These strategies include implementing single- and multi-criteria approaches to ABC classification, segmenting accessories based on frequency and value, calculating safety stock levels, and defining appropriate service levels for different categories of items. By incorporating usage frequency and value into the classification process, we aim to enhance the accuracy of forecasts, optimize inventory levels, and improve overall service performance.

Different scenarios have been defined based on different sales orders for a group of products, sharing the most common accessories, in order to observe the trends and try the different derived classes on those actual orders over a certain period of time. These scenarios help to track each engine's accessories that have been sold together. Consequently, different service levels were extracted for different scenarios which leads to an adjustable overall service level.

Furthermore, our analysis suggests the importance of aligning service levels with the significance of items and their sensitivity to stockouts. By prioritizing items based on their characteristics and assigning appropriate service levels, Volvo Penta can ensure sufficient stock of high-demand items while avoiding excessive inventory of low-demand items.

7. Discussion

Volvo Penta faces a significant challenge in managing its inventory effectively. The company's current approach involves handling a large number of items individually, leading to issues such as excessive stock levels and operational inefficiencies. Consequently, Volvo Penta struggles to maintain a balanced inventory, with resources often misallocated across various items.

The presence of "lumpy demand" further complicates Volvo Penta's inventory management practices. This term refers to irregular demand patterns, where certain items are needed sporadically and are difficult to predict. As a consequence, Volvo Penta must decide between maintaining high stock levels of these items to prevent stockouts or risking shortages by keeping leaner inventories. This uncertainty adds another layer of complexity to the planning process, making it challenging to achieve optimal inventory levels. To effectively address the issue of lumpy demand, Volvo Penta should explore advanced forecasting techniques capable of capturing and predicting irregular demand patterns more accurately. Additionally, the company could benefit from consolidating or categorizing items based on their demand profiles to streamline inventory management processes.

In this study, four different methods—volume, value, multiplied, and joint ABC—were applied and tested, yielding relatively varied results. The multiplied method, in particular, may produce inaccurate results due to significant differences between volume and value; multiplying these factors can amplify the differences and cause misleading judgments in the classification of components. Additionally, the joint method, which combines both volume and value dimensions, did not result in a considerable improvement over using a single value metric as it was expected. However, it can still be considered as the better solution since it considers both volume and value and leads to acceptable high results. These findings suggest that further investigation is needed to determine the most effective classification solution for the company's components depending on its situation. A deeper analysis could help identify the optimal approach for accurately classifying components and improving inventory management.

At the first step, all accessories and attach rates for one engine were extracted. To obtain the overall service level, the service levels of all accessories attached to the engine were multiplied together, resulting in very low overall service levels. To address this issue, scenarios were developed to investigate actual orders with a limited number of accessories sold in each order, rather than considering all accessories together. This approach led to more accurate and realistic results, which can be effectively implemented across different scenarios.

Additionally, it is not that simple to suggest one ABC classification method for a company, since there are many factors that would affect the results such as cost, resources and complexity level. It is suggested that all the methods can be examined and the best solution should be chosen depending on the company's capabilities and priorities.

It is evident that Volvo Penta's current inventory management approach is inadequate for addressing these challenges. It is suggested that Volvo Penta can use the proposed excel tool to classify all the accessories and determine the service level and safety stock for each. After periods of testing these classifications, the SL percentages can be revised according to the company’s expectation and capabilities. This classification would help Penta to have better insight into the different classes and inventory strategy for each category which consequently lead to better forecasting and inventory management. It is also recommended for Penta to incorporate this classification tool and relevant formulas into their current ERP system (RapidResponse), to have a coherent system which connects all the classification, service level, safety stock and MOQ for better forecasting and analysis for the planning team.

However, it is suggested for Volvo Penta to consider the entirety of the inventory landscape rather than focusing solely on individual items. By adopting this approach, Volvo Penta can gain a comprehensive understanding of demand patterns and make informed decisions regarding inventory allocation and replenishment. This would require a long-term plan and an advanced MRP system which considers and plans all the engines and accessories together.

In conclusion, Volvo Penta must reevaluate its inventory management strategies to overcome the challenges posed by excessive stock levels and irregular demand patterns. By embracing a more holistic approach to planning and leveraging advanced forecasting techniques, the company can achieve a more balanced inventory, improve operational efficiency, and ultimately enhance customer satisfaction.

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9. Appendix

Appendix A –Questionnaires used during interviews

- Can you please introduce yourself and your role at Volvo Penta?

- How long have you been working with Volvo Penta, and what are your main responsibilities related to inventory management of accessories?

- Can you provide an overview of Volvo Penta's operations process in terms of accessories? (flow from supplier to end customer)

- What are the key challenges Volvo Penta faces in managing inventory of accessories for its engines? Any bottlenecks?

- Can you describe the process of determining stock levels for accessories, including safety stock considerations?

- Do you know about the forecasting process? Do you know how RapidResponse facilitates accurate demand forecasting and constraint management for accessories?

- Do you know how Volvo Penta measures service level for engine packages, particularly regarding accessory availability?
-
- What steps does Volvo Penta take to ensure timely availability of accessories to maintain high service levels for customers?

- What specific goals does Volvo Penta aim to achieve through optimizing its accessory inventory management?

- How does Volvo Penta currently measure its service level for engine packages, and what are the desired improvements?

- Can you explain Volvo Penta's current approach to inventory management, considering models such as Economic Order Quantity (EOQ) and ABC analysis?

- How does Volvo Penta incorporate Just-In-Time (JIT) principles in its manufacturing processes, if at all?

- How does Volvo Penta define and measure service levels in its inventory management processes?

- How many suppliers are involved and how are they connected to Penta? Are powertrain plants also suppliers?

Appendix B- Standard Normal Distribution table

Service Level	Service Factor		Service Level	Service Factor
50.00%	0		90.00%	1.28
55.00%	0.13		91.00%	1.34
60.00%	0.25		92.00%	1.41
65.00%	0.39		93.00%	1.48
70.00%	0.52		94.00%	1.55
75.00%	0.67		95.00%	1.64
80.00%	0.84		96.00%	1.75
81.00%	0.88		97.00%	1.88
82.00%	0.92		98.00%	2.05
83.00%	0.95		99.00%	2.33
84.00%	0.99		99.50%	2.58
85.00%	1.04		99.60%	2.65
86.00%	1.08		99.70%	2.75
87.00%	1.13		99.80%	2.88
88.00%	1.17		99.90%	3.09
89.00%	1.23		99.99%	3.72

Appendix C- A sample of Multi criteria ABC classification

Name	Value	Volume	ABC Value	ABC Volume	SL	Multi Classification
23690214	3,910.00 kr	251	A	A	97.00%	Critical
23826872	43,395.79 kr	433	A	A	97.00%	Critical
22767098	4,318.00 kr	52	A	B	97.30%	Important
21920108	644.68 kr	101	B	A	97.30%	Important
22987016	233.32 kr	279	C	A	98.50%	Intermediate
3588406	3,333.00 kr	8	A	C	98.00%	Intermediate
78490781	657.66 kr	41	B	B	98.00%	Intermediate
21923022	688.58 kr	2	B	C	98.50%	Low concern
24107331	273.88 kr	46	C	B	98.50%	Low concern
22727775	48.31 kr	1	C	C	98.80%	Lowest concern

Appendix D- An example of multi categorization for two different scenarios for D13 & D16.

Scenario1:

Multi		
Name	**ABC**	**SL**
3588406	Intermediate	98.00%
21468362	Important	97.30%
21468368	Non-critical	98.80%
21935378	Low concern	98.50%
874388	Intermediate	98.00%
		90.94%
Volume		
Name	**ABC**	**SL**
21468362	A	99.00%
21935378	B	98.00%
874388	B	98.00%
3588406	C	97.00%
21468368	C	97.00%
		89.46%
Value		
Name	**ABC**	**SL**
3588406	A	97.00%
21468362	B	98.00%
874388	B	98.00%
21468368	C	99.00%
21935378	C	99.00%
		91.30%
Value*volume		
Name	**ABC**	**SL**
3588406	B	98.00%
21468362	A	97.00%
874388	B	98.00%
21468368	C	99.00%
21935378	C	99.00%
		91.30%

Scenario 2:

Multi		
Name	**ABC**	**SL**
877768	Low concern	98.50%
21468356	Important	97.30%
21674226	Important	97.30%
		93.25%
Volume		
Name	**ABC**	**SL**
877768	C	97.00%
21468356	A	99.00%
21674226	A	99.00%
		95.07%
Value		
Name	**ABC**	**SL**
877768	B	98.00%
21468356	B	98.00%
21674226	B	98.00%
		94.12%
Volume*value		
Name	**ABC**	**SL**
877768	B	98.00%
21468356	A	97.00%
21674226	A	97.00%
		92.21%

Appendix E- SS Calculated table

name	value	volume	ABC Value	ABC Volume	SL	Multi Classification	M2311	M2312	M2301	M2402	M2403	M2404	Z factor	LT	AVG Demand	Sigma	SS	SS per month
22081500	256.52 kr	7	C	C	98.80%	Non-critical	2	2	0	3	5	3	2.33	29	2.5	17	39.61	7
22798188	417.93 kr	2	C	C	98.80%	Non-critical	2	2	3	0	0	0	2.33	44	1.2	10	23.3	4
3886263	348.31 kr	6	C	C	98.80%	Non-critical	1	3	6	8	2	11	2.33	33	5.2	37	86.21	14
21923022	688.58 kr	2	B	C	98.50%	Low concern	12	10	9	9	9	6	2.05	30	9.2	55	112.75	19
21939133	500.00 kr	54	C	B	98.50%	Low concern	26	18	97	65	87	31	2.05	31	54.0	368	754.4	126
47711291	140.42 kr	42	C	B	98.50%	Low concern	6	21	3	3	66	26	2.05	3	20.8	181	371.05	62
24247544	4,213.00 kr	7	A	C	98.00%	Intermediate	84	44	41	98	114	42	2.05	24	70.5	452	926.6	154
24328307	14,754.00 kr	9	A	C	98.00%	Intermediate	0	1	2	1	4	0	2.05	31	1.3	11	22.55	4
24246943	16,931.00 kr	5	A	C	98.00%	Intermediate	9	5	14	9	12	9	2.05	26	9.7	59	120.95	20
24247597	14,171.00 kr	43	A	B	97.30%	Important	6	2	6	0	29	2	1.88	35	7.5	74	139.12	23
24180809	34,684.57 kr	50	A	B	97.30%	Important	7	1	16	9	5	0	1.88	30	6.3	49	92.12	15
24247626	19,843.34 kr	56	A	B	97.30%	Important	20	7	24	0	0	18	1.88	35	11.5	89	167.32	28
23690214	3,910.00 kr	251	A	A	97.00%	Critical	47	22	58	56	86	63	1.88	34	55.3	346	650.48	108
23826872	43,395.79 kr	433	A	A	97.00%	Critical	19	6	22	31	61	51	1.88	30	31.7	219	411.72	69

Appendix F-Scenarios results of Multi-criteria ABC classification for marine engines D4/D6

Multi						
Scenario	Attached accessories per order	Critical	Important	Intermediate	Low Concern	Non-critical
1	15	3	6	4	0	2
2	14	4	6	3	0	1
3	7	1	3	3	0	0
4	10	2	3	4	0	1
5	14	3	3	5	2	1
6	14	2	4	5	2	1
7	7	1	3	2	0	1
AVG sold components	**12**	**2**	**4**	**4**	**1**	**1**
AVG SL of the package	**78.57%**	**97.00%**	**97.30%**	**98.00%**	**98.50%**	**98.80%**

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