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Inventory Planning

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Opinnäytetyön tarkoitus on luoda tehokas varastotasojen hallinnointitapa, mikä perustuu data-analytiikan hyödyntämiseen. Työn tuloksena syntyy liiketoimintaälyllä (Business Intelligence, BI) höystetty ratkaisu, jonka avulla voidaan automatisoidaan varastonhallintaa. Opinnäytetyön tuotoksena syntynyt varastonhallintamenetelmä tulee tuottamaan kuukausittain raportteja kuukausittaiseen Sales and Operations Planning tapaamiseen.

Alusta, jonka avulla varastotasoja seurataan on Microsoftin keittämä PowerBI. PowerBI käyttää tässä työssä datalähteenä datavarastoa (DWH), joka on koostettu yrityksen Enterprise Resource Planning (ERP) järjestelmän käyttämästä Structured Query Language (SQL) relaatiotietokannasta käyttäen hyväksi dimensionaalista datamallinnusta. Yrityksen käyttämä ERP järjestelmä on yhteydessä samaan tietokantaan, joten sama, ajantasainen tieto saadaan analytiikkatyökaluun aina kerran päivässä.

Työn käytännönosassa määritetään varmuusvarastot sekä uudelleentilauspisteet kriittisille nimikkeille sekä kyseisten nimikkeiden toimitusaikaa toimittajalta seurataan. Myös kyseisten nimikkeiden keskiarvokysyntää, keskiarvotoimitusaikaa sekä näiden hajontaa seurataan.

Nimikkeet segmentoitiin käyttäen hyväksi ABC-XYZ analyysia. ABC analyysi luokittelee nimikkeet niiden kumulatiivisen varastoarvon mukaan sekä XYZ analyysi luokittelee nimikkeet kysynnän vaihtelun mukaan.

Työn teoriaosuus pitää sisällään toimitusketjun hallintaa sekä riskejä, jotka ovat ajankohtaisia toimitusketjun haavoittuvuuden näkökulmasta. Teoriassa myös vertaillaan eri tuotantomalleja kuten Make to Stock (MTS) ja Engineer to Order (ETO) sekä miten nämä vaikuttavat kysynnän ennustettavuuteen.

Avainsanat:	Inventory Planning, Safety Stock, Re-order Point, Dimensional Modelling, Business Intelligence, Sales and Operations Planning, Customer Order Decoupling Point

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Abstract

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The objective of this thesis is to develop an effective stock management strategy using Business Intelligence (BI) tools for BlueFors Oy. This strategy is designed to automate inventory management, ensuring that the company's stock levels are maintained efficiently.

This thesis utilizes Microsoft's PowerBI as the primary platform for monitoring inventory levels. PowerBI connects to a data warehouse (DWH) that originates from the case company's Structured Query Language (SQL) relational database, using dimensional data modeling. The Enterprise Resource Planning (ERP) system used by BlueFors Oy is connected to the same database DWH utilizes, so the same up-to-date information is always available in the analytics tool and updated once a day.

The practical aspect of this thesis focuses on determining Safety Stock and reorder points for critical SKUs, along with monitoring supplier lead times for these items. Key metrics such as the average demand for SKUs, lead times, and their standard deviations are also analyzed. Part of this study is the segmentation of SKUs using the ABC-XYZ analysis, a method that categorizes SKUs based on their cumulative inventory value (ABC) and the variability of their demand (XYZ).

The theoretical part of thethesis includes supply chain management topics and the associated risks that are topical from the point of view of supply chain vulnerability. Additionally, the thesis briefly compares different manufacturing models, such as Make to Stock (MTS) and Engineer to Order (ETO).

The outcome of this thesis is a BI-based solution that generates monthly reports for the Sales and Operations Planning meetings, thereby optimizing inventory management for BlueFors Oy. With the implementation of these tools and strategies, efficient inventory management can be established, resulting in improved stock level profiles. This outcome not only streamlines the inventory management process but also provides a scalable solution for future adaptations in the company's operational strategies.

Keywords: Inventory Planning, Safety Stock, Re-order Point, Dimensional Modelling, Business Intelligence, Sales and Operations Planning, Customer Order Decoupling Point

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Abbreviations

ERP	Enterprise Resource Planning
PBI	Microsoft Power Business Intelligence
BI	Business Intelligence
PDCA	Plan, Do, Check, Act
ROP	Re-Order Point
SCM	Supply Chain Management
SS	Safety Stock
SKU	Stock Keeping Unit
EOQ	Economic Order Quantity
WC	Working Capital
NWC	Net Working Capital
DWH	Data Warehouse
SQL	Structured Query Language
S&OP	Sales and Operations Planning
KPI	Key Performance Indicator
CRM	Customer Relationship Management
SRM	Supplier Relationship Management

SIOP	Sales Operations and Inventory Planning
OTD	On-time Delivery
IDS	Inventory Days of Supply
DSI	Days Sales of Inventory
DII	Days in Inventory
DOH	Days on Hand
DIO	Days Inventory Outstanding
MRP	Material Requirements Planning
DDMRP	Demand Driven Material Requirements Planning
BOM	Bill of Materials
MTO	Make to Order
ETO	Engineer to Order
ATO	Assemble to Order
CTO	Configure to Order
MTS	Make to Stock
DTO	Design to Order
MPS	Master Production Schedule
DRP	Distribution Requirements Planning

ATP	Available to Promise
DOS	Days of Supply or Days of Stock
COGS	Cost of Goods Sold
DAX	Data Analysis Expressions
HML	High, Medium, Low
MVP	Minimum Viable Product
CFE	Cumulative Forecast Error
MAD	Mean Absolute Deviation
MSE	Mean Squared Error
MAPE	Mean Absolute Percentage Error
RMSE	Root Mean Square Error
JIT	Just-in-Time
MC	Mass Customization
CODP	Customer Order Decoupling Point
OPP	Order Penetration Point
ASC	Agile Supply Chain
LSC	Lean Supply Chain
HSC	Hybrid Supply Chain

“MAM”	(**M**ake-to-order), ATO (**A**ssemble-to-Order), **M**TS (Make-to-stock).
DC	Decoupling Point
POQ	Production Order Quantity
LFL	Lot-for-Lot
PPB	Part Product Balancing
FSN	Fast, Slow, Non-Moving
SDE	Scarce, Difficult, and Easy
VED	Vital, Essential, Desirable
TWS	Target Weeks of Supply
ISO	International Organization for Standardization

1 Introduction

The thesis examines the implementation of Inventory Planning. Inventory Planning has a central role in Supply Chain Management.

A key topic in Supply Chain Management is deciding how much inventory to have. When developing inventory management plan, trade-offs between the advantages and disadvantages of holding inventory should be acknowledged and compared. In some situations, trade-offs steer to decide towards a small inventory over large one, or vice versa (Lee Krajewski et al. 2016 p. 340). In some cases, deciding on inventory size needs a boarder analysis, due to scarcity of components, for example.

The challenge for the thesis is stock management that is not controlled. The current inventory management method results in stockouts and overstocking. The study for the challenge started from identifying the most critical Stock Keeping Units (SKU) from production continuity perspective.

In order to determine optimal inventory levels, available data is analysed for determining optimal order points order intervals. Inventory Planning directly impacts the cash flow and profits of any company (Lisa Schwarz, 2019).

Inventory Planning is important because Inventory Planning can help to ensure that customer and internal demand is met. Inventory Planning can help to reduce the customer lead time, which can increase sales rate as product availability is ensured.

Inventory Planning can help to meet stock targets, which consist of avoiding over-stocking and stockouts, Net Working Capital (NWC) optimization, minimize inventory holding costs and avoid stocking of slow moving or dead stock, which can lead to write-offs.

1.1 Business Context and Case company

BlueFors Oy specializes in cryogen-free dilution refrigerator measurement systems and operates strongly within the quantum computing ecosystem. The aim is to deliver the most reliable and easy to operate systems on the market which are of the highest possible quality. BlueFors Oy is a market leader in the cryogenics sector (BlueFors Oy, 2023).

The business challenge addressed in this thesis is the improvement of inventory management for BlueFors Oy by integrating Business Intelligence (BI) tools. This challenge involves streamlining the process of stock management to prevent overstocking and understocking, both important for operational efficiency and cost-effectiveness. The goal is to utilize BI solutions like Microsoft's PowerBI for real-time data analytics, enhancing decision-making and forecasting in inventory control. The inventory management visualizations were first tested in Excel and then PowerBI with Excel files extracted from the Enterprise Resource Planning (ERP) system as the source data. This was done in order to test the functionality of the visualization plan in order to support development of data model for the inventory data visualization.

The inventory planning project initiative is translated into a business context for dimensional data model and data warehouse development purposes, which will be the source data for inventory related analysis. The Data Warehouse (DWH) is developed by an external party but defined based on the needs of the business users.

The thesis does not include visuals, or other related information of the inventory data model or analytics dashboards due to delay in the development process, and presented figures and tables are from data fetched from ERP where calculations are performed by using Excel and PowerBI to test the validity for the DWH and Microsoft Power Business Intelligence (PBI) use.

1.2 Objective of the thesis

The objective of this thesis is to develop an effective stock management strategy using BI tools and to increase control over inventory related processes for BlueFors Oy. This strategy is designed to automate inventory management, ensuring that the company's stock levels are maintained efficiently.

The goal of Inventory Planning is to give the company a common plan to operate within when it comes to inventory management and to make demand and supply to meet in order to guarantee timely order deliveries for customers and internal needs.

The outcome of this thesis is a BI-based solution that generates monthly reports for the Sales and Operations Planning meetings and decision making, optimizing the inventory management for BlueFors Oy. With the implementation of BI tools and other stock management strategies, efficient inventory management can be established, resulting in improved stock level profiles.

1.3 Scope of the Thesis

The scope of the thesis consists of necessary theory to support the implementation part of the inventory planning process and the development of the dimensional data model that is used for analysing the inventory related data.

When the scope is fulfilled, a systematic management process can be created which is aligned with the high level business goals.

Scope of the Inventory Planning Process

The scope includes an efficient inventory management plan, including determining safety stock (SS), re-order point (ROP) and integration of the inventory planning process as part of the monthly Sales and Operations Planning process (S&OP). The inventory planning project drafts the general format for the supply side of monthly S&OP meeting.

The thesis evaluates the suitability of the ROP taking into consideration the technical limitations of the Enterprise Resource Planning system and what is the best way to implement this stock control parameter.

The thesis focuses on purchased SKUs from critical key suppliers, and for this thesis three different suppliers were chosen for analysis. In the implementation section, data from Supplier A is presented, including ABC-XYZ segmentation, safety stock, ROP, supplier lead time variation over time and planning Bill of Materials (BOM) forecast error. The planning BOM forecast error includes planned needs as well but with non-confirmed dates, which skews the demand in near future months, and for this solution is presented, and a solution to add systematicity to forecasting is suggested as well besides implementation of the inventory planning analytics tool.

Scope of the Data Model and Analytics

The scope includes development of analytics tools to support the inventory management. This includes the definition of the business context for the development of Dimensional Data Model for the Data Warehouse and finally, the Power BI dashboard, where important Key Performance Indicators (KPI) are monitored. In PBI, it easy to create reports. The strengths of PBI are its self-service capability.

The scope for the data model development part includes drafting a “mock-up” of the desired Data Model for the DWH. The “mock-up” data model guides the DWH development. The DWH is developed by external personnel.

Data model specification scope includes definition of dimensions and fact table and columns including measures (metrics, KPI). Data tables are chosen based on which ERP tables are used by the business process related to the inventory planning and how it is done on the ERP side.

1.4 Methods Used

The methods used in the inventory planning part consist of inventory parameter definition for a few critical suppliers, such as SS and ROP.

SS was evaluated by using different SS calculations and how they affect the size of the SS and ROP. Equation with independent demand and lead time was chosen.

Then, the chosen suppliers were segmented using ABC-XYZ analysis based on historical data of demand of the past 12 months per SKU ID per supplier. In the proposed solution, the segmentation class of one supplier is included.

Then, it was studied what is the best way to implement the ROP within the ERP system. It turned out that there were limitations regarding how to do this, and ways how to overcome this is discussed within the theory section. The end result of the thesis does not utilize the ROP implementation in the way it was intended to be used during the making of the thesis, as ERP related process changes are required before this can function as intended, which is outside the thesis scope. Testing the ERP ROP functionality was done in the simulation environment but this was not documented for the thesis.

The data model is designed by dimensional modelling, and finally the modelled data can be accessed with BI user interfaces like the Microsoft PowerBI using DWH as data source.

1.5 Contents of the Thesis

In this thesis, Business Intelligence (BI) will be used to automate the inventory management process. BI aids to re-define important SKU parameters automatically each month. With the help of BI, stock level recommendations are received monthly. Frequent updating is important in order to avoid either overstocking or stockouts if there are changes in demand. BI is quick to catch insights regarding demand and lead variation and how they develop over time.

The thesis examines segmentation of SKU for inventory management purposes. In theory section, different segmentation methods, coefficient of variation and how the results can be interpreted is explained. Forecasting and Error measurements are also included, as forecasting is often included as part of inventory planning.

Other contents include basics of Supply Chain Management, Supply Chain risks and shocks, and comparison of outsourcing vs. insourcing as a result of surviving supply chain disruptions with minimal business impact and description and comparison of manufacturing models, such as Engineer to Order (ETO), Makw to Order (MTO) and Make to Stock (MTS). Also, Dimensional Modelling is explained to support the work. For the Dimensional Data Model and PBI visualization, KPI metrics are developed in order to gain valuable analytical insights.

The outcome is efficient inventory management that creates automatically generated purchase related insights for the procurement department when the stock level falls under set parameters. The final outcome of the thesis is a continuous inventory review process.

In this thesis, for simplicity purposes a normal distribution of demand and lead time is assumed, even though that is rarely the case. In situations with high standard deviation of demand or lead time other SS equations than those based on normal distribution should be used, but for this thesis the knowledge is not needed, and therefore left out.

2 Theory

The theory section discusses Supply Chain Management, S&OP process, Segmentation, Coefficient of Variation, Inventory Planning and Supply Chain Planning KPI, Material Requirements Planning, SSs, ROP, Manufacturing Models, Forecasting, Frozen Planning, Dimensional Data Modelling and Business Intelligence, including facts, dimensions and measures, data warehousing and PowerBI as a tool.

Also, supply chain risks and ways to mitigate risks, focusing on insourcing vs. outsourcing is discussed due to this being a topical subject due to recent world events.

KPI theory is required in the PBI report construction. In this context, KPI are known as Measures. KPI include common measurable performance metrics such as Days of Inventory Outstanding (DIO), Days of Supply (DOS) and Inventory age, also from segmentation viewpoint based on SKU stock turn performance.

2.1 Supply Chain Management

Supply Chain Management is the process of aligning processes with suppliers' operations to the extent it is possible and to make customer orders match supply and demand by internal scheduling practices, which includes managing and matching the flow of materials, services, and information that is available of customer demand (Lee Krajewski et al. 2016 p. 23).

Supply Chain Processes encompass both internal and external operations related to the company (Lee Krajewski et al. 2016, p. 46). Information on customer demand can be acquired through Customer Relationship Management and forecasting. Supply Chain Management (SCM) often needs to manage the frequently conflicting goals of the participants within the supply chain (Dennis Alexander Minnich, 2007, p.7).

Manufacturing Supply chains transform raw materials into products that are then sold to the customer. A manufacturing company must manage material and information flows. Material flow is the flow of material between and within different Supply Chain nodes and Information flows refer to the transfer of information between the Supply Chain nodes, both upstream and downstream (Dennis Alexander Minnich, 2007, p.7).

It is important to acknowledge what are upstream and downstream actors within the supply chain. The upstream supply chain includes all of the activities that are related to the company's suppliers, meaning all the activities it takes to get the material from the supplier to the manufacturer. The downstream supply chain refers to the activities that take place after the product has left the company premises and begin its journey to the customer (Masterclass, 2022).

Besides aligning supply and demand, it is important to measure the On Time Delivery (OTD). If the OTD is low, it can be a sign of upstream Supply Chain issues along internal manufacturing capacity issues. Often low OTD is caused by misaligned S&OP process. Low OTD performance can be used to assess S&OP process maturity. A Low OTD often translates to demand and growth challenges (Philip Lee, Scott Sparks, 2020).

Information transferred between supply chain actors may be about customer orders, demand forecasts, inventory levels and capacity availability. The information can be shared with only part of the actors within the supply chain and can be updated with varying frequencies. The information and material flows are not independent of each other and they are often interlinked. How these influence each other might not always be easy to predict (Dennis Alexander Minnich, 2007, p.7).

2.2 Supply Chain Risks, Vulnerabilities and Resilience

Most of the regular supply chain risks can be managed either by contracts or service-level agreements (SLAs) (Sunil Bakshi, 2021). Themes commonly

discussed in literature regarding SCM and success of supply chains in the future are preventing disruptions and ensuring risk mitigation (Amelie Meyer et al. 2021).

Different managerial acts can be taken to mitigate risks and enhance the supply chain resilience. Enhancing resiliency is therefore a key driver in reducing supply chain vulnerability (Zhitao Xu et al. 2020). Resilience in supply chains is the ability to absorb shocks and recover.

Supply chain disruptions can be caused by different types of external events that a company does not have control over. Despite there being ways to mitigate possible risks, assessing what risks are possible and what is their impact if the risk realizes is important.

Resilience of a supply chain resilience is the ability of a supply chain to withstand stress and recover from disruptions. Resiliency helps to withstand normal volatility and more severe disruptions (Schuster, R et al. 2021). During disruptions, trade-offs between efficiency and resiliency should be made (Sarah Hippold, 2020)

Resilient supply chains should have visibility regarding logistics providers and distribution channels as well on top of suppliers and their suppliers. Gaining visibility into supplier and their suppliers helps to evaluate upstream supply chain risks (Schuster, R et al. 2021).

In general, supply chain vulnerability can be separated into five distinct categories, which are planning and supplier network, transportation and logistics, financial resiliency, product complexity, and organizational maturity (Zhitao Xu et al. 2020). For example, outsourcing can dramatically increase the exposure to risks (Becky Ham, 2022).

In order to increase resiliency, the exposure, vulnerabilities and potential losses should be assessed. The findings can help companies to make decisions about required buffers, for example (Schuster, R et al. 2021). For example,

domestication can increase the supply chain resiliency but it also requires massive resources, such as skilled work force and investments. Other alternatives to domestication are near-shoring and insourcing.

Below are some suggested topics that can be considered when enhancing the resilience of supply chains.

Enhancing Resiliency by Increasing Visibility

Visibility and the effective response to disruptions in the supply chain are one of the most discussed topics related to supply chain resilience. Enhancing visibility can start from identifying the tier-1 suppliers that are affected by the crisis and the lower tier suppliers that are affected by crisis, which in the case of Covid-19 was lockdowns. When one supplier is affected, the other suppliers within the supply chain network are affected as well due to ripples (Zhitao Xu et al. 2020).

Mitigating Risks

Severe supply chain disruptions have made companies to re-think concerns over access to market during disruptions and re-think how resilient their supply chains are and what is their environmental sustainability (Ben Aylor et al. 2020).

The traditional way of designing supply chains included focusing on cost efficiency and high service levels. Purchasing and procurement activities have been taking advantage of global sourcing to minimize costs and gain access to products that are not locally available, at least not with competitive prices (Ben Aylor et al. 2020).

To mitigate risks, suppliers can be segmented, on top of spend, based on revenue impact, if supply chain disruptions occur. Diversifying the supplier in the segments with a high revenue impact is one thing to do when improving the resiliency of the supply chain (Sarah Hippold, 2020).

If a company has identified suppliers who are in the most vulnerable position regarding supply chain disruptions, the time it takes to respond to crisis can be significantly reduced. For example, collaborative demand forecast is something that can be done immediately a crisis has emerged and the affected parties identified. Changes in demand can either experience a sharp rebound or decrease in demand due to lack of confidence (Zhitao Xu et al. 2020).

To mitigate risks, tier-2 and tier-3 suppliers should be mapped. A global supply chain consists of several actors, where the lower tier actors play an important role in the functionality of the overall supply chain. For example, a firm which has more than 900 tier-1 suppliers where each can have over 500 tier-2 suppliers and it is not an easy task to keep track of the performance of the tier-2 suppliers in these volumes (Zhitao Xu et al. 2020)

For example, at least five million companies worldwide have one or more tier-2 supplier in the Wuhan region, China (Zhitao Xu et al. 2020), where the Covid-19 initially started to spread. Keeping track of the different tier suppliers can boost the resiliency of the supply chain as it is easier to mitigate risks on time as they arise before they have a more serious effect on the supply chain functionality.

What can be done is to review the product portfolio and map the customer base in order to draft operational priorities, in the cases where the manufacturing company has to reduce its capacity. Manufacturers can aid the important supply chain actors in order to speed up the recovery of the supply chain in matters, such as legal and financial assistance to support business recovery. In the emergence of crisis, collaboration should be established with critical and strategic suppliers (Zhitao Xu et al. 2020).

Multi-supplier strategies are also beneficial (Sarah Hippold, 2020). For this reason, nationwide investment related discussions are held more frequently whether to invest in critical resources and decrease dependency in countries with different political aims, for example. This implies a shift toward insourcing thinking.

In the emergence of a supply chain shock, a multi-supplier strategy gives companies more choices to switch suppliers from primary material flows to alternative material flows, which rebalances the supply. Ideally, the suppliers are located in different geographical areas to minimize geographical risks (Schuster, R et al. 2021)

Supplier Diversification

It is also important to be aware of possible alternative suppliers and materials which could be sourced, such as local substitutes. Local suppliers can offer high availability of materials when a global crisis such as the Covid-19 is placing restrictions. When drafting plans for developing alternative material sourcing, the tier-2 and tier-3 suppliers should be analyzed regarding their supply chain vulnerability (Zhitao Xu et al. 2020).

Supplier diversification and capacity redundancy can reduce risk of supply chain disruptions in the long term. While an enhanced supplier base can increase the responsiveness of a supply chain and its ability to withstand crisis, it does not always come without a cost. Increased costs can weaken the competitiveness of products in the global market. Thus, attention should be paid to how increased costs impact the final product, as in the end the customer is sensitive to price changes in the final product (Zhitao Xu et al. 2020).

A resilient supply chain should have a few alternative suppliers, as diversity and transparency of supply chain enables to switch suppliers swiftly to alternative suppliers if the geographical location of the supplier is affected by a crisis (Amelie Meyer et al. 2021). While global sourcing enables increased efficiency of the supply chain, local sourcing enables a more responsive supply chain (Zhitao Xu et al. 2020).

Reviewing Inventory Policies

When a risk is faced the inventory policies should be reviewed. This can include balancing of predicted demand and the current capacity of the suppliers, which

should be taken into consideration when making renewed plans for capacity. This can affect the sizing of the safety stock (Zhitao Xu et al. 2020) since the supply capabilities of lower-tier suppliers are limited. For example, ensuring that inventory is located outside of high-risk area is essential in preventing supply chain disruptions.

Moving from global to regional supply network has been a strategy of some supply chain leaders to mitigate supply chain risks. According to supply chain pulse survey by McKinsey & The Company, the majority of respondents increased their inventory and finished items stock to withstand supply chain shocks rather than diversifying supplier base with regional suppliers. Smarter ways than increasing inventories could be researched that ensures resilience and inventory costs that are under control (Knut Alicke et al. 2022)

This again, would require revisiting the inventory policies. According to the survey, 97 % of respondents applied inventory increase, dual sourcing and regionalization methods as a way to boost the supply chain resilience (Knut Alicke et al. 2022)

For example, industries such as chemicals and commodities were able to reduce the supply chain disruption and how it affected the operations by making structural changes in their supply chains, such as nearshoring and network redesign (Knut Alicke et al. 2022)

Besides investing into a safety stock, preparing for supply-side risks with strategic shock should be considered (Jim Kilpatrick, 2022) especially when sourcing from areas where there is a high risk for geopolitical conflicts. For example, palladium and neon are both critical materials for the semiconductor industry, where Russia is a major supplier for both. Some semiconductor companies had prepared for this risk by stockpiling important materials (Jim Kilpatrick, 2022).

Infrastructure Investment Discussion from Crises Point of View

It is important to note that China is a very dominant supplier of different kinds of components. Reducing dependency on China will require a considerable amount of investments and time. For example, Intel aims to reduce its dependency on China by building semiconductor fab in Ohio, US worth of $20 billion (David Simchi-Levi, Pierre Haren. 2022). The US-China trade war is a major motivator to reduce dependency on China.

For example, Schneider electric, the elevator & automation company, announced shifting its production to North America. The reason for this is to boost regional capacity (David Simchi-Levi, Pierre Haren. 2022).

Companies alone cannot solve the supply chain related challenges and government involvement is required. For example, the U.S. CHIPS Act and European Chips act are both governments supported programs to reduce the regional dependency on countries like Taiwan and South-Korea. The Ukrainian conflict also boosts the European battery strategy to enhance the capabilities of Europe to become a leader in advanced battery systems (David Simchi-Levi, Pierre Haren 2022). Similar strategies are expected to rise in the upcoming future.

Until infrastructure investments in regional localization are realized, supply chains should be stress tested i.e. what degree of volatility they can withstand before severe disruptions and make plans for supply chain resiliency, as supply chain disruptions are going to increase (David Simchi-Levi, Pierre Haren. 2022).

Infrastructure investments are not only a concern of the aforementioned companies, and it is a topic to discuss for many technological industries in the future in order to secure supply and ensure the reliability in operations, and to avoid geopolitical conflicts, for example. As the trade is becoming increasingly politicized where knowing your customer and knowing the origin of BOM components is increasingly important, also from a sustainability point of view, larger benefits in the long run than just a more resilient supply chain can be achieved.

2.2.1 Supply Chain Shocks

Some known global supply chain shocks are the Covid-19, War in Ukraine, Geopolitical topics such as trade wars and the Evergreen containership blocking the Suez Canal. the Cybersecurity issue poses threats to supply chains as well, but this is not discussed here.

Covid-19

The Covid-19 virus caused disruptions in areas such as manufacturing, processing, transport, logistics and caused significant shifts in demand (Zhitao Xu et al. 2020)

In general, supply chains can recover from more local disasters faster than from global disasters, such as the Covid-19. Other known disasters, but with less global impact before Covid-19 that took place are the 2011 mega-earthquake in Japan, the 2003 SARS outbreak in China, and the 2004 tsunami in Indonesia (Zhitao Xu et al. 2020)

All of the natural disaster events listed above have led to material and product shortages, but the supply chain recovered from this disaster in a much shorter time frame, which in case of these disasters has been within weeks.

The recovery of the supply chains from Covid-19 took much longer due to its scope and magnitude, as the virus was not limited to a specific geographical area and therefore the Covid-19 affected the whole supply chain, from the supply sources all the way to the end customer (Zhitao Xu et al. 2020)

For example, the suspension of commercial air-traffic during the Covid-19 put limitations on the air cargo capacities, making it harder to transport goods, as approximately 50%–60% of all airfreights are transported in the cargo compartment of commercial airplanes. Truck and maritime cargo also suffered due to truck drivers being under stringent restrictions with limited ability to pick up

containers, which caused disruptions in container ship deliveries. Maritime freight corresponds to 90% of global trade volume (Zhitao Xu et al. 2020).

Besides transportation related issues, the Covid-19 caused several other different supply chain disruptions, stemming from shortcomings of governments of different countries aiming to stop the spread of the virus (Sunil Bakshi, 2021). The Governments placed restrictions on travel, forcing factories and outlets to temporarily shut down and imposing mandatory confinement on all inhabitants. This all has obviously affected the performance of the supply chain due to of lack of labour, material shortages and tightened controls on logistical systems (Zhitao Xu et al. 2020).

On top of factory lockdowns, transportation disruptions and panic buying behaviour of companies reinforced the crisis. Panic buying led to component shortages, such as components critical to the automotive industry. From component shortages stemmed discussion on topics such as trade restrictions, nationalist policies and the promotion of the domestication of industrial activities (Ben Aylor et al. 2020).

The rapid change on supply chain route possibilities forced supply chain professionals and companies to think of alternative routes. the Sudden halt of rail transport increased lead time of products due to having to shift the transportation mode to sea cargo. Especially some European customers were not accustomed to the longer lead times. Changing the supply route also led to increased operational costs, as some companies in China designed their shipping operations based on close and cheap rail access (Joachim Arts et al. 2022)

War in Ukraine

The Covid-19 was not the only major event in the modern society causing supply chain disruptions. The conflict in Ukraine reinforced the need to have resilient supply chains in place, as disruptions in upstream supply chain of Russia and Ukraine will continue to disrupt supply chains (Jim Kilpatrick, 2022).

The Russian invasion in Ukraine has caused many countries to place sanctions on Russia and its citizens (Beth Stackpole, 2022). Sanctions include forbidding trade and freezing assets, for example.

It is important to note that Europe has a major reliance on Russia regarding crude oil and gas (Jim Kilpatrick, 2022). The increase in energy prices due to sanctions made some manufacturers to re-think the profitability of their operations and reduce their output, while for some products the demand decreased due to companies lowering their spend due to the crisis financially affecting them.

Besides Russia being a critical energy supplier for Europe, Russia also has major natural resources. One example is Palladium used in car catalysators and its price has increased as much as 80 %.This has affected the production of cars and is a major reason LMC Automotive has decreased its forecast of light vehicle sales in Europe by 2 million over the next two years (Jim Kilpatrick, 2022). Cars are just one example of the manufactured items which the crisis has affected.

According to Dun & Bradstreet, there are approximately 15,000 Tier 1 suppliers in Russia and 7.6 million Tier 2 supplier that are related to supply chains of global companies. For example, more than 374,000 businesses, of which 90% are in the United States, are relying on Russian suppliers (Jim Kilpatrick, 2022).

Besides dramatically increased energy costs, the wartime crisis caused disruptions in the flow of goods and created products and food shortages around the world. Countries where poverty is high were the most affected, and the worst affected area of food shortage was Africa, as Russia restricted ships transporting food, such as barley, leaving from Ukrainian ports (Beth Stackpole, 2022). The food supply or related humanitarian crisis is not within the scope of the thesis, but it is acknowledged only as a consequence of the sanctions, as after all, the result is a supply chain disruption even if the side effect is endangering survival in poverty ridden areas.

The more relevant example of war time supply chain disruptions for manufacturing firms is the production of wiring harnesses in Ukraine, which caused disruptions in many manufacturing companies across Europe (Jim Kilpatrick, 2022). Wiring harnesses that are manufactured in Ukraine by a German company Leoni caused shortages which affected the production of Volkswagen and BMW in Germany (David Simchi-Levi, Pierre Haren. 2022).

The war has also caused changes in priorities and also increased demand in products such as semiconductors due to increasing needs for defence equipment production, which created a demand shock for semiconductors (Joachim Arts et al. 2022). This obviously created a shortage of semiconductors for less-defence critical manufacturing industries resulting in production disruptions.

The war in Ukraine has also created discussion about bringing supply chains closer to the operations. Bringing supply chain actors closer can offer governments and companies more control over the supply chain functions, while removing the dependency on foreign actors, which increases the volatility of the supply chain (Jim Kilpatrick, 2022). This is discussed later in the following subchapters related to insourcing, outsourcing, friend-shoring among others.

The war in Ukraine also has emphasized the need to find alternative suppliers. the Diversification of supplier base might mean accepting changes related to supply chain dynamics, such as changes in the supply mode, lead time and temporary shortages. The changes in the market and supply chain also creates new opportunities to fill in market gaps that can answer to the new volatile situation, such as creating new business models. Crises are often a catalyst for change and can give active participants an opportunity to capitalize on it (Beth Stackpole, 2022).

During the war in Ukraine, transportation route changes, similar to during Covid-19 had to be made. Using the Russian infrastructure for transportation was halted due to the sanctions Russia had placed on top of trade restrictions. As the rail route passing through Russia was essentially blocked, an alternative rail

route experienced growth in use, called the middle corridor, departing from China via Kazakhstan, the Caspian Sea, the Black Sea, and Turkey (Joachim Arts et al. 2022). For example, Odessa, the largest seaport in Ukraine handling over 40 tons of cargo annually is halted due to the war (Lisa Caldwell, 2022), contributing to material shortages and supply chain bottle necks as routes need to be re-planned to different ports, and port congestion is another limiting element already in the congested supply chains.

Geopolitical Issues

Geopolitical crises have accelerated the detaching of the dependency on China for components and finished goods and Russia for transportation infrastructure and raw materials. Especially Western countries are now looking into localized or regional souring strategies.

Overreliance on politically conflicted areas which provide critical products or commodities can encourage steps towards supply base diversification. Companies also could assess no-go-zones, where the risks and changes of sanctions poses a greater risk than the benefits of sourcing from the region (Peter Liddell et al. 2022)

Due to trade restrictions, companies might also need to seek for customers in different regions if legal or commercial exposure is at risk. This can, however, increase costs and lead time but can enhance business continuity when new markets are explored. This requires strong procurement governance. Companies should keep eye on all sanctions and possible future sanctions and assess their business impact (Peter Liddell et al. 2022)

Evergreen

The Evergreen container ship got stuck in the Suez Canal in Egypt. The horizontally wedged container ship blocked the flow of traffic for almost a week. The Suez Canal in Egypt accommodates the passing of more than 50 ships on average each day, accounting for approximately 12 % of global trade (Pippa

Stevens, 2021). The Evergreen container ship was also holding up trade valued at over $9 billion per day, equivalent to $400 million worth of trade per hour or $6.7 million per minute (Koustav Das, 2021)

The canal being blocked caused more than 350 vessels in total to wait for their turn to pass the canal due to the blockage, as the blockage cut traffic flow for both directions. Due to the blockage, shipping companies such as Hapag-Lloyd rerouted their vessels around the Cape of Good Hope, adding at least a week of additional sailing time, leading to higher fuel costs (Pippa Stevens, 2021)

Due to ships having to wait for their turn to pass by the canal, the ships were forced to change their schedule regarding when they visit their next port. This caused cascading effects such as port congestion and container shortages, which was already an issue during the Covid-19 (Pippa Stevens, 2021)

Conclusions

In conclusion, the Covid-19 has disrupted movement of goods in different industries, ranging from raw materials to finished products, disturbing the effectiveness and responsiveness of Global Supply Chains (GSC) as well as affecting the customs policies causing import and export related restrictions and sealing or borders (Zhitao Xu et al. 2020). As China is a major manufacturing hub, the shutdowns severely affected factories, leading to issues for manufacturing companies globally in obtaining the components required for product assembly.

The pandemic exposed supply chain vulnerabilities, which make companies re-evaluate their sourcing strategies and dependence on single-source suppliers, and supplier base diversification is seen as a topic to increase supply chain resilience. Insourcing is also seen as an alternative option.

Regarding the war in Ukraine, the sanctions further disrupted the supply chains in the form of shortages, reduced output and lower demand, as companies were adjusting their operations and capacity to match the changed situation.

Secondly the sanctions and trade restrictions reminded supply chain professionals once again how reliant the world is on global supply chain infrastructure.

Table in Appendix 1 lists risks related to major world events and how to mitigate them. Geopolitical issues have been excluded.

Especially companies operating under Just-in-time (JIT) were severely disrupted as stockouts happened more frequently, since companies were relying on on-time shipments of goods. Similar disruptions occurred also due to the war in Ukraine and the Evergreen container ship case. Disruptions were severe due to the functionality of JIT principle, which relies on minimal inventory and production when it is actually needed. the JIT operating model is very vulnerable to supply chain disruptions. Factories operating under the JIT principle will experience component issues and may need to halt production (Pippa Stevens, 2021)

2.2.2 Outsourcing vs. Insourcing Supply Chain Functions

When a company wants to insource items, the company wants to produce those parts internally instead of outsourcing them to external suppliers. Outsourcing is a widely used term for acts that are not performed by the company itself, and outsourcing can be for example subcontracting, off-shoring or contract manufacturing. The governance over these methods can be different, but geopolitical risks are present depending on the area.

Most companies today have outsourced and extended its productions and supply chain activities, and on top of increased dependency on global suppliers and actors, the complexity of the supply chain network has increased. This increases the vulnerability of the supply chain network (Bozarth and Handfield, 2016, p. 226).

As the supply chains are growing in complexity due to emerging technologies, companies are experiencing constant pressure to answer to customer requests

and reduce lead time. Outsourcing supply chain functions has therefore been a hot topic in order to increase efficiency (Gary Wollenhaupt, 2020).

In general, before the pandemic, most supply chains focused on eliminating redundancy in sourcing, reducing fixed costs and increasing efficiency. As the pandemic hit, the efficiency-optimized supply chain has become less resilient. Disruptions and supply chain stress decreased the flexibility and efficiency (Schuster, R et al. 2021). Recovering from the supply chain shock did not happen within weeks as we know it.

Outsourcing and insourcing of supply chain functions, such as logistics or purchasing manufactured items, are two different strategies for managing the supply chain functions. Different supply chain shocks and risks can be a catalyst for decision making whether to outsource or insource supply chain functions. Especially if the components are critical, assessing whether to outsource vs. insource, similar to make-or-buy analysis is beneficial.

For example, when there is an only a short-term need, insourcing might be an appropriate choice. Outsourcing is beneficial when costs need to be reduced in operations where special expertise is required (Surbhi S, 2020). Functions that are commonly outsourced are transportation, domestic brokerage, warehousing and contract logistics (Gary Wollenhaupt, 2020).

Due to supply chain risks stemming from changes in different geographical areas, insourcing critical materials has been gaining a great deal of interest, or at least the topic of investing into resources in the same geographical area. Deciding which functions to outsource and what to keep in house are company specific decisions, which depends on the resources and capabilities of the company.

On the other hand, outsourcing enables the company to focus on its core business expertise, as the company does not need to invest into expertise or infrastructure in areas that can be outsourced. This can lead into cost reduction and economies of scale (Surbhi S, 2020).

When outsourcing, the company should be able to give up control. Especially processes that are routine and easily repeatable, are good to go for outsourcing, as are processes that are not core processes of the company. However, control should be maintained over mission critical segments of the supply chain (Gary Wollenhaupt, 2020).

Advantages and Risks Comparison

One of the benefits of insourcing is that sensitive and confidential information can be handled securely. When outsourcing operations, sensitive and confidential information might be at risk (Surbhi S, 2020). Thus, when something is critical from an intellectual property perspective, it is a good idea to insource. Insourcing gives better control over quality.

The downsides of outsourcing include having very limited managerial control over the company who is performing the outsourced tasks. Insourcing uses the in-house developed methods and has very high managerial control over how things are done.

	Outsourcing	Insourcing
Pros	Potential cost savings	Sensitive information is more secure.
	Access to specialized expertise	More resilient operations
	Flexibility and Scalability of operations in response to demand changes	Internal Expertise
	Ability to focus on core business expertise and customer service.	Control over processes
	Frees up capacity and capital for core business expertise	Efficiencies possible of company culture well established
Cons	Sensitive information is at risk for getting into the wrong hands or malicious use	Higer initial investment
	Reduced Quality of Service	Might need more in-house talent
	Dependency on external partners	Reduced Flexibility
	Increased operational risks	Reduced Innovation due to loss of core focus

Table 1. Outsourcing vs. Insourcing Risks and Advantages comparison. Listed points not limited to only these.

It is important to note that the company who is outsourcing functions is always responsive to some degree of the actions and performance of the outsourcing partner. If the outsourced actor provides poor quality, it will reflect on the company that outsourced the activity and may become a target for customer complaints (Gary Wollenhaupt, 2020).

Friend-shoring

Pandemics, the War in Ukraine and Geopolitical issues covering topics such as trade wars have also been a catalyst for insourcing, localisation, near-shoring or “friend-shoring” decisions.

Friend-shoring means sourcing from geographical areas that could be seen as strategic allies, where there are the investment capability and skills. Friend-shoring means the reorchestration of critical supply chains by swapping risky suppliers to partners that could be a close ally in a less geographically conflicted area (Jim Kilpatrick, 2022). Friend-shoring from likeminded regions could be seen as a viable alternative.

2.3 Responsive and Effective Supply Chains

For understanding the concepts of responsiveness and efficiency in supply chains, it is important to distinguish between these two characteristics (Dennis Alexander Minnich, 2007, p.13).

Efficiency and responsiveness are two different objectives of supply chain management. Responsiveness is the ability of the supply chain to respond within an appropriate time-scale to customer requests or changes in the market and effectivity if the focus is on reducing costs and resources are used wisely only for value adding activities (Dennis Alexander Minnich, 2007, pp.4-5).

Responsiveness and efficiency are interrelated concepts and these concepts can be directly and/or indirectly interlinked in supply chain settings. Interactions among the supply chain actors can either reinforce or cancel out supply chain management initiatives (Dennis Alexander Minnich, 2007, pp 4-5).

A positively reinforcing supply chain requires structural changes, which may consist of a shared information system between actors within the supply chain network (Dennis Alexander Minnich, 2007, p.20). the Bullwhip effect can be managed by efficient Supplier Relationship Management (SRM) practices, while also considering the suppliers' suppliers.

For example, real-time information availability or the lack of it can either magnify or reduce the bullwhip effect. The bullwhip effect commonly reduces demand

and time transparency and time efficiency which in turn reduces the real time information exchange (Dennis Alexander Minnich, 2007, pp.4-5).

For example, higher stock levels allow for more flexibility to react to changes in customer demand and reduce the required lead time. Increased inventory levels on the other hand reduce the efficiency of the supply chain, as holding excess inventory is costly in both holding and capital costs (Dennis Alexander Minnich, 2007, p.17).

Increasing inventory can imply a reliance on a forecast that could be inaccurate, which can leave the company with lost sales, obsolete products, or both (Dennis Alexander Minnich, 2007, p.17). If the company relies on forecasting for inventory management purposes, dealing with forecast inaccuracies should be acknowledged. Having intuition and being able to interpret different forecasting methods and error measurements and what they might signal is essential.

The responsiveness of the supply chain requires continuous monitoring of customer demand and the ability to quickly respond to changes in demand.

2.3.1 Responsive Supply Chains

Information flows are often a concern in responsive supply chains. the Information flow should be well established in order to prepare for inventory optimization and available production capacity against demand fluctuations. Sharing information regarding inventory with suppliers might alleviate issues stemming from information flows (Dennis Alexander Minnich, 2007, pp 2-3). However, often for business reasons many companies do not want to share information flows.

Responsive supply chains are able to react quickly to uncertainties in demand (Lee Krajewski et al. 2016 p. 512). When a company experiences the aforementioned, it would be a good idea to take a look at the supply chain and evaluate its responsiveness.

A responsive supply chain is characterized by flexibility, agility, ability, adaptability (Envista, 2022), improvisation and resilience (Robert Glenn Richey et al. 2021). The more quickly issues can be communicated across members of the supply chain, the more change there is that the customer is not affected. A responsive supply chain should focus on building fair contracts with suppliers. The terms should be fair for the supplier and management team responsible for making contracts with suppliers should consider their financial situation (Envista, 2022).

Flexibility focuses on the willingness and ability to adjust operations based on understanding of and interaction with external factors. It involves coping with environmental dynamics through established procedures (Robert Glenn Richey et al. 2021).

Agility focuses on the ability of the organization or supply chain to make immediate process-level changes in response to external factors. Agile companies or supply chains are able to quickly react to changing supply and demand conditions (Robert Glenn Richey et al. 2021).

Adaptability focuses on the willingness and ability to strategically adjust operations based on external factors in order to respond to shifts in markets (Robert Glenn Richey et al. 2021).

Improvisation focuses on the willingness and ability of a company or supply chain to adjust managerial actions without prior planning as an emergency response to immediate needs arising externally. Supply chains that are able to improvise utilize available resources to address immediate challenges (Robert Glenn Richey et al. 2021).

Resilience is the ability of organization or supply chain to resist disruptions and recover operational capability after disruptions. Resilience requires the supply chain to have the capacity for resistance and the capacity for recovery. Despite disruptions, resilient supply chains are able to maintain operational continuity (Robert Glenn Richey et al. 2021).

In order to stay competitive, companies in responsive supply chain typically frequently introduce new services or products and due to the innovative nature of companies in the responsive supply chain, these companies usually enjoy high contribution margins (Lee Krajewski et al. 2016 p. 513),

Typical competitive advantages of responsive supply chains can be fast delivery times, customization, variety, volume flexibility, and superior quality. Responsive supply chains should have fast reaction time, which helps companies to avoid keeping inventory with high holding cost, inventory that needs to be sold with discount (Lee Krajewski et al. 2016 p. 513), inventory that does not turn well or needs to be writ off.

Improving the responsiveness of the supply chain might come with a cost. There are three primary reasons or methods how the responsiveness can be increased, which are the need to maintain excess inventory, bigger capacity and investments in order to reduce lead times.

The costs of increasing the supply chain responsiveness needs to be compared to the opportunity cost of lost sales resulting from stockouts due to less efficiently managed supply chains or not being able to deliver products to the customer on their desired date.

The Main characteristics of responsive supply chains is to avoid stock-outs and prioritize changing customer requirements. SSs, excess capacity and safety lead times all provide a time buffer to be able to react to demand variability more efficiently and inventory levels, lead-times, available capacity and batch size are important characteristics of responsive supply chains (Dennis Alexander Minnich, 2007, p.17). This is development goal of BlueFors Oy.

Higher stock levels allow for more flexibility to react to changes in customer demand and reduce the required lead time. Increased inventory levels on the other hand reduce the efficiency of the supply chain, as holding excess inventory is costly in both holding and capital costs. Increasing inventory can imply a reliance on a forecast that could be inaccurate, which can leave the company

with lost sales, obsolete products, or both. Thus, increase in inventory might improve responsiveness but be suboptimal by different metrics. Besides putting focus on increasing inventory levels to be more responsive, variability reductions can be more beneficial than inventory increases (Dennis Alexander Minnich, 2007, pp.17-18). By reducing variations, multitude of benefits can be achieved.

By having well established Customer Relationship Management (CRM) and SRM practices on top of plans to achieve reduced lead time for materials, it is easier to produce more reliable forecasts of demand (Lee Krajewski et al. 2016 p. 511).

2.3.2 Efficient Supply Chains

In an efficient supply chain, the focus is on maintaining high manufacturing utilization rates, generating high inventory turns, minimizing inventory levels and selecting suppliers based for cost and quality (Dennis Alexander Minnich, 2007, p.13). As it can be concluded that effective supply chains seem to lean towards reduced inventory, it should be noted that while minimized inventory is financially effective, it might not be able to respond to demand fluctuations.

In efficient supply chains, demand is predictable and rather easy to forecast, compared to responsive supply chains where demand is unpredictable with high forecasting errors. Product variability and contribution margin is low in efficient supply chains and high in responsive supply chains. In efficient supply chains, new products are introduced infrequently and in responsive supply chains new products are frequently introduced (Lee Krajewski et al. 2016 p. 512).

2.3.3 The Bullwhip Effect

The bullwhip or whiplash effect is named after the physics of a slammed whip, where the movement of the whip creates larger variation of movement near the tip of the whip and decreases gradually towards the handle of the whip. The

bullwhip effect analogy explains that small fluctuations in demand can be amplified as they move upstream within the supply chain, which can result in significant fluctuations in inventory levels and costs.

The bullwhip effect is caused by industrial dynamics where time varying behaviours of industrial companies is accounted for. The bullwhip effect is an outcome of the strategic interactions among rational supply chain members (Lee, H. et al. 1997)

Causes for the bullwhip effect include lack of communication and coordination between different actors of the supply chain. Some of the basic inventory management policies used by companies can amplify the bullwhip effect and lead to undesirable behaviour within the supply chain. Some basic inventory management policies include ROPs (Lee, H. et al. 1997).

The bullwhip effect can be somewhat maintained by improving the information flow among the supply chain, which can include information sharing, coordination, and the use of more responsive ordering policies. Sharing inventory data among members of the supply chain plays a pivotal role in improving supply chain coordination and dampening the bullwhip effect. When reducing the bullwhip is successful, it can lead to significant cost savings and increased efficiency in supply chains (Lee, H. et al. 1997)

Other than lack of communication and coordination, the bullwhip effect is affected by demand signal processing, rationing game, order batching, and price variations (Lee, H. et al. 1997).

Rationing Game

Rationing is common in product markets during the growth phase when demand exceeds supply. Here it is important to note that the case company in this thesis, BlueFors Oy, is a growth company and thus the rationing behaviour should be acknowledged.

The rationing gaming and shortages occur when demand exceeds supply. The rationing game can be alleviated by placing restrictions on customers (Lee, H. et al. 1997). When there are no existing practices present to restrict customers, such as allowing them to make changes to orders freely, the behaviour can create further problems that reflect back to the other supply chain actors. Customers can be restricted e.g. by using frozen planning, extending lead time or making them pay more the later the changes are requested during the delivery process.

2.4 Sales and Operations Planning

Sales and Operations Planning process, also known as S&OP, plays a major role in effective supply chain management. Having a well-performing strategy in place can be a major competitive advantage in today's global markets. With S&OP, it is possible to improve customer service, reduce working capital, cut costs, minimize operational risks risk, and shorten response times (Sri Aparajitha et al. 2011). This makes S&OP a key management process with strategic objectives.

S&OP considers issues such as demand forecasts, cost factors and risk profiles. Often, the S&OP process is not properly constructed if the company experiences product stockouts in some SKUs and inventory build-up in other SKUs (Sri Aparajitha et al. 2011).

Characteristics of well-defined S&OP include efficient information flow, segmentation of products, channels, and customers on the basis of demand patterns (Sri Aparajitha et al. 2011). Demand patterns, customer needs, product mix, supplier lead times and service level requirements experience variations through periods and thus monitoring is required. When these are not managed, results can be unpredictable (Philip Lee, Scott Sparks, 2020). When the S&OP process is implemented, it gives the company one common plan to operate within.

S&OP often starts with making of a demand plan. The demand plan is the statement what the company expects to be taken out of the inventory and supply plan is the answer to how to meet the demand. Drawing up the demand plan consist of discussing concerns, restrictions and objectives with the participative functions. When the demand plan is drafted, a supply plan comes up next. Usually, the demand and supply planning is an iterative back-and-forth process. The plan resulting from the S&OP process is the inventory plan. The plan consists of what needs to be manufactured, what materials need to be available, and when they should be ready in order to meet the expected demand. The culprit is to determine the optimal amount if inventory (Dave Turbide, 2018 A).

2.4.1 Monthly S&OP Process

The monthly S&OP meeting is a great way to get all important functions together. There is no single way to have to monthly S&OP Process. The below example discussed 5-step process, where the final step is the Executive S&OP, where major issues are brought to the executive level. The five-step process is commonly used and consists of the following stages: Data gathering, demand plan, supply plan, pre-S&OP, and finally, the executive S&OP meeting where potential action steps are decided (Kate Eby, 2017). Another alternative S&OP process consist of six steps, which are Forecasting (Data gathering), Demand planning, Supply planning, Pre S&OP meeting, Executive S&OP meeting and S&OP Finalization (Asana, 2022). It is important to note that the 5 or 6 step processes are not the only way to do the monthly S&OP process and there can be company or situation specific adaptations.

In the case example discussed by Caroline Geelmuyden and Emma Rasmusson, the five steps are explained more in detail. In this Monthly S&OP method, two days of time was allocated for each consecutive step before step 5 to work on plans. The five-step process ensures that all necessary participants are up to date of developments regarding supply and demand planning (Caroline Geelmuyden, Emma Rasmusson, 2019). The authors also emphasize the importance of documentation for better understanding why a change was made,

which can assist in future decision-making. Documentation can include thoughts, strategies, and changes made to the forecast. This documentation should be easily accessible. When there is a decision making history available, it is easy to explain the S&OP process to new participants (Caroline Geelmuyden, Emma Rasmusson, 2019).

Step 1 in the monthly S&OP process involves data gathering, where participants ensure they have sufficient information to support their decisions. This information might include last month's results, customer information, details about planned campaigns, forecasts, current inventory status, and capacity plans (Caroline Geelmuyden, Emma Rasmusson, 2019).

Step 2 involves demand planning. In this step, potential changes are discussed, and forecast accuracy, service level, and stock volumes are reviewed. Documentation of customer or supply-related events that affect the forecast is brought in to support decision-making (Caroline Geelmuyden, Emma Rasmusson, 2019).

Step 3 involves supply planning. In this step, production plans, forecasts, stock balances, production capacity, plant service levels, and documentation of events that have affected the production plans, for example, can be discussed (Caroline Geelmuyden, Emma Rasmusson, 2019).

Step 4 involves a pre-meeting. The purpose of this step is to align the supply plan with the demand plan. The inputs for Step 4 are generated during the previous steps, which include the demand plan, supply plan, KPI performance, budgets, and income statements. In addition to balancing the demand and supply plans, adjustments can be made based on financial budgets, considering the constraints between supply and financial objectives. Step 4 often consists of the senior management members related to these functions. The output from this step should be a balanced demand and supply plan within the agreed budget. Issues requiring executive-level attention are collected for the final step (Caroline Geelmuyden, Emma Rasmusson, 2019).

In Step 5, which is the final step of the monthly S&OP process, issues are escalated to the executive level. Here, financial and operational targets are approved. Inputs to this step include a balanced demand and supply plan, unresolved issues, consolidated process measurements, and KPI performance. The output of Step 5 is an approved demand and supply plan (Caroline Geelmuyden, Emma Rasmusson, 2019).

Inventory Planning as part of S&OP

Inventory plan is included in the S&OP process, even though it is not explicitly mentioned in the process (Dave Turbide, 2018 A). In fact, Inventory Planning is a major factor in S&OP and for this reason, the term Sales Operations and Inventory Planning (SIOP) is often used interchangeably with S&OP (Brya Ball, 2015).

SIOP provides visibility into operations and indicates what needs to change in operations if potential issues arise (Philip Lee, Scott Sparks, 2020). The ability to handle multiple inputs and process them into a single output is a sign of a mature demand planning process. A key point here is the ability to work in cross-functional teams to capture all necessary information to improve the S&OP process (Brya Ball, 2015).

SIOP provides answers to questions such as changes in inventory over periods and what the inventory turnover ratios are. An increase or decrease in inventory can suggest that there is a problem in inventory management or somewhere in the supply chain. This could be a sign of future issues related to customer service, working capital, capacity, operating costs, or growth. Issues could arise from raw materials aging or growing disproportionately compared to sales. This usually means that the forecast is inaccurate, the capacity to produce is insufficient, or the process of receiving raw materials is suboptimal (Philip Lee, Scott Sparks, 2020).

The aforementioned issues are familiar to companies using Material Requirements Planning (MRP) and forecasting, which assumes infinite capacity. These

issues can be alleviated by using Master Production Scheduling (MPS). Besides raw materials, these same issues can apply to Work in Progress (WIP) stocks (Philip Lee, Scott Sparks, 2020).

When drafting the inventory plan, it is important to allocate some extra inventory to compensate for demand variability, forecast error and supply chain risks. Warehousing capacity limitations should be considered as well (Dave Turbide, 2018 A). The extra inventory level is determined when evaluating suitable SS and ROP levels.

When supply and demand do not align, many problems can arise, such as stockouts, overstocking, lost sales, markdowns, write-offs, poor capacity utilization, and declining service levels (Sri Aparajitha et al. 2011).

2.5 Segmentation

Segmentation is an important aspect of inventory management and S&OP. Product segmentation divides the company's products into groups based on characteristics such as volume, demand variability, and predictability. Product segmentation helps to understand demand patterns in more detail when allocating resources within the company (Sri Aparajitha et al. 2011). By segmenting products, companies can prioritize their S&OP processes and focus on areas that need more attention in order to achieve a better balance between predictability and flexibility.

Segmenting products influences inventory management. Products with highly predictable demand may need fewer stock buffers and can be managed more or less automatically compared to products that are highly volatile. Segmentation can reveal highly volatile, low-volume products which are kept in stock. These SKUs might require discussion about whether they should be kept in stock for assemblies.

For example, one could perform a cost-value analysis to evaluate whether to discontinue production for highly volatile and low-volume SKUs and whether capacity should be freed up for higher-value products. Product segmentation can improve a company's ability to manage supply and demand more effectively (Sri Aparajitha et al. 2011).

When creating product segments, product "buckets" can be created based on volume and demand predictability. Each product segment is characterized by different sales volume, revenue generated, or contribution margin. Segmentation analysis can be used as a tool to create strategies for each product buckets. Strategies might include maintaining stability for high-volume, low-volatility products, managing high-volume products with high volatility, and conducting deeper research on high-volume products (Sri Aparajitha et al. 2011). For example, the ability to segment demand provides important insights into increasing service levels and focusing on correcting problem areas without increasing stock (Brya Ball. 2015). In general, it is important to consider differences between SKUs in terms of their characteristics such as cost, sales value, consumption rate, and demand variability (Esra Agca Aktunc et al. 2019).

Since it is impractical to assign inventory control policies for each SKU individually, SKUs are grouped into segments or buckets based on statistical data. Efficient inventory management does not allocate the same control mechanism for all inventory classes. Instead, control methods should be applied to SKUs based on their economic importance, for example. The aim of efficient inventory management is to minimize costs for the company and maximize service for the customers (Faraz Khan et al. 2019).

2.5.1 ABC Analysis

For the ABC analysis, the financial value of inventory must be calculated by multiplying the quantity of each SKU's material by its unit price. Then, the SKUs are sorted from highest to lowest and calculated cumulatively based on the desired percentage of the total for each SKU class. The ABC analysis usually

follows the Pareto principle. Pareto principle states that 80% of effects are due to 20% of the cause (also known as the 80/20 rule). However, in ABC analysis, the percentage values are not fixed and they can be defined depending on specific requirements, such as 70, 20, and 10% (Esra Agca Aktunc et al. 2019). Pareto diagrams are often used to visualize the data.

The literature reviewed suggests that A-class SKUs are the most important and valuable for operations and thus must be closely monitored. Class B SKUs are of average importance but should still be monitored. Class C SKUs are trivial, and little effort can be directed towards them. SKUs in different classes require different management principles (Esra Agca Aktunc et al. 2019).

The main principle of ABC analysis is based on the fact that a small percentage of SKUs often represents a significant financial value of the total inventory for the company. On the other hand, a relatively large number of SKUs often represents only a small part of the financial value of the inventory (Marcela Malindzakova et al. 2022). ABC analysis can be conducted using the historical demand of the past 12 months, for example, by accounting for the amount of a specific SKU used within a year multiplied by its average price. It’s possible to use the last price as well, but the average price is commonly used.

ABC analysis comes with multiple benefits such as improved inventory optimization, forecasting, strategic resource allocation, cost control, holding costs, and turnover rate. It can also provide valuable information for supplier negotiations. Some good assumptions for ABC analysis are to categorize SKUs based on the speed of inventory turnover for the specific SKU. SKUs with fast turnover rates pose a higher risk for stock-outs. However, in basic level ABC analysis assumptions are not used.

ABC analysis can be used to segment SKUs based on tied capital. A significant amount of capital is tied to A-class SKUs, making it important to classify which SKUs require close monitoring. Despite being a tool to rank SKUs based on their financial value, ABC analysis should still be used objectively. For example,

A-class SKUs require the most managerial attention, while B-class SKUs can be managed mostly with automated control principles. The control of C-class SKUs should be as simple as possible and ideally grouped into regions, suppliers, or end-users (Larry Lapide, 2006). There can be also two types of A-SKUs: fast-moving but cheap, and slow-moving but expensive. Distinguishing between these should be done if a company wants to conduct a more comprehensive inventory classification.

For example, A-class SKUs could be reported frequently during inventory reviews (Chris Caplice, 2006 E). B-class includes SKUs of intermediate importance and C-class contains the least important SKUs (Marcela Malindzakova et al. 2022) from financial perspective. B-class SKUs are reported infrequently or in an aggregated manner (Chris Caplice, 2006 E)

Regarding C-class SKUs, it is important to spot the SKUs with low value but that are still important to manage, i.e. an SKU may be of low financial value but still be scarce to source from the markets. C-class SKUs can be reported only on an aggregated level as well. For C-class SKUs, identification and disposal of dead inventory is important. SKUs that should be disposed can be evaluated for example by evaluating the Days of Supply/Stock (DOS) for each SKU. If DOS is greater than x > years, closer look could be beneficial (Chris Caplice, 2006 E). For this reason, DOS monitoring can be beneficial.

Identifying the Long Tail Inventory

The long tail inventory is also called the C-material spend (Riccardo Drentin et al. 2018). Long tail SKUs are similar to C-class SKUs in ABC segmentation, as both, long tail and class C SKU represent SKUs that contribute little to the overall spend. However, it is important to note that long tail SKUs can also include SKUs from class B or even class A, where SKUs have high value but otherwise low consumption frequency. Some characteristics between these two classifications overlap but they are not necessarily identical. Other methods to identify the long tail SKU from ABC C-class is required in cases like this.

Another good segmentation principle is to segment based on demand, where the current inventory is compared against historical demand and forecasts regarding the demand. This way, the fast-moving, active SKUs can be identified, as well as excess inventory of the fast-moving SKU, SKUs with long-tail characteristics, or obsolete SKUs (Paolo Baldesi et al. 2019). For identifying root causes for slow moving SKUs, SKUs could be segmented based on the average duration the SKU is kept in stock or SKU Age, which is the duration the SKU is held in stock.

2.5.2 ABC-XYZ/FSN/HML/VED/SDE

ABC-XYZ/FSN/HML/VED/SME analyses are tools used in inventory management to classify products based on their variability/sales volume/price. Both approaches, segmentation based only on ABC, or any combination analysis aims to improve demand forecasting and inventory management by segmenting products based on their characteristics. The two most common methods for SKU classification techniques are the ABC analysis and the Fast, Slow, Non-Moving (FSN) or XYZ technique. In the ABC-XYZ or ABC-FSN method, these techniques are combined.

Segmenting items into categories requires data collection and periodic reviewing, which can make the process resource-intensive. However, with data-analytics and BI tools this can be automated.

Besides combining ABC-XYZ which is common, it is also possible to add third classification to the matrix. For example, ABC–VED–FNS Matrix was constructed in the work of Tafesse Gizaw and Awol Jemal (2021).

Appendix 3: Segmentation Method Comparison lists pros and cons of each segmentation method.

XYZ Analysis

In the XYZ analysis, demand for X SKUs has very little variation, which means forecasting demand can be done more accurately. Demand for Y SKUs fluctuates more, but the demand can still be reasonably predicted, though forecasting will be less reliable. Demand for Z SKUs has high variation and thus, forecasting is difficult. The combination of ABC and XYZ analyses helps identify SKUs based on both demand and demand variance (Esra Agca Aktunc et al. 2019). It is good to remember that A-class is not necessarily of high demand but it can be high price and low demand.

For example, products with high volume and high demand volatility might need to be reviewed more frequently than those with low volatility (Sri Aparajitha et al. 2011). For this, ABC-XYX segmentation could be useful.

FSN/FMSN Analysis

The FSN stands for The Fast, Slow and Non-Moving (FSN) Method. Corresponding letters are Fast (F), Normal (N), Slow (S) and Dead (D). In FMSN analysis, medium moving class is included. Fast-moving can also stand for X, Slow-moving for Y and Non-moving for Z (or ZZ/Z0) is often described as the deadstock.

The FSN method does not segment consumption variability, but it segments the rate at which the SKU sells to classify the SKU. The higher the figure, the faster the moving speed (Thymen van der Poll, 2017). The FSN helps to identify non-moving or slow moving SKUs and separate them from fast moving SKUs.

Segmentation can be used in other operational areas than just inventory management when it comes to stock amounts. FSN-based analysis can help improve warehouse operations by locating the fastest-moving goods in easier-to-reach stock locations within the warehouse. To get rid of slow-moving or dead stock, bundling SKUs with fast-moving stock is also an option to clear unwanted inventory (Finale Inventory, 2023).

HML Analysis

The HML method stands for High, medium, low (HML) classification segments SKUs based on their unit price and the method emphasizes controlling of high cost SKUs (Thymen van der Poll, 2017).

VED Analysis

Vital, Essential, Desirable (VED) analysis is based on Criticality & Impact (PiLog Group, 2023) or functional importance. VED classification aims to guide inventory management decisions by considering the significance of items in the production process and their potential impact on operational continuity (Exceed College, 2023).

Vital class SKUs are essential materials, where non-availability can halt business operations. Thus, these materials should be stocked at all times. Essential SKUs are materials where a certain amount is needed, and a minimum amount is sufficient to keep production running. The desirable class refers to materials that do not affect production continuity, meaning that production can run with or without these materials (Exceed College, 2023).

SDE Analysis

Scarce, Difficult, and Easy (SDE) method classifies items based on their supply scarcity (Melanie, Unleashed software, 2018). Scarce products are short in supply. Items in the difficult class may consider aspects such as restricted accessibility or limited suppliers. The Easy class includes SKUs that are easy to acquire (Gonzalo Aguilar, 2022).

SDE Analysis is vital in industries where the materials used are scarce. Thus, this classification can help formulate proper inventory policies (Malik Shawal, n.d.).

ABC-XYZ Analysis Example

ABC-XYZ analysis can be used to obtain information about SKUs for more accurate inventory management decisions (Esra Agca Aktunc et al. 2019).

The analysis consists of nine classes in the case of ABC-XYZ, which are AX, AY, AZ, BX, BY, BZ, CX, CY, and CZ. Each of these classes has very different properties (Esra Agca Aktunc et al. 2019) and thus, they should be managed differently. SKUs with no future demand are commonly classified as ZZ or Z0.

2.5.3 Limitations of the ABC Analysis

The limitations of ABC segmentation should be acknowledged. It is important to note the company specific demand patterns because the ABC analysis does not distinguish demand patterns, as in only focuses on monetary value of SKUs.

One example is a new product without past demand history or other seasonal products. Thus, the ABC analysis might not reflect reality. Secondly, the concept of value blindness can be accounted for. For example, an SKU might be of low value but still be of significant importance to keep in inventory to optimize manufacturing operations.

ABC analysis can enhance over or undersupply issues, and there is a risk of ignoring B and C class SKUs, which might cause production disruptions, as the analysis does not focus on inventory turns. Also, the opposite can occur and cause inventory to build up (Abby Jenkins, 2020).

Also, Master thesis by Heta Haikonen (2021) lists other limitations of the ABC analysis, which are that the method often ignores item specific KPIs. Other often ignored features can be the fill rate, lead time and order frequency (Sheikh-Zadeh et al. 2021). Especially in ETO companies, understanding the theoretical background of the inventory and inventory management model(s) is important, which goes beyond segmentation.

Bikeshedding

When conducting an ABC analysis, it is important to acknowledge certain common biases. One such bias is known as “Bikeshedding”, which refers to the tendency of individuals to spend excessive time on trivial or less significant issues. This often results in a shift of focus away from matters of greater importance (Raza Abbas, 2020). Such situations may arise where inventory managers focus excessively on debating or adjusting SKU classifications, rather than focusing on the strategic implications derived from ABC analysis. To prevent Bikeshedding, clear objectives and criteria for ABC analysis should be set. This includes a periodic review and update of parameters (Raza Abbas, 2020).

2.5.4 Coefficient of Variation

The best practice for conducting XYZ analysis is to use the Coefficient of Variation (CV). The coefficient of variation can be calculated from demand. The higher the CV, the more uncertain the demand becomes.

$$CV = \frac{Standard\ Deviation\ of\ Demand}{Average\ Demand\ in\ a\ period}$$

If demand is stochastic, then the lead time has a probability distribution, which could be normal or any other shape of probability distribution. The distribution is normal in an ideal and optimal situation.

If the CV is high other SS equations than those assuming normal distribution should be used, but those are not on the scope of the thesis.

The CV can be used to guide which SS equation to use if the data is not normally distributed. In these cases the SS equations can be tailored to the specific probability distribution shape (Thymen van der Poll, 2017). In most cases, the normality assuming SS equations are good to begin with as the formulas can give a good approximation (Alberto Santini, 2019).

A useful rule of thumb to keep in mind is that non-normally distributed lead time or demand exists in cases where the CV is more than 0.5. On the other hand, when the CV is less than 0.5, the normal distribution provides a good enough approximation. If the CV is greater than or equal to 0.5, the demand can be considered to follow a Gamma distribution. Slow-moving SKUs can be assumed to follow a Poisson or Compound Poisson distribution (Thymen van der Poll, 2017).

The CV can also guide order policies. For example, if the CV is more than 0.2, it may indicate that the demand is too fluctuating for Economic Order Quantity (EOQ) order policies, as EOQ assumes non-fluctuating demand. If the CV is less than 0.2, then EOQ policies are suitable, assuming other criteria of the EOQ assumptions are met (Winston, 2004, p. 872; van der Poll, 2017). Thus, the results from the XYZ analysis can be used a guidance in choosing appropriate order policies.

2.6 Inventory Planning Key Performance Indicators

Inventory consists of materials that a company holds in order to meet customer needs and future demand. Inventory can include products in process, finished goods, raw materials, and final products that the company has in stock and can utilize either to finalize or start production (Faraz Khan et al. 2019). Because inventory plays such a vital role in companies, measuring its performance is important.

Inventory management KPIs are metrics that help monitor and make decisions about the stock a company holds. It’s important to note that different stakeholders might require different inventory information, and the KPI is often modified based on what needs to be measured. Using KPIs to measure inventory performance can help companies optimize their inventory and material management, provide insight into simplifying product portfolios, and aid in resizing manufacturing cycle times (Paolo Baldesi et al. 2019; Ryan Brukardt et al. 2021).

Due to some fragmentation in definitions, there is no universal standard for defining KPIs. Therefore, maintaining criticality is important when determining the best KPI definition for a specific use case. Different sources may use different terms, formulas, or interpretations of the same KPI. Some sources may use variations of these formulas, where there can be variation between whether using weeks or months instead of days or using average inventory for a period instead of ending inventory, or an average of both.

For example, Days on Hand (DOH), Days Sales of Inventory (DSI), and Inventory Days of Supply (IDS) can be acronyms for the exact same KPI. All of these KPIs measure the average number of days it takes to sell the inventory the company has on hand.

Having consistently defined KPIs in place can help companies gain analytical insight into stock segmentation, identify root causes for low turnover for SKUs, and develop actions to increase sales and reduce the cost of SKUs in certain segments, such as slow-moving stocks (Paolo Baldesi et al. 2019).

In some cases, it can be beneficial to use different KPIs on different segments of inventory, which could be based on ABC analysis, for example. SKUs can be segmented based on grouping, or they can be analyzed individually. Below are presented some common Inventory Management KPI’s.

Days of Inventory Outstanding

Days Inventory Outstanding (DIO) represents the number of days it would take to run out of inventory without receiving replenishment orders. Measuring IDS helps to gain insight into the size of the inventory. It’s important to remember that while keeping too much inventory in stock ties up capital, the inventory on hand should also be sufficient to satisfy demand (Abby Jenkins, 2021). Days Inventory Outstanding (DIO) is also known as Inventory Days of Supply (IDS), Days in Inventory (DII), Days Sales in Inventory (DSI) and the Average Age of Inventory (Adam Hayes, 2023).

The lower the number, the quicker the inventory is turned into cash. Conversely, the higher the figure, the longer it takes to convert the inventory into cash. IDS is calculated in monetary value based on the definition provided below. It is good to remember that the equation below is just one way to calculate the IDS.

$$IDS\ (Monthly) = \left(\frac{Average\ Inventroy\ in\ a\ Month}{Monthly\ Demand}\right) * 30$$

Also, Days of Supply or Days of Stock measures a similar metric, as all definitions measure either how long it takes for a company to sell its inventory or how many days' worth of sales the inventory currently on hand can meet.

Inventory Days of Supply

The formula below measures how long the inventory on hand will last, considering the current stock and average daily consumption (Institute for Business Forecasting and Planning, 2023). The number of days in a year on average is 365, which is typically used in calculations. The number of days used in the equation can be adjusted.

$$Days\ of\ Supply = \frac{Current\ Stock}{Average\ Daily\ Consumption}$$

Or

$$Days\ of\ Supply = \left(\frac{Ending\ Inventroy\ Value}{Cost\ of\ Goods\ Sold}\right) * 365$$

The above formulas can be extended to months and Weeks on Hand as well. Months on hand indicates the number of months the inventory on disposal lasts if no replenishment purchases are made and sales continue as forecasted (Abby Jenkins, 2021).

Inventory Turns

Inventory Turns measures the number of times the inventory is turned or consumed within a specific period, usually a year (Sofia Rachad et al. 2017). Inventory Turns is an inventory measure obtained by dividing Cost of Goods Sold (COGS) by the Average Aggregate Inventory value maintained during the year (Lee Krajewski et al. 2016 p. 508) or it can be also calculated by using the average inventory when talking about specific SKUs.

$$Inventory\ Turns = \frac{Cost\ of\ Goods\ Sold}{Aggregate\ Inventory}$$

Or

$$Inventory\ Turns = \frac{Cost\ of\ Goods\ Sold}{Average\ Inventroy}$$

Improvement in inventory turnover can be achieved by enhancing the order fulfilment process, which reduces the finished goods inventory and accelerates the order-to-cash process. It is important to note that inventory represents a financial investment, as it ties up funds that could be used more profitably elsewhere (Lee Krajewski et al. 2016 pp. 508-510). Working Capital (WC) is an important financial term. Both Weeks of Supply and inventory turns impact WC, as inventories tie up WC. This is the money used to fund ongoing operations. If an organization successfully decreases the weeks of supply or increases inventory turns, it translates into a reduction in the working capital needed to finance inventory.

Inventory can be improved by reducing the need to store excess raw materials and work-in-process inventory stock. A sensitivity analysis is a good tool to analyse what effects the reduction of inventory of specific SKUs or increases in the annual sales have on weeks of supply or inventory turns (Lee Krajewski et al. 2016 p. 508). Sensitivity analysis can help to optimize operations on wider scale. Improvements in weeks of inventory and inventory turnover can be

achieved by enhancing customer relationships, order fulfilment, or supplier relationship processes. If a company successfully reduces supplier lead times, it positively impacts the weeks of supply and inventory turnover ratio (Lee Krajewski et al. 2016 p. 511).

2.6.1 Inventory Valuation

Some common Inventory valuation figures that can be calculated are Average Aggregate Inventory value, Weeks of Supply and Inventory Turns (Lee Krajewski et al. 2016 p. 508). Average Aggregate Inventory value is the total average value of all SKUs held in inventory.

$$Aggregate\ Inventory = Raw\ Materials + Work\ in\ Process + Finished\ Goods$$

Weeks of supply is an inventory metric calculated by dividing the average aggregate inventory value by the cost of sales per week.

$$Weeks\ of\ Supply = \frac{Aggregate\ Inventory}{\frac{Cost\ of\ Goods\ Sold}{Weeks\ of\ Operation}}$$

For example, SKU proliferation or segmentation can also be utilized to set Target Weeks of Supply (TWS) levels. The target level signifies the weeks of supply that the company aims to have in stock to meet demand. Maintaining TWS at the SKU level is often quite laborious, so it could be done at the class level instead (Benjamin Robert Martin, 2010).

At times, the reason for a small inventory stem from the fact that inventory represents a temporary monetary investment. This investment can include costs such as opportunity cost and cost of capital due to the money tied up in the inventory. Factors that can affect inventory valuation include holding and handling costs, taxes, insurance, and shrinkage. The EOQ can assist in determining the ideal stock size (Lee Krajewski et al. 2016 p. 340).

2.6.2 Inventory Age

Inventory age can be improved by improving inventory turnover ratio. Automatic alerts in the inventory reports can be set to alert when inventory turnover falls below certain limit, which can signal of a probable risk of aging inventory (Wasp Barcode Technologies, 2023).

Monitoring inventory ageing can help to spot slow moving and non-moving SKUs. It can also help to gauge how long on average SKU is kept in inventory, along with quantifying the costs of holding inventory (Danielle Bauter, 2022)

Inventory Age can be improved, besides monitoring the inventory turns, by reducing the time it takes to turn the inventory into sales. This increases the inventory turns and decreases the inventory age. The inventory turn KPI can be used to detect the SKUs that are not moving or are slow moving. Measuring inventory age can help to formulate adequate actions. For example, the inventory can be too large. Downsides of aging inventory are that this type of inventory can become less sellable and keeping non-moving inventory in stock occupies the storage space from fast moving SKUs (Danielle Bauter, 2022)

2.7 Inventory Decisions

Typical manufacturer spends more than 60 % of its total income on purchases (Lee Krajewski et al. 2016 p. 507). Thus, inventory Management has direct impact on the operating cash flows of organizations, performance and profitability. The capital productivity of a company can be improved if the inventory is managed efficiently. This can further improve the competitive advantage (Faraz Khan et al. 2019).

There are three levels of inventory decisions. These are strategic Supply Chain Decisions, Strategic Deployment Decisions and Tactical or Operational Replenishment Decisions (Chris Caplice, 2006 A).

Supply Chain decisions answer to questions such as what alternatives there are to inventory or how should the product be designed (Chris Caplice, 2006 A). Alternatives to inventory can be vendor maintained inventory, for example.

Deployment decisions answer to questions such as which SKUs should be stoked, how these SKUs should be controlled and how much and where these SKUs should be stored. SKUs might be perishable (Chris Caplice, 2006 A) which puts more constraints into inventory management and determining ideal order quantity is less straightforward.

Replenishment decisions answers to questions such as how often the inventory status is determined, when to order replenishments and in what quantities. Inventory replenishments are affected by several factors, such as demand characteristics, is it stable or variable, known or random, continuous is discrete (Chris Caplice, 2006 A).

When forecasting, lead time characteristics should be considered. Lead time can be instantaneous, constant or variable, meaning deterministic or stochastic (Chris Caplice, 2006 A). Depending on the historical demand pattern, suitable forecasting method should be chosen.

Inventory review time can be continuous or periodic (Chris Caplice, 2006 A) and this affects the replenishment order policy. Inventory policy can be either (R,S), periodic or cyclic review policy, or (s,Q), a continuous review policy, or (R,s,Q) a periodic review policy, where inventory review is done every R period (Nicolas Vandeput, 2021).

Inventory management can be single-or multi-echelon (Chris Caplice, 2006 A). If sales and inventory data are shared among the supply chain members, such as suppliers and/or supplier’s suppliers, the supply chain as a whole can be implement as echelon-based inventory control, which can result in superior performance results (Lee, H. et al. 1997)

The capacity and resources can be either unlimited, limited or constrained (Chris Caplice, 2006 A). Capacity can be a constraint in the inventory planning process. For example the effect of capacity utilization in inventory management is something that can be studied if inventory optimization is the goal. Some studies show a strong correlation between capacity utilization and value chain performance (Faraz Khan et al. 2019).

The planning horizon can be single, finite or infinite (Chris Caplice, 2006 A). The planning horizon is determined by the S&OP process.

Some terms common to functional classification of inventory are cycle stock, SS, pipeline inventory, decoupling stock, congestion stock and anticipation inventory (Chris Caplice, 2006 A). Decoupling stock is the point where the inventory is separated from the rest.

Inventory decisions should consider the inventory position and order point. Order point is a function of the inventory model. Different inventory positions are on hand, on order, committed and backorders (Edgar E. Blanco, 2016). On-hand inventory is the quantity of materials that is currently on stock which is ready to be used. On-hand inventory can also include inventory that is stored off-site, such as vendor maintained inventory.

2.8 Inventory Planning

Common goal of Inventory Planning is to manage the inventory in order to have right amount of stock at the right time, to meet demand, performance targets and to minimize inventory costs and capital tied to excess inventory.

Two different approaches to Inventory Planning are MRP and Demand Driven Material Requirements Planning (DDMRP). MRP is a push system, meaning it starts production based on forecasted demand. On the other hand, DDMRP is a pull system. MRP follows the current demand and thus, traditional MRP based

Inventory Planning relies heavily on ROP and SS. MRP is discussed in more detail as it is the most relevant inventory planning method for BlueFors Oy.

The service level, often used as a parameter in SS equations is just a number from the Z table. Larger service level corresponds to larger SS and further ROP. ROP and SS are explained under the corresponding chapter.

Inventory During Different Stages

On order is the inventory that is currently being ordered for replenishments. On order inventory can be also considered as the pipeline-inventory. Most manufacturing companies have pipeline inventories if their operations include turning raw materials into finished goods.

The inventory in transit (pipeline, on order inventory) should be tracked alongside the on-hand inventory in order to have an overview of how much inventory is tied up in capital, and how much inventory can be sold or processed into various goods.

Knowing the on-hand and in transit order helps manufacturing firms to plan ahead what they can manufacture and when customer orders can be fulfilled. The inventory pipeline should be monitored for SKUs that pose a risk to be classified as dead stock (Kristina Lopienski, 2021) and for which the order amounts should be reviewed.

2.8.1 Safety Stock Formulas

SS is important parameter in MRP based inventory optimization. It is good to remember the assumption that most of the SS formulas assumes that the variability is normally distributed around the mean. In most cases, it is rather unrealistic that the variability in either demand or lead time is perfectly normally distributed (Nicolas Vandeput, 2021).

Other than normally distributed probability density functions do exist that can be used for inventory analysis purposes, such as Gaussian, logistic, gamma, lo-normal and Weibull. Choosing the correct inventory policy while considering the shape of the probability distribution can help to optimize the relationship between overage and underage costs. For example, higher service level increases the overage cost. Underage costs are costing that stem from missed sales (Ashkan Mirzaee, 2017), often resulting in stockouts or shortage costs. The service level is included in majority of normal distribution assuming SS equations.

Optimizing overage and underage costs is an important part of inventory optimization. Overage and underage costs are known issues from the operations research problem known as The Newsvendor Problem. However, this problem is beyond the scope of the thesis, as are the assumptions of non-normal distributions in Safety Stock equations.

For example, demand is often skewed to the right, characterized by generally low demand qty with a few exceptionally high outliers that distort the normal variability. When the data is skewed and an equation assuming normality is used, extreme outlier events are assumed to have a low probability. Depending on the desired service level, the significance of this decreases; for example, when a low service level such as 90% is acceptable (Nicolas Vandeput, 2021). When data is not normally distributed, the mean values become skewed, potentially resulting in either excessively high or low SS levels. Another common mistake in determining SS is the assumption of an incorrect ordering or inventory policy.

Safety Stocks, excluding equation based on forecast error pros and cons comparison table is included in Appendix 2.

Normal distribution with uncertainty of demand and lead time, independent relationship

The equation considers service level Z, lead time, demand standard deviation, demand and lead time standard deviation. In this equation, the Z-score

multiplied by the square root of the sum of the squares of the individual variabilities. Lead time is not squared.

This equation works fairly well in situations where demand and lead time variability are independent and both of them are influenced by different factors. The equation assumes that the data set where the standard deviation is taken is normally distributed (Peter L. King, 2011).

The equation below is used in the SS calculations in the implementation section. In this formula, the first two terms under the square root describe the variation in demand over the average lead time, while the second term describes the variation in supply compared to the average demand. In summary, the first two terms describe demand variability, and the last term describes supply variability (Sujit Singh, 2021 A).

$$Z * \sqrt{L * \sigma^2_{Demand} + \mu^2_{Sales} * \sigma^2_{Leadtime}}$$

For example, a high coefficient of variation CV value indicates significant variation in demand, allowing the CV to be used further to examine the demand variation. If the CV is low, then the last two terms are of greater importance regarding the average demand. The higher the average demand is, then larger SS is required compared to preparing for demand fluctuations explained by the first two terms. It is also a reasonable assumption that an increase in the CV (reflecting variability in demand) will result in an increased SS. However, when the CV is high, the average demand, measuring the required supply, contributes very little to the SS calculation (Sujit Singh, 2021 A).

The service level Z in SS calculations can be used to adjust the inventory management parameters of different SKU classes. A cycle counting can be assigned to SKUs of significant importance, while also keeping in mind that SKUs with lower monetary value in ABC segmentation class B and C can be of significant importance, and those should be separately distinguished (Abby Jenkins, 2020) regarding implementation of service level.

When the demand and lead time are not independent of each other, another equation must be used (Peter L. King, 2011), explained next.

Normal distribution with uncertainty of demand and lead time, dependent relationship

When the relationship between demand and lead time variability is depended, it could imply that variation in lead time correlates with a variation in demand or vice versa (Peter L. King, 2011; ABC Supply Chain, 2023).

$$Z * \sqrt{L} * \sigma_{Demand} + Z * \sigma_{Lead\ time} * \mu_{Sales}$$

Normal distribution, Variability in Demand

When there is variability in demand, the below equation can be used (Peter L. King, 2011)

$$Z * \sqrt{L} * \sigma_{Demand}$$

Normal distribution, Variability in Lead Time

The previous equations assumes that the main culprit is the variability of demand. The below equation focuses on the lead time variability. When the variability in lead time is the main issue, the following SS equation can be used (Peter L. King, 2011).

$$Z * \sigma_{Lead\ time} * \mu_{Sales}$$

Max – Average Formula

The Max-Average equation assumes that the history will repeat itself. The Max-Average equation ensures that inventory is managed against extreme demand fluctuations. The equation is very simple to use but it often results in very high SS that is not reasonable. To get realistic results, outliers must be identified.

Outliers are singular events with higher lead time or demand than typically and this can throw off the result. The max should reflect the average maximums and only then the average should be taken.

Even if outliers are excluded, the SS equation covers the most extreme demand cases and the stock will be high all the time, increasing inventory holding costs and negatively affecting the inventory turn ratio. This is contradictory to goals of inventory management, which include reducing inventory holding costs and increasing inventroy turn ratio. High stock amount, however, is able to serve customers better and increase responsiveness of the supply chain.

$$(Max\ Lead\ Time\ \times\ Max\ Sale) - (Average\ Lead\ time\ \times\ Average\ Sale)$$

Safety Stock based on Forecast Error

A company can have different kinds of stocks besides SS, such as anticipation stocks and cycle stock, which is based on demand forecast. This is the stock amount that is expected to be sold when the forecasted demand realizes. SS alone is not always linked to the forecasting accuracy as its function is to act as a buffer against demand variations (Sujit Singh, 2021 B)

It is possible to use forecast error variance instead of the average demand and then take the variance of the average value. With this method, the SS levels either fluctuates up or down depending on the forecasting accuracy (Sujit Singh, 2021 B)

Often, the MAPE is used to measure the forecast error when calculating the parameter for the SS calculations. As MAPE is a classic measure of forecasting accuracy, using MAPE makes sure that the SS strategy is synchronized with the demand planning initiative (Demand Planning.net). Another source uses MAD for the forecast based SS (David McPhetrige, 2016)

Equation to calculate SS based on forecast error could be the one presented below, but it is not suitable to be used for SS calculations as estimating SS

should not be based on future (David McPhetrige, 2016) and other stocks like anticipation stock are more suitable for that kind of purpose.

$$Z * Z_{factor} * \sqrt{Lead\ time\ during\ forecast\ period * MAD}$$

Here, the Z is the service level and Z_{factor} is 1,2533 or $\sqrt{\frac{\pi}{2}}$ which enables the equation to be modified to MAD instead of using the standard deviation, MAD is the absolute difference between forecasted demand and realized demand (David McPhetrige, 2016).

2.8.2 Service Level

Depending on the ABC-XYZ segmentation, different service levels can be given to SKU in different segments. For example, the service rate or AX SKUs can be higher than for CZ SKUs (Frepple, n.d.). Thus, service level can be used to adjust the safety stock level. Service level determines the probability of not having a stock-out.

For example, if a company wants to have a 95% service level, meaning that there is only a 5% chance a stockout happens, the service level would be 1.65 A 100 % service level is almost never used as in reality that is unattainable and results in unrealistically high safety stocks.

The service level score for the desired service level can be found from the normal distribution table.

Service Level	Z-Score
0	50 %
0.5	69.15 %
1	84.13 %
1.5	93.32 %
2	97.73 %
2.5	99.38 %
3	99.86
4	99.997

Table 2. Z score table.

The Z score assumes normal distribution, the safety stock proposals might not always be sized right. The Z score does not have a linear behaviour, which can be observed from the Z score table.

2.8.3 Re-Order Point

ROP is the point when a new order is placed to a supplier. The surplus to the SS should cover the lead time of the SKU on top of demand variation. For example, if the SKU lead time is three months, the ROP surplus should correspond to consumption of three months, where the SS acts as a cushion for unexpected demand fluctuations.

Going below the SS in between of replenishment periods sometimes is considered healthy and it is a sign the SS and ROP are correctly defined. If the stock falls below minimum stock often between replenishments, it is time to evaluate the size of the stock levels again.

$$Average\ Monthly\ Sales * Lead\ time\ in\ Months + Safety\ Stock$$

For example, WC can be increased by making changes on ROP policies (Heta Haikonen, 2021), and for example, a low inventory turn can be a sign that ROP policies should be reviewed.

Economic Order Quantity

Economic Order Quantity (EOQ) could be the amount ordered when the ROP stock level is reached.

EOQ can be included in MRP-based inventory management. EOQ considers the cost of holding each SKU in stock, which may not always be simple to determine. It also takes into account the cost of ordering each SKU, which can also be challenging to determine. The optimal point for EOQ is when the costs of holding inventory and ordering are equal.

$$\sqrt{\frac{2 * Demand\ in\ a\ year * Ordering\ costs\ in\ a\ year}{Holding\ costs\ per\ unit\ in\ a\ year}}$$

The quantity determined by the EOQ is the amount that should be ordered when the stock level of an SKU reaches the ROP level. From the equation it can be determined that demand and ordering costs increase the order lot size and on the other hand, holding cost decrease the lot size. The more expensive it is to hold the SKUs, the smaller the EOQ lot will be.

It is important to note that the EOQ has some assumptions, such as the demand is stable, lead times are known and the price per SKU is fixed (Demand Solutions, 2014). In EOQ, only the ordering and holding costs are accounted for.

Besides assuming constant demand, other assumptions are that the demand is continuous, the lead time is instantaneous and the review period is constant.

EOQ assumes single-echelon inventory management with unlimited capacity and resources.

The standard EOQ formula does not account for supplier discounts or shortages, assumes SKUs are non-perishable, and operates on an infinite planning horizon (Chris Caplice, 2006 A). From this information, it can be concluded that EOQ is not suitable for SKUs that are scarce or have spoilage constraints. However, extensions to the EOQ formula exist which considers multi-location, incremental, one-time discounts or all unit discounts (Chris Caplice, 2006 B).

If EOQ is considered as model for setting order quantity, its sensitivity to order size, demand and order cycle time should be evaluated (Chris Caplice, 2006 A).

Other Review and Replenishment Policies

Review and Replenishment policy can be determined based on segmentation class and the policy can be either continuous or periodic. Inventory can be replenished using policies such as Lot for Lot (LFL), Production Order Quantity (POQ), or Part Product Balancing (PPB), which determine how much to order, in addition to EOQ (Muhammad Saeed, 2012).

LFL policy only orders against needs, which minimizes inventory obsolescence and it is a good choice for manufacturing environments where customized parts are needed. LFL cons can be long lead time and inaccurate forecasting.

2.9 Manufacturing Models

Different Manufacturing models can be used to reduce customer lead time. Depending on the nature of the demand, most efficient supply chain strategy should be chosen (Lee Krajewski et al. 2016 p. 512).

The manufacturing model can determine where the bottleneck in the supply chain is located. Modern supply chains are very diverse in terms of products

due to mass customization (MC), dynamic production and changing customer demand (Muhammad Saeed, 2012). .

Supply chains typically include various manufacturing models, such as Assemble-to-Order (ATO) and MTO, for example. When upstream processes in the supply chain are controlled, this leads to smoother operations downstream. Managing operational constraints can improve the customer delivery process. In order to achieve a smooth customer delivery process, the operational constraints within the supply chain should be identified (Muhammad Saeed, 2012).

Depending on the manufacturing model, forecasting or scheduling strategy can be different, depending on the management decisions.

Appendix 4: Manufacturing Model Comparison lists pros and cons of manufacturing models ETO, MTO, MTS, ATO.

2.9.1 Customer Order Decoupling Point

The CODP separates the point in the supply chain where the order is either customer order or forecast driven. Depending on the manufacturing model, CODP location within the supply chain is different. CODP is also known as Order Penetration Point (OPP).

The CODP separates the upstream and downstream activities of the particular manufacturing model, meaning that before the customer order, the activities are forecast driven and after customer order, the activities are customer order driven. The decoupling point also separates the value adding activities (Muhammad Saeed, 2012)

When transforming between manufacturing models, the transformation phase requires updating of demand and control system on top of planning tools and their reliability (Mason and Towill 1999). For example, this should be done when moving from ETO to MTO (Muhammad Saeed, 2012) or between any other manufacturing model, as the shift in CODP can affect the supply chain

efficiency or responsivity. It is good to note that if the position of the CODP and manufacturing plan are not aligned, supply chain inefficiencies can be more present (Aldo Sante Duchi, 2017).

The need for inventory control and at which stocking levels is a consequence of the CODP position (Aldo Sante Duchi, 2017) and thus, the CODP is a starting point for inventory policy design (Heta Haikonen, 2021).

For example, ATO, MTO and Design-to-order (DTO) are popular designs in responsive supply chains (Lee Krajewski et al. 2016 p. 512) and MTS model is popular in effective supply chains. Other models are Configure-to-Order (CTO) and ETO.

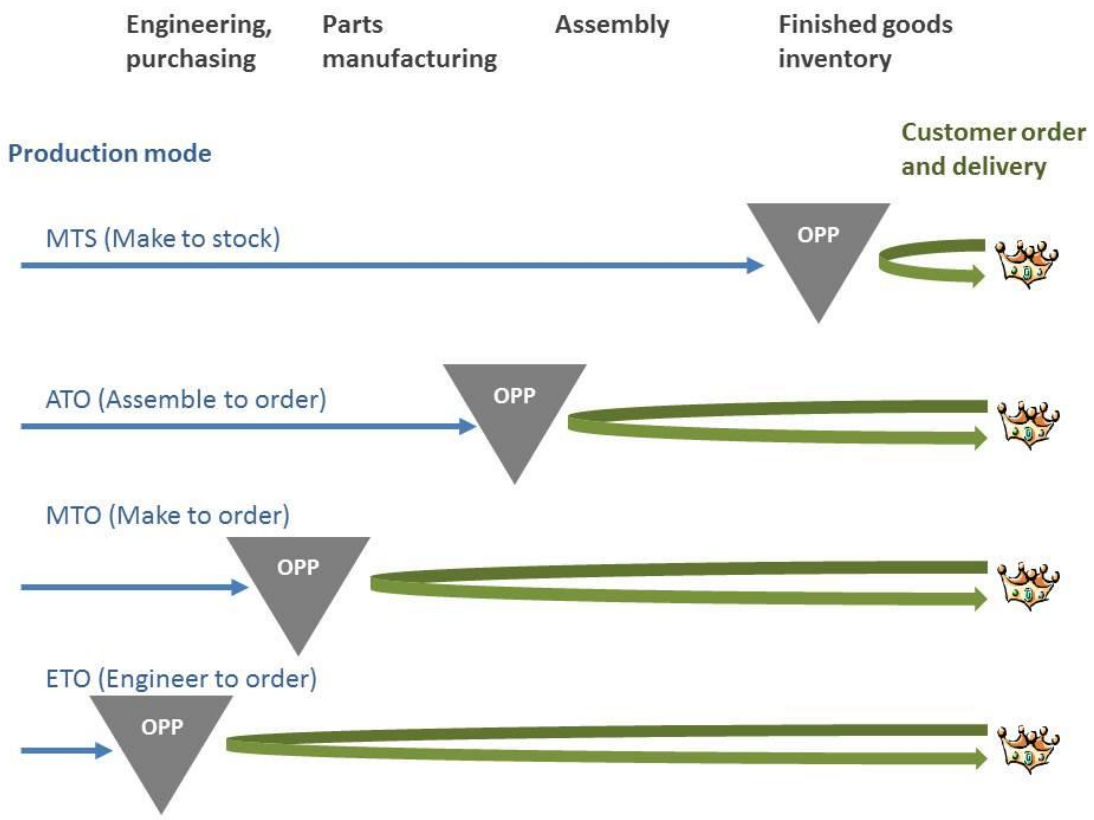

Figure 1. OPP – Order Penetration Point (Logistiikan Maailma, 2023)

Make to Stock (MTS)

One way to increase efficiency of supply chains is to use Make-to-stock (MTS) manufacturing model (Lee Krajewski et al. 2016 p. 512). Second solution is to reduce variability in order to increase efficiency.

Inventory related issues, such as disproportionate growth or aging of finished goods inventory is often the culprit of suboptimal alignment of forecast, demand plan, and Inventory Planning. In an MTS environment, monthly process is required to balance demand and supply (Philip Lee, Scott Sparks, 2020).

Main disadvantage of MTS is the reliance on the accuracy of forecasts. Forecast inaccuracy can lead to excess inventory, ineffective use of working capital and material spoilage (Thomasnet, 2019).

MTS approach is the opposite of MTO. MTO, is characterized as pull-type method and MTS is a push-type method, as products are pushed to production based demand forecast (Thomasnet, 2019).

Assemble to Order (ATO)

Assemble-to-Order (ATO) is the simplest manufacturing method after MTS. ATO is located in between MTS and MTO and all the engineering work has been completed previously. ATO products are catalogue products and customer specific modifications are not possible outside pre-defined options. As customers can choose from available options, diverse needs can be still served while the variety can be reduced. The level of configuration allowed in ATO is less than in CTO.

Make-to-order (MTO)

MTO should be chosen when the end-product SKU is highly customized, modular design is not possible, and the components used have highly erratic demand nature due to varying consumption rates among end SKUs, leading to lumpy

and unpredictable overall demand (E. Powell Robinson Jr. et. Al, 2008) making forecasting hard and inaccurate.

Companies that generally adopt the MTO approach may have raw materials in stock to produce or assemble products belonging to the final product, but the final product itself is not kept in stock. MTO is defined as a pull-type production method since demand is generated by direct customer order (Thomasnet, 2019). MTO allows a certain degree of product customization, where customers can choose from a set of predefined options or configurations.

MTO drawbacks include longer lead times to customers, as final products are not kept in stock. Depending on the complexity, lead time can be several months or longer, depending on the manufacturing queue and other factors. As MTO products are customized, they often cost more (Thomasnet, 2019).

Configure to Order (CTO)

Configure to Order (CTO) is a manufacturing model that shares characteristics of MTO and ETO. In CTO, customers can select from pre-existing components to configure their product. This model allows for a higher level of customization than MTO but requires less engineering work than ETO, since CTO products are known to function within specified configurations. The CTO model typically offers a catalogue of predefined components and supports modularity.

CTO products may vary significantly between orders as they are assembled from these predefined parts. By using pre-defined parts, it is possible to reduce inventory by offering selected combinations without full customization possibility.

Engineer to Order (ETO)

Engineer-to-Order (ETO) is often used manufacturing model for highly customized end products and each project is designed according to the specific requirements of individual customers. In ETO, production planning and project

management coordination is needed regarding design and procurement of customer specific components. As ETO manufacturing is always based on some customer specification and the final products are always built as projects, and project management practices are needed to finalize the delivery (Juha-Pekka Suomela, 2020).

Four different ETO archetypes exist. For example, a complex ETO can be a power plant built from scratch, where there is low standardisation and automation. In a basic ETO, such as asphalt mixing plant or a cable car, the standardization and automation levels are moderate. A repeatable ETO, such as bus or elevator, has high level of standardization and automation. The fourth archetype is a non-competitive ETO, where the repeat rate is very low and reflects companies where there are over 750 full-time employees working on customer-specific engineering, where over 2000 hours is allocated on one unit, and thus the classification for this is also complex (Paul Schönsleben n.d.). Non-competitive ETO thus relies on high volumes and time spent on engineering work. It is important to note that these definitions are not universal.

While each ETO project is usually unique and customized to some extent, between the different customer deliveries there are often features that remain consistent and engineering modifications are only moderate, enabling companies to utilize the similarities between orders.

2.9.2 “MAM” strategy in parallel with ETO

“MAM” parts consist of MTO (Make-to-order), ATO (Assemble-to-Order) and MTS (Make-to-stock) components. The so called ““MAM” parts” have already been designed and/or manufactured, making monitoring of them easy and there is no need for additional design work. “MAM” parts can have different inventory control strategies, similar to segmentation.

Often an ETO order consists of ETO and so called “MAM” class parts. Parallel processes for ETO and “MAM” components of the order could be considered.

“MAM” parts are typically processed in three steps, including offer preparation, production/assembling and delivery. On the other hand, ETO parts are processed differently, starting from feasibility and change study, engineering, supplier search and evaluation and evaluation for data maintenance and upgrade (Aicha Amrani et al. 2010).

When “MAM” strategy is applied, the “MAM” items should be managed accordingly to the specific manufacturing model, whether it is MTS, ATO, or MTO. Design of new parts which falls under ETO classification could be managed in parallel with “MAM” components, which can provide benefits such as reduced lead time (Aicha Amrani et al. 2010).

Risk associated to ETO and “MAM” parts is not the same, which should be acknowledged. Often the “MAM”-risks are known while ETO-parts risks should be identified case by case. Risk is either related to product or order fulfilment process (Aicha Amrani et al. 2010).

In ETO environments, capitalizing on the knowledge from past ETO components can lead to a competitive advantage. For example, an item initially considered as ETO can, after knowledge capitalization, be regarded as a "MAM" part. This can enable a faster order fulfillment process and the reuse of existing data for manufacturing purposes. Using existing data can help to solve new customer order problems more rapidly (Brière-coté et al. 2009; Aicha Amrani et al. 2010) and increase inventroy management efficiency.

ETO to “MAM” and component re-use is outside of the scope of the thesis but the concept is acknowledged from materials management perspective. Acknowledging the different strategies for each manufacturing model is beneficial when operating in mixed model environment.

Material Shortage Challenges of ETO and MTO

The material shortages regarding ETO might be different, as ETO projects might require more unique materials with long lead times and they might be

scarce to source. The customer order (i.e. project specific) components in ETO are sourced separately, which adds up to the lead time.

Despite if the final product being different between customers, the ETO orders often include standardized sub-assemblies, for example, which are re-used between different customer projects. These standard component and sub-assemblies demand can be forecasted, as well as stock parameters can be defined passed on past demand data. Keeping items stocked that are commonly used helps to complete customer projects faster.

Need for Inventory Control

ETO manufacturing is highly variable, but some characteristics might similar than in MTO (Willner et al. 2016). For example, a MTO can consist of a “Product family with many variants” and ETO is “According to (changing) customer orders”, also seen as a project based order (Aldo Sante Duchi, 2017)

ETO environment is also described as dynamic, where there are “strong fluctuations in mix and sales volume in short and medium term” and uncertain, which can be described as “unknown product parts; uncertainties of lead times, cost and capacities; process uncertainties” and complex, including aspects such as “complex capacity situation, multi-project character of the situation” (Aldo Sante Duchi, 2017; Olhager, 2003; Willner et al. 2013) and due to this, supply chain processes in ETO environments are highly unpredictable and their controllability is low (Konijnendijk, 1994) and because of this, delivery performance is a key competitive factor (Aldo Sante Duchi, 2017).

It is good to acknowledge that most of ETO companies are not exclusively producing only ETO products, and most of the revenues come from MTO products (Aldo Sante Duchi, 2017). In these cases, the order is only configured to the customer needs, but no exact engineering work is performed (Amaro et al. 1999).

Product configurations can be displayed within a solution space, which can be represented by a product configurator (Aldo Sante Duchi, 2017). Defining the product solution space or explaining it in the theoretical part of the thesis, is beyond the scope. However, this method is commonly used for ETO products that use at least a moderate level of standard components. The larger the solution space, the more challenging inventory management can become, as it involves tracking multiple items and/or suppliers while maintaining a high level of customer service. It is also good to acknowledge that the definition for “engineering work” may vary when it comes to ETO.

2.10 Forecasting

Demand forecasting attempts to predict the future and typically consist of statistical or causal models. Forecasting is done routinely, which can be monthly or weekly (Chris Caplice, 2006 C). Demand planning goes hand in hand with forecasting, as demand plan develops plans what the future demand will potentially look like. Demand planning is part of S&OP and includes input from multiple stakeholders.

Forecasting methods that use time series rely on knowledge of past occurrences to predict future events. Time series can reveal potential trends, which are typically linear, but can also be exponential or quadratic. Forecasting can also reveal seasonal variations, which are periodic in time. Cyclical forecasting is not tied to calendar but demand is still considered to be periodic. Forecasting can reveal that the historical data is very sporadic and unpredictable (Chris Caplice, 2006 C).

Time series are easy to construct based on the desired model and in time series forecasting, the importance of history should be assessed. For example in cumulative forecasting methods, all history is equally important. When forecasting, it is important to find a model that is both sensible and statistically valid before deciding which forecasting method to use (Chris Caplice, 2006 D).

When considering the lead time demand, which is the demand that is expected to realize during the duration of the lead time (Thymen van der Poll, 2017), different forecasting methods can be used. For example, if the historical demand is 10 SKU per month on average, and the lead time is 3 months, then the lead time demand is 10the 3 = 30 SKU, if assuming simple time series forecasting, such as moving average or naïve.

Time Series Forecasting

Naïve forecasting considers the most recent history to be of the most importance.

Time series models are moving average, considering only the last N observations and it is a mix of cumulative and naïve forecasting (Chris Caplice, 2006 C).

Exponential Smoothing

Exponential smoothing assumes different weight for each observation, which are weighted with a smoothing constant alpha (Chris Caplice, 2006 C). Demand forecasting for high volume products is successfully often most successful when using exponential smoothing methods (Ralph D. Snyder et al. 2010). When the alpha is 1, it is same as naïve forecasting.

Trend Adjusted Exponential Smoothing

Trend adjusted exponential smoothing considers smoothing factor alpha and trend adjustment parameter beta. Beta can either decrease or increase the forecast figure based on nature of the demand (Chris Caplice, 2006 C).

Linear and Quadratic Forecasting

Linear and quadratic forecasting methods are based on time series forecasting methods that use regression models to fit a linear or a quadratic function based

on historical demand expressed as data points relative to time. Linear and quadratic forecasting are both sensitive to outliers.

Planning BOM/Planning Bill/Average BOM

For example, kits and sub-assemblies can be forecasted with parent-child or planning bill methods (Larry Lapide, 2006). Planning bill is also known as Planning BOM. If a company manufactures configurable products, a planning BOM of kits, subassemblies or main products can be constructed with different weight based on the demand. When the demand mix changes, the planning BOM can be adjusted. Thus, the planning bill can be useful for determining demand and placing orders, especially for SKUs with longer lead times.

When using planning BOM it is important to distinct demand that is BOM depended on and BOM independent. Also, some SKUs might be used in several builds, which should be accounted cumulatively for the total planning bill (Tracey Baker, 2021)

Using the planning bill allows forecasters to account for a variety of possible options, as the planning bill represents the average combinations that can be sold. Planning bills can be utilized in MPS, MRP, and Distribution Requirements Planning (DRP) systems (Oracle Help Centre, 2013).

In conclusion, the planning bill can be viewed as the "average BOM," which takes the average of all sold configurations and can then be used for demand forecasting purposes. It is important to evaluate the reasonableness of the planning bill, and different weighting coefficients can be applied to modify the equation for calculating the average.

2.10.1 Demand Patterns

The forecasting method should be chosen according to the demand pattern. From a statistical viewpoint, it makes sense to base the choice of forecasting

based on the demand type. Different methods should be used depending on whether the demand is erratic or stable (Jonas Borgman, 2022).

Trend lines or exponential smoothing can be used to forecast short or medium term demands. For recognizing patterns, using polynomial trendline analysis while paying attention to the chi square value might be useful. Thus, it makes statistical sense to apply a different equation when calculating the demand for a product with erratic demand compared to one with slow demand (Jonas Borgman, 2022)

It can be beneficial to detect the outliers from the data in order to cleanse the data set used for forecasting. It is important to be aware that sometimes the outliers can be a genuine demand pattern, despite the outliers only appearing in the data sporadically. By identifying outliers, it is possible to improve forecasting and SS calculation accuracy. This can help to avoid over or understocking (Jonas Borgman, 2022). Same logic where outliers are assessed can be applied when calculating the SS based on mean and standard deviation.

When cleansing data, some intuition is needed to determine whether outliers are occasional anomalies or genuine demand patterns. For example, the same pattern may repeat itself annually (Jonas Borgman, 2022).

Forecasting accuracy can be monitored with control charts which helps to visualize significant deviations. Deviations and forecasting performance can be monitored in a tabular format as well. How often the forecast is updated is decided on case by case. When visualizing either demand or forecasting error, it is good idea to use conditional formatting tools to indicate the outliers if the qty deviates a certain amount from the mean.

2.10.2 Segmentation from Forecasting Viewpoint

Segmentation is important from forecasting viewpoint. For example, for new products life cycle method can used. For mature products, time series are more appropriate considering trend and seasonality (Larry Lapide, 2006)

Products that have been promoted or campaigned can be forecasted with time series and cause-effect methods (Larry Lapide, 2006)

Slow moving or SKUs with sporadic demand can be forecasted by Croston's or Poisson distribution methods (Larry Lapide, 2006)

Cannibalized SKUs can be forecasted using dependent or life cycle methods (Larry Lapide, 2006). Cannibalization in manufacturing can refer to a situation where a product is dismantled and its parts are used for more critical assemblies due to material shortages, for example. This can cause disruptions, such as delays to other customer orders. It is important to note that dismantling poses a risk for damage and other quality related issues. Products can be either cannibalized due to repair purposes or where a part might be needed for testing in more critical orders. Thus, it is not a bad idea to collect a list or other information of SKUs that gets cannibalized.

2.10.3 Forecasting Error Measurements

The validity of a forecast can be evaluated based on its accuracy, which means how well the forecast compares to the actual demand. It is also important to evaluate any bias in the forecasting process (Chris Caplice, 2006 D).

Forecasting errors, when using models other than historical ones, can stem from incorrect intuition or optimism. Sometimes, forecasts can contain strategic components, where demand is either purposely overestimated or underestimated. Demand can be forecasted higher to be on the safe side to not run out of materials and under-estimated when there is a reason the SKU might not be needed anymore, such as replacing the SKU with another SKU in production.

Common Error measurements are: CFE (Cumulative Forecast Error), MAD (Mean Absolute Deviation), MSE (Mean Squared Error), MAPE (Mean Absolute Percentage Error), MPE (Mean Percentage Error), RMSE (Root Mean Squared Error).

CFE measures the cumulative deviation of forecasted values compared to the actual realized demand over a given time period. The total CFE is the sum of all forecast errors, and the total cumulative CFE and can positive or negative.

MAD is the absolute value of CFE. Total MAD can be calculated by summing all the observations and then taking the average.

MSE is MAD squared. Total MSE is calculated by summing all observations together and then taking the average.

MAPE is MAD divided with realized demand for the same period.

MPE is the average percentage difference between the forecasted values and the actual realized value, and it can be either positive or negative unlike MAPE, which considers the absolute difference.

RMSE is the square root of the MSE.

Error measurements CFE, MAD, MSE, MAPE are used in the implementation part.

Dealing with Forecast Inaccuracies

The Sales and Operations planning (S&OP) process provides an input to the MPS process and further to the MRP Process. The idea of an MRP process is to provide plan for lower level BOM needs (Robert G. Ratcliffe, 2020).

Often issue is the conflicting interest of planning and purchasing departments, where planning wants to guarantee stock levels that won’t run out but also won’t

be too much, often results in the purchasing department placing too large orders, meaning that there is a tendency to order more than necessary to cover for the fluctuating demand. When the demand management process improves, the high level S&OP plan will become more efficient, which in turn ensures that the MPS and MRP processes are under better control, leading to improved planning of lower level components and thus reducing the excess inventory (Robert G. Ratcliffe, 2020).

Often, planners and buyers are responsible for forecasting. The forecasts they use are typically based on historical data, for example, the moving average method, which is just a prediction of the future and can often be inaccurate. When planners and buyers produce the forecasts, they may not be the most suitable groups for this task. The responsibility should shift more towards salespeople, who have the best view of the market (Robert G. Ratcliffe, 2020). Forecast focus of salespeople should be on the top level products and component forecast is better to be managed by other groups, such as planners or buyers.

Sales forecast should be produced on a regular basis by salespeople as the sales department is best suited to do so. It is important to understand that a forecast is still prone to errors. However, forecast than no forecast at all is still a better choice. A salesperson should not be disadvantaged by providing the forecast even when the forecast is compared to real actual realized demand (Robert G. Ratcliffe, 2020).

When demand is only sporadic, it is said to be intermitted. Companies with large-scale inventory typically have SKUs on stock which demand is intermittent and has low volume consumption (Ralph D. Snyder et al. 2010).

SKUs with intermitted demand might be of high value, and thus segmentation between value or importanacy to production should be conducted. Segmentation of products can help to deal with forecast inaccuracies or with implementation of different forecasting methods than time-series, such as market research.

When forecasting, it is beneficial to account for optimism bias, a psychological tendency towards wishful thinking. Forecast optimism might stem from customer demand signals rather than the forecasting process itself (Petter Næss et al. 2015). This bias can influence the forecaster's personal intuition regarding the accuracy of their forecasts.

Finally, forecasting inaccuracies can result from misinterpretations of strategy, and there is often a fine line between strategic misrepresentation and optimism bias. Personnel involved in forecasting may benefit from producing favourable forecasts (Petter Næss et al. 2015). It can be concluded that management should ensure that the strategy is interpreted correctly.

2.11 Frozen Period and Slushy Period

The Frozen, Slushy and Liquid periods are terms relates to MPS, where time fences are set for manufacturing processes. MPS is defined depending on production capacity, inventory levels, demand, efficiency, capacity utilization and lot sizes (R Amaranti et al. 2019).

When considering the sizing of the time fences, it is important to take into account the work created for manufacturing departments due to changes. BlueFors Oy utilizes a lot of MTS products, which are then utilized to build ETO/MTO products. Based on received orders or anticipated demand, in-house stock products that are common to many final assemblies are manufactured.

Before beginning to implement the frozen planning system, some policies should be reviewed regarding non-frozen interval policy, planning horizon length, frozen interval length and re-planning frequency. Besides internal policies regarding frozen planning, four different environmental factors should be considered, which are natural order cycle length, vendor flexibility, demand range and demand lumpiness (E. Powell Robinson Jr. et al. 2008).

When thinking of applying the frozen interval strategy, the total lead time, planning horizon, plan re-run frequency and the planning bucket length should be considered. Among these factors, the frequency of planning reruns most significantly affects the responsiveness of the plan. The higher the rerun frequency, the more responsive it is to customers.

Only the frozen period should be firmly implemented, while the slushy period should stay flexible to allow for modifications. When entering a new frozen period, a new firm plan is created that reflects developments from the initial frozen cycle and updates to the forecast (Shaun Snapp, 2010). By taking flexibility reducing measures, companies can optimize their entire supply chain and achieve better market position (Andreas Hahn, n.d., p. 48) and respond to customer demand with less disruptions. By having frozen period set up the company can serve their customers and stick to their promised lead time more often. Dividing planning into periods is a common practice in classical planning systems.

Last-minute changes require greater organizational effort, leads to process inefficiencies through the whole supply chain and as a result, a weaker position in competition with other companies (Andreas Hahn, n.d., p. 48) which should be considered early on, when the competitive situation is still manageable.

The time fencing concept is important and time fences are used to maintain the flexibility of production schedules, while accounting for changing demand situation due to sudden orders or change requests to MTO products (R Amaranti et al. 2020).

Liquid non-frozen interval strategy enables any changes to be made to the orders.

Frozen Period

Frozen period is the planning horizon where no changes are typically allowed. The frozen period should stay unchanged in order to not to cause disruptions to production and to increase stability in the operations and prevent chaos. The

frozen period might also be necessary to prepare sub-assemblies in time for the main production (Marcela Malindzakova et al. 2022). The policing of the frozen period and under which circumstances changes are allowed should be defined to guide decision making more efficiently.

In order to make changes to the frozen period, a policy requiring senior managements approval should be implemented as capacity and materials are reserved for specific customer orders and changes to lead to increased costs or otherwise disrupted production. Frozen period length is determined by demand time fences (Pak Supply Chain, 2010). Demand time fence examples are DTF (Demand Time Fence) and PTF (Planning Time Fence) (R Amaranti et al. 2020). Typically, orders within the non-frozen can be modified regarding timing and quantity over the subsequent planning cycles. Allowing modifications to be only made after the frozen time fence helps to maximizes the scheduling flexibility (E. Powell Robinson Jr. et. Al, 2008)

As the Frozen production fences production and sets time intervals for which a company doesn't change its production plan for a product. For example, if the plan is frozen for a month, the plan is frozen and no changes are accepted. The period after that can be changed and adjusted for changing demand. The idea of frozen periods is to minimize disruption to schedules as production disturbances decrease efficiency. It is important to acknowledge that frozen periods also result in reduced flexibility, agility and responsiveness (Steve Banker, 2019).

When frozen periods are used, Frozen Ordering System (FOS) is a viable and recognized term to describe the planning process. For the duration of FOS, Demand forecasts have been confirmed for the entire duration of the frozen period. Determining the length of the frozen period involves considering the trade-offs between decision making frequency and the validity and availability of information at the decision time. In the beginning of each new frozen period, the inventory levels are analysed every T period and based on available stock a

sequence of manufacturing activities are scheduled for the duration of the frozen period (Zhaotong Lian et al. 2006).

In most cases, the frozen period is between two to three months and the planning horizon is usually shorter than lead time for materials. This is one of the reasons that changes to plan during the frozen period directly affects the whole supply chain. The changes to orders might affect the other customers of the company as well, if the changes require components reserved for another customer within the frozen period, and the lead time is not able to cover the need (Marcel te Lindert, 2023). With the frozen period the bullwhip effect can be also controlled, as it I can exclusively describe the uncertainty of the supplier (Andreas Hahn, n.d., p. 48).

Calculating the frozen period length typically consist of accounting for the order review time and lead time. The length of the frozen period decreases the responsiveness of the company, so there is a trade-off between responsiveness and flexibility, as the philosophy behind the frozen period is to reduce customer flexibility in order to achieve less disrupted manufacturing operations. However, despite customer flexibility is reduced the company is able to respond to customer demand with increased punctuality (Shaun Snapp, 2010).

Slushy Period

After the frozen period, which length can be determined case-by-case, a slushy period of length of X is following. Changes to the slushy period are allowed if justified (Marcela Malindzakova et al. 2022). Thus, the slushy period can accommodate changes to production plan to certain extend. Determining the amount of amount of schedule flexibility allowed within the non-frozen time period, or the slushy period, which is the period from the frozen time fence to the end of the planning horizon is important from planning frequency perspective.

In the slushy zone, production capacity and material reservations are less committed to specific customer orders. In the slushy zone, changes to orders can be negotiated between sales and manufacturing. In the slushy zone, ensuring

availability of capacity and material resources should be guaranteed before changes are approved (R Amaranti et al. 2020). Having schedule and order modification flexibility can cause disruptions to inventory management and preparing for order modifications affecting inventory levels and subsequent manufacturing or design load changes should be accounted for.

Liquid Zone

A liquid zone, which follows the slushy period, enables any changes to be made as long as the changes stays within the capacity limits set by the production plan (Pak Supply Chain, 2010). Changes made to the different planning zones requires different management and approval processes. If the changes are outside the cumulative lead time period, the easier the change requests are to implement (R Amaranti et al. 2020).

2.12 Event Based Planning

Besides frozen and slushy planning, another viewpoint is to employ event-based planning. A pure frozen planning does not allow changes, but event based planning differentiates in a way that it allows changes made based on event significance. Event based planning requires constantly up to date information about stock, order and work progress in order to be able to make informed choices (Shaun Snapp, 2010).

3 Dimensional Data Model

Having a data model conceptualizes the Data Warehouse (DWH) and helps identify both important and redundant data. Additionally, the Data Model aids in defining relational tables, desired data fields, primary keys, and foreign keys (David Taylor, 2023).

Since data models are built around business needs, it is important to involve various business stakeholders in defining the requirements to create a coherent data model. This process begins with collecting information about business requirements from different stakeholders. The collected information is then structured and transformed into a database design (IBM, n.d.).

Typically, dimensional modelling consists of four steps. These steps are 1. Selecting the business process i.e. the Business Context, 2. Declaring the granularity, 3. Identifying the dimensions and 4. identifying the facts (Kimball Group, 2013). The business process generates events that translates to facts in the fact table.

The data model abstraction level can be typically described with three different levels. These are conceptual, logical and physical data models (IBM, n.d.).

The Conceptual data model provides a big-picture view of the business context, detailing how data is organized and which business rules are applied. This model is often created during the initial project requirement definition phase. It can include characteristics and constraints of the data, relationships between data entities, and definitions of data integrity requirements (IBM, n.d.).

Logical data models are less abstract and provide a more in-depth description of the desired concepts and relationships between data elements. These models do not specify any technical system requirements but identify attributes such as data types, their corresponding lengths, and the relationships between different data fields. Logical data models are typically suitable for Data Warehouse (DWH) or reporting systems development (IBM, n.d.).

Physical data models provide a schema for how the data is going to be stored within a database. The physical data model has the lowest abstraction level. The physical model should be so clear that the design can be directly used to implement a relational database, including all the required tables, primary and foreign keys to link the relations (IBM, n.d.).

3.1 Data Modelling

Data modelling consolidates multiple data sources into a single semantic model, offering a structured, streamlined view of the data (Microsoft Azure, 2023). When visualized, the data model should provide clear and actionable insights that are understandable to everyone. It serves as a blueprint of what the Data Warehouse (DWH) should resemble when the combined fact table is developed. The development of the data model may involve several iterations concerning definitions, required data fields, and fields that will be excluded.

Granularity

The grain or level of granularity determines the level of detail of the data, where atomic level is the most detailed level that is generated by the business process. Each dimension or fact should be consistent with the granularity level (Kimball Group, 2013).

Business Context for Data Modeling

The business context provides a framework for the development initiative and includes detailed description of the data model. The business context refers to the specific circumstances and conditions of the Data model and PBI view. The PBI solution is tailored to the specific use case based on the specifications.

The context should make clear the requirements, objectives and challenges of the solution. The requirements often are unique to each business case. Having clear requirements, objectives and challenges formulated is essential for efficient development process. The outcome should support the company’s

strategic goals, address specific issues and provide meaningful insights for business users of the data model and PBI dashboard.

The organizational workflow and processes affect how data is generated and utilized. Therefore, the PBI report should consider the data’s meaning, source, and other relevant aspects to ensure a coherent understanding. Additionally, the data's quality should be considered, including identifying relevant data sources, such as data tables, and defining how to classify and filter the data. This may involve adding different row-level security restrictions based on the viewer's role.

It is also important to consider the business needs and what the business users expects. Executives, managers, and different office role staff might have different requirements and needs. The data model should provide clear and actionable insights for everyone to understand.

3.2 Facts, Dimensions and Measures

In database and data warehouse use cases, facts, dimensions, and measures are often used to model and organize data. A data model enables efficient data analysis. The distinction between facts and dimensions influences data models and the ways in which data can be visualized (Dashboard Fox, 2022).

Dimension tables provides descriptive attributes to the fact table in BI applications. Dimensions can be used for filtering and grouping facts (Kimball Group, 2013). When dimensions are determined, the desired columns from the dimensional table can be selected to expand the informational value of the fact table.

A fact table should only focus on a single business process. However, dimensional tables can be re-used for different business processes with separate fact tables (Kimball Group, 2013).

Facts

Facts represent the numerical or quantitative data in an analysis and can be any measurable quantity or attribute within a dataset. Essentially, the fact table serves as a record-keeping tool and it is not directly influenced by the reports generated from it. The fact table should include those events that are recognized as important by the business need and always contains a Foreign Key (FK) that links to a corresponding dimension (Ralph Kimball & Margy Ross, 2013, pp. 41-42). Over time, as more events are recorded, the fact table can grow in size.

Facts can be summarized, or various values can be calculated from them using mathematical functions like sum, average, maximum, and minimum. Examples of facts include SKU ID, Customer ID, time stamp of the event, quantity sold, or quantity received and goods sold.

Multiple dimensions can be linked to the fact table. The dimensions give more context to the data, and dimension data can be qualitative.

Dimensions

The dimensions of a fact are stored in a dimension table, which is linked to the fact table by a foreign key (Dashboard Fox, 2022). Often, dimensions provide additional information to fact tables, resulting in fewer rows in dimension tables compared to fact tables.

Measures

A measure is a calculated property of a fact that provides relevant metrics. Measures are similar to Key Performance Indicators (KPIs). The data model should support the calculation of different measures, and the construction of the tables should be designed to enable these calculations. In Power BI, calculating various measures is made easy through the use of Data Analysis Expressions (DAX).

3.3 Data Warehouse

Data Warehouse is a relational database and its structure or schema of the data is determined based on the business requirements, which are then optimized for SQL querying. The Data model, DWH use case and PBI dashboard are developed based on the business context definition.

The DWH, besides being a relation database, is a centralized repository for data that stores structured data and/or semi-structured data for reporting and analysing purposes. Using a DWH can enable businesses to make more informed business decisions. Data can flow into the DWH from various sources, such as business applications and relational databases (Microsoft Azure, 2023), thus necessitating its organization in a centralized manner.

As the DWH can store large amounts of data, it is especially useful for reporting and Business Intelligence use cases. The PBI report is directly connected to the DWH, which is the data source. The DWH and PowerBI are complementary technologies for analysis purposes. Core reporting in a DWH setting refers to the process of generating reports from data stored within the DWH (Microsoft Azure, 2023).

Since business definitions can vary between functions, a DWH presents an opportunity to align the definitions and goals of different business functions. For this reason, it is important to describe the intended use of the model, such as analysing data for demand and supply-related questions.

Some weaknesses include the requirement for a strong understanding of data modeling and PBI architecture to maintain the DWH (Senturus, 2022).

Benefits of Data Warehouse

Benefits of DWH can be the ability to consolidating data from multiple sources into one single source, including storage of historical, cleansed, and

transformed data with better security and access control to data, data analytics and visualization (Microsoft Azure, 2023).

The benefits of DWH combined with PBI are visualized reports, automated insights, historical data availability and combined data from multiple resources.

When designing the DWH, it is important to consider the long-term and ad-hoc goals of the company, the nature of the data, the number of integrated data sources, whether workflows will be automated, and how the data will be analyzed. The requirements determine how the DWH will be built and vary depending on the complexity of the needs (Microsoft Azure, 2023). Understanding the business context is crucial for defining the requirements.

3.4 PowerBI

PowerBI is a cloud-based analytics tool which enables businesses to visualize data using the unified, scalable platform with self-service capabilities for Business Intelligence purposes. To get the most out of PBI in conjunction with DWH, the business context needs to be clearly defined. The business context or business case for the data model development for this thesis is explained under proposed solution section.

PBI enables quick access to processed data for valuable decision making. The DWH's ability to store historical data and snapshots aids decision-makers when deviations in data are detected. For example, automated snapshots taken at the end of each month can provide important information for comparing the status of KPIs across different periods and historical data enables detecting possible trends or seasonality in data. Because the data can be consolidated from multiple sources in the DWH, it can help the company to see the bigger picture.

The measures in PB are written by utilizing DAX. Each measure performs some type of aggregation, such as sum, average or count (Metropolia PBI Course, 2023).

Business Intelligence

In general, the goal of BI is to improve business performance, leverage business information, business analyses, and support decision making. The designed BI application can provide better business insights. BI can automate and streamline decision making process (Steve William, 2016).

Typically, BI is divided into three categories, which are performance management processes, revenue generating processes and operating process. Operational class includes activities like purchasing, manufacturing, logistics, demand forecasting, S&OP as an example (Steve William, 2016).

For manufacturing companies, BI provides high-quality information and analyses about key aspects of operations, offering the means to analyze and classify data by plant, customer, product, business unit, and so on. BI also enhances the capability to conduct predictive analytics, allowing for the identification of changes in demand patterns before they become issues (William, S., 2016, pp. 64, 114).

For example, BI can automate various tasks that were previously completed manually using Excel. This approach allows for more efficient use of time and reduces errors in work-related tasks.

A general BI-enabled business improvement project begins by recognizing the business need before the development on the dimensional data model starts. The business needs can be uncovered by discussing them with business representatives in order to understand their objective (Kimball Group, 2013).

BI tools can be scorecards, dashboards, multidimensional analyses, ad hoc analyses , advanced analytics, predictive analytics, and alerts (Steve William, 2016). In the background of BI use cases, there is usually a defined data model.

Data Visualization in PBI

It is important to visualize the data in a coherent manner. The relevant information should be visualized in a way that decision making becomes easier. By visualizing data, understanding of complex data sets due to data displaying of patterns, trends and how the data has evolved. Data visualization helps to map the data into chunks or buckets that are easier to interpret (David Brown et al. 2018) and thus, visualisation helps to communicate the data more clearly.

If data is not visualized, some data can become unactionable due to not being able to see the patterns, trends or how the data has evolved (David Brown et al. 2018). Depending on the nature of the data, the visualization method should be chosen appropriately. A good data visualization synthesizes and contextualizes all of the relevant information of the dataset (Netquest, n.d.).

The lay-out scheme is also an important part of the report. In the layout, the visual elements of the report should be placed in an organized manner to the report or layout is easy to understand. When all the visualization elements are integrated in the report in an easy to grasp manner, the infographic value of the report increases (Netquest, n.d.).

The visualized KPI should make sense and additional descriptions what the data presents should be made available for the report users. In some cases, users can be given access to the data to verify its correctness (Pricewaterhouse-Coopers LLP, 2007).

In the case of the thesis, the data is direct query from ERP database where users can cross check the correctness of events. For example, a KPI rising or decreasing might not always mean action needs to be taken but it can be a signal of a trend that has been recognized previously, and the KPI will probably return back to normal limits.

If there is industry specific terminology in the KPI’s report, the terminology should be explained as well. Also, KPI’s used should be relevant as well. Often

it is a good idea to include metrics that directs the company towards a strategic goal. Typically a good number of KPI’s is between 4-10 in order to not lose sight (PricewaterhouseCoopers LLP, 2007).

It is also possible to use “other performance indicators” that are less important, but in such case, these “KPI’s” should be clearly distinguished from the important metrics (PricewaterhouseCoopers LLP, 2007).

Data Analysis Expressions (DAX)

DAX enables the creation of calculated columns and measures. Adding columns and measures enables addition of new data to the table. In order to be able to create calculated columns or measures, the data model should be modelled in a functional manner as the model affects how the calculated columns are calculated.

DAX uses velocity database engine and returns the results from the stored data. Data is stored in columns instead of rows (Metropolia PBI Course, 2023)

PowerBI utilizes IntelliSense which helps to autocomplete the DAX code and help to discover the user to discover new DAX functions (Metropolia PBI Course, 2023)

4 Current State Analysis

Before the work on the thesis began, the company had no Inventory Planning practices in place. This caused stock-outs and overstocking. Stock-outs cause delayed customer orders and manufacturing disruptions.

Regular and systematic Inventory Planning practices were missing, including maintenance of inventory parameters, maintenance of critical availability, which is impacted by out of date inventory parameters. It was not decided who is responsible for Inventory Planning or maintaining SKU specific parameters, which causes inefficient handling of inventory related issues. Often and for many SKU, the SKU parameters were not correct and up to date.

Reasons which were enhancing issues to meet customer demand include selling to customers with too short lead time, causing stock levels to deviate from plan. Causes for selling with too short lead time are past habits during time when demand was not so high and promising availability was less complex to estimate, and out-of-date inventory parameters or insufficient knowledge.

Second important missing feature was the lack of control regarding last-minute changes to orders. In the past and currently, last minute customer changes were accepted without consequences to the customer, such as extra-cost or delayed shipment out of the original, which caused delayed shipments of other customers order and internal manufacturing scheduling conflicts.

It is important to note that a forward looking plan was not established, which guides the company to have better control of inventory for the future. This includes a plan how to manage growing demand efficiently.

Current state analysis findings included high increase in stock levels without corresponding demand to even out of growth in stock. Besides having unreasonably high stock for some SKUs, on the other hand, the material shortage list, which is created weekly, visualises the missing SKUs in the backlog, current week and up to three next following weeks that will potentially cause production

related problems. By systematic inventory management, the list of missing materials should gradually begin to decrease.

Current Main Forecasting Method

Currently, in the company the main forecasting method is Planning Bill. Thus, forecasting method is often highly inaccurate, often resulting in excess forecasting, or sometimes not able to cover for unexpected needs.

The deletion of manufacturing Works created to cover excess forecasts and the need to delete the Works is a monthly observation during balancing of workload. The high forecast error increases manual ERP entry related work significantly, and it would be ideal to find more effective ways to handle the over-forecast issues, in order to focus more on activities that create value, for example, besides gaining better control over inventory.

Currently, there is no analysis done of the Planning BOM forecast creators regarding how much of them are converted into actual needs and how much of the forecast needs are removed.

Manufacturing Models Used Currently

BlueFors Oy has few baseline system options, for which customers specific engineer can be allocated based on the wishes of the customer.

BlueFors Oy manufacturing models are mainly ETO, under which can fall assemblies that are considered as MTO and MTS, for example. Classification of the products under the manufacturing models or time spend for design process on average is outside the thesis scope.

ETO orders have a project management approach, which is usually a distinguishing management principle between ETO and MTO. Considering that the final product is a customer delivery project, where coordination between customer and sales, engineering, installation and so on is needed, handling

projects as ETO is simpler, even if the specific customer order does not include any unique engineering work.

By looking at the order history of the case company, the systems are not exactly the same on a general level between customers. Thus, the BOM of each system is different, indicating that there is a clear design process.

Despite the products being ETO, the BOM of many orders includes mainly stocked products or internally manufactured standardized sub-assemblies, but some parts are often engineered based on customer specific dimensioning, despite the engineering process just including variation in dimensions and not necessarily innovating something “new”, and old accumulated knowledge can often be utilized for the “engineering work”.

Appendix 4: Manufacturing Model Comparison lists pros and cons of manufacturing models ETO, MTO, MTS, ATO.

Appendix 4 can provide further insight into the different manufacturing models used by the case company from inventory management perspective.

Forecasting Focus of the Manufacturing Model

In ETO manufacturing models, commonly forecasting is not the focus, because order request is only triggered once there is a need, i.e. they follow a LFL principle. This is mainly for engineering specific items.

Alongside ETO, components or assemblies that fall under MTS and/or MTO require forecasting for baseline components and sub-assemblies common to all orders. This is essential to ensure streamlined production capable of withstanding demand volatilities. The majority of the components are common to many orders, and overstocking or understocking these components can create various issues, as discussed in the theory section. Due to variability in systems, the demand for baseline parts is often erratic.

5 Proposed Solution

The proposed solution for inventory management is a Business Intelligence based analytical tool. The BI tool is designed to streamline and enhance the efficiency of managing inventory levels by providing real-time insights and data analysis. BI reporting will integrate with existing systems to gather and process inventory data, allowing for more accurate decision-making. The BI tool will also feature customizable dashboards and reporting functions, enabling business professionals to easily monitor key performance indicators and trends. The proposed solution aims to optimize stock levels, reduce costs, and improve the overall operational efficiency of inventory management. The inventory reporting will provide insight into S&OP process.

S&OP is closely linked to Inventory Planning. S&OP consists of aligning sales, production, and inventory plans to meet customer demand. Inventory management will be integrated within the monthly S&OP process and aligned with higher-level business goals. S&OP process discusses inventory development-related events and so on in a cross-functional setting.

The input of Inventory Planning to the monthly S&OP process includes data and insights gathered from the PowerBI inventory dashboard.

Initially, the focus is on purchased SKUs, and then the Inventory Planning process is extended to include other processes such as service kits and manufactured items. Purchased items are easier to control regarding calculating the stock parameters, as there is no need to consider the routing of manufactured SKU or different production stages, such as having raw materials, WIP stock, semi-finished and finished goods.

Manufactured items are excluded from the first phase of the inventory planning project because the processes involved in handling them are different as they move through the manufacturing chain via different routings, and might include raw material stock, sub-assemblies, WIP or final products.

5.1 Solution for Analytics

PowerBI dashboards are used for analysis insights. To be able to utilize PowerBI for data analysis, the data model needs to be defined, as the inventory monitoring and planning is done by utilizing data accessed through PowerBI using DWH as a data source.

It is possible to use different data sources in PBI, but the solution for the proposed inventory analysis is to use DWH. The best way to do this is to develop a consolidated DWH. Processing data that is non-consolidated makes data reporting slow.

Once the data model is finalized, data can be accessed through PowerBI. Insights from the data can be accessed and inventory related decisions can be made required in the “Gather Data” step.

Data validity confirmation

The data validity was first confirmed in Excel and then in a PBI using the same raw Excel files as source material. In the original Excel, inventory calculations were performed by using Pivot tables and charts. The data model development was then easier to start when the functionality of data was tested, and the testing in Excel and PBI helped to identify required tables and columns. As the data worked well in Excel and BPI with data from ERP, the DWH data can be also confirmed to be correct regarding calculations logic.

5.1.1 The Business Context of the Data Model

The DWH model should be described in detail in the business context, and there should be no room for misunderstanding in order to have a swift development process.

Because the DWH is developed by external personnel, drafting the business context is a requirement for the developers. Once the business need is

recognized, the granularity for the fact tables is decided. The granularity of the data model is daily. the Time period considered spans the past 24 months and includes all future demands.

A Mock-up of the desired data model is made on Excel as informational material for the DWH developers to supporting with the DWH development. In the Mock up description, the combined fact table and identified dimensions are described along with their table names that can be SQL queried.

5.1.2 Data Model Description

The inventory data model development, i.e. the business process to be analyzed starts by identifying the business process. The DWH is optimized and transformed to fill the requirements stated in the business context of the inventory model. The DWH provides a single source of truth for the whole company. .

The inventory model provides an efficient way to create and view stock projection value using SKU last price for valuation purposes along with a way to see the sum of total demand per SKU, also on aggregate level.

The inventory model provides an efficient way to create and monitor SS proposal formula based on average demand, demand standard deviation and actual lead time. The actual lead time can be compared with lead time data from the SKU master.

In the model, the demand is defined as material reservations for internal needs and sales orders currently in the books. It is also discussed if stock transfers are seen as demand during the project.

The data queried from the DWH should then be arraignable or filtered based on data type, which can be either material reservation, purchase order, sales order or works. These are the main identified data tables.

The data model includes differentiating between actual and open demand. Actual demand is consumed demand and open demand is demand that is in the future and confirmed in more or less firmed date. These can be differentiated by different columns used in the ERP system.

Facts Related to This Thesis

Constructing the data model for the DWH includes having to know the table and column names from the ERP system. These are tables that are used by the business process. Then, the multiple tables are combined together to form a single consolidated data view to act as the fact table. From these tables, identifying columns stating whether the event is Work, Purchase Order, Material Reservation or Sales order is essential. Qty is + for incoming material and - for outgoing material.

Dimensions Related to This Thesis

The fact table is linked to several dimensions with FK and PK for optional descriptive information for the user. The Dimensions are decided based on required descriptive data. The data model includes a few different dimensions, such as time and customer dimensions.

Measures Related to This Thesis

A short description of the measures is included, along with how the report visuals should look like. The measures are calculated from fact table. The measures that will be part of the inventory model for example are Rolling lead time and demand for 3, 6 and 12 months, actual lead time in days and months, realized and open demand.

Priority 2-4 measures are DOS, DIO, Inventory Aging, and others. The non-first priority measures are not focused on the first Minimum Viable Product (MVP). These measures, or KPI, are also explained in the corresponding theory section.

In short, the data model and the measures are developed based on the definitions stated in the business context. In this case, the business context of the inventory data model is to be able to efficiently create and view stock projections in an aggregated level. Measures are calculated from facts.

The measures enable improved control over the inventory. Inventory control can be improved by accurate inventory budget control and utilization of measures regarding how well material management performs (Heta Haikonen, 2021). KPI can be used as a performance management tools.

5.1.3 Description of the PowerBI view

The PBI view with the help of the DWH running on the background, refreshed once a day is able to visualize stock projection, which shows the stock projection and how it develops in time buckets over time, taking monthly snapshots.

In the company ERP system, stock projections are viewed per SKU in “Balance Profile” module. The developed data model creates a replica of this view by combining several different tables to a single table on the DWH side. On top of combining different tables, measures are needed.

In the inventory data model, the stock projection will be viewable per supplier, supply mode, and so on. The stock projection is able to view consumption and replenishment orders in combined manner, including other specifications requirements described by the business context.

The daily, weekly, monthly, quarterly and yearly buckets are included and can be sliced within the PBI view. The formula used to count these should show the value based on last day value, which is the last day of the month.

Visuals that will be included in the PBI view are stock projection in time buckets, which is able to view consumption and replenishment orders in combined manner.

The fluctuation of demand is compared against average demand. Besides average demand, demand variation and how it varies from the mean is visualized. Demand variation includes taking the standard deviation of historical data and putting the information in a graph.

When visualizing Lead time, Actual lead time is compared against lead time from SKU master data, which is the latest accepted average lead time that is stored in the ERP system. Variation in actual lead time is also measured. This is compared against average of actual lead time.

5.2 Steps

The solution suggestion for the problem beings with mapping out important steps for the Inventory Planning project. The Inventory Planning process consist of six steps. The 6 step process is an end-to-end process excluding the review step, which is a continuous process.

Figure 1. Process Chart of the Inventory Planning Process

5.2.1 Define Stocked SKU

In the first step, SKUs that need inventory management are identified.

SKUs are classified by conducting ABC-XYZ analysis for critical SKUs. Different inventory management methods are then applied to the SKU's in each corresponding class. The management principles of different segmentation classes will be decided later on and these were not the focus of the thesis.

Pros and Cons of ABC and XYZ, among others, are included in Appendix 3 table.

Item ID	Supplier	ABC Total %	ABC Class	CV	XYZ Class
Item 1	Supplier A	64,68 %	A	0,94	Y
Item 2	Supplier A	11,69 %	B	1	Y
Item 3	Supplier A	10,16 %	B	0,95	Y
Item 4	Supplier A	9,41 %	C	0,89	Y
Item 5	Supplier A	1,98 %	C	1,1	Z
Item 6	Supplier A	0,98 %	C	1,09	Z
Item 7	Supplier A	0,13 %	C	3,54	Z
Item 8	Supplier A	0,01 %	C	0,33	X

Table 3. ABC analysis and calculation on CV is performed. ABC Analysis in this case is for A < 75% B < 90% and rest is C. Limits for CV are >1 “Z”, >0.75 “Y” and otherwise X.

For the segmentation, the time frame was last 12 months. The columns Spent, Average quantity ordered and Standard Deviation are not included in the table.

5.2.2 Gather Data

The gathered data includes data of demand, actual lead time, lead time from ERP system for lead time comparison, minimum stock and supply mode. In the thesis, only purchased SKUs are analysed.

From the gathered data, an inventory projection data model is developed which is later on used to visualize data.

The gather data steps include drafting the business context for the dimensional modelling, which included identifying the tables from the ERP system that are used by the business process.

The demand history was studied for ROP and SS for critical suppliers. For the SS and ROP, average monthly sales were calculated based on rolling 12-month historical demand data, considering the actual average lead time. The actual Lead Time is the difference between order placing and receiving data. The standard deviation of both lead time and demand is required for the equation.

5.2.3 Define Inventory Levels

In the third step, based on the gathered and analysed data, new SKU parameters are defined. These include minimum stock and lead-time updates. In this context, minimum stock and safety stock means the same thing.

There are multiple possible equations for determining the SS, but the one with variability in demand and lead time is used in this thesis work. Different SS equations are compared in the corresponding chapter.

The equation used considers service level Z, lead time, demand standard deviation, demand and lead time standard deviation.

The first step in any SS calculation is to measure the demand variability and demand standard deviation.

As the demand is not constant over time, determining in which time buckets the demand is measured it can affect the statistical distribution of the demand. In this thesis, the demand is measured in monthly buckets.

$$Safety\ Stock = Z * \sqrt{L * \sigma^2_{Demand} + \mu^2_{Sales} * \sigma^2_{Leadtime}}$$

When the minimum stock is defined, it is important to note that there might be some characteristics that cannot be seen from the data. Various considerations should be taken into account, such as contractual questions, constraints, supplier relationships among others. Max-stock can be defined for SKUs if applicable due to size limitations, but this is adjusted manually.

5.2.4 Define Re-order Point

ROP (ROP) is defined based on previously analysed data. ROP is the point when a new order is placed. ROP is larger than the SS. ROP considers lead-time defined during the previous steps.

Target stock levels regarding the SS account for unexpected demand or delayed replenishment orders. This ensures that that there are no disruptions to operations.

$$Average\ Monthly\ Demand * Lead\ time\ in\ Months + Safety\ Stock$$

An important step in implementing the ROP is to evaluate suitability of ROP from ERP technical limitations perspective. Because of ERP system technical limitations, ERP related process changes need to be implemented to get the ROP feature to function as desired. This would require, for example confirming the material reservations for a pre-defined time according to Frozen planning principle.

Previously it was not controlled in which sales order stage the material is reserved and excluded from available stock. This is a concurrent development topic/project but falls outside the scope of this thesis.

When the stock falls below the defined ROP, an automated purchase proposal is generated. In critical purchases, the ROP rules and such are given less attention and decisions are based on other reasons.

The order policy, such as EOQ, or some other, is not within the scope of the thesis. Regarding the amount ordered at the ROP, using EOQ for BlueFors Oy Inventory Planning may not be feasible because for many SKUs used, SKUs need to be sourced strategically. EOQ is only vital for SKUs that has a regular stable demand.

In the below calculation for SS, the service level 1 is used.

Item ID	Current Balance	LT from ERP Data	Rolling 12 Months LT	Purchase Time Difference in %	SS Rolling 12 Month Data	SS ERP Data	ROP LT Rolling 12 Month	ROP ERP Data
Item 1	114970	4	5	0,2	9928	9580	31740	27262
Item 2	16246	4	6	0,6	5366	5150	18443	13554
Item 3	21381	4	3	-0,2	5232	5379	14894	18129
Item 4	8679	4	7	0,9	1615	1556	6008	3843
Item 5	4517	4	3	-0,3	425	475	1705	2260
Item 6	222	4	1	-0,7	63	107	121	280
Item 7	22	4	3	-0,4	17	22	48	73

Table 4 Example ROP and SS Change Suggestions based on Rolling 12 Month Data.

Average Qty Ordered 12 Months, Stdev.P Demand Total and Stdev.P Lead Time are excluded to make the table fit and this information is not necessary to show.

Table 4 demonstrates the changes of the purchase time (lead time), which is compared against the ERP entered purchase time (=lead time) with the new calculated lead time based on the past 12 months.

Table 4 is from PowerBI calculations, in which the validity of the data was tested before DWH development.

For example, if the % deviates by N amount, an automated alert is sent to responsible personnel, indicating that further action should be taken. The variation in lead time is reflected back to the safety stock calculation and ROP.

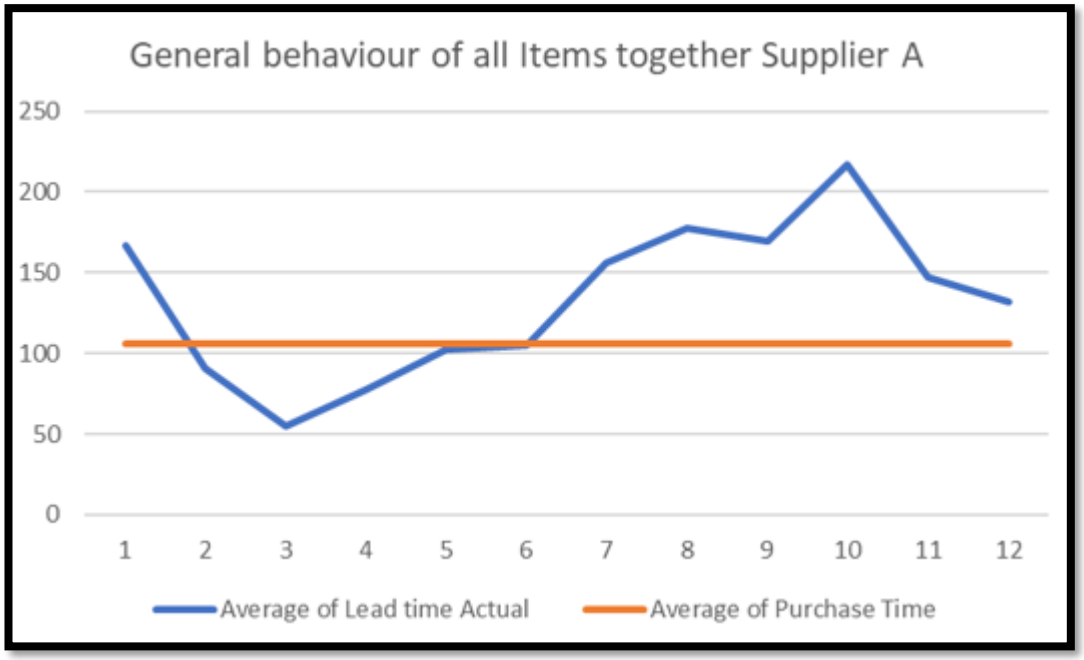

Figure 2 Average Lead Time Behaviour of Supplier A. All Items Aggregated Together.

A similar graph than Figure 2 is presented per Item and per supplier in the inventory model data view. a Similar graph is included in the PowerBI view, where lead time behaviour over time can be sliced based on item ID.

All items from the same supplier might not be comparable in terms of lead time, and for this reason only items with same characteristics regarding lead time should be aggregated for accurate results.

Other things to consider are the suppliers supply capacity and can the supplier answer to the requested demand, as the inability to meet demand can jinx the data. If it is known that the supplier is unable to respond to demand or there are sourcing issues from lower tier suppliers, the lead time performance timeline can give insight that new management methods could be considered.

5.2.5 Implement

Parameters and processes are implemented. During the implementation step, co-operation with procurement and manufacturing departments about inventory management concepts will be established.

The stock target levels will be visualized by using automated PowerBI reporting. The visualization tool created helps provide a good idea of overall inventory performance. With PowerBI and inventory related data fetched from data warehouse designed in earlier phases, automated inventory management aiding reporting and analysis can be performed.

From the available data tables, important inventory management KPI can be measured. Measurements in PowerBI can be calculated by DAX and they are calculated from the available fact table that is included in the data model.

Inventory KPI’s implemented during the first phase are classified based on their importance from 1 to 3.

In the implemented PBI view and data model, the data in PBI is updated once a day. The minimum stock and ROP proposals are updated monthly. The inventory projection visualized. The inventory projection was one of the business case definitions for the data model. Stock projection is calculated on daily level.

The developed DWH did not finish on time, and for this reason the example view is not available. However, Figure 2 and Table 4 are similar that will be implemented in the DWH solution.

Segmentation shown in table 3 will not be implemented in the DWH view developed by the external developers. The ABC-XYZ or similar segmentation is done based on specific requirements, at least in the beginning phases.

5.2.6 Review

Review monthly, adjust if needed. The review process is continuous and follows the Plan-Do-Check-Act principles.

The review process includes the input to the monthly S&OP, which will be an inventory review with procurement. In the S&OP meeting, alerts generated by deviations in data and new minimum stocks and lead times are updated if necessary to the ERP system.

Automated alarms can be implemented in the report, which generates an alert when KPI deviate according to specification. Alerts are created when stock falls below certain level and for purchased SKUs lead times.

When and if new SS and ROP levels are reviewed, and if the value of stock exceeds amount X, an authorization to increase stock levels is needed from procurement leadership personnel.

Table 5 below illustrates potential inputs to the monthly S&OP. The developed inventory model can help to deliver data as input to the review meetings. It is important to acknowledge that this is not the only way to conduct S&OP and it is not the form that will be implemented in the case company. However, table 5 aids to gauge what the developed inventory model and PBI reporting can provide in terms of inputs.

	Monthly S&OP Process		Pre S&OP Meeting
Step 1	Gather data to support decision making (Forecasting) **Last months results** **Inventory status** Capacity plans? Forecasts?	Step 4	Input to this meeting is from previous steps (Align supply with sales) Demand plan Supply plan **KPI performance** Budgets and income statement?
Step 2	Demand planning Discuss possible changes **Review service level** **Review stock volumes** Review Forecasting accuracy Document demand related events that might affect forecast?	Step 5	Executive S&OP Meeting Potential issues are brought to executive level Financial and operational targets are approved Input demand and supply plan Input unresolved issues **KPI performance**
Step 3	Supply Planning Review production plan and capacity Document events affecting the production plan Review Forecast **Review Stock Balance** Review plant service level Review forecast	Step 6	S&OP Finalization Monitor demand and supply plan realization **Use KPI for monitoring**

Table 5. Example steps and contents of monthly S&OP. Contents adapted from chapter 2.4.1 “Monthly S&OP Process”.

In table 5, columns with underlined text can be potential inputs to the S&OP process from the inventory planning perspective. KPI is provided in the data analytics PBI view which can be used to monitor inventory performance and take actions if needed.

5.2.7 Plan-Do-Check-Act (PDCA)

BlueFors Oy is International Organization for Standardization (ISO) 9001 certified and thus continuous improvement practices are required. The Plan, Do, Check, Act (PDCA) cycle is also implemented on the Inventory Planning level “review” step. PDCA is a quality management method widely used as a continuous improvement tool both in service and manufacturing sectors (Sarah Isniah et al. 2020).

The Plan-Do-Check-Act plays a central role in the Inventory Planning process. The PDCA is an iterative process for continuous improvement. The PDCA cycle is also known as the Deming Cycle. As Figure 3 suggest, the PDCA is a loop and not an end-to-end process.

Plan

In the plan phase, a problem is identified. A problem can also be something that needs to be improved. In the plan phase, it is good to take note what elements are missing, as in why there are no management processes in place for the said problem. In the plan phase, it is good to think what the ideal outcome would be and how to get there. In the Plan phase, inventory parameters analysed during the previous stage are implemented and the procurement should stick to the set Inventory levels as planned.

Do

In the Do stage, the plan is executed according to the plan. In the do phase, it is a good idea to start small first with a controllable workload. In this thesis, the inventory parameters were defined and tested for a few suppliers.

Check

In the Check phase, the results are monitored, evaluated and/or review and analysed. Each of the four steps does not need to last a certain time, but if a deviation from the process is noticed it is recommended to directly move to the check phase and find a root cause for the issue and make correction in the following act phase.

Act

In the Act phase, corrective steps are taken if needed. If there are no modifications to the plan defined in the Check phase, then continue with the plan.

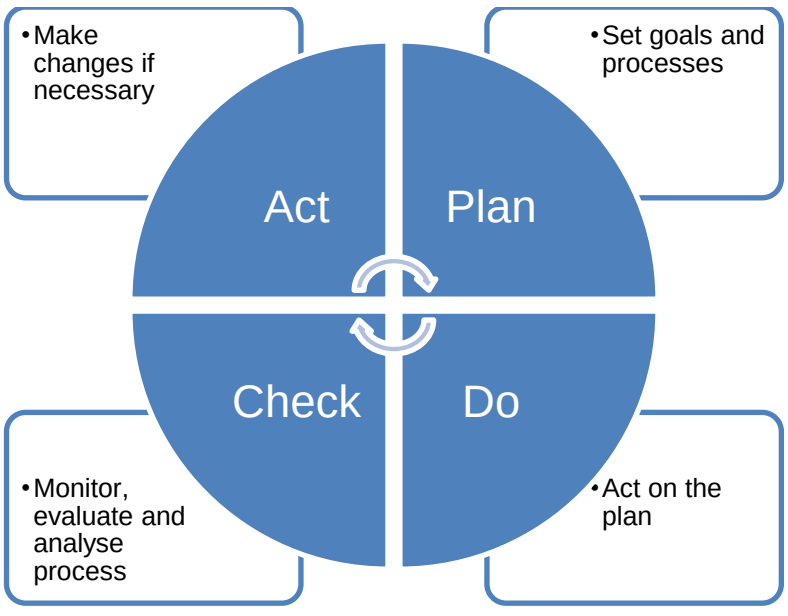

Figure 3. PDCA cycle.

5.3 ROP and Forecasting

While the ROP provides a simple and straightforward way to manage inventory levels, there are situations where ROP alone is not sufficient. Example situations are highly variable demand, which is difficult to predict, long lead times, or scarcity. In cases like these, forecasting methods can provide additional insights into inventory related decision making when deciding appropriate stock levels and when placing orders.

ROP can perform quite well with items with shorter lead time and with SKU with low supply disruptions. When the lead time is long, there is a high risk for supply disruptions.

Evaluating the use of ROP against forecasting needs is sometimes useful inventory management practice when deciding between order policies, i.e. whether material flow should flow continuously or based on ROP. Ordering against forecasted needs has a higher risk for over-stocking if the existing stock is not considered or there is still plenty of old stock left before placing and receiving new replenishment orders.

In conclusion, both ROP and forecasting strengths and weaknesses are different and the methods can be used together to optimize inventory levels. To improve forecasting, implementing the frozen planning method can stabilize the different demand windows and help with forecasting, as it brings predictability for the future demand buckets.

Different forecasting methods are explained under Forecasting chapter 2.10, including different forecasting error measurements.

6 Further Development Ideas

Already recognized further development ideas for the inventory management are presented first. After that, more or less closely related development ideas are explained. Some of these ideas are recognized on some level during the making of the thesis but the majority of these ideas came from reference material and their work implementation when writing the theory section.

Further stages of Inventory Planning

In the second stage, in-house manufactured SKUs are included in the analysis. In the scope of in-house manufactured SKUs, a plan how to analyse and visualize manufactured SKUs should be developed. Additionally, 2nd and 3rd class of importance KPI metrics are implemented that fall outside the MVP of the Data Model and PBI View.

The Inventory Planning project is later extended to cover all other purchased SKUs excluding bulk SKU.

Tracking the Cycle / Inventory Turn Performance

Because Inventory Age is one of the non-first priority measures within the BI report scope, segmenting items based on the inventory turn performance for further inventory performance management decisions is something that could be done.

Items can be also grouped based on their inventory turns or cycle time. Then it is possible to take the cumulative percentage of total item class occupied within same inventory turn timeframe. When classifying items based on cycle time, it is possible to see whether the inventory turn improves due to changes in material management methods when comparing current results with historical data (Heta Haikonen, 2021). Thus, tracking the inventory turn or cycle performance can be a signal of good inventory performance or it can be a sign that there is room for improvement.

Tracking Order Specific Item ID growth

Two lists of parts can be analyzed: one includes unique parts used only once, and the other contains engineering-specific parts initially designed for specific customer orders but used infrequently. These lists can be examined later, if needed, for better insight into engineered parts.

For the thesis work, it was not needed to track customer specific engineering parts and how much of total Item ID count % these occupy. However, for later analysis use cases it could provide some insights which item ID are customer specific and could the created item be utilized in other scenarios.

Determining the Planning Horizon

The planning horizon is determined later when the frozen period or similar management policy is implemented, which is required for ERP ROP implementation from the technical limitations perspective. Thus, further development ideas focus on the Frozen and slushy planning horizons in order to stabilize manufacturing operations. A current problem in BlueFors Oy is constant changes to the production plan. This can be managed with a frozen and slushy period. Implementing the Frozen Planning method would get rid of the ERP technical limitations problem.

Forecasting is hard and stock-outs and overstocking should be treated as manageable issues. Freezing order periods gives BlueFors Oy better resources to manage issues regarding demand.

Multi-location Inventory Management

Challenges of multi-location SCM and warehousing should be accounted for. Multi-stock management will bring opportunities but also challenges. When it comes to Inventory optimization in the supply chain, the focus is on where to hold inventory in the distribution network in order to deliver the desired level of

customer service, considering restrictions and cost targets (Dave Turbide, 2018 B).

For example, multi-location inventory might consider SKUs that are stored in larger quantities to be located closer to the supplier and distributed in smaller quantities more often, while others want to keep inventory closer to the customer for faster shipments (Dave Turbide, 2018 B). In these locations, the SKUs might be consumed internally or shipped to customer. It could be more beneficial to store SKUs closer to the customers location if it is viable for the company to store and use said SKUs in the location closer to certain customer segments.

BlueFors Oy already has other locations in Finland and abroad, so managing inventories in different locations and where it would it be best to store certain SKUs is something that needs to be addressed. Regarding multi-location inventory, authorization rights need to be re-considered, for example, who can pick up material and from where.

Tracking on-order SKUs

Further development ideas include systematically tracking on on-order or pipeline inventory in order to gain better insights into incoming replenishments, i.e. this could be viewed in an automated PBI report. Currently there is no “easy and fast” way to track this.

Improving Forecasting

As it can be interpreted from the practical forecasting section, the forecasting method currently in use has a very high error rate, which is the planning BOM or average BOM. If forecasting is improved, the result could deliver predictions of future demand with smaller forecast error rate. The demand is also calculated wrongly due to the fact that material reservations are frequently changed.

Often, the products BlueFors Oy manufactures are based on MTS, MTO or ETO principle. Products that are highly complex with significant variability of parts may require varying forecasting and sourcing strategies.

Adjusting the CODP and shifting between manufacturing models if possible can improve forecasting, **as** the point where forecast vs. customer order driven approaches are separated shifts. If it is possible to stabilize the demand by shifting the CODP, forecasting methods in use can be evaluated again.

Shifting Key Factors in "MAM" strategy

Shifting key factors regarding shifting from ETO to other manufacturing models are presented in the ESTIMTE work. Repetition of demand, storage costs and bargaining power of customer are factors in the shifting strategy (Aicha Amrani et al. 2010). The characteristic presented in the ESTIMATE work could be considered when developing inventory planning or other supply chain activities in the future.

For example, moving from ETO supply chain to ATO supply chain could be beneficial in order to achieve performance objectives (Aicha Amrani et al. 2010). This claim is similar to MC products shifting the product differentiation towards the end of the supply chain. This requires changes in product design and the subject itself is not relevant to inventory planning as it is more relevant for product design. However, shifting between manufacturing models can improve inventory management.

Exploring the Possibilities of Reducing Variation

Having high variation among products enhances inventory management issues and stock management becomes less predictable. When variety is reduced, SKUs can be produced as MTS with standard lead times. The benefits of reducing variation include better control over inventory as less components needs to be controlled. On the other hand, order flexibility is reduced.

When variety is reduced, customers are still able to order configured SKUs based on their needs but with extra costs and the order progress for this kind of order is only triggered by a confirmed order. The lead time for heavily customized products should thus be longer. Currently, the lead time for customized orders is poorly controlled. There could also be a price increase to reflect the increased efforts.

A longer lead time allows the company to source necessary components without negatively affecting stock due to configured orders, which can directly affect how other customers can be served.

Reducing variability by increasing modularity or product standardization as part of transferring at the moment highly customized MTO SKUs to MTS manufacturing model that are commonly ordered could provide some benefits. By reducing the variety and only considering bestselling products, those SKUs can be manufactured according to MTS and customer demand can be answered within shorter notice. Asking customers for feedback what they would like and analysing past orders is a good starting point going from MTO to MTS in some products.

By reducing the variety, SKUs might need to be modularized. BlueFors Oy's product offering is very configurable and manufactured SKUs heavily vary between different customer projects. Thus, SKUs might need to be standardized to some average configuration options. For example, some sub-assemblies have been problematic to BlueFors Oy and reducing the variety in these could potentially remove many recurring problems.

Modular product design is one way to reduce variation as it offers a greater degree of component reuse, when less components are used and same components can be used in multiple assemblies. Modular design also reduces fixed costs of developing individual product variants, increases responsiveness to customers, enables higher product variety to customers, reduces of

development lead time, and improves customer service (P. K. Hansen and H. Sun, 2010).

For example, MTS SKUs reduces variability, forecasting errors and increases the ability to meet customer demand with a reduced lead time, increasing sales possibilities. MTO manufacturing model would still be available but handling them should be done within the Frozen and slushy periods.

When product variation is decreased, so is variation in the manufacturing process. Reducing variation in both product features and manufacturing processes usually means decreased product defects and improved product quality. As the product and production quality improves, less quality related costs are incurred to the company. Quality related costs can be either internal or external costs.

Variety is known to decrease product defects and improve product quality, which can lead to decreased production cost and re-work needed, which can improve the manufacturing rate. At the same time, the operational efficiency increases.

Preventing Stock Cannibalization

The impact of cannibalization on customer order delays should be assessed or evaluated based on how many times products had to be cannibalized now that BlueFors Oy is experiencing very high growth. There is a risk that the cannibalization instances will happen more frequently. Cannibalized SKUs ID could be collected and analyzed for better inventory control polices.

Cannibalization comes up every now and then during the weekly meetings, when some parts need to be taken out of other assemblies to finalize final testing stages, for example. Cannibalization can be prevented by improved forecasting practices or by improving internal processes regarding customer change requests, where last minute changes to orders are accepted without considering the consequences for other customers.

One solution to prevent item cannibalization is to implement frozen period, extra costs or longer lead time to the customer requesting change. Even if the cannibalization process can provide short-term benefits by minimizing downtime, it is not a sustainable solution in the long run. Cannibalization should only be temporary solution.

Establishing Available to Promise Levels

Available to promise (ATP) is the stock available which is not reserved or allocated for any orders. Defining the ATP stock is important as it gives insight to sales into how much of on-hand inventory can be promised to customer without affecting other orders.

Defining the ATP clarifies definition of the customer lead time as well. Defining the ATP requires coordination with sales and production. The available to promise stock does not remain stable and it should be reviewed periodically. Establishing more accurate customer lead times also disrupts the inventory less. Definition of ATP can help to keep lead times in check when it comes to customer order deliveries. Currently, ATP is not established and knowing the ATP quantity is not easily available.

The ATP can be implemented in every stage of the supply chain, including downstream, midstream, and upstream and it should be connected to CODP due to the fact that DP point separates the forecast-driven parts of a supply chain from the order-driven part (Muhammad Saeed, 2012). Establishing the ATP can smoothen operations.

In the midstream supply chain, which consist of ATO items, for example, the components produced and purchased are driven by the forecast and final products are driven by customer orders. In ATO environments, the ATP can be measured on component level based on the master plan (Muhammad Saeed, 2012), which in the case company could be the high level plan of final products, under which the other manufacturing strategies fall.

When considering the midstream supply chain and ATO environment, the availability of raw material, sub-assemblies, and the availability of existing capacity of the processes for final products should be clearly defined (Muhammad Saeed, 2012). While there are deparment specific capacity plans on top of capacity for final products, the ATP of these is not assessed and the information is not easily available. In an ideal situation the ATP figure is frequently updated.

Segmenting Backorders

Backorders are orders that cannot be fulfilled due to insufficient stock levels. For example, a customer making an order where some components are lacking, different order scheduling strategies should be given to those customers. Backorder situations can happen when demand exceeds supply and the supplier lead time is long compared to time scale the SKU is needed in production, Backorder situations can be put to hold and not to promise order before adequate stock is available. Backorder management requires efficient communication with customer along with inventory management.

Backorder rate formula (David Luther, 2022):

$$Backorder\ Rate = (delayed\ orders\ due\ to\ backorders / total\ orders\ placed)\ x\ 100$$

Backordering can offer some benefits, such as avoiding deadstock in cases where the company only purchases goods required to fullfill an order only after the order has been confirmed. However, it is not always the optimal choice due to reasons such as long lead time and operational efficiencies.

From the inventory management perspective, segmenting SKUs that experience backorders can help formulate better inventory control strategies for those SKUs.

Hybridization of Supply Chain Strategy (Lean, agile and hybrid supply chains)

Supply chain can be categorized into three different types, which are lean supply chain (LSC), agile supply chain (ASC) and hybrid supply chain (HSC). The LSC is best for improving internal manufacturing efficiency when the demand is stable and forecasting can be done accurately (Muhammad Saeed, 2012; Wang et al. 2004). In responsive supply chains due to MC and varying customer demands, having stable demand and good forecasting accuracy is not a default.

ASC on the other hand focuses on responding to more varying customer requirements, enabling quicker delivery and lead time flexibility with the help of various IT systems for information exchange. ACS puts more emphasis on knowledge management and empowering employees. ASC also emphasises having different supply chain strategies for different manufacturing models, also accounting for their lifecycle (Muhammad Saeed, 2012; Wang et al. 2004). More about knowledge intensive processes can be found from the dissertation of Aldo Sante Duchi (2017). In the case company, further supply chain developments could be to develop the supply chain towards a more hybrid/agile approach, considering lean approach in the manufacturing operations.

HCS combines LCS and ACS. HCS is capable of creating a supply chain that meets the needs of complex products. HCS enables MC by postponing product differentiation into final assembly (Muhammad Saeed, 2012). This could be combined by reducing variation. HCS would be ideal for the case company because the products are complex to manufacture. Postponing product differentiation into the final assembly phase might require product modularization or design changes, and this is out of the scope of the thesis. In this situation, ETO+”MAM” strategy can be considered (Aicha Amrani et al. 2010) to add systematization and predictability to production process and enhance item segmentation.

In customized supply chains with different manufacturing models, lean and agile methods could be used, or a combination of these, leagile. Leagile is capable of supporting mixed model production better than lean or agile methodology alone, and Leagile can support mass production efficiency when a company produces a variety of products. Leagile can enable efficient internal manufacturing operations (Muhammad Saeed, 2012). Leagile could be explored further in the case company despite Lean being already practiced.

It is good to acknowledge the limitations of lean regarding its performance implications (Hackman and Wageman, 1995). Lean methods work the best when applied upstream from the CODP (Naylor et al. 1999) and agile methods are more efficient when applied downstream from the CODP (Muhammad Saeed, 2012). Thus, Lean processes could be implemented to processes upstream from the decoupling point (DC) and agile to points that are downstream from the DC (Naylor et al. 1999; Muhammad Saeed, 2012).

As BlueFors Oy operates according to the ETO model with personalized customer demand, it is not easy to achieve the desired level of responsiveness in supply chains solely based on inventory levels (Muhammad Saeed, 2012) . Variable customer demands also increase the risk for inventory obsolesce. Further studies for process improvement could include studying the CODP and bottle necks in MC supply chains according to the TOC principle.

7 Conclusions

The key to successful inventory planning consist of ability to accurately forecast demand, optimize inventory levels, and implement effective replenishment strategies. In this thesis, inventory planning is discussed as part of monthly S&OP.

In this thesis, data-driven approach was utilized. By adopting data driven approach, it is possible to achieve improved inventory optimization and improve the competitiveness in the market due to the increased ability to serve customers on time. Inventory data provides valuable insight into this. Also, creating reports for review meetings during the monthly S&OP is more convenient with help of data driven tools.

This thesis work established the foundations for systematic inventory control for BlueFors Oy. With the help of the DWH and PowerBI, inventory status, i.e. stock projection, can be followed up daily. The stock projection records incoming purchase orders, replenishments, consumption from BOM and outbound shipments.

Replenishment strategy examples are Re-order point and Periodic stock replenishment strategy. In this thesis, ROP is chosen. Once a method to implement ROP on the ERP side is established, only then the ROP can be implemented in practice as part of inventory management in a way that ROP triggers purchase proposals. Implementing the ROP within the scope of the thesis project was not done in practice, as that is an ERP related change discussed in different development projects. However for reporting purposes, ROP calculations were established.

The inventory parameters are updated once a month, based on changes in demand and lead time.

For the chosen suppliers, items were segmented based on ABC-XYZ principle, but within the thesis work no specific actions were implemented between the

different segments. What was done included defining the inventory parameters such as Safety Stock and Re-order point.

Before any forecasting improvements can be made, a firmed planning horizon could be used. Without this in place, it is hard to grasp what the demand, once stabilized for a certain period, would look like. Secondly, firming orders would make the production planning more stable due to the exclusion of sudden demand changes. For unexpected capacity requirements, safety capacity can be used.

From inventory planning perspective, there is no need to forecast or keep on stock customer order specific items.

Items that can be forecasted in order to decrease the customer order lead time are items that either frequently or infrequently assembled into final products. For these items, deciding whether to stock or not to stock should be established. During the later phases of the inventory planning project, the inventory analysis is implemented to cover the majority of stocked items, however if there will be exceptions those were not defined during the project.

Stock parameters and demand forecast is based historical data. Different methods can be used to estimate the possible demand. In many cases assessing future demand is important in order to secure parts and not to order too much or too little of them.

The Proposed solution to add stability into inventory planning is to implement the Frozen planning principle, but this was not implemented during the making of the thesis, but it is observed that implementing this would alleviate many problems. Because this is not something that can be completed within the timeframe of the thesis, this part is moved in Further Development Ideas under the chapter “Determining the Planning Horizon”.

Overall, this thesis provides insights into the importance of inventory planning and its role in serving customers on time.

References

1 Lisa Schwarz. (2019). Oracle Netsuite. Essential Guide to Inventory Planning https://www.netsuite.com/portal/resource/articles/inventory-management/essential-guide-to-inventory-planning.shtml%20Accessed%20%2019.04.2023 Accessed 19.2023.

2 Aktunc, E.A., Basaran, M., Ari, G., Irican, M., Gungor, S. (2019). Inventory Control Through ABC/XYZ Analysis. In: Calisir, F., Cevikcan, E., Camgoz Akdag, H (eds) Industrial Engineering in the Big Data Era. Lecture Notes in Management and Industrial Engineering. Springer, Cham. https://doi.org/10.1007/978-3-030-03317-0_15 Accessed 19.2023.

3 BlueFors. (2023). Cryogen-free Dilution Refrigerator Measurement Systems https://bluefors.com Accessed 04.05.2023.

4 Lee, H. L., Padmanabhan, V., & Whang, S. (1997). Information Distortion in a Supply Chain: The Bullwhip Effect. Management Science, 43(4), 546–558. http://www.jstor.org/stable/2634565 Accessed 09.05.2023

5 Sarah Isniah. Humiras Hardi Purba. Fransisca Debora. (2020). Jurnal Sistem dan Manajemen Industri. Plan do check action (PDCA) method: literature review and research issues. Accessed 11.05.2023.

6 Demand Solutions. (30.04.2014). EOQ, RIP? The Decline and Fall of a Great Idea https://www.demandsolutions.com/ds-blog/abstracts/eoq-rip-the-decline-and-fall-of-a-great-idea/ Accessed 11.05.2023.

7 Dennis Alexander Minnich. (2007). Doctoral Thesis. Efficiency and Responsiveness of Supply chains in the High-Tech Electronics Industry A System Dynamics-Based Investigation https://madoc.bib.uni-mannheim.de/33153/1/Dissertation_MinnichDennis.pdf Accessed 11.05.2023.11.05.2023.

8 ABC Supply Chain. (2023). SS Formula & Calculation: 6 best methods https://abcsupplychain.com/safety-stock-formula-calculation/ Accessed 11.05.2023.

9 Malindzakova, M., Garaj, P., Trpčevská, J., & Malindzak, D. (2022). Setting MRP Parameters and Optimizing the Production Planning Process. Processes. http://dx.doi.org/10.3390/pr10040690 Accessed 13.05.2023.

10 R Amaranti. C R Muhammad. M V Septandri. (2020).Determining the changes in the Master Production Schedule (MPS) at the company with

Make to Stock (MTS) and Make to Order (MTO) strategies https://iopscience.iop.org/article/10.1088/1757-899X/830/4/042003/pdf Accessed 13.05.2023.

11 Oracle Netsuite. (28.11.2020). Abby Jenkins. ABC Analysis in Inventory Management: Benefits & Best Practices https://www.netsuite.com/portal/resource/articles/inventory-management/abc-inventory-analysis.shtml Accessed 13.05.2023.

12 Raza Abbas. (23.11.2020). LinkedIn. Periodic review and update of parameters is necessary but should not be excessively frequent. https://www.linkedin.com/pulse/abc-analysis-inventory-raza-abbas Accessed 13.05.2023.

13 Venkadesh Seetharaman. (19.03.2019). SAP Community. Demand Driven Replenishment DDMRP in S/4 HANA Configuration Setup https://blogs.sap.com/2019/03/19/demand-driven-replenishment-ddmrp-in-s4-hana-configuration-setup/ Accessed 13.05.2023.

14 E. Powell Robinson Jr. Funda Sahin Li-Lian Gao. (2008). International Journal of Production Research. Master production schedule time interval strategies in make-to-order supply chains https://www.bauer.uh.edu/doctoral/scm/docs/sahin-1.pdf Accessed Accessed 13.05.2023.

15 Zhaotong Liana. Abhijit Deshmukhb. Jin Wangc. (24.02.2006). Int. J. Production Economics 103 (2006) 648–655. The optimal frozen period in a dynamic production model

16 Steve Banker. (16.12.2019). Logistics VIewpoints. Achieve a Responsive Supply Chain Without Creating Supply Chain Chaos https://logisticsviewpoints.com/2019/12/16/achieve-a-responsive-supply-chain-without-creating-supply-chain-chaos/ Accessed 13.05.2023.

17 Supply Chain Movement. (16.02.2023). Marcel te Lindert. Sales & operations execution prevents distractions in S&OP process https://www.supplychainmovement.com/sales-operations-execution-prevents-distractions-in-sop-process/ Accessed 13.05.2023.

18 Andreas Hahn. (n.d.). University of Applied Sciences Bremerhaven, Germany. CERTAINTY AGAINST FLEXIBILITY – THE CONCEPT OF FROZEN HORIZON – CHANCES, PROBLEMS AND SOLUTIONS

19 Thomasnet. (03.10.2019). Make to Order vs. Make to Stock: What's the Difference? https://www.thomasnet.com/insights/make-to-order-vs-make-to-stock/ Accessed 29.05.2023.

20 Abby Jenkins. (12.01.2021). Oracle Netsuite. A Comprehensive Guide to Supply Chain Metrics & KPIs https://www.netsuite.com/portal/resource/articles/erp/supply-chain-kpis-metrics.shtml Accessed 29.05.2023.

21 Shaun Snapp. (02.03.2010). Brightwok Research and Analysis. How to Best Understand the Frozen Planning Period. https://www.brightworkresearch.com/frozen-period/#Characteristic_1_How_to_Determine_or_Calculate_the_Frozen_Period Accessed 29.05.2023.

22 Funda Sahin. E. Powell Robinson. Li-Lian Gao. (02.10.2008). International Journal of Production Economics Volume 115, Issue 2, October 2008, Pages 528-541. Master production scheduling policy and rolling schedules in a two-stage make-to-order supply chain https://www.sciencedirect.com/science/article/abs/pii/S0925527308002132 Accessed 29.05.2023.

23 Pak Supply Chain. (2010). Chapter 3: Master Scheduling https://paksupplychain.blogspot.com/2010/11/3-master-scheduling.html Accessed 29.05.2023.

24 Robert G. Ratcliffe. (2020). Consulting. Forecasting in a Make-to-Order (MTO) Environment https://robert-g-ratcliffe-consulting.com/forecasting-in-a-make-to-order-mto-environment/ Accessed 29.05.2023.

25 Petter Næss. Jeppe Andersen. Morten Skou Nicolaisen. Arvid Strand. (2015). Journal of Transport and Land Use Vol. 8, No. 3, 2015. Forecasting inaccuracies: A result of unexpected events, optimism bias, technical problems, or strategic misrepresentation? https://www.jstor.org/stable/26189165 Accessed 29.05.2023.

26 Sri Aparajithan. (15.08.2011). Boston Consulting Group. Sales and Operations Planning The Hidden Supply-Chain Engine https://www.bcg.com/publications/2011/supply-chain-management-go-to-market-strategy-sales-operations-planning-hidden-supply-chain-engine 30.05.2023.

27 Caroline Geelmuyden, Emma Rasmusson. (2019). Lund University. Improving the Sales and Operations Planning process at a Swedish dairy company https://lup.lub.lu.se/luur/download?func=downloadFile&recordOId=8985081&fileOId=8985088 30.05.2023.

28 Philip Lee, Scott Sparks. (2020). Trivista. Sales, Inventory, & Operations Planning How to unlock transformational change in enterprise value https://trivista.com/wp-content/uploads/2020/10/Unlocking-Transformational-Value-Through-SIOP.pdf 30.05.2023.

29 Dave Turbide. (05.12.2018 A). Dassault Systems. Isn't S&OP Really Inventory Planning? https://blog.3ds.com/topics/manufacturing/isnt-sop-really-inventory-planning/ Accessed 30.05.2023.

30 Dave Turbide. (12.09.2018 B). Dassault Systems. Inventory Optimization in the Supply Chain https://blog.3ds.com/topics/manufacturing/inventory-optimization-in-the-supply-chain-delivers-desired-performance-at-minimal-cost/ Accessed 30.05.2023.

31 Dave Turbide. (13.08.2018 C). Why is Optimization Important for Supply Chain Planning? https://blog.3ds.com/topics/manufacturing/why-is-optimization-important-for-supply-chain-planning/ Accessed 30.05.2023.

32 Kate Eby. (19.04.2017). Sales and Operations Planning (S&OP): Process, Challenges, and Expert Tips https://www.smartsheet.com/sales-operations-planning-101 Accessed 30.05.2023.

33 Asana. (29.12.2022). Sales and operations planning (S&OP): A project manager's guide https://asana.com/resources/sales-operations-planning Accessed 30.05.2023.

34 P. K. Hansen. H. Sun. (17-20.05.2010). INTERNATIONAL DESIGN CONFERENCE DESIGN 2010. A COMPREHENSIVE VIEW ON BENEFITS FROM PRODUCT MODULARIZATION

35 Envista. (28.09.2022). What Is a Responsive Supply Chain and How Can Your Company Build One? https://envistacorp.com/blog/what-is-a-responsive-supply-chain-and-how-can-your-company-build-one/ Accessed 30.05.2023.

36 Robert Glenn Richey. Anthony S. Roath. Frank G. Adams. Andreas Wieland. (05.10.2021). Wiley Online Library. A Responsiveness View of logistics and supply chain management https://doi.org/10.1111/jbl.12290 Accessed 30.05.2023.

37 MasterClass. (30.08.2022). Upstream Supply Chain: How Upstream and Downstream Differ https://www.masterclass.com/articles/upstream-supply-chain Accessed 30.05.2023.

38 Microsoft Azure. (2023). What is a data warehouse? https://azure.microsoft.com/en-us/resources/cloud-computing-dictionary/what-is-a-data-warehouse/#data-warehouse-definition Accessed 31.05.2023.

39 Senturus. (2022). Requires someone with a strong understanding of data modeling and BI architecture to maintain and augment.

https://senturus.com/blog/power-bi-with-and-without-a-data-warehouse/ Accessed 31.05.2023.

40 Dashboard Fox. (12.08.2022). What are Measures, Facts, and Dimensions (And How Do They Impact Business Intelligence)? https://dashboardfox.com/blog/what-are-measures-facts-and-dimensions-and-how-do-they-impact-business-intelligence/ Accessed 31.05.2023.

41 Chris Caplice. (2006 A). ESD.260/15.770/1.260 Logistics Systems. Inventory Management: Fundamental Concepts & EOQ https://ocw.mit.edu/courses/esd-260j-logistics-systems-fall-2006/120bf3cdc3e9b1947ae2a8d0a264d901_lect7.pdf Accessed 01.06.2023

42 Chris Caplice. (2006 B). ESD.260/15.770/1.260 Logistics Systems. Inventory Management Extensions to EOQ https://ocw.mit.edu/courses/esd-260j-logistics-systems-fall-2006/4851a27cb396c065d7b7c0fafa50d039_lect8.pdf Accessed 01.06.2023

43 Chris Caplice. (2006 C). ESD.260/15.770/1.260 Logistics Systems. Demand Forecasting I Time Series Analysis https://ocw.mit.edu/courses/esd-260j-logistics-systems-fall-2006/107446a7d15453bf194f05a4c6098c93_lect3.pdf Accessed 01.06.2023

44 Chris Caplice. (2006 D). ESD.260/15.770/1.260 Logistics Systems. Demand Forecasting II Causal Analysis https://ocw.mit.edu/courses/esd-260j-logistics-systems-fall-2006/f2396de71c17e2d45d69aa506eda27ce_lect4.pdf Accessed 01.06.2023

45 Larry Lapide. (2006). Lecture to 2007 MLOG Class. Demand Forecasting, Planning, and Management. https://ocw.mit.edu/courses/esd-260j-logistics-systems-fall-2006/f68878913b1a3c3d6b800b2b63b6c4cb_lect6.pdf Accessed 01.06.2023.

46 Oracle Help Centrer. (2013). D Edwards World Forecasting Guide. Chapter 14: Understand Planning Bill Forecasts https://docs.oracle.com/cd/E26228_01/doc.93/e20706/ch_under_plan_bill_for.htm#WEAFC238 Accessed 01.06.2023.

47 Chris Caplice. (2006 E). ESD.260/15.770/1.260 Logistics Systems https://ocw.mit.edu/courses/esd-260j-logistics-systems-fall-2006/0f257fe6c8b83a24840d9b1017491950_lect13.pdf Accessed 01.06.2023.

48 Ralph D. Snyder. J. Keith Ord. Adrian Beaumont. (18.05.2010). RESEARCH PROGRAM ON FORECASTING Center of Economic Research Department of Economics. The George Washington University. Forecasting the Intermittent Demand for Slow-Moving SKUs https://www2.gwu.edu/~forcpgm/2010-003.pdf Accessed 01.06.2023.

49 Kristina Lopienski. (18.10.2021). ShipBob. What is Pipeline Inventory? Definition + Formula to Drive Growth https://www.shipbob.com/blog/pipeline-inventory/ Accessed 01.06.2023.

50 Institute for Business Forecasting and Planning. (2023). Days of Supply (DOS). https://ibf.org/knowledge/glossary/days-of-supply-dos-70 Accessed 01.06.2023.

51 Adam Hayes. (30.05.2023). Investopedia. Days Sales of Inventory (DSI): Definition, Formula, Importance https://www.investopedia.com/terms/d/days-sales-inventory-dsi.asp Accessed 04.06.2023.

52 Steve William. (2016). Business Intelligence Strategy and Big Data Analytics: A General Management Perspective https://opac.atmaluhur.ac.id/uploaded_files/temporary/DigitalCollection/MmM4YjE5ODVkN2IyNzcxYjFhZjVmMDMzNzA4ZGRlOGVmOGJlMjEyNg==.pdf Accessed 04.06.2023.

53 David Luther. (07.09.2022). Oracle NetSuite. 33 Inventory Management KPIs and Metrics for 2022 https://www.netsuite.com/portal/resource/articles/inventory-management/inventory-management-kpis-metrics.shtml Accessed 04.06.2023.

54 David Taylor. (08.04.2023). Guru99. What is Data Modelling? Types (Conceptual, Logical, Physical) https://www.guru99.com/data-modelling-conceptual-logical.html Accessed 04.06.2023.

55 IBM. (n.d.) What is data modeling? https://www.ibm.com/topics/data-modeling Accessed 04.06.2023.

56 David Brown, Ann Swift, Dr Edward Smart. (2018). Data Analytics and Decision Making. Institute of Industrial Research University of Portsmouth https://connectedeverythingmedia.files.wordpress.com/2018/09/data-analytics-and-decision-making.pdf Accessed 22.06.2023.

57 Netquest. (n.d.) Visualize It! A Comprehensive Guide to Data Visualization https://www.netquest.com/hubfs/docs/ebook-data-visualization-EN.pdf?hsCtaTracking=ffb22d35-151f-46b0-a4c3-

299791ae9a11%7Caee3d698-906e-411e-af70-808b6ae3d4ab Accessed 22.06.2023

58 Finale Inventroy. (2023). Chapter 11: The Fast, Slow and Non-Moving (FSN) Method https://www.finaleinventory.com/online-guides/essential-inventory-management-techniques/fast-slow-and-non-moving-fsn-method Accessed 22.06.2023

59 Kimball Group & Kimball University. (2013). Kimball Dimensional Modelling Techniques http://www.kimballgroup.com/wp-content/uploads/2013/08/2013.09-Kimball-Dimensional-Modeling-Techniques11.pdf

60 Ralph Kimball, Margy Ross. (2013). The Data Warehouse Toolkit. The Definitive Guide to Dimensional Modelling. Third Edition

61 Metropolia PBI Course. (2023). Lesson 5: Data Analysis, Accessible with Metropolia University of Applied Sciences credentials https://moodle.metropolia.fi/course/view.php?id=6770 Accessed 22.06.2023.

62 Ryan Brukardt. Isabelle Klinghoffer. Allie Owens. Michael Park.(03.05.2021). McKinsey & The Company. Rethinking inventory management in defense https://www.mckinsey.com/industries/aerospace-and-defense/our-insights/rethinking-inventory-management-in-defense#/ Accessed 06.07.2023

63 Paolo Baldesi. Florent Kervazo. Hugues Lavandier. (07.11.2019). McKinsey & The Company. Turn slow-moving inventory into fast profits https://www.mckinsey.com/capabilities/operations/our-insights/turn-slow-moving-inventory-into-fast-profits Accessed 06.07.2023.

64 Riccardo Drentin. Mauro Erriquez. Carsten Nee. Marco Ziegler. (06.06.2018). McKinsey & The Company. Long tail, big savings: Digital unlocks hidden value in procurement https://www.mckinsey.com/capabilities/operations/our-insights/long-tail-big-savings-digital-unlocks-hidden-value-in-procurement Accessed 06.07.2023

65 Peter L. King. (2011). APICS magazine. CRACK THE CODE: Understanding SS and mastering its equations .

66 Nicolas Vandeput. (05.10.2021). Medium. The 4 Biggest Mistakes When Using the SS Formula https://nicolas-vandeput.medium.com/the-4-biggest-mistakes-when-using-the-safety-stock-formula-1f3cc93bcb1 Accessed 07.07.2023.

67 Ashkan Mirzaee. (2017). A Thesis presented to the Faculty of the Graduate School at the University of Missouri-Columbia. ALTERNATIVE

METHODS FOR CALCULATING OPTIMAL SS LEVELS. https://mospace.umsystem.edu/xmlui/bitstream/handle/10355/62067/research.pdf?sequence=2&isAllowed=y Accessed 07.07.2023.

68 Thymen van der Poll. (2017). University of Twente: bachelor's Thesis: Improving stock levels in retailers' stores by proposing a model based on literature and historical data http://essay.utwente.nl/73977/1/van_der_Poll_BA_BMS.pdf Accessed 09.07.2023.

69 Alberto Santini. (06.11.2019). Normal demand and normal lead time; is lead-time demand normal? https://or.stackexchange.com/q/44 Accessed 09.07.2023.

70 Winston, W. L. (2004). Operations research (ISE): applications and algorithms. Belmont, CA: Duxbury.

71 Frepple. (n.d.) How to compute a SS? https://frepple.com/blog/how-to-compute-a-safety-stock/ Accessed 09.07.2023.

72 Sujit Singh. (29.06.2021 A). Arkieva. Using Coefficient of Variation to Drive SS Related Decisions https://blog.arkieva.com/coefficient-of-variation-safety-stock-decisions Accessed 09.07.2023.

73 Sujit Singh. (31.08.2021 B). Arkieva. Relationship Between Forecast Accuracy and SSs https://blog.arkieva.com/forecast-accuracy-safety-stocks/ Accessed 12.07.2023.

74 David McPhetrige. (29.11.2016). Operational Excellence Society. Should SS Include Demand Forecast Error? https://opexsociety.org/body-of-knowledge/safety-stock-include-demand-forecast/ Accessed 12.07.2023.

75 Jonas Borgman. (04.01.2022). 8 best inventory demand forecasting techniques https://www.eazystock.com/blog/8-best-inventory-demand-forecasting-techniques/ Accessed 12.07.2023.

76 Lee Krajewski. Naresh Malhotra. Larry Ritzman. (2016). Operations Management: Processes and Supply chains, 11th Global Edition

77 PricewaterhouseCoopers LLP. (2007). Guide to key performance indicators Communicating the measures that matter.

78 Faraz Khan. Dr. Danish Ahmed Siddiqui. (2019). Social Science and Humanities Journal. Impact of Inventory Management on Firm's Efficiency – A Quantitative Research Study on Departmental Stores Operating in Karachi. http://sshj.in/index.php/sshj/ Accessed 12.07.2023.

79 Sofia Rachad. Zineb El Idrissi Larabi. Benayad Nsiri. Bahloul Bensassi. (2017). International Journal of Applied Engineering Research. Inventory Management in Closed Loop Structure Using KPI.

80 Wasp Barcode Technologies. (2023). TOP 10 INVENTORY MANAGEMENT KPIs Key Performance Indicators for Maximizing Profit and Efficiency in Your Warehouse Operations.

81 Danielle Bauter. (2022). Fit Small Business. Inventory Aging Report and Why It Matters https://fitsmallbusiness.com/inventory-aging-report/ Accessed 13.07.2023.

82 Benjamin Robert Martin. (2010). A dissertation submitted to the Graduate Faculty of North Carolina State University in partial fulfillment of the requirements for the Degree of Doctor of Philosophy. Inventory Management, Metrics, and Simulation

83 Tracey Baker. (03.06.2021). EazyStock. Bill of Materials inventory management – how to improve BOM forecasting and planning https://www.eazystock.com/uk/blog-uk/bill-of-materials-inventory-management-bom-forecasting-and-planning/ Accessed 13.07.2023.

84 Gary Wollenhaupt. (04.02.2020). Supply Chain Dive. Logistics: To insource or outsource? https://www.supplychaindive.com/news/logistics-insource-outsource/571612/ Accessed 18.07.2023.

85 Surbhi S. (02.06.2020). Key Differences. Difference Between Insourcing and Outsourcing https://keydifferences.com/difference-between-insourcing-and-outsourcing.html 20.07.2023.

86 Sunil Bakshi. (12.05.2021). ISACA. Is Outsourcing Truly Considered Risk Sharing? https://www.isaca.org/resources/news-and-trends/newsletters/atisaca/2021/volume-12/is-outsourcing-truly-considered-risk-sharing 20.07.2023.

87 Bozarth, C. B., and Handfield, R. B. (2016). Introduction to Operations and Supply Chain Management, Global Edition, 4th Edn. London: Pearson Education Limited.

88 Amelie Meyer. Wiebke Walter. Stefan Seuring. (11.03.2021). Frontiers. The Impact of the Coronavirus Pandemic on Supply Chains and Their Sustainability: A Text Mining Approach

89 Becky Ham. (15.06.2022). MIT News. Department of Civil and Environmental Engineering. Companies use MIT research to identify and respond

to supply chain risks https://news.mit.edu/2022/companies-use-mit-research-identify-respond-supply-chain-risks-0615 20.07.2023.

90 Xu, Z., Elomri, A., Kerbache, L., & El Omri, A. (2020). Impacts of COVID-19 on Global Supply Chains: Facts and Perspectives. IEEE Engineering Management Review, 48(3), 153-166. doi: 10.1109/EMR.2020.3018420. 20.07.2023.

91 Sarah Hippold. (23.06.2020). Gartner. 6 Strategies for a More Resilient Supply Chain https://www.gartner.com/smarterwithgartner/6-strategies-for-a-more-resilient-supply-chain 20.07.2023.

92 Schuster, R., Nath, G., Rodriguez, P., O'Brien, C., Aylor, B., Sidopoulos, B., Weise, D., & Datta, B. (29.06.2021). Boston Consulting Group. Real-World Supply Chain Resilience https://www.bcg.com/publications/2021/building-resilience-strategies-to-improve-supply-chain-resilience 20.07.2023.

93 Ben Aylor. Bitan Datta. Megan DeFauw. Marc Gilbert. Claudio Knizek. Michael McAdoo. (03.08.2020). Boston Consulting Group. Designing Resilience into Global Supply Chains https://www.bcg.com/publications/2020/resilience-in-global-supply-chains 21.07.2023.

94 Beth Stackpole. (06.07.2022). The European Sting. How is the war in Ukraine impacting the global supply chain? https://europeansting.com/2022/07/06/how-is-the-war-in-ukraine-impacting-the-global-supply-chain/ 21.07.2023.

95 Joachim Arts. Chris Mejía. Pascal Wolf. (01.06.2022). MIT Center for Transportation & Logistics. Supply Chain Lessons From the War in Ukraine https://ctl.mit.edu/sites/ctl.mit.edu/files/2023-02/MIT-SCALE-Ukraine-SCM-Implications-Summary.pdf 21.07.2023.

96 Jim Kilpatrick. (25.03.2022). Deloitte Insights. Supply chain implications of the Russia-Ukraine conflict https://www2.deloitte.com/uk/en/insights/focus/supply-chain/supply-chain-war-russia-ukraine.html 21.07.2023.

97 Knut Alicke. Edward Barriball. Tacy Foster. Julien Mauhourat. Vera Trautwein. (2022). Mckinsey & The Company. Taking the pulse of shifting supply chains. Our latest survey shows global supply chains on the move. 21.07.2023.

98 Simchi-Levi, D., & Haren, P. (27.03.2022). How the War in Ukraine Is Further Disrupting Global Supply Chains. Harvard Business Review. https://hbr.org/2022/03/how-the-war-in-ukraine-is-further-disrupting-global-supply-chains Accessed 21.07.2023.

99 Peter Liddell. Chris Clements. Iain Prince. Robert Barrett. (2022). KPMG. Supply chain considerations from the conflict in Ukraine. How to stay on top of your supply chain.

100 Pippa Stevens. (29.03.2021). CNBC. The ship that blocked the Suez Canal may be free, but experts warn the supply chain impact could last months https://www.cnbc.com/2021/03/29/suez-canal-is-moving-but-the-supply-chain-impact-could-last-months.html Accessed 22.07.2023.

101 Patrick Rigoni. (23.12.2018). LinkedIn Blog. Why using Z-factors and service level percentages for stocks is total Ban San https://www.linkedin.com/pulse/why-using-z-factors-service-level-percentages-stocks-total-rigoni Accessed 22.07.2023.

102 Lisa Caldwell. (18.06.2022). Forbes. The War In Ukraine: Lessons For Manufacturers, https://www.forbes.com/sites/lisacaldwell/2022/07/18/the-war-in-ukraine-lessons-for-manufacturers Accessed 22.07.2023.

103 Paul Schönsleben. (n.d.) ETH Zurich. 7.4.1 Classical Procedure and Different Archetypes of Engineer-to-Order (ETO) https://opess.ethz.ch/course/section-7-4/7-4-1-classical-procedure-and-different-archetypes-of-engineer-to-order-eto/ Accessed 22.07.2023.

104 Juha-Pekka Suomela. (2020). UNIVERSITY OF VAASA. School of Technology and Innovation. Thesis: Selection Criteria of Engineering-to-order Manufacturing Suppliers for Project Deliveries.

105 Aldo Sante Duchi. (2017). ETH Zurich Doctoral Thesis. Models and practices of cooperation between R&D and Engineering in an ETO operations environment Supporting product development and order specification processes https://www.research-collection.ethz.ch/handle/20.500.11850/174250 Accessed 22.07.2023.

106 Aldanondo, M. and Vareilles, E. (2008), “Configuration for mass customization: How to extend product configuration towards requirements and process configuration”, Journal of Intelligent Manufacturing, Vol. 19 No. 5, pp. 521–535.

107 Schönsleben, P. (2016), Integral Logistics Management: Operations and Supply Chain Management within and across Companies, CRC Press.

108 Amaro, G., Hendry, L. and Kingsman, B. (1999), “Competitive advantage, customisation and a new taxonomy for non-make-to-stock companies”, International Journal of Operations & Production Management, Vol. 19 No. 4, pp. 349–371.

109 Olhager, J. (2003), “Strategic positioning of the order penetration point”, International Journal of Production Economics, Vol. 85 No. 3, pp. 319–329.

110 Willner, O., Rippel, M., Wandfluh, M. and Schönsleben, P. (2013), “Development of a business process matrix for structuring the implications of using configurators in an engineer-to-order environment”, in Emmanouilidis, C., Taisch, M. and Kiritsis, D (Eds.), IFIP Advances in Information and Communication Technology, Vol. 397, Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 278–285

111 Konijnendijk, P.A. (1994), “Coordinating marketing and manufacturing in ETO companies”, International Journal of Production Economics, Vol. 37 No. 1, pp. 19–26.

112 Willner, O., Powell, D., Gerschberger, M. and Schönsleben, P. (2016). Exploring the archetypes of engineer-to-order: an empirical analysis. International Journal of Operations & Production Management, vol. 36, no. 3, pp. 242-264.

113 Sheikh-Zadeh, A., Rossetti, M.D. and Scott, M.A. (2021). Performance-based inventory classification methods for large-Scale multi-echelon replenishment systems. Omega (Oxford), vol. 101, pp. 102276.

114 Heta Hakonen. (2021). Master’s Thesis. LAPPEENRANTA-LAHTI UNIVERSITY OF TECHNOLOGY LUT School of Engineering Science Degree Programme in Industrial Engineering and Management. DATA ANALYTICAL APPROACH TO INVENTORY MANAGEMENT DEVELOPMENT IN ENGINEER-TO-ORDER PRODUCT MANUFACTURING

115 Muhammad Saeed. (2012). Master’s Thesis. Department of Management and Engineering Division of Production Economics Linköping Institute of Technology. Lean thinking in the supply chain operations and its integration with customer order decoupling point and bottlenecks

116 Hackman, J.R., Wageman, R. (1995). “Total quality management: empirical, conceptual, and practical issues”. Administrative Science Quarterly, Vol. 40, No 2, pp. 309–342.

117 Naylor, J. B., Naim, M. M. Berry, D. (1999). “Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain”. International Journal of Production Economics, Vol. 62, pp. 107-118.

118 Mason Jones, R., Towill., D. (1999). “Using the information decoupling point to improve supply chain performance”. International journal Logistics Management, Vol. 10, pp. 13–26

119 Wang, G., Huang, S. M., & Dismukes, J. H. (2004). Product-driven supply chain selection using integrated multi-criteria decision-making methodology. International Journal of Production Economics, 91, 1-15.

120 Brière-coté A., Rivest L., Desroches, A. (2009). Adaptive generic product structure modelling for design reuse in engineer-to-order products, Computers in Industry .

121 Aicha Amrani. Salah Zouggar. Marc Zolghadri. Philippe Girard. (2010). 2010 Management and Control of Production Logistics. University of Coimbra, Portugal. Supporting framework to improve Engineer-To-Order product lead-times.

122 Koustav Das. (30.03.2021). India Today. Explained: How much did Suez Canal blockage cost world trade https://www.indiatoday.in/business/story/explained-how-much-did-suez-canal-blockage-cost-world-trade-1785062-2021-03-30 Accessed 22.07.2023

123 PiLog Group. (2023). Material Criticality Analysis Criticality Ranking for Material Enabling better process control https://piloggroup.com/material-criticality-analysis.php#0 Accessed 13.08.2023.

124 Melanie. Unleashed Software. (10.12.2018). Should You Be Using SDE Analysis to Classify Your Inventory? Accessed 13.08.2023.

125 Gonzalo Aguilar. (26.02.2022). What does SDE in inventory analysis stand for https://www.blyp.ai/a/question-hub/shopify-entrepreneurs/what-does-sde-in-inventory-analysis-stand-for Accessed 13.08.2023.

126 Exceed College. (2023). Top Inventory Management Tools and Techniques – SDE, VED, FSN Analysis https://exeedcollege.com/blog/top-inventory-management-tools-and-techniques/ Accessed 13.08.2023.

127 Gizaw, T., & Jemal, A. (2021). How is Information from ABC-VED-FNS Matrix Analysis Used to Improve Operational Efficiency of Pharmaceuticals Inventory Management? A Cross-Sectional Case Analysis. Integrative Pharmacy Research and Practice, 10, 65-73. https://doi.org/10.2147/IPRP.S310716 Accessed 13.08.2023.

128 Logistiikan Maailma. (2023). ORDER PENETRATION POINT – OPP. https://www.logistiikanmaailma.fi/en/production/order-penetration-point-opp/ Accessed 13.08.2023.

129 Malik Shawal. (n.d.) Your Article Library. VED Analysis, SDE Analysis and FSN Analysis https://www.yourarticlelibrary.com/business-

management/marketing-management-business-management/ved-analysis-sde-analysis-and-fsn-analysis/69363 Accessed 13.08.2023.

Appendix 1: Supply Chain Shocks Risks and Countermeasures

Event	Risks	Countermeasures
COVID-19 Pandemic	Disruption of production in affected regions	Diversify sourcing and production locations
	Shortage of labour and constraints due to spread of the virus	Develop alternative suppliers
	Transportation and logistics delays	Establish safety stock levels
	Increased costs due to demand fluctuations	Strengthen communication within the supply chain
	Border restrictions and customs delays	Implement real-time tracking and visibility
War in Ukraine	Disruption of raw material supply	Identify secondary suppliers or substitutes
	Transportation and logistics disruptions	Maintain safety stock for critical components
	Currency fluctuations and financial risks	Hedge currency exposure
	Political instability and regulatory changes	Collaborate with local partners and authorities
Evergreen	Blockage of a major trade route	Diversify shipping routes and carriers
	Delayed shipments and port congestions	Optimize inventory and distribution strategies
	Loss and damage to cargo	Insure high-value shipments
	Reputational damage to involved companies	Strengthen crisis management and communication

Appendix 2: Safety Stock Methods Comparison

Method	Pros	Cons
Normal distribution with uncertainty of demand and lead time, independent relationship	Accounts for both demand and lead time variability Easy to calculate with historical data Suitable choice when there is variability in demand and lead time Variation in lead time does not imply a variation in demand or the other way around	Assumes normal distribution of demand and lead time Assumes independence between demand and lead time May not be accurate if there is a relationship between demand and lead time. May not accurately reflect real-world dependencies between lead time and demand
Normal distribution with uncertainty of demand and lead time, dependent relationship	Accounts for both demand and lead time variability and potential dependencies Considers both demand and lead time uncertainty Assumes that demand and lead time are dependent, which can be a realistic assumption in some cases Variation in lead time can imply variation or demand or the other way around	Assumes normal distribution of demand and lead time May not be accurate if there is no relationship between demand and lead time. Requires knowing of whether there is dependency between lead time and demand Calculating correlation between demand and lead time can be complex, depending on the method (not included in the equation)

Normal distribution, Variability in Demand	Considers variability in demand Suitable when there is only variability in demand Easy to calculate with historical data	Does not consider variability in lead time The formula can lead to stock-outs if variability in lead time is significant Demand is assumed to be normally distributed
Normal distribution, Variability in Lead Time	Considers variability in lead time Suitable when there is only variability in lead time Easy to calculate with historical data	Does not consider variability in demand May lead to overstocking if demand variability is significant Lead time is assumed to be normally distributed
Max – Average Formula	Can provide a quick estimate of safety stock levels Easy to calculate with historical data No assumption of normal distribution for either demand or lead time	May not be as accurate as other methods that consider more factors such as demand and lead time uncertainty. Does not account for demand or lead time uncertainty

Appendix 3: Segmentation Method Comparison

Inventory Segmentation Method	Pros	Cons
ABC	Effective in managing inventory by classifying products based on their cumulative cost % Simplified Decision-Making	May overlook slow-moving but important items. Limited Perspective Ignores items with lower value but which are potentially important Doesn't consider demand variability Ignores consumption patterns Overemphasis on High-Value Items Lack on context as sole focus is on monetary value
FMSN	Considers consumption patterns. Identifies slow-moving and non-moving items Can aid in optimizing inventory turnover Can helps reduce excess or obsolete inventory Helps categorize items based on consumption frequency Potential to improve stock management and space usage	Doesn't account for demand variability. Ignores value or importance of items. May not address items with irregular patterns. Limited focus on criticality
XYZ (1/2)	Accounts for demand variability Addresses issues with unpredictable demand.	Doesn't consider value or importance of items.

ZYX (2/2)	Helps optimize stock levels for different items.	
HML	Effective in classifying products based on their unit price Can help to manage budget and spending Can supports cost-effective inventory management.	Doesn't account for demand variability Ignores importance of items May not address items with irregular patterns.
VED	Focuses on criticality of items Effective in classifying inventory based on its functional importance Helps prioritize inventory management efforts by highlighting critical and essential items Can improve supply chain resilience through better planning Can enables better planning and replenishment strategies for crucial inventory. Potential to optimize costs by investing more in vital and essential categories and less in the desirable class.	Doesn't account for demand variability. Ignores value or importance of items. May not address items with irregular patterns. Requires careful consideration and validation of categorization for each item. Only focusing on criticality might not provide a comprehensive view of overall inventory management needs. Determining criticality can be subjective
SDE (1/2)	Considers supply scarcity of items. Helps prioritize items based on availability. Identifies items that may face shortages. Can assist in managing supply chain risks. Supports contingency planning for shortages.	Doesn't account for demand variability. Ignores value or importance of items. May not address items with irregular patterns. each product needs to be managed on an individual basis despite classification

SDE (2/2)	Future planning regarding sourcing can be improved	

Appendix 4: Manufacturing Model Comparison

Inventory Approach	Pros	Cons
Engineer-to-Order (ETO)	Highly customized products can satisfy unique customer requirements For some items, can minimize inventory holding costs if parts ordered on order basis For some items, reduced risk of excess inventory and obsolescence Greater customer satisfaction than MTO Can improve cash flow due to reduced inventory or waste	Longer lead times due to design and engineering process Complex supply chain coordination and management Production costs can be high Limited standardization may hinder economies of scale Limited ability to forecast and plan demand Coordination challenges between production and order management can exist May require additional inventory for common components
Make-to-Order (MTO)	Flexibility to accommodate customer preferences For some items, can minimize inventory holding costs if parts ordered on order basis Can improve cash flow due to reduced inventory or waste Ability to offer customizations without full ETO complexity	Longer lead times for production and delivery Coordination challenges between production and order management can exist Unstable demand which can be hard to forecast due to several variations May require additional inventory for common components
Make-to-Stock	Shorter lead times	Higher risk of excess inventory and holding costs

(MTS) (1/2)		
	Efficient production planning based on forecasted demand	Limited flexibility for customization and responding to unique demands
	Economies of scale in production are possible	Higher costs associated with managing and forecasting inventory levels
	Faster response to sudden increases in demand as there is no customization	Potential for stockouts if demand exceeds forecasts
		Potential over overstocking
MTS (2/2)		Potential for inventory obsolescence if demand changes rapidly
Assemble-to-Order (ATO)	Faster delivery compared to ETO and MTO	Requires inventory of sub-assemblies and components
	Reduced lead times due to partial pre-assembly	Limited ability to offer highly customized solutions
	basic parts of the product are already manufactured but not yet assembled.	Lack of supply of inventory that is ready to sell
	Less risk of having unsold units on hand	Coordination challenges between production and order management can exist
	Better cost control compared to ETO	May have higher production costs due to smaller batch sizes (cannot utilize economies of scale)
	Allows for some level of product customization	Difficulty in managing configurations and variations