



Warehouse planning and management

Case Medituote

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Abstract

Suomen Medituote Oy has been facing a predicament relating to high warehouse fill rate. To alleviate this, the company's internal material flow between two warehouses was selected for analysis. The goal was to find ways to decrease the amount of incoming goods while also ensuring the goods concerned would not run out before the re-order date.

The research began with analysis of existing data to determine important variables regarding the products within the material flow. The demand of the products in question was also visualised in graphs to better understand the demand patterns. Using existing knowledge and the data, formulas to determine case specific re-order point and quantity were developed. These were then used together to develop a tool to determine the need and quantity of new orders.

The tool in question was tested in a simulation conducted in Excel-environment. The simulation was done three times to account for variance in the demand. After observing the results, it was recommended to Medituote that they would test the tool developed in a real scenario.

Keywords/tags (subjects)

Warehousing, Intralogistics, Warehouse planning, Warehouse management, Inventory management, Excel-based simulation

Miscellaneous (Confidential information)

Contents

1	Introduction	4
1.1	Situation and objective	4
1.2	Research	7
1.2.1	Research methods and boundaries	8
2	Warehouse planning	8
2.1	Structure of the warehouse	10
2.2	Inside the warehouse	12
3	Warehouse management	14
3.1	Operations of a warehouse	14
3.2	Operation management	18
3.3	Warehouse risk management	20
3.3.1	Health and safety	21
4	Inventory management	25
4.1	Inventory planning	25
4.2	Inventory control	29
4.3	Inventory balancing	34
5	Application	35
5.1	Re-order point and quantity	43
5.2	Simulation	44
6	Results and discussion	52
6.1	Conclusion and further research	54
	References	55
	Appendices	57
	Appendix 1. ROP & ROQ -calculator	57

Figures

Figure 1	Location criteria groups (adapted from Demirel <i>et al</i> , 2010)	10
Figure 2	Average in- or outbound flow (adapted from Halbeisen & Segerlund, 2015)	13
Figure 3	Warehouse functions and material flows (adapted from Rushton <i>et al</i> , 2022)	15
Figure 4	Warehouse floor area usage (adapted from Baker & Perotti, 2009)	16
Figure 5	Warehouse costs (adapted from Rushton <i>et al</i> , 2022)	17
Figure 6	Supply chain risks (adapted from Ho <i>et al</i> , 2015)	20
Figure 7	Causes of major injuries (adapted from Health and Safety Executive, 2007)	22

Figure 8 Causes of over-3-day absence injuries (adapted from Health and Safety Executive, 2007)	22
Figure 9 Ballpoint pen partial disassembly	27
Figure 10 Calculating the number of decisions (adapted from Relph & Milner, 2015)	28
Figure 11 Illustration of Honeycombing	31
Figure 12 Inventory tracking card (adapted from Müller, 2002)	33
Figure 13 Inventory conditions (adapted from Relph & Milner, 2015)	35
Figure 14 Product 1 demand pattern	36
Figure 15 Product 2 demand pattern	36
Figure 16 Product 3 demand pattern	37
Figure 17 Product 4 demand pattern	37
Figure 18 Product 5 demand pattern	38
Figure 19 Product 6 demand pattern	38
Figure 20 Product 7 demand pattern	39
Figure 21 Product 8 demand pattern	39
Figure 22 Product 9 demand pattern	40
Figure 23 Product 10 demand pattern	40
Figure 24 Product 11 demand pattern	41
Figure 25 Product 12 demand pattern	41
Figure 26 Product 13 demand pattern	42
Figure 27 Product 14 demand pattern	42
Figure 28 ROP in general	43
Figure 29 ROP case specific	43
Figure 30 ROQ	44
Figure 31 Number of pallets brought in	47
Figure 32 Product 8 Inventory level	47
Figure 33 Product 3 Inventory level	48
Figure 34 Pallets in at ROP=6 days	49
Figure 35 Product 1,2&3 Inventory level at ROP = 5 days & Average demand	50
Figure 36 Product 1,2&3 Inventory level at ROP =6 days & Average demand	50

Tables

Table 1 Determining starting stock	45
Table 2 Starting data with average demand	45

Table 3 Starting data with added st.dev.	46
Table 4 Starting data with subtracted st.dev.	46
Table 5 Total inventory level at ROP = 5 days.....	51
Table 6 Total inventory level at ROP = 6 days.....	51
Table 7 % of inventory at ROP = 5 days	52
Table 8 % of inventory at ROP = 6 days	52

1 Introduction

Suomen Medituote Oy is a Finnish sanitation and healthcare wholesaler based in Jyväskylä, providing a wide variety of products ranging from soft paper and detergents to personal protection equipment. Their customer-base consists of public, private, and 3rd sector operators. If they need cleaning equipment, odds are they are a customer of Medituote (Medituote, 2023).

Founded in 2012, Medituote was at first quite a small operator, with a turnover of around 2,6 million at the end of 2019. However, due to managing to secure a massive deal in early 2020, their turnover tripled within the next year, and by the end of 2021 was 6 times higher than in 2019 (Finder, n.d.).

While growth is a major objective for any company, too much of anything at once is not an ideal situation. Medituote would very likely have collapsed under that growth, as evident by the 2020 financial result being almost 140 thousand in the negative (Finder, n.d.), had they not become a subsidiary of Berner Oy, a Finnish family company (Berner, n.d.).

1.1 Situation and objective

Currently, Medituote operates two warehouses. For clarity, let us call them *primary* and *secondary warehouse*. The day-to-day operations of picking, packing, and shipping happen in the primary warehouse. The secondary warehouse acts as an intermediate storage for a portion of their inventory, and items are moved from there to the primary warehouse once a week. It is worth noting that the secondary warehouse is unmanned, and when the truck used to move items into the primary warehouse arrives, people are sent to the secondary warehouse to help the driver load the truck.



The primary warehouse is at the moment suffering from high fill rate, as more items are arriving per week than leaving. To alleviate this problem, this thesis aims to optimise the material flow from secondary to primary. The objective is to have the transferred material be enough for one week, while not taking up any more space than is necessary. At the present moment, a rough estimate is made at the end of the week of how much needs to be transferred in at the beginning of next week.



This method is easily hampered by delays in the order-process. Be it a technical difficulty or slow picking rate, an order that was planned to leave during a given week might not, and thus the products brought over for that order do not leave until next week, all the while taking up space. And at the same time, more products are brought over to satisfy next week's orders. This takes up more space and starts to slow down the picking process even further. Add an increase in orders to the mix and you will end up with a clogged warehouse faster than you can say it.



1.2 Research

This thesis aims to find a solution to high warehouse fill rate through following research questions:

1. Why is warehouse space management important?
2. How can possible excess stock be dealt with and why should you deal with it?
3. What are the causes of stock-level to storage space disproportion?

The purpose of these questions and their answers is to give understanding about the predicament in question, and for the second one in particular, provide suggestions for moving forward. They should also help ensure that the starting point remains avoidable.

1.2.1 Research methods and boundaries

Research methods used in this thesis are review of existing literature about the topic, including books and previous theses, and analysing unit data received from the company's warehouse management system. This analysis is done using a spreadsheet-program, such as Microsoft Excel. And while obvious, it should be mentioned that the different products are in this thesis referred to as "Product 1", "Product 2", et cetera.

The review of existing literature is concentrated into three topics. These are "warehouse planning", "warehouse management", and "inventory management". The first topic considers the beginning of operations and futureproofing them. The second looks into the risks, challenges, and their solving in day-to-day operations. The third topic covers the specifics of managing inventories.

It has also been agreed that the research and analysis is limited to the company's internal logistics between two warehouses. While this material flow does not contain every single stock keeping unit (hereafter SKU) of the company, there are 14 individual SKU's, some with more than a thousand pickings during the year. In addition to being a major material flow, it is also easier and faster to adjust due to the proximity of the warehouses to each other. Additionally, this creates the necessary limits to the thesis itself, which is also important.

2 Warehouse planning

Every operation and project starts with a plan, at least if one wants it to succeed. For warehousing, the first step is to define the process, as recommended by Dominic Halbeisen and Stefan Segerlund (2015) in *Intralogistics: A Guide to Warehouse Planning*. They argue that "every process is made up of customers and suppliers, even if the process takes place entirely within the same company" (Halbeisen & Segerlund, 2015, p. 37). Definition of the process can be linked to defining the operation of our new warehouse, and what are the requirements of that operation. The requirements of storing raw materials are quite different from what finished goods require. And within those categories are subcategories. A product may require a certain type of container or temperature.

There are a few ways to define the type of warehouse operation. A simple division to procurement, production, and distribution is given by Heinrich Martin in *Warehousing and Transportation Logistics* (Martin, 2018). A procurement warehouse provides materials to production, a production warehouse works in the middle as an interim storage, and a distribution warehouse stores the finished product and provides customer service by handling shipping. This is however not the only way to divide operation types.

Literature on warehousing provides different ways to classify operations. In their book *Warehouse Management: The Definitive Guide to Improving Efficiency and Minimizing Costs in the Modern Warehouse* (Richards, 2021), Gwynne Richards divides the operations to ten different types. These are:

1. Raw materials storage
2. Intermediate, postponement, customisation or sub-assembly facilities
3. Finished goods storage
4. Consolidation centres, sequencing centres and transit warehouses
5. Trans-shipment or break-bulk centres
6. Cross-dock centres
7. Sortation centres
8. Fulfilment centres
9. Reverse logistics centres
10. Public sector warehousing

Along with choosing the type of warehouse operations, a choice of location has to be made. It has to serve its purpose and be as cost-effective as possible. The different criteria can be placed into five distinct groups: costs, labour, infrastructure, markets, and macro environment, as demonstrated by Demirel *et al* (2010).

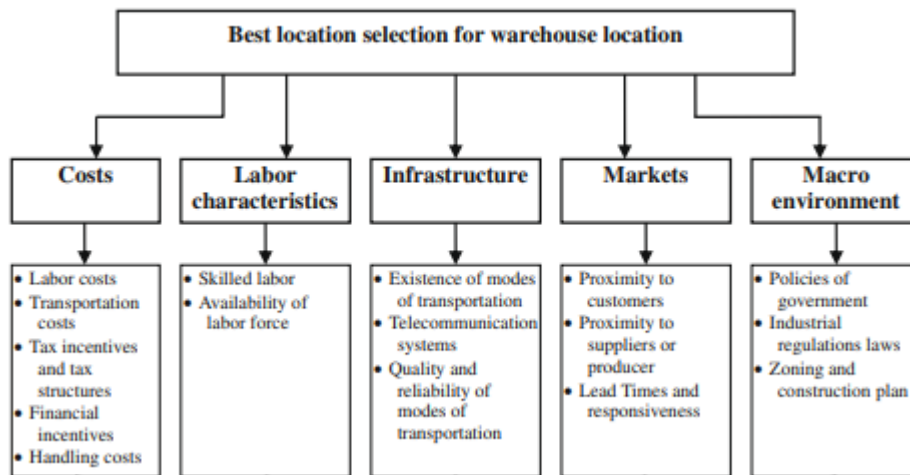


Figure 1 Location criteria groups (adapted from Demirel *et al*, 2010)

With the type of operation and the location decided, the next step is the warehouse building. There are both structural and interior considerations to be made.

2.1 Structure of the warehouse

The preferred situation would be a warehouse that has been designed and built just for that purpose. That opportunity rarely presents itself however, and most likely one will have to make do with what one gets. Before the start of operations, the condition of the warehouse should be assessed. To help with this, Stuart Emmett provides some pointers in *Excellence in Warehouse Management*. In general, consider the structure and surrounding area, fire safety, security, and loading bays in the assessment.

When assessing the structure itself and the area around it, some points of consideration suggested by Emmett (2005) are thus:

- What are the walls made of? Here concrete is the preferred option.
- What is the condition of the electric wiring?
- Is your company the only tenant? Is there physical separation between multiple tenants?
- What are the others storing?
- Is there yard storage, rubbish, or vegetation at the site?
- Does the local area have a history of flooding?
- Are there facilities for staff welfare and what are they?

Next up is fire safety, which is an important point to consider, because no matter how small the mistake is, the damage will be massive without proper safety procedures. For this, consider the amount and location of fire protection equipment like hand extinguishers and whether they are properly maintained, ensure the fire alarm connects to a place that is manned around the clock, check that sprinklers and smoke detectors are in place and work, enforce an effective no-smoking policy, and have working procedures for supervising hot work like welding (Emmett, 2005).

Theft

A warehouse with large amounts of sometimes very valuable materials is a prime target for burglary. While external theft is certainly a problem, Emmett (2005) points out the unfortunate reality that internal theft is more common than external. The 80/20 -rule, also known as the Pareto-principle, can be applied here as well. 80 percent of theft is internal, and 20 percent is external.

There are some signs to help with determining if there is theft going on. Missing and discrepant documents, product stacks that just so happen to be in front of a security camera, employees have smoke breaks frequently, and products being in a wrong location are some of them (Emmett, 2005).

So how does one mitigate internal theft? Install security for everyone entering and leaving the premises, this includes visitors and suppliers. Ensure the warehouse is well lit, has no blind spots, and is not congested. When selecting new employees, stay aware of the fact that people who take the job only to steal exist, and conduct as thorough background checks as the law requires and allows for. Stress to employees the importance of being honest, integrity, and what happens to thieves who are caught. Also, a leader should be the model of honesty (Emmett, 2005).

For external theft, have burglar alarms on all doors and openings and make sure they work and are connected to the police or a security company. Build a fence at least 2,2 metres tall, consider perimeter lighting, and have a modern access control system like a keypad (Emmett, 2005).

In security, something that has risen in the last two decades is information security (INFOSEC). A company's computer system contains a lot of important and valuable information, which should be protected from theft and loss. Some pointers from Emmett (2005) to help with this:

- Is there an INFOSEC-policy?
- Are there specific staff members for specific security responsibilities?
- Is information a main asset of your organization?
- Is there prevention of unauthorized access?
- Have safeguards for information such as back-ups been implemented?
- Is information access effectively controlled?
- Are security requirements part of system development or a packaged software solution?
- Is meeting legal requirements ensured?

In 2017, a case study related to the security of Internet of Things (IOT)-devices was done, titled *Blockchain for IoT Security and Privacy: The Case Study of a Smart Home* (Dorri et al, 2017). While conducted in the context of an individual person's home, there could be potential to extend this to an organisation.

Loading bays

Finally, the fourth point: loading bays. These are critical for the warehouse to function properly and be able to send and receive material. For the area around the bays, consider the vehicle turn-around time and space for vehicle manoeuvring. For the bay itself, look at the condition of the dock leveller plates, how long does it take to move them, and are they long and gradual enough so fork-lifts don't ground (Emmett, 2005).

2.2 Inside the warehouse

Designing the interior is a major part of a working warehouse. Halbeisen and Segerlund (2015) present how warehouse planning can be done for palletised goods, something that is well connected to the problem at hand.

Loading units

Big part of a warehouse is loading units, which Halbeisen & Segerlund (2015) argue to be, out of all design factors of a warehouse, the single most restrictive. They recommend listing every possible loading unit that requires handling, and then proceeding through a series of 14 questions that determine information required for quotation requests of racking, and to determine in- and out-bound flows. For the latter, they present the following formula:

$$\text{Hourly average inbound / outbound flow} = N_{\text{pallets}} * \text{Turnover}_a \div N_{\text{working weeks/year}} \div N_{\text{shifts/week}} \div 8 \text{ hours}$$

Figure 2 Average in- or outbound flow (adapted from Halbeisen & Segerlund, 2015)

Once every loading unit has gone through the questionnaire, the result is a census of loading units. After that, they are categorised using different characteristics. The one's Halbeisen and Segerlund (2015) recommend are: turnover (low-mid-high), first in-first out (FIFO) or last in-first out (LIFO), need of load support (yes or no), dimension and weight ranges (these can be separated if necessary), and necessity of picking (yes or no).

After the loading units have been categorised, there is one last thing to decide. Is the same warehouse solution used for all categories, or should each category have its own solution. Halbeisen and Segerlund call this decision to "be of utmost importance" (Halbeisen & Segerlund, 2015, p. 51). This is due to solution adaptation requiring adhering by the strictest requirement in the categories of the stored loading units, which in turn affects the costs (Halbeisen & Segerlund, 2015).

Cost-effectiveness is one of the arguments Halbeisen and Segerlund (2015) state for combining multiple different warehouse solutions together. However, they also argue that having a dedicated system for the most demanding load category because of some unpredictability in what will the load categories be in the future. In the end, the decision should be based on the customer's requirements (Halbeisen & Segerlund, 2015).

Picking system

After careful analysis of the loading units, a system for picking is on the drawing board. A challenge which Halbeisen and Segerlund (2015) emphasise as complex. Picking ties up working capital, is a major cost driver, and ramps up space consumption due to needing to store less than full loads for picking. In planning picking operations, consideration should be on number of orders picked per hour, average pick-up time for an order, and pallets picked per order (Halbeisen & Segerlund, 2015).

Information technology

In a modern warehouse the Information Technology (IT) systems are big part of the process. No matter how well the rest of the warehouse system is, improperly done IT system or improper integration will cause problems. Halbeisen and Segerlund (2015) go as far as stating a warehouse system “is bound to fail” (Halbeisen & Segerlund, 2015, p. 53). Due to this and the fact that not all companies have the newest IT system on the market, it is recommended that the IT department be part of the planning process (Halbeisen & Segerlund, 2015).

3 Warehouse management

One might think that once the warehouse has been designed and set up, the stressful part is over and it’s all smooth sailing here on out. The management of a warehouse, especially a large one, is however a position filled with challenges. Generally, because of this, a warehouse manager as a position is quite high up the corporate ladder in a company (Rushton et al, 2022). Like Liam Neeson, a warehouse manager has to have a particular set of skills.

3.1 Operations of a warehouse

While every warehouse is an individual and designed to fulfil whatever it is required to do in that particular part of the supply chain, there are common operations that show themselves one way or another. All humans may look different, but we still do the same basic tasks of eating, sleeping, and such. For warehouses, these are, as presented by Rushton et al (2022), receiving, reserve storage, picking, sortation, packing, and shipping.

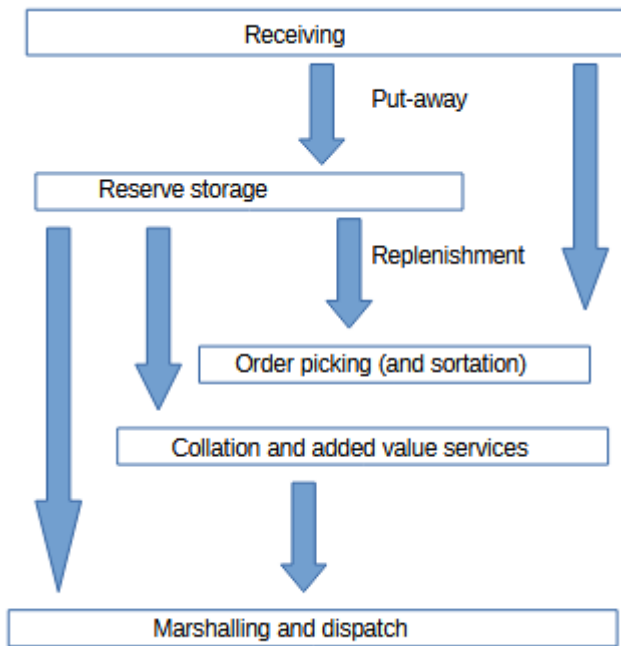


Figure 3 Warehouse functions and material flows (adapted from Rushton et al, 2022)

In receiving, the transport is unloaded and compared with a document that states what should be coming in, like a purchase order. Once clear, the transport is recorded as *received* and placed either into reserve storage or sent straight to picking. This step can include repackaging the transport to a more suitable format and quality checks (Rushton et al, 2022).

Most of the inventory is held in the reserve storage. From there, it's moved either straight to dispatch if the order size requires, or to fill a picking location. Of the operations, storage takes usually the most floor area, as shown in a report by Baker and Perotti (2009).

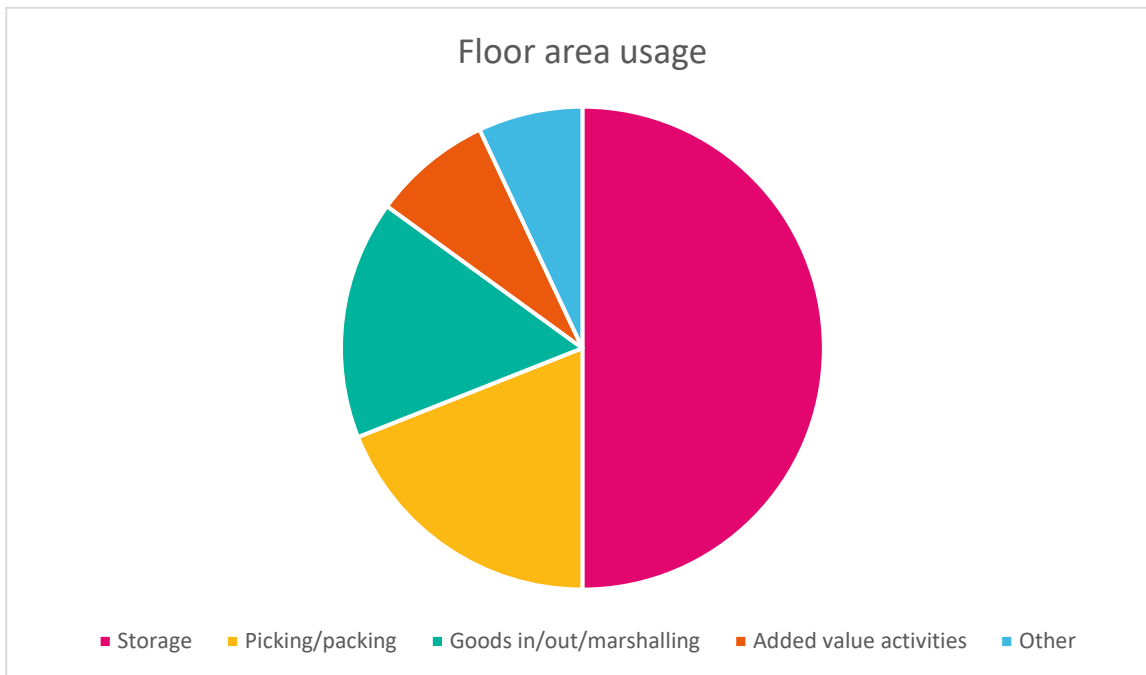


Figure 4 Warehouse floor area usage (adapted from Baker & Perotti, 2009)

Picking, “a key warehouse operation”, as Rushton *et al* (2022, p. 275) put it. An order is made up of “lines”, which are given quantities of specific SKUs. Depending on the quantity and the warehouse layout, either a full pallet can be taken from the reserve storage, or the needed amount is gotten from the picking area. The reason picking is seen as a key operation is that it requires major percentage of the staff, and it has to be done right to get accurately picked and delivered orders. In the case of many small orders, they can be batched together as a single order for picking. Before dispatch, the batch needs to be *sorted* back to the individual orders (Rushton *et al*, 2022).

A picked order is then packed. This can be done in a separate packing station, or by picking the items directly into the pallet, roll-cage, or carton, whichever is used to dispatch the order. Packing may also involve value-adding or other activities, such as labelling (Rushton *et al*, 2022).

Once an order is finished, it is delivered, or marshalled, to the dispatch area, where they wait for a vehicle to pick them up and deliver to whatever the next part in the supply chain is. The dispatch area can also serve as a receiving area for returned goods if there is no separate warehouse for them (Rushton *et al*, 2022).

Costs in warehousing

Warehouse operations are costly. According to Rushton et al (2022, p. 277), “warehousing typically accounts for about 20 to 25 percent of logistics costs, while the carrying costs for the inventory within them account for a further 20 to 25 percent”. Meaning a company can spend up to half of its logistics budget on warehousing. While the detailed division of costs depends on the warehouse operation, the so-called “conventional warehouse” can have its costs divided as thus (Rushton et al, 2022):

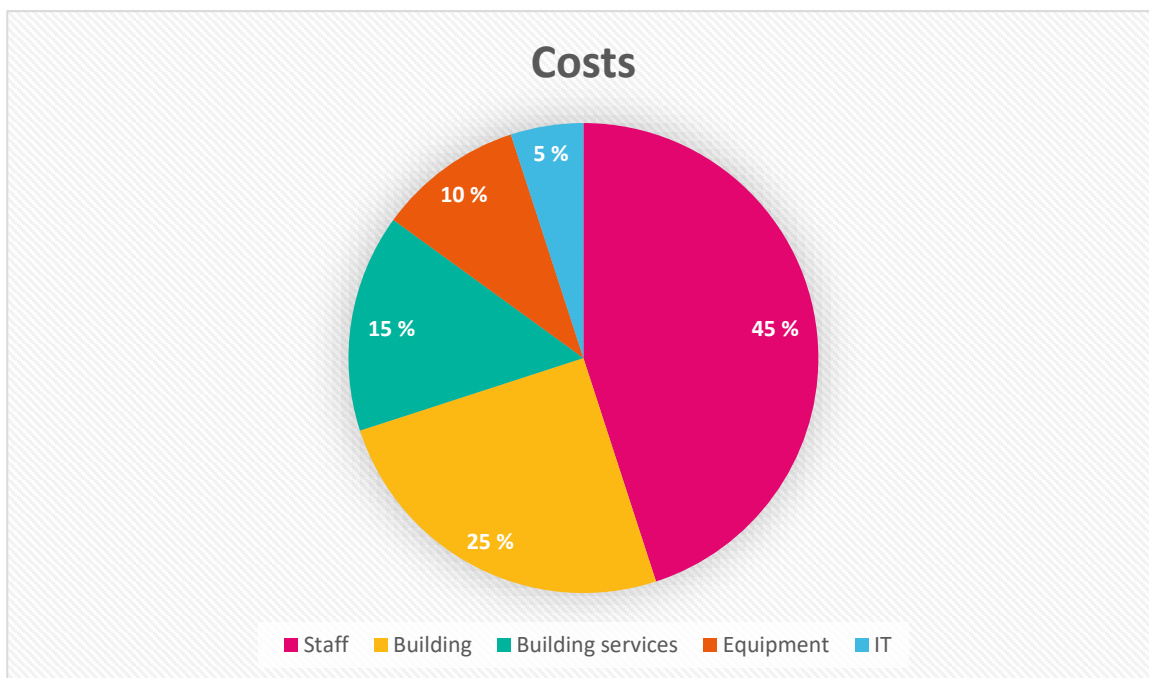


Figure 5 Warehouse costs (adapted from Rushton et al, 2022)

It should be noted that these are not set in stone. Staff can have a range of 45 to 50, equipment 10 to 15, and IT 5 to 10 percent. However, what this demonstrates is that the physical building and staff should be effectively designed and used. Rushton et al (2022) also points out that warehouses with a high level of equipment automation or complex information systems can have their costs in those areas significantly higher than shown above.

3.2 Operation management

Now that the operations within a warehouse are known, they can be managed. The responsibilities of a warehouse manager, as provided by Rushton et al (2022) are capacity and workload planning, performance monitoring, staff management, process improvement, legal requirements, and a few others.

Capacity planning is concerned with long- and medium-term situation, and futureproofing activities. Things like seasonal peaks and large nationwide campaigns are important to be prepared for in advance, so you “don’t get caught with your trousers down” so to speak. Generally, a seasonal peak comes in three stages of storage, sales, and returned goods peak (Rushton et al, 2022).

Something that can throw wrenches into planning are big campaigns like Black Friday. Alongside shortening the timeframe the peaks occur in, they can also cause peaks to overlap one another. This necessitates planning for a season even before the previous one has properly started, especially with automated systems, so there is enough time to test everything before the peak starts (Rushton et al, 2022).

Short-term planning

When long- and medium-term planning is concerned with capacity, short term is all about workload and staffing. This is because when demand changes, labour needs change alongside it. Luckily staff resources are fast to allocate with overtime and temporary workers (Rushton et al, 2022).

Staff level is only a part of workload planning. Other factors to include are the necessary amount of warehouse trucks, autonomous mobile robots (AMRs), if applicable, and capacity limitations for different parts of the warehouse. These limitations, in addition to capacity and workload planning, should be considered in real time as well to manage both the processing and release of orders. Therefore, Rushton et al (2022) argue that the planning “should be integrated into the company’s overall sales and operations planning or integrated business planning processes” (Rushton et al, 2022, p. 380).

Performance monitoring

Performance monitoring on continuous basis is big part of process improvement. The service and costs standards for warehouses are quite tight and meeting them is often a requirement to be a successful business. With a need to achieve multiple objectives at once, it is not uncommon for a warehouse to have a lot of different performance metrics, such as service level, stock integrity, and personnel. As Rushton et al (2022) point out, there are many roles for warehouses, and selecting the right metrics is done on a case by case-basis. While listing every individual metric is not feasible, they can be classified into categories, like leading and lagging, single and joint, and external and internal (Rushton et al, 2022).

In addition to process improvement, the performance metrics should be considered when determining a warehouse's operational parameters such as number of SKUs. Standardising these parameters is extremely difficult due to, as stated before, every warehouse being individual, and should be done very carefully. Rushton et al (2022) recommends that when operational parameters are changed, these changes should be linked to key performance indicators (KPIs).

While monitoring warehouse activities can lead to detailed data about performance, which is quite useful, especially to large warehouses. However, there is a flipside. As Rushton et al (2022) points out, the quality of the working environment can suffer due to over-monitoring of workforce. Even the most well-equipped warehouse will have a hard time functioning without people. While there are automation solutions for small and medium-sized enterprises (SMEs), like the one tailored by Cassettari et al (2021), most of them are not suited for SMEs due to high investment cost and inherent suitability to large and diverse product lines (Cassettari et al, 2021).

Staff management

With people being a resource of greatest importance, management should decide on an effective staff policy that aims to attract, motivate, and retain employees. For different features in this policy, Rushton et al (2022) suggests things like financial incentives, employee autonomy, and good working conditions.

Good working conditions are oftentimes also required by law. In Finland, this is manifested in the Occupational Safety and Health Act of 2002, which applies to everything with the exception of mil-

itary and voluntary exercises by the Defence Forces and the Border Guard (Finlex, 2023). Depending on the stored goods, there may also be separate regulations related to them, examples being food and hazardous substances (Rushton et al, 2022).

In addition to these, management can have a lot of other responsibilities. Examples include keeping inventory accurate, cleaning, security, and environment.

3.3 Warehouse risk management

As previously mentioned, a warehouse is part of a supply chain, be it internal or external. Therefore, the warehouse risk management is also part of the idea of Supply Chain Risk Management (SCRM). Through an extensive study in 2015, Ho *et al* categorised risks as follows:

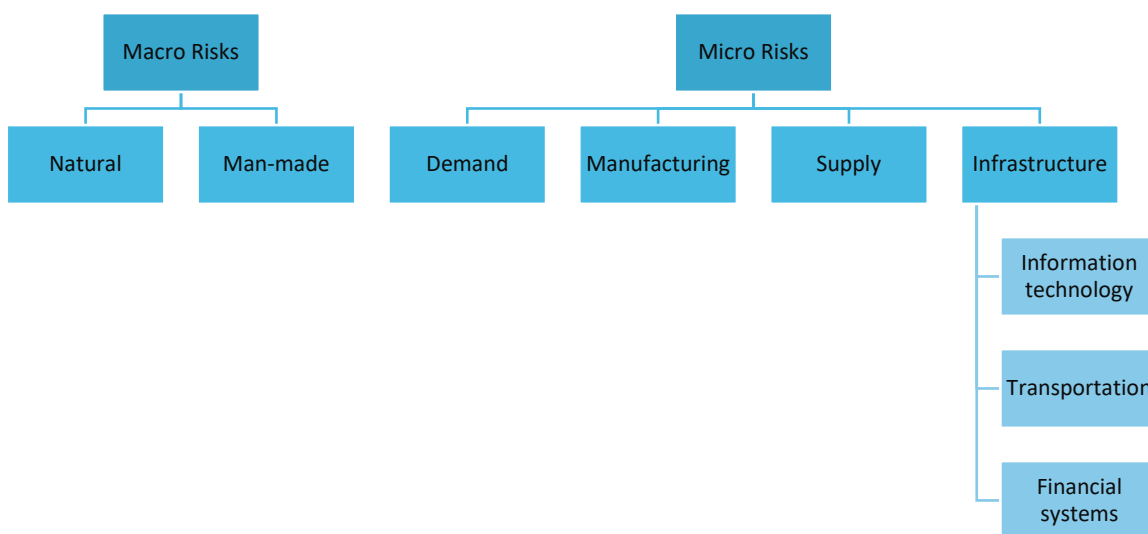


Figure 6 Supply chain risks (adapted from Ho et al, 2015)

Natural risks are events like earthquakes, floods, wildfires et cetera, while man-made relates to armed conflicts, political instability, and the like. These macro risks, while generally bearing more major negative impact, occur on a very infrequent basis. These should be considered during the planning stages. Emmett (2005) suggests looking into if the local area has a history of flooding, and if proper fire safety procedures are in place when selecting the location. Mitigation of man-made

risks comes down to observing the political climate in the destination. Micro risks on the other hand are more common, but usually have less negative impact on the company (Ho et al, 2015).

In their study, Ho et al (2015) identified a multitude of different factors for micro risks. In demand, these factors include inaccurate forecasting, uncertain demand, short lead times and life cycles, and changes in competition. Manufacturing risk factors link to either employee health and safety or production challenges, and supply risks stem from inability for competitive pricing, outdated technology, difficulties with suppliers, and failure to meet required quality to name some. (Ho et al, 2015).

IT, transportation, and financial systems are grouped by Ho et al (2015) under infrastructural risks. Their reasoning is that “any disruptions in these systems can also lead to serious problems in a supply chain” (Ho et al, 2015, p. 5035). An example is major political strike in Finland in March of 2024, which caused some petrol stations to run out of fuel due to affecting the logistics and transportation sectors (Yle News, 2024). Other infrastructural factors are IT system compatibility issues, lack of transport alternatives, price fluctuations, and many others (Ho et al, 2015).

3.3.1 Health and safety

Employee health and safety are among risks related to manufacturing but can be extended to any part of the supply chain. In the context of warehousing, the United Kingdom Health and Safety Executive (HSE) has published a guidebook on employee health and safety, made in tandem with the Warehousing Health and Safety Forum, which is a joint entity consisting of representatives from trade associations, unions, and employer organizations (Health and Safety Executive, 2007).

According to HSE (2007), most major injuries in warehousing are caused by slipping or tripping, manual handling, and falls from height, with 26 %, 18 %, and 16 % respectively. For injuries resulting in an absence of more than 3 days, manual handling is the cause in 46 % of cases.

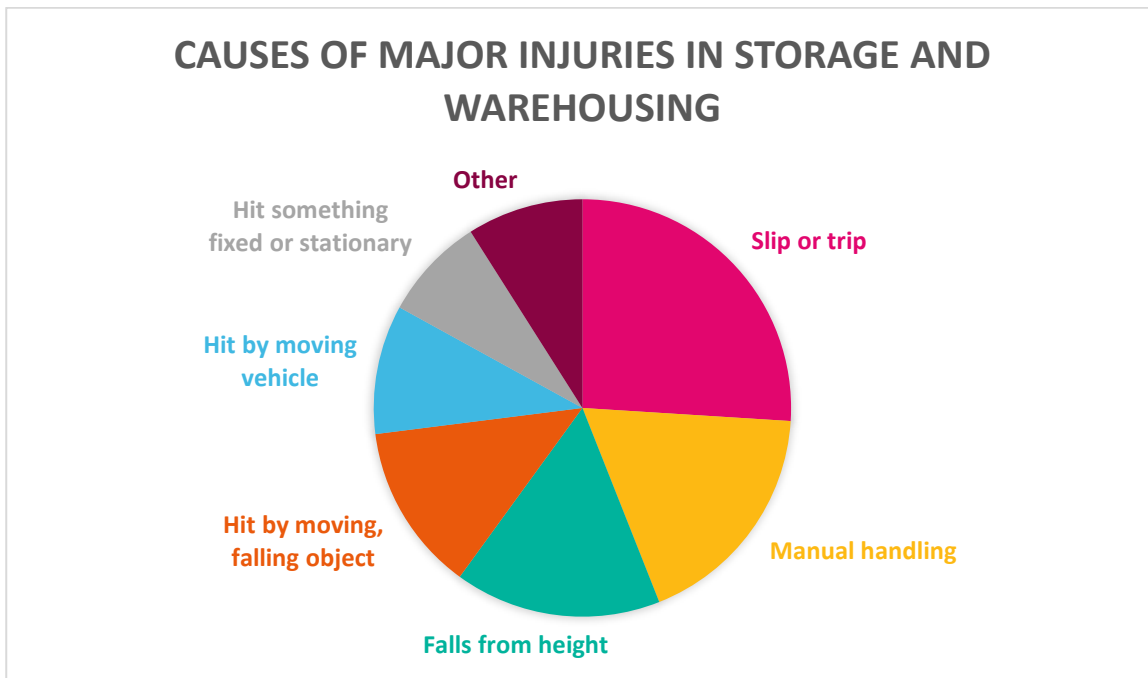


Figure 7 Causes of major injuries (adapted from Health and Safety Executive, 2007)

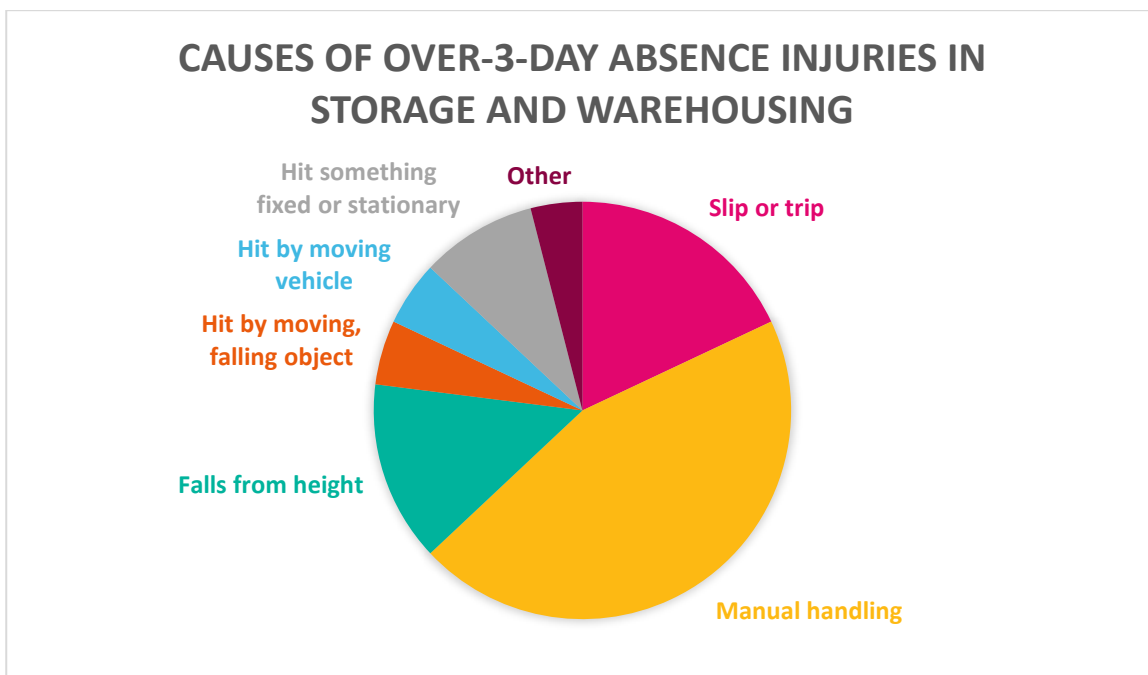


Figure 8 Causes of over-3-day absence injuries (adapted from Health and Safety Executive, 2007)

To mitigate injuries, HSE recommends beginning with a risk assessment, where warehouse management examines what can result in harm to people. To help with assessing risks, HSE breaks it down to five steps. First, identify hazards. Second, discern who could come under harm and in

what way. Third, evaluate risks and conclude necessary precautions. Fourth, record and implement, and fifth, review and update (Health and Safety Executive, 2007).

According to a Canadian insurance company Zensurance, the preparedness for events beyond their control resulting in unexpected loss and damage is one of the top challenges for warehouse management. No matter how smoothly operations are running, there is always a possibility that an accident happens. Alexandria Anthony lists nine common accident-types and suggestions on how warehouse management can mitigate them (Anthony, 2023).

Two from this list, *fire* and *theft*, have already been gone through in *Warehouse planning*-section, so these will not be covered here. The recommendations given by Anthony (2023) are very similar to what Emmett (2005) has written on the subject.

First, there are physical injuries from *slipping, tripping, and falling*. They can result from messy floors, obstacles, slippery walkways etc. Some suggestions are to keep floors clean, remove obstacles from where people walk, clean snow and ice from drive- and walkways, keep the warehouse well lit, make sure mats and carpets are stationary, and enforce safety footwear-requirement (Anthony, 2023).

Less common but slightly more dangerous is *exposure to harmful substances* such as chemicals. Accidents can result from improper storage, labelling, or waste disposal, and in addition to human injuries, may cause environmental and property damage. It is recommended that proper emergency procedures are in place, safety manuals exist and employees follow them, the materials are stored in a designated, well-ventilated, dry, and cool area and are labelled correctly, the containers are designed to hold the materials (sealable, weather-proof), the storage is regularly inspected and documented, and safety equipment requirements are enforced (Anthony, 2023).

Alongside slipping, tripping, and falling, *falling objects* are a common cause of physical injuries. Stacking items can result in a sudden fall if their movement or storing position is off balance. And because physics, more height means more energy, resulting in more damage, either to the prod-

uct, a person, or both. To mitigate, do not store anything heavy high up, ensure the items are securely in place when on an elevated surface, train employees on proper stacking methods and identifying unsafe ones, and again, enforce safety equipment (Anthony, 2023).

Mechanical and electrical malfunctions resulting in *equipment failure* are frequent as well. Be it a forklift, a freezer, or the heating, ventilation, and air conditioning (HVAC) system, the warehouse most likely needs it to operate effectively, or at all. In addition to losing that specific piece of equipment, it can result in a domino effect that derails the productivity of the entire warehouse. Therefore, all the equipment, machinery, systems and whatnot should be regularly maintained, their performance monitored, and employees trained to use and store them properly (Anthony, 2023).

Emmett (2005) mentioned “history of flooding in the local area” as a point of consideration when choosing the place for your warehouse. *Flooding and water damage* is both immediately destructive and has long-lasting consequences if not properly taken care of. Water damage can lead to mould and air-quality problems, a severe risk of employee health. Mitigation comes down to working water pumps, regular flood assessment and immediate problem addressing, keeping products off the floor, or storing them in water-resistant containers, staying aware of local weather conditions, having clean drains outside the warehouse, water-resistant doors and windows, and training employees to spot hazards and report them (Anthony, 2023).

Employee safety is important. In addition to the previously mentioned hazards, there are many other ways for *employees to get injured*, or in the worst case, die. It should be ensured that employees are trained on safety techniques, especially with machinery. Also, regular risk assessment should be conducted, and employees should be empowered to make reports of any hazards or incidents. For labour-intensive tasks, use of machinery should be allowed when at all possible (Anthony, 2023).

Finally, general *product damage* and resulting loss of inventory, be it through mishandling by an employee or collapsed shelving unit. As with equipment failure, employees should be trained to properly handle products. Shelving units, racks, tools, machinery, and pallets should periodically

be inspected, and when damage occurs, make documentation to help with identifying ways to mitigate damage in the future (Anthony, 2023).

4 Inventory management

Relph and Milner (2015, p.7) define inventory management as “a process of directing and administering the holding, moving, and converting of raw materials through value-adding process to deliver finished products to the customer”. The job of an inventory manager is to monitor inventory levels through different policies and controls. They decide the stock level of a given product, determine the re-order point (ROP) and the re-order quantity (ROQ).

Inventory management can be analogous to tightrope walking. On one side there is low inventory, which comes with availability problems, failing to deliver orders, and continuous shortage management, or “firefighting”. On the other, there are the problems of over-stocking, tying up money to assets, and slower reaction speed (Relph & Milner, 2015). Finding the perfect balance between these two sides is not easy, just ask Philippe Petit.

Inventory management can be divided into three pillars: *plan*, *control*, and *balance*. Together, these pillars hold up the imaginary building of inventory management, and if any one of these pillars is weak, the whole thing collapses Relph and Milner (2015).

If inventory management seems so complicated, one might consider whether they need inventory at all. Inventory managers around the globe can breathe a sigh of relief as Max Müller (2002) gives their job a reason to continue existing. The book *Essentials of Inventory Management* lists six important reasons: predictability, demand fluctuation, supplier unreliability, price protection, discounts, and lower cost of ordering. In an ideal world, there would be exactly what is needed exactly when it is needed. This however is not the case, so inventory management it is.

4.1 Inventory planning

To find the perfect position on the inventory management tightrope, a plan is required. To create one, first it should be understood what the demand pattern for a product is like. Is it a straight line

or are there major spikes up or down? Also under consideration should be the value-add requirements for a given product, and what category should it be placed in (Relph & Milner, 2015).

The plan has to accomplish one thing: balance the needs of the business with what is actually possible. Knowing the demand, it is decided what is sold, where it is stored, how much of it is stored, and at what cost. To help with this, parameters that help with the balancing are identified, such as order frequency and minimum order quantity (Relph & Milner, 2015).

Relph and Milner (2015) list inventory planning into four steps:

1. What is the current status of the inventory?
2. Does current inventory line up with the business target or is something else needed?
3. What is needed to do to achieve the business target and how difficult is it going to be?
4. Which actions need to be taken?

As Relph & Milner (2015, p. 76-77) state: “when a simple inventory management approach works, there is no need to overcomplicate the situation”. However, the larger an organisation becomes, the more complex and more careful inventory management becomes. In general, organisations have three levels of objectives: long-, medium-, and short-term. All of these contain different factors affecting inventory management.

These objectives are managed with strategic-, tactical-, and operational-level decisions. For example, a strategic decision may be the production volume per factory or country. A tactical decision would then be making a more detailed production plan for one of these factories, and at operational level, the daily, weekly, and/or monthly production schedule is decided (Relph & Milner, 2015).

This may still sound simple but let us examine the process a bit closer. Strategic decisions are usually very simple financial decisions, such as “reduce inventory by X%”. However, doing this is not as simple as just cutting total inventory by a given percentage. First, the products where inventory

can be reduced without compromising the business have to be identified. Then it must be examined whether cutting these products actually meets the goal. To help with this, a useful tool known as a Materials Requirements Planning (MRP) system can be used (Relph & Milner, 2015).

MRP however, is not a quick and easy solution. In Finnish, the lovely alliteration of “*oikotie on-
neen*”, or “shortcut to happiness” in English, could be used. The process of testing the how’s and where’s of inventory reduction is a long one, especially if wanted to be done effectively. The decisions, which number in many, are first processed by the MRP in a what-if environment, and the result from that needs to be tested against what is desired. This might go on for a couple of iterations before the right result emerges (Relph & Milner, 2015).

On top of that, the volume of data concerned is rarely small, no matter if you are a wholesaler or a manufacturer. For an easy example, find a ballpoint pen and disassemble it. While there are some that cannot be disassembled without permanently breaking them, most capped or spring-loaded ones can be dis- and reassembled many times over.



Figure 9 Ballpoint pen partial disassembly

From the above picture we can see 7 separate parts. There is also at least one part inside the body of the pen which could not be removed, and the actual ballpoint is separate from the ink tank, but that cannot be reassembled and would result in ink spilling out, so I did not physically split them. So, there are a lot more individual parts than the appearance would suggest. Now consider something bigger or more complicated, like your phone or car. All of these parts have parameters like lead time, batch sizes, and safety stock attached to them.

To get the number of decisions for the MRP, Relph and Milner present a simple calculation. Take the number of parts, in the case of our ballpoint pen, let’s go with 9, and the parameters, which typically is a minimum of 10.

$$N_{parts} \cdot N_{parameters} = N_{decisions}$$

Figure 10 Calculating the number of decisions (adapted from Relph & Milner, 2015)

Putting the numbers in, the amount of decisions comes to 90. Now consider a product with 50, 100, or a 1000 individual parts. With ten decisions per part, the numbers get quite high quite quickly, so setting parameters for individual parts is not very efficient, and thus it is better to group them. Using similar inventory characteristics, we can easily reduce the number of decisions to a more sensible level (Relph & Milner, 2015).

For engineers, the old saying “if it isn’t broken, don’t fix it”, becomes “if it isn't broken, it doesn't have enough features yet”. Over the years the MRP has seen a lot of development, as demonstrated in *The Handbook of Logistics and Distribution Management* (Rushton et al, 2022). First came the MRPII, or Manufacturing Resource Planning, which added things like cost accounting, maintenance and stock management, and personnel levels to the original system. This MRPII is itself often part of an Enterprise Resource Planning (ERP)-system, where finance and transactions are included as well. A link from MRPII to Manufacturing Execution System (MES) also generally exists, providing order flow control (Rushton et al, 2022).

New technologies are also vital in providing information for decision-making. Internet of Things, artificial intelligence, and Big Data are all providing something, be it immediate updates, the ability to plan complex operations, or the required analytics for the other two (Rushton et al, 2022). While these do have their own security concerns, as discussed in a previous section, the necessary speed and level of decision making is difficult to achieve without them.

All in all, when making an inventory plan, start by understanding the demand pattern for each product. The patterns should be the basis for the choices that concern the particular products, no matter the level of decision making. And when making these decisions, understand the full volume of the data that is being dealt with.

4.2 Inventory control

With a plan, the walk on the inventory management tightrope can continue. Next, the style should be considered, as not all of them are suitable for tightrope walking. As with walking, there are different ways to control inventory, and finding the one that works best for the specific inventory conditions is important.

Inventory control is stock integrity management. Because movement of inventory is a physical process, accurate tracking of where in the process the inventory is, and what are the quantities moving, is required. Keeping the record accurate is very important, as inaccuracies lead to problems in inventory balancing (Relph & Milner, 2015).

To help with tracking, a system should be designed and set up. Müller (2002) comes to aid once again and provides a checklist of what one must do to sustain accuracy of inventory. First, have a working locator system that the whole facility uses. Second, track a product the entire time it is inside your facility. And third, ensure the records of item storage and movement are up to date.

Starting with the locator systems, there are three commonly used ones. They are memory, fixed, and random. Which of these is the best in your scenario, depends on what one wants to maximise. Is it the usage of space, equipment, or labour? Item accessibility? Cost reduction? The one with the most importance should be picked, as optimising all of them is near impossible due to conflicts of these considerations with each other (Müller, 2002).

The most basic locator system is memory. The base idea is “someone will remember it, no need to write it down”. Memory system is simple, relatively free from paperwork or data entries, and allows to maximise the use of space. It is also unnecessary to bind a specific stocking location and a specific SKU (Müller, 2002).

There are however a lot of conditions, most of which have to exist, for this system to be effective. The storage locations have to be limited in both number and size, item variance has to be limited, items have to be easily identifiable and separatable by vision, the size of workforce has to be very small, the workers cannot have duties that take them away from the storage area, no radical changes to item types making up the inventory, and stock has to move slowly (Müller, 2002).

Other negatives of this system in addition to all these conditions are the strong reliance to a small group of people, or in the worst case a single person, who can forget, become ill, be on vacation, or just stop caring. Also, if they cannot remember where something is, it effectively does not exist until found again. There are times when a memory system does work, but they are few and far between (Müller, 2002).

In a fixed location, every storage location is reserved for one specific SKU, and nothing else is allowed to be placed there. In a less extreme case, a place may have multiple SKUs, but again, only those SKUs can be there. On the upside, an item is always in the same place. On the other hand, a fixed system requires a lot of space because of two reasons: it has to be planned based on the highest stock level for a given SKU, and honeycombing (Müller, 2002).

The first reason is based on the fact that, when there is a strictly defined location for each item, that location has to be able to contain the full volume of that particular item. Hence, the total space requirement is the sum of cubic space of every item at full volume (Müller, 2002).

For example, we have three products: A, B, and C, with full volumes of 1000, 600, and 400 respectively. Therefore, the total volume is 2000. In a fixed locator system, there must always be room to store that 2000, even if the products are not at full volume at the same time. This is because the system does not allow storing product A in area designated for product C, no matter if C is less than 400.

Honeycombing is the situation where there is available space, but it's not fully used for one reason or another. It can occur both horizontally and vertically, taking away both area and volume. Honeycombing is something that cannot be avoided due to product shapes, location system rules and so forth. What can be done is minimisation of the frequency and reach of it (Müller, 2002).

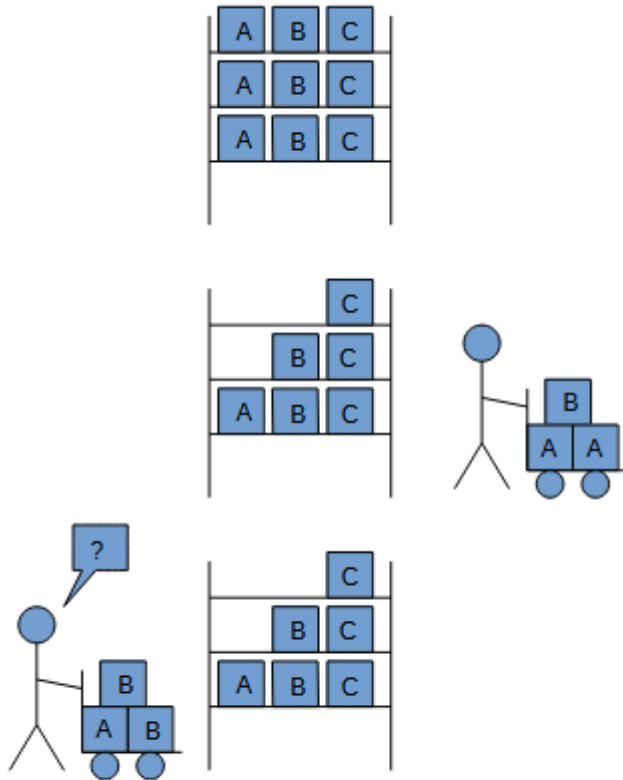


Figure 11 Illustration of Honeycombing

Level of honeycombing for a warehouse can be determined through either ratio analysis or using cubic space. In ratio analysis, the number of empty storage locations is divided by the total number of storage locations. The result is the percentage of empty space of total storage space. In the cubic space -method the total volume of empty space is divided by the total volume of storage space instead. Comparing these two methods, the cubic space- method accounts for the variance in storage space size, which the ratio method does not account for (Müller, 2002).

Applying the ratio method to the above picture, there are 9 storage spaces in total, and 2 of them stay empty (one can be filled with Product A). Hence, our ratio is 2 divided by 9, which is 0,222..., or 22,2 %. There is now a baseline to compare future changes against and see whether they result in improvement or not.

The positives of a fixed system are knowing immediately where something is, reduced training time of new hires, receiving and stock refilling are simplified and expedited, products can be aligned in a sequence (product 01, product 02 etc.), individual lots can be strongly controlled which aids with *first in first out* -method, products can be positioned near their final point-of-use, and a product can be placed where it's most suitable depending on its characteristics (Müller, 2002).

Negatives are high contribution to honeycombing, high space requirement, and the inflexibility of dedicated systems. If in a sequential alignment a product is added or removed from the middle, everything must be moved to keep the items in the desired sequence (Müller, 2002).

Similar to fixed system is zoning, where products are stored based on a particular characteristic. Grocery stores are a great example of this. The positives are the ability to isolate SKUs, flexibility in moving an item from one zone to another, ability to add new SKUs to a zone without the need to move large amounts of other SKUs to make room, and flexible planning, as there is no need to consider the total volume an SKU takes like in a fixed system. On the other hand, zoning might create unnecessary administrative complexity, it could contribute to honeycombing, and it requires that stock movement information is updated (Müller, 2002).

To maximise the use of available space, a random location system can be used, where no designated positions exist, and items are placed wherever there is space. However, unlike in a memory system, every item has an address which is marked down on either a computer or on paper. Once the SKU leaves, the marking is removed, and address potentially assigned to a new SKU. Random system combines the flexibility of memory with the control of fixed and zoning (Müller, 2002).

While a random system allows the maximisation of the use of space and knowledge of where an item is at a given time, it also requires updating the location information, and for a small number of SKUs it may be more complicated than necessary. In short, one must choose between maximum utilization of space and minimal administration (Müller, 2002).

As Müller states: "Very few systems are purely fixed or purely random" (Müller, 2002, p.62). To get the best of both worlds, a combination system can be used. In it, only select few items are in

fixed locations, and the rest are placed randomly. Generally, the most important items to the organisation would be fixed. Which ones they are depends on what the organisation wants to achieve with the locator system (Müller, 2002).

As mentioned at the beginning of this section, a working locator system supports the main process of inventory control: tracking. Increasing, decreasing, and moving items in and out of the facility has to be followed accurately to prevent record discrepancies. The approach Müller (2002) recommends is radio frequency (RF) capable mobile bar code scanners (Müller, 2002). Despite technology moving forward, the use of radio frequency identification (RFID) to track inventory has remained, as demonstrated by Jones (2019).

If RFID cannot be utilized for one reason or another, there are a multitude of ways to update inventory. A slightly older technical option is to use a non-RF bar code scanner that stores whatever information is fed to it, which can then be moved to a computer system. Less technical way is to use paper cards or something similar, and manually move the information from paper to computer. If there are no computers available, the tracking is done on paper. Figure 12 provides an example (Müller, 2002).

STOCK MOVEMENT REPORT			
SKU#	_____		
DATE	_____	TIME	_____
QUANTITY	_____		
FROM	_____	TO	_____

Figure 12 Inventory tracking card (adapted from Müller, 2002)

In the end, the tracking method used does not matter. The important point is that information about changes in inventory is accurate and updated as soon as possible. The longer it takes to update the database, be it on a computer or in a card index, the higher the chance for errors, lost inventory, and increase in costs becomes (Müller, 2002).

4.3 Inventory balancing

Now that there is both a plan, and a style, the walk on the inventory management tightrope can be started. With inventory balancing, inventory plan is managed on a daily or weekly basis. Following the rate of supply and demand, the inventory flow through process, and if the whole process from supply to throughput and into fulfilling demand is balanced. Normally all of this is handled by the business systems, and to do it correctly, a good inventory plan and control is needed, and in addition good measurement of performance (Relph & Milner, 2015).

Early on in this chapter the consequences of low and high inventory levels were mentioned. While both the initial plan and control method exist to mitigate and prevent both states, balancing also plays a role here. Being below minimum and above maximum stock, states which Relph and Milner (2015) refer to as *underage* and *overage* stock respectively, are places to be avoided.

Underage's importance is quite obvious. Being below minimum stock can quickly result in a shortage, where stock level is defined as 0. The effect of overage is not as immediately apparent as with a shortage, and some overage is inevitable. If not acted upon however, the overage will continue to grow, and storage space starts to run out. The two questions answers should be gotten to are how much overage is there, and how long will it last. The latter is also referred to as *overage dissipation* (Relph & Milner, 2015).

Dissipation can be defined as *the time it takes for an item to return to its optimum level*. When the stock level of an item falls below maximum, it is no longer overage. This is however not the end of dissipation. That happens only when the stock has reached minimum, as prior to that, every time a new order comes in, the stock will jump above maximum and is in overage again (Relph & Milner, 2015).

As dissipation is length of time, it can be expressed as such. Knowing how many days it takes for a product to dissipate can be useful in categorising and prioritising. Dissipation time can be seen as directly proportional to the level of worry. Faster dissipation means less worry about that particular item. Focus should be directed at the items with a slow dissipation (Relph & Milner, 2015).

Condition	Stock level
Shortage	0
Underage	below min.
Optimum	between max. and min.
Overage	above max.
Severe overage	two times max.
Excess	above 12 month demand
Surplus	above 24 month demand

Figure 13 Inventory conditions (adapted from Relph & Milner, 2015)

Using the above categorisation, the appropriate level of action for each condition can be deemed. For example, the larger the overage, the higher up in management the decision should be made. It should also be noted that the next order is immensely important when managing overage (Relph & Milner, 2015).

5 Application

To solve the problem of overage stock, the start should be the analysis of current situation. In total, there are 14 separate SKUs with varying demand patterns and somewhat varying lot sizes. The demand patterns are thus:



Figure 14 Product 1 demand pattern



Figure 15 Product 2 demand pattern



Figure 16 Product 3 demand pattern



Figure 17 Product 4 demand pattern



Figure 18 Product 5 demand pattern

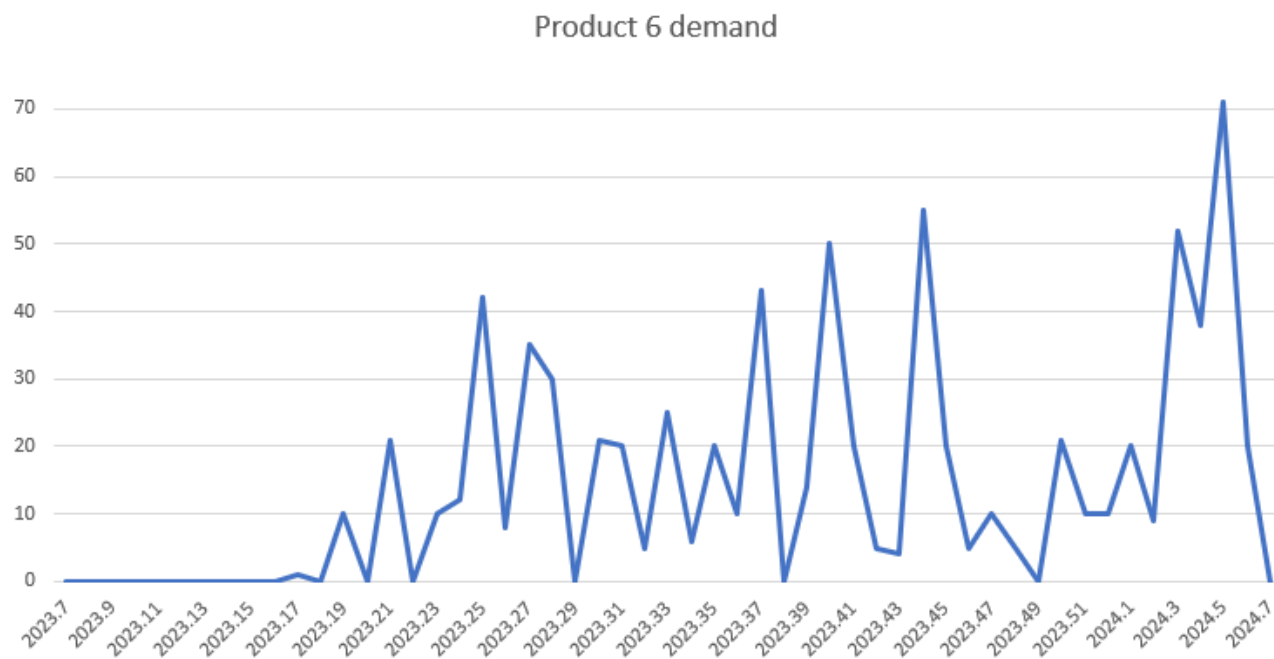


Figure 19 Product 6 demand pattern



Figure 20 Product 7 demand pattern



Figure 21 Product 8 demand pattern



Figure 22 Product 9 demand pattern

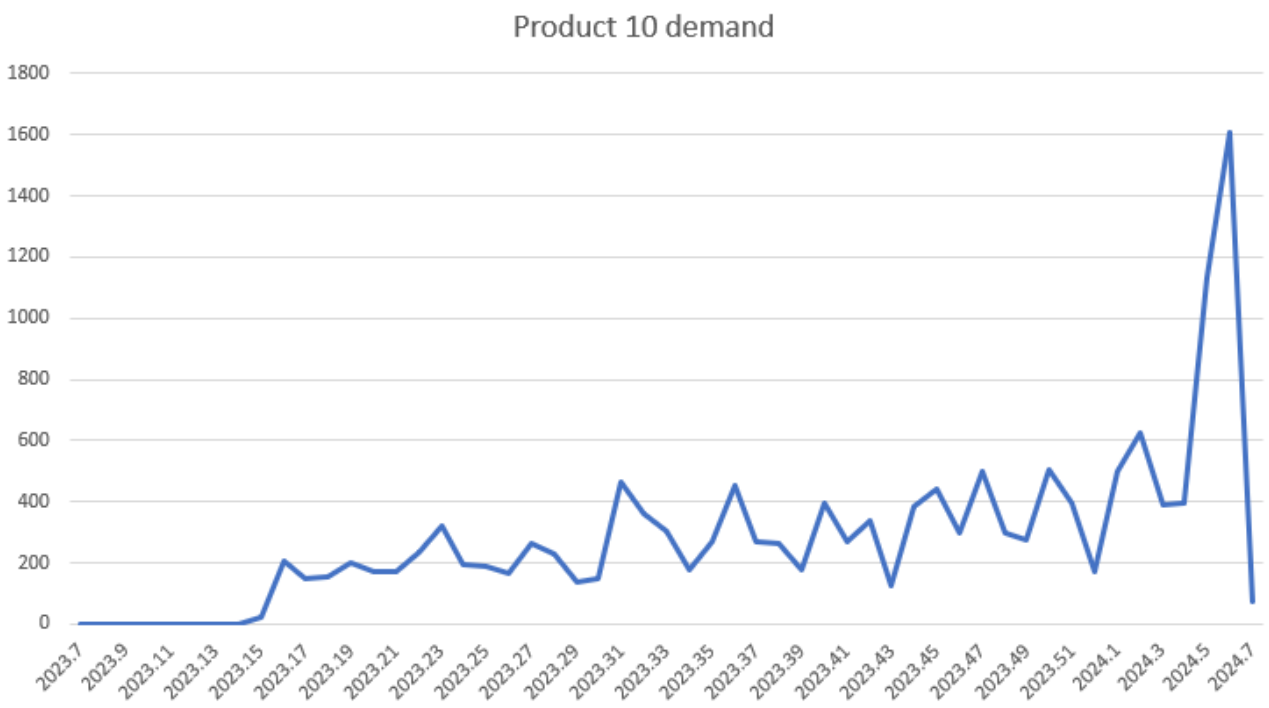


Figure 23 Product 10 demand pattern



Figure 24 Product 11 demand pattern



Figure 25 Product 12 demand pattern



Figure 26 Product 13 demand pattern



Figure 27 Product 14 demand pattern

5.1 Re-order point and quantity

In general, ROP is calculated using the average demand, lead time, and predetermined safety stock. The formula however assumes that the order date can be virtually any day of the week. In this case however, the date is fixed, so this needs to be taken into account when determining the ROP. The general formula for ROP looks like this:

$$ROP = (\text{Lead time} * D_{\text{average}}) + \text{Safety stock}$$

Figure 28 ROP in general

In this general formula, the ROP is placed at a fixed stock level and the date of order floats with the demand. With a fixed order date, the ROP has to account for the time between order dates. The new formula looks like this:

$$\frac{\text{Inventory level}_{\text{Friday}}}{D_{\text{average}}} > 5$$

Figure 29 ROP case specific

All in all, this formula is used to determine whether there is a need to order. The left side determines how many days the existing stock will last with average demand. If this number is greater than five, the stock is expected to last until the next order date. If not, the ROQ has to be determined.

There are effectively three limits that affect the ROQ. The storage unit, the medium of transport, and order date. The products are stored and moved in full pallets, so a half-pallet cannot be transported between warehouses. The transport in question is limited to 18 pallets, and preferably there would be only one trip from secondary to primary warehouse. And finally, the order date is fixed, so the quantity has to last until the next order date.

$$\sum_{1}^{14} \frac{5 * Dave_{px}}{N_{px}} \leq 18$$

Figure 30 ROQ

What is being calculated in figure 30 is the sum of the ROQs for each of the 14 products. The formula determines the ROQ in pallets for each product, and then adds them together to see whether the sum remains within the limit.

5.2 Simulation

Using the formulas presented in figures 29 and 30, a period of 6 weeks was simulated in Excel. The starting inventory levels were determined by dividing the pallet size with average daily demand, and seeing how many full pallets are required for the stock to last 5 business days.

Product	Pallet stockout	2 Pallet stockout	3 Pallet stockout	4 Pallet stockout
1	43,27	86,53	129,80	173,06
2	6,09	12,18	18,28	24,37
3	8,32	16,64	24,96	33,27
4	23,11	46,21	69,32	92,43
5	23,81	47,62	71,43	95,24
6	170,18	340,37	510,55	680,74
7	5,54	11,08	16,62	22,17
8	1,43	2,85	4,28	5,71
9	2,65	5,29	7,94	10,59
10	9,10	18,21	27,31	36,42
11	16,24	32,47	48,71	64,95
12	2,36	4,71	7,07	9,43
13	2,71	5,42	8,13	10,84
14	15,64	31,28	46,93	62,57

Table 1 Determining starting stock

Product	Pallet size	D(ave) (day)	Pallets in
1	24	0,55	1
2	60	9,85	1
3	42	5,05	1
4	32	1,38	1
5	300	12,60	1
6	600	3,53	1
7	600	108,28	1
8	600	420,54	4
9	600	226,65	2
10	600	65,91	1
11	600	36,95	1
12	600	254,64	3
13	600	221,32	2
14	600	38,36	1

Table 2 Starting data with average demand

Counting the “pallets in” -column, it adds up to 21, which is greater than the limit of 18. However, as table 1 points out, this is necessary to have the stock last five business days and by extension for the simulation to start.

In addition to using the average demand, the simulation was also conducted with demand that has the standard deviation added into, and subtracted from, it. These results reflect the demand at its highest and lowest respectively, based on the available data.

Product	Pallet size	D(ave) (day)	Pallets in
1	24	1,10	1
2	60	21,94	2
3	42	13,02	2
4	32	2,55	1
5	300	31,54	1
6	600	6,96	1
7	600	199,95	2
8	600	764,07	7
9	600	369,46	4
10	600	118,52	1
11	600	73,70	1

12	600	382,97	4
13	600	346,75	3
14	600	74,66	1
			31

Table 3 Starting data with added st.dev.

Product	Pallet size	D(ave) (day)	Pallets in
1	24	0,01	1
2	60	-2,24	1
3	42	-2,92	1
4	32	0,22	1
5	300	-6,34	1
6	600	0,09	1
7	600	16,60	1
8	600	77,00	1
9	600	83,83	1
10	600	13,29	1
11	600	0,21	1
12	600	126,30	2
13	600	95,89	1
14	600	2,06	1
			15

Table 4 Starting data with subtracted st.dev.

Subtracting the standard deviation from average demand provided some interesting results. While negative demand is technically possible, as it means that more products are returned than sold, realistically it is very unlikely.

This simulation works by first taking the inventory level on a Monday, and then subtracting the average daily demand five times to get the inventory level on a Friday, the re-order date. Then it divides the Friday inventory by daily demand to see how many days it takes for the stock to run out. If this variable "Stockout" is less than five, the simulation tells to order more. The ROQ is then counted by following the formula on figure 30.

In this section some highlights will be made. First is the number of pallets brought in during the simulated period, which is also the first demonstration of how negative demand completely breaks the simulation.

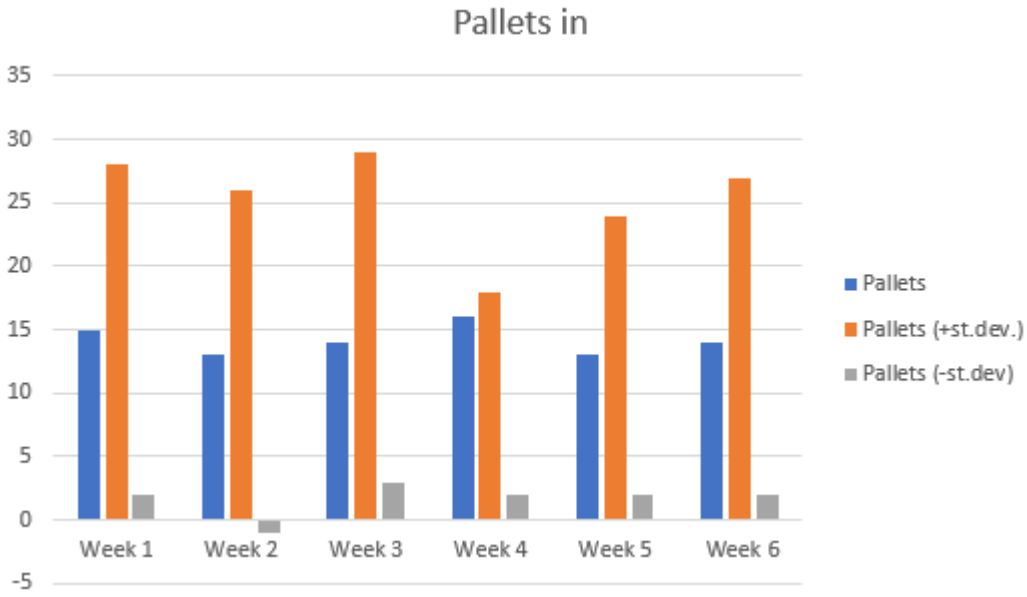


Figure 31 Number of pallets brought in

Then a couple of examples, one demonstrating the “normal” pattern of change in inventory level, and the other not as much.

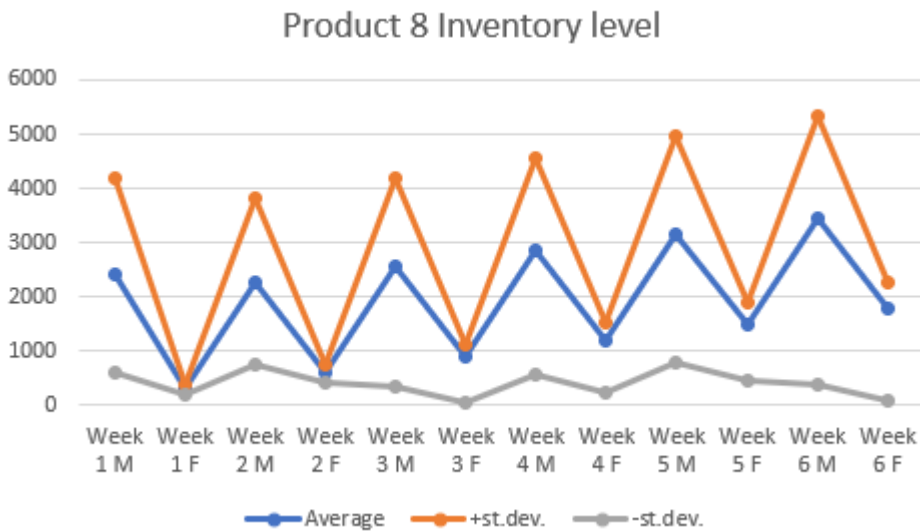


Figure 32 Product 8 Inventory level

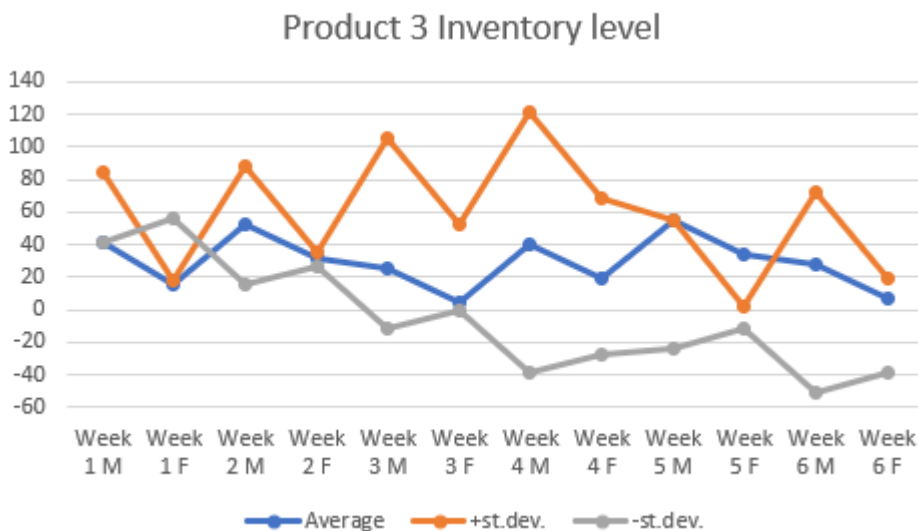


Figure 33 Product 3 Inventory level

Figure 32 shows the standard sawtooth model, more prominently with average demand and standard deviation added. Subtracted standard deviation also has the sawtooth, but it is not as visible as with the other two. Figure 33 on the other hand shows the effect of negative demand in two ways. First, the inventory level goes below 0 and stays there, and second, the increase and decrease of inventory are backwards.

This backwards sawtooth is a direct result of negative demand. To calculate inventory level on Friday, the simulation subtracts the demand for each day and the expected result is lower inventory level. However, because in multiplication two negatives make a positive, it starts to increase the level. To then decide if there is a need to order more, the simulation calculates the stockout, by dividing with negative demand.

Division with negative demand results in a negative number of days, meaning we effectively already ran out of stock. This in and of itself is not a major problem, but because the next point is checking if the number of days is below 5, it causes more problems. As the simulation has now decided that an order has to be placed, it calculates the ROQ, by dividing 5 times the demand with number of units in a pallet. The result is again negative, meaning instead of bringing in more pallets, the simulation removes them.

The cause behind the negative demand is large standard deviation, which is not a preferred situation, as it ultimately means the actual demand is harder to predict. In the simulation, one way to prepare for this is to increase the threshold for the ROP. Instead of five, the order might be placed when the stockout would happen in ten days.

Testing this provided interesting results yet again. For average demand, setting the ROP to six immediately pushed the number of pallets coming in to 19. This is however only the case when every product has the same ROP threshold. Some products could be sacrificed in favour of others to drop the level below 18.

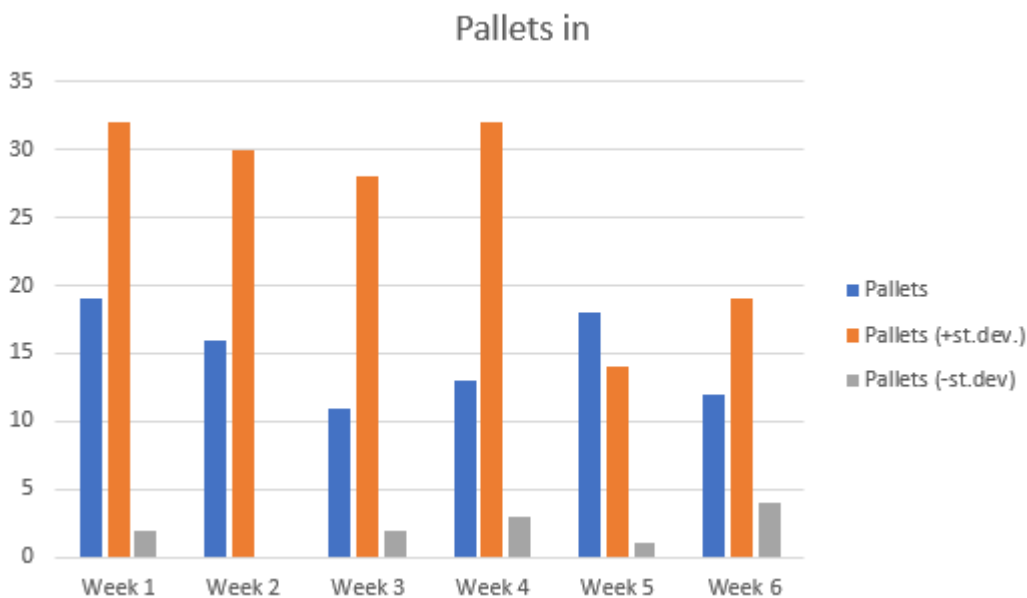


Figure 34 Pallets in at ROP=6 days

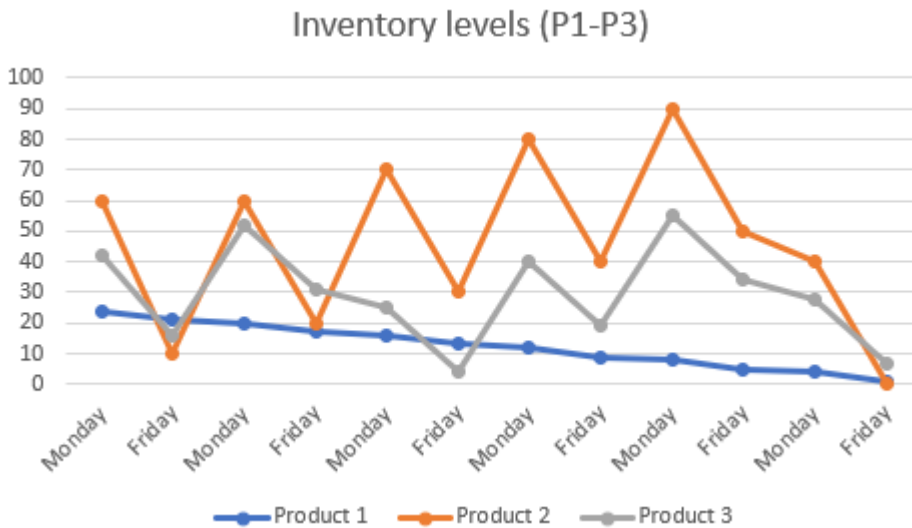


Figure 35 Product 1,2&3 Inventory level at ROP = 5 days & Average demand

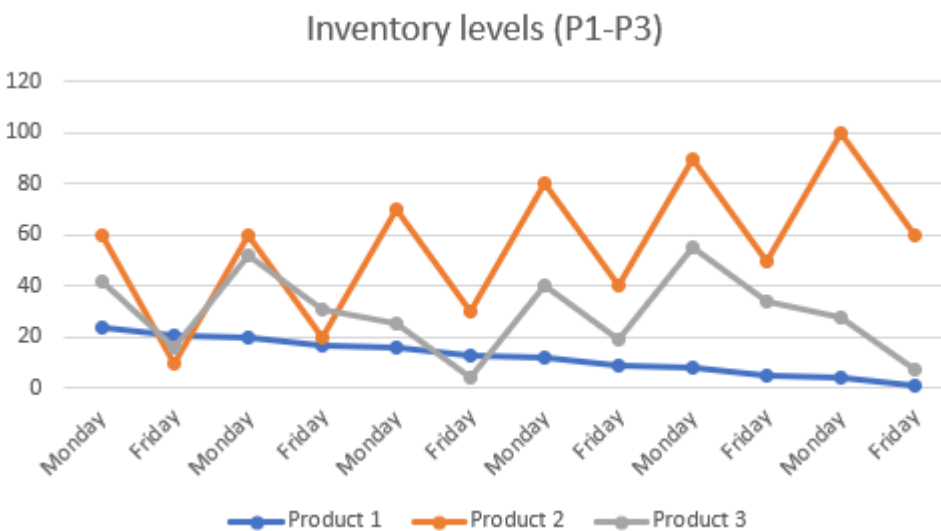


Figure 36 Product 1,2&3 Inventory level at ROP =6 days & Average demand

Figures 35 and 36 demonstrate the difference between a threshold of 5 and 6 days. Both of these options have associated risks with them. With a low threshold, there is less inventory taking up space, but the odds of falling victim to standard deviation are higher. Increasing the threshold lowers the risk posed by deviation but increases the required inventory space.

Total inventory	Average	+st.dev.	-st.dev.
Week 1 M	10 058	14 960	6 458
Week 1 F	3 024	2 918	4 429
Week 2 M	9 514	14 809	6 614
Week 2 F	3 883	5 173	4 989
Week 3 M	9 731	15 596	5 377
Week 3 F	4 100	5 960	3 755
Week 4 M	9 990	17 875	5 703
Week 4 F	4 359	8 239	4 081
Week 5 M	10 581	14 978	4 871
Week 5 F	4 950	5 342	3 249
Week 6 M	11 338	14 833	5 137
Week 6 F	5 707	5 197	3 515

Table 5 Total inventory level at ROP = 5 days

Total inventory	Average	+st.dev.	-st.dev.
Week 1 M	10 058	14 960	6 458
Week 1 F	3 024	2 918	4 429
Week 2 M	11 914	16 669	6 614
Week 2 F	6 283	7 033	4 989
Week 3 M	13 931	19 316	5 977
Week 3 F	8 300	9 680	4 355
Week 4 M	12 390	22 075	5 703
Week 4 F	6 759	12 439	4 081
Week 5 M	11 181	25 922	5 471
Week 5 F	5 550	16 286	3 849
Week 6 M	14 398	20 353	5 137
Week 6 F	8 767	10 717	3 515

Table 6 Total inventory level at ROP = 6 days

One final highlight is the percentage of total inventory for each product over the course of the simulation. The table has been coloured with the following rules: Green = less than 1%, Blue = greater than 1% but less than 5%, Purple = greater than 5% but less than 10%, Orange = greater than 10% but less than 20%, and Red = greater than 20%.

% of total inventory	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		
	Product	Monday	Friday	Monday	Friday	Monday	Friday	Monday	Friday	Monday	Friday	Monday	Friday
	Product 1	0,24 %	0,69 %	0,21 %	0,44 %	0,16 %	0,32 %	0,12 %	0,21 %	0,08 %	0,10 %	0,04 %	0,02 %
Product 2	0,60 %	0,33 %	0,63 %	0,52 %	0,72 %	0,73 %	0,80 %	0,92 %	0,85 %	1,01 %	0,35 %	0,00 %	
Product 3	0,42 %	0,53 %	0,55 %	0,80 %	0,26 %	0,10 %	0,40 %	0,44 %	0,52 %	0,69 %	0,25 %	0,12 %	
Product 4	0,32 %	0,83 %	0,24 %	0,44 %	0,15 %	0,22 %	0,07 %	0,02 %	0,29 %	0,51 %	0,20 %	0,30 %	
Product 5	2,98 %	7,84 %	2,35 %	4,46 %	1,64 %	2,66 %	0,96 %	1,03 %	3,14 %	5,68 %	2,36 %	3,80 %	
Product 6	5,97 %	19,25 %	6,08 %	14,50 %	5,74 %	13,27 %	5,41 %	12,04 %	4,92 %	10,22 %	4,43 %	8,53 %	
Product 7	5,97 %	1,92 %	5,77 %	2,96 %	6,23 %	4,20 %	6,64 %	5,25 %	6,80 %	5,78 %	6,85 %	6,01 %	
Product 8	23,86 %	9,82 %	23,92 %	15,27 %	26,43 %	21,68 %	28,71 %	27,19 %	29,90 %	29,92 %	30,52 %	31,14 %	
Product 9	11,93 %	2,18 %	10,92 %	3,40 %	11,36 %	4,83 %	11,72 %	6,06 %	11,69 %	6,67 %	11,49 %	6,94 %	
Product 10	5,97 %	8,93 %	8,45 %	13,91 %	4,87 %	5,12 %	7,45 %	11,01 %	3,91 %	3,03 %	6,03 %	7,36 %	
Product 11	5,97 %	13,72 %	3,97 %	5,92 %	1,98 %	1,10 %	6,09 %	10,55 %	4,00 %	5,56 %	2,10 %	1,58 %	
Product 12	17,90 %	17,39 %	21,77 %	27,09 %	26,69 %	38,49 %	13,24 %	6,97 %	17,47 %	16,77 %	20,95 %	23,76 %	
Product 13	11,93 %	3,08 %	11,26 %	4,76 %	11,95 %	6,76 %	12,56 %	8,47 %	12,73 %	9,31 %	12,69 %	9,69 %	
Product 14	5,97 %	13,49 %	3,88 %	5,54 %	1,81 %	0,54 %	5,84 %	9,84 %	3,69 %	4,77 %	1,74 %	0,75 %	

Table 7 % of inventory at ROP = 5 days

% of total inventory	Week 1		Week 2		Week 3		Week 4		Week 5		Week 6		
	Product	Monday	Friday	Monday	Friday	Monday	Friday	Monday	Friday	Monday	Friday	Monday	Friday
	Product 1	0,24 %	0,69 %	0,17 %	0,27 %	0,11 %	0,16 %	0,10 %	0,13 %	0,07 %	0,09 %	0,03 %	0,01 %
Product 2	0,60 %	0,33 %	0,50 %	0,32 %	0,50 %	0,36 %	0,65 %	0,59 %	0,80 %	0,90 %	0,69 %	0,68 %	
Product 3	0,42 %	0,53 %	0,44 %	0,49 %	0,18 %	0,05 %	0,32 %	0,28 %	0,49 %	0,61 %	0,19 %	0,08 %	
Product 4	0,32 %	0,83 %	0,19 %	0,27 %	0,11 %	0,11 %	0,06 %	0,01 %	0,28 %	0,45 %	0,16 %	0,19 %	
Product 5	2,98 %	7,84 %	1,88 %	2,75 %	1,15 %	1,31 %	0,77 %	0,67 %	2,97 %	5,06 %	1,86 %	2,48 %	
Product 6	5,97 %	19,25 %	4,85 %	8,96 %	4,01 %	6,55 %	4,36 %	7,77 %	4,66 %	9,12 %	3,49 %	5,55 %	
Product 7	5,97 %	1,92 %	9,64 %	11,38 %	4,35 %	2,07 %	10,19 %	12,27 %	6,44 %	5,15 %	9,56 %	10,76 %	
Product 8	23,86 %	9,82 %	24,14 %	18,99 %	27,08 %	25,17 %	37,68 %	44,16 %	22,93 %	15,87 %	24,03 %	20,27 %	
Product 9	11,93 %	2,18 %	13,76 %	11,65 %	16,55 %	16,84 %	9,45 %	3,91 %	16,43 %	16,76 %	17,38 %	18,20 %	
Product 10	5,97 %	8,93 %	6,75 %	8,59 %	3,40 %	2,53 %	6,00 %	7,10 %	3,70 %	2,70 %	4,75 %	4,79 %	
Product 11	5,97 %	13,72 %	3,17 %	3,66 %	1,39 %	0,54 %	4,91 %	6,81 %	3,78 %	4,95 %	1,65 %	1,03 %	
Product 12	17,90 %	17,39 %	17,38 %	16,74 %	18,64 %	19,01 %	10,68 %	4,50 %	16,54 %	14,95 %	16,50 %	15,47 %	
Product 13	11,93 %	3,08 %	14,03 %	12,49 %	16,96 %	17,80 %	10,13 %	5,46 %	17,41 %	19,12 %	18,33 %	20,00 %	
Product 14	5,97 %	13,49 %	3,10 %	3,42 %	5,57 %	7,49 %	4,71 %	6,35 %	3,49 %	4,25 %	1,37 %	0,49 %	

Table 8 % of inventory at ROP = 6 days

Few things can be concluded from this. Products 1 to 4 tend to be small contributors to inventory space, while especially product 8, and to a lesser extent 12 and 13 make up a lot of the inventory at a given time.

6 Results and discussion

In the beginning, these three questions were stated:

1. Why is warehouse space management important?

2. How can possible excess stock be dealt with and why should you deal with it?
3. What are the causes of stock-level to storage space disproportion?

Through the literature review, it has been identified that proper space management in a warehouse contributes to both the functioning and safety of the warehouse. A well-designed inventory locator and tracking system, and good inventory balancing are key elements in managing warehouse space. Every employee is also responsible for keeping the items off places they are not supposed to be in, and ensuring the items are properly stacked when in racking.

Excess or overage stock generally goes away on its own, known as overage dissipation. When managing overage, future order management is important to both allow the dissipation to happen and to prevent it from happening again. The causes of overage range from mistakes in order volumes to haphazard planning. Overestimating a seasonal peak can cause temporary overage, while a badly designed inventory control system can increase the dissipation time. If the previous seasonal peak has not dissipated when preparation for another one starts, the cycle is ready.

The main problem this thesis set out to solve is long term overage. Through analysing inventory data, an Excel-based tool to determine if an order needs to be made and how large it should be, has been developed. The tool can be found in appendix 1. This tool has been tested in a simulated environment and has provided results. However, there are some things that should be taken into account.

First is the span of the inventory data. The dataset used starts from February of 2023 and ends February 2024. Some of the products however, as evident from the demand patterns, only have data from summer 2023 onward. While the amount of data is sufficient for the purposes of this thesis, using data that spans for example two years could provide more accurate data, and by extension improve the model presented.

Second is the limits of the testing environment. While the simulation itself runs as intended, the results are contained within the Excel-file, and are in essence a reflection of the optimal situation. Further research and testing could be done after a year to obtain data from a longer time span, which would especially help with the products with less than 10 months of data.

Concerning the reliability of the sources used in the theoretical base of the thesis, some notes should be made. At the time of writing, some of the sources used are more than 20 years old. To the best of my knowledge and judgement, the information from these sources is still applicable in the context they have been used.

6.1 Conclusion and further research

All in all, it is recommended that Medituote would test the Excel-tool presented in this thesis and determine its useability in a real situation. The simplicity of the tool means it should also be easy to integrate into Medituote's warehouse management system.

As previously mentioned, further research should be carried out with more inventory data to both better determine the effectiveness of this model and potentially develop it further. Other potential development projects concerned with the same problem are related to picking and storage solutions.

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Appendices

Appendix 1. ROP & ROQ -calculator

Service level		days
Daily demand		units
Inventory level (Friday)		units
Pallet size		units
Stockout	=Inventory_level__Friday/Daily_demand	days
Place order	=IF(Stockout<Service_level;"Yes";"No")	
Order level	=IF(Place_order="Yes";ROUNDUP((Service_level*Daily_demand)/Pallet_size;0);0)	pallets