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Storage Location Assignment Problem for Small and Medium-Size Third Party Logistic Providers

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Global Manufacturing Management
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Preface

This Master thesis was conducted during the spring of 2020 as the final part of the 2-year master's degree program, Global Manufacturing Management, at the Norwegian University of Science and Technology (NTNU).

During this semester, the world has been facing one of its largest global challenges in the last decade. With the COVID19 situation locking down the whole society, universities and industries have been through tough times. This has naturally given some extra challenges for my thesis. Traveling restrictions and isolation at my home offices limited the contact and the time to receive data from Leman (case company), in this extraordinary situation.

The secondary data was central for my original thesis scope and should have been received in February. The data did not turn up until May due to the COVID19 situation and software problems at Leman Denmark, who was supposed to deliver the requested data. In light of this, while waiting, I had to think alternatively and started to discover and define other interesting angles within the topic. Therefore, after discussing with my network, the case study was dedicated to describing the challenges that the case company faces on a broader level. Investigating how these challenges could be solved was very interesting and relevant, giving a holistic assessment of the challenges of an SME-3PL. When the data finally arrived, I could start analyzing the challenges more in-depth.

I would like to thank my supervisors through this process, especially Hans-Henrik Hvolby, for his useful comments, feedback, and advice. I would like to thank everyone at Leman, for providing me with case-relevant information and for hosting two company visits, and Mathias Holm from Brynild and Anita Romsdal for initiating and supporting the project. Further, I would like to thank my girlfriend for being supportive in the last months of writing this thesis, and my mom for advice and for correcting the thesis in the last weeks of the process.

Summary

The research of this master thesis was initiated to investigate which storage policies for the storage locating assignment problem (SLAP) are most applicable for Small and Medium-Size Third-party Logistics (SME-3PL) providers. To guide the research, these research questions (RQs) were established:

RQ1*: Which storage policies exist for solving the storage location assignment problem (SLAP)?*

RQ2: *Which storage policies for SLAP are most applicable for SME-3PL providers with multiple clients?*

The objective of the thesis was to answer these research questions and conduct a case study of an SME-3PL provider. This case study was initiated to investigate the challenges that lead to increased internal travel time in warehousing. The objective of the case study was to:

1. Describe AS-IS situation for the SME-3PL provider
2. Identify and analyze challenges that increase internal travel time for the SME-3PL provider.
3. Provide improvement suggestions to reduce the internal travel time at the SME-3PL provider

The methodology used in this master thesis is a combination of a literature study and a single case study. The literature study was conducted to investigate SLAP and the storage policies that are applied to perform it. Further, the literature study investigated the characteristics of 3PL providers and common challenges in 3PL warehousing. The case study itself was conducted by company visits, interviews, and quantitative methods to investigate the challenges in an SME-3PL warehouse.

The findings of the literature study were three main storage policies for SLAP; *dedicated storage*, *random storage*, and *class-based storage*. The main storage policies have subcategories that are characterized by which criteria the storage location is selected. The selection of storage policies depends on three key factors; the complexity of the warehouse environment, available information, and turnover rate within the warehouse. Class-based storage was identified as the most flexible of these three main categories, as it utilizes available information and is suited for a complicated warehouse environment. The literature study also identified these common challenges among 3PL provides:

- A large variety of SKUs and clients, leading to many different requirements
- Limited information of the SKUs stored in the warehouse
- Limited information and communication technology (ICT) capacity
- A limited degree of automatization, hence a significant degree of manual labor

Insights from the case study were applied to confirm these challenges. They were then used to evaluate which of the storage policies is applicable to the warehouse environment of a 3PL provider. The research indicates that a class-based policy is most applicable to these complex warehouse environments. The research stresses that class-based policy has some implications that must be addressed to improve its utilization of storage space and reduction of internal travel time.

The case study describes the AS-IS situation at SME-3PL provider, where six challenges were identified as causes of increased internal travel time. After the initial investigation of all, and a selection process, one was investigated more in-depth. The case company currently uses a class-based storage policy. During the company visit, a somewhat unstructured approach of assigning SKUs to classes was identified. The analysis shows that this further has to lead to too many SKUs being assigned to class A, resulting in fast moving SKUs with high turnover is being picked from others less convenient storage zones, since the A storage zone is full. By comparing the current classification of SKUs against the Pareto approach, shows that the case company has 50% more SKUs assigned to class A than the Pareto approach suggests. In addition, the result of the case study shows that rearranging a few SKUs within the warehouse could reduce the travel time by 5% for the picking of the respective SKUs. It was identified that some of the misclassifications were due to a lack of information regarding clients' demand patterns. A suggested TO-BE was established that suggests a more structured process to assign SKUs to classes and the sharing of information between a client and the case company. Last, a discussion of the feasibility of this process was evaluated.

The generalizable results from the case study identify that SME-3PL has limited resources to perform activities such as periodic reviews of client's SKUs and need information from clients to assign SKUs appropriate classes. The results of the research indicate that a lack of information sharing between SME-3PL providers and clients is more due to ICT capacity than the willingness to share data.

Sammendrag

Bakgrunnen for denne masteroppgaven var å undersøke hvilke lagerprinsipper for å løse lagerlokasjonsproblemer (SLAP) som er best egnet for små og mellomstore tredjepartslogistikkleverandører (SME-3PL). Problemstillingen ble formulert som to veiledende forskningsspørsmål (RQ):

RQ1: Hvilke eksisterende lagringsprinsipper finnes for å løse lagerlokasjonsproblemer (SLAP)?

RQ2: Hvilke av lagrinsprinsippene for SLAP er best egnet for SME-3PL leverandører?

Målet for denne oppgaven var å svare på disse forskningsspørsmålene, og gjennomføre et casestudie av en SME-3PL leverandør. Formålet med casestudien var å identifisere utfordringer som fører til økt intern reisetid på et lager hos en SME-3PL. Formålet ble videre delt inn i tre delmål:

1. Beskrive nåværende situasjonen for SME-3PL leverandøren
2. Identifisere og analysere utfordringer som øker den interne reisetiden for SME-3PL leverandøren
3. Anbefale forbedringsforslag for å redusere den interne reisetiden hos SME-3PL leverandøren

Metodikken brukt i denne masteroppgaven var en kombinasjon av en litteraturstudie og en casestudie. Litteraturstudien ble utført for å undersøke SLAP og de forskjellige lagerprinsippene. Videre i litteraturstudien ble generelle utfordringer hos 3PL leverandører undersøkt. Casestudien ble utført gjennom bedriftsbesøk, intervjuer og kvantitative metoder for å besvare delmålene og formålet.

Fra litteraturstudien viste funnene at det i hovedsak er tre lagringsprinsipper aktuelle for SLAP; dedikert lagring, tilfeldig lagring og klassebasert lagring. Disse lagringsprinsippene har underkategorier, hvor inndelingen er gitt etter hvilke kriterier de ulike prinsippene bruker på å avgjøre lagringslokasjonen. Tre faktorer er spesielt avgjørende for valg av lokasjonen; lagerets kompleksitet, tilgjengelighet av informasjon og omløpshastigheten i lageret. Studien viser at klassebasert lagring ble identifisert som den mest fleksible av de tre prinsippene ettersom den bruker all tilgjengelig informasjon og er godt egnet for et lager med høy kompleksitet. Litteraturstudien identifiserer også disse generelle utforingene for 3PL leverandører:

- Et stort spekter av lagerbeholdningsenheter (SKU-er) og klienter, som fører til mange forskjellige krav som 3PL leverandøren må etterfølge
- Begrenset informasjon angående SKU-er som blir lagret
- Begrenset informasjon - og kommunikasjonsteknologi (IKT) kapasitet

- En begrenset grad av automatisering, som resulterer i mye manuelt arbeid

Observasjonene i casestudien ble satt i sammenheng med litteraturstudien og bekreftet de nevnte utfordringene. Casestudiene ble videre brukt til å evaluere hvilket av de aktuelle lagerprinsippene som er best egnet for lagermiljøet til en SME-3PL leverandør. Forskningen indikerer at et klassebasert lagerprinsipp er best egnet for disse komplekse lagringsmiljøene, men understreker videre at det aktuelle lagerprinsippet har implikasjoner som krever videre bearbeiding for en bedre utnyttelse av lagringsplassen og med mål om å redusere den interne reisetiden på lageret.

Casestudien beskriver AS-IS situasjonen hos en SME-3PL leverandør, hvor seks utfordringer ble identifisert som årsaker til økt intern reisetid. I startfasen ble alle seks utfordringer undersøkt, men etter en seleksjonsprosess ble én selektert til et nærmere dybdestudie. Den aktuelle casebedriften bruker et klassebasert lagringsprinsipp. Under et bedriftsbesøk ble det identifisert en ustrukturert tilnærming til tildeling av SKU-er til klasser. Analysen viser at dette har ført til at altfor mange SKU-er blir tildelt lokasjon i klasse A. Det resulterer videre i at SKU-er med høy omløpshastighet blir plassert i mindre lukrative lagerplasser, ettersom lagringssone A blir full. Ved å sammenligne den nåværende klassifiseringen av SKU-er med en Pareto-tilnærming , kommer det fram at casebedriften har 50% flere SKU-er tildelt klasse A enn Pareto-tilnærmingen foreslår. Resultatet fra casestudien viser at omorganiseringen av noen få SKU-er på lageret kan redusere reisetiden med 5% for plukking av de respektive SKU-ene. Det ble også identifisert at noen av feilklassifiseringene skyldtes manglende informasjon om klientens etterspørsel. En mulig TO-BE ble foreslått som et resultat av casestudien, for å sikre en mer strukturert tilnærming til inndelingen i klasser i denne typen lagerprinsipp. I tillegg ble det foreslått en mer åpen informasjonsflyt mellom klient og casebedrift i et forsøk på å minimere feilplasseringen i lageret. Til slutt ble muligheten for å implementere denne TO-BE situasjonen evaluert.

De generaliserbare resultatene fra casestudien identifiserer at SME-3PL har begrensede ressurser til å utføre aktiviteter som periodisk gjennomgang av klientenes SKU-er. De er derfor avhengig av informasjon fra klienter for å kunne tildele SKU-er passende klasser. Resultatene fra forskningen indikerer også at mangelen på informasjonsdeling mellom SME-3PL-leverandører og klienter kan skyldes IKT-kapasiteter mer enn viljen til å dele data.

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Abbreviations

SKU- Stock keeping unit

Unit-load- A pallet loaded with goods

WMS – Warehouse Management System

SLAP- Storage Location Assignment Problem

I/O area- In-and Outbound Area

3PL providers- Third-Party Logistics Providers

EDI- Electronic Data Exchange

COI- Cube per Order Index

DOS- Duration of Stay

SME- Small-Medium-sized Enterprise

SME-3PL- Small-medium sized third-party logistics providers

ICT- Information and Communication Technology

Fast movers- SKUs with a high turnover rate

1. Introduction

The purpose of the introduction is to describe the research topic, problem statement, research objective, and research scope

1.1. Introduction to the research topic

Warehousing is an essential part of any supply chain. The major role of a warehouse includes buffering material flow throughout the supply chain to accommodate variability in demand, merging of products from various suppliers for combined delivery to customers, and value-added tasks as pricing, labeling, and product customization (Gu, Goetschalckx et al. 2007). The goals of warehouse management are to achieve high customer service, keep control of inventory status, to minimize the total physical effort, and provide communication to customers (Stephen N.Chapman 2017) In an effort to achieve more efficient warehouse management companies outsource warehouse management operations to Third-party logistics (Hereafter, 3PL) providers (John J. Bartholdi 2019). 3PL providers stores stock-keeping units (hereafter: SKUs) for multiple clients, allowing them to merge different items in size and turnover, resulting in saving storage space and increasing efficiency in handling operations (Shi, Zhang et al. 2016). 3PL providers also utilize economies of scale and complementary seasons to achieve more efficient warehousing, which companies would not be able to achieve on their own (John J. Bartholdi 2019).

Warehouse operation can be divided into four main categories; *receiving, put-away, order picking*, and *shipping* (Gu, Goetschalckx et al. 2007, Bahrami, Piri et al. 2019, John J. Bartholdi 2019). Order picking is a complicated and often labor-intensive process that determines the warehouse performance significantly (Faber, de Koster et al. 2013). Order picking is the most time-consuming of the warehouse operations, and the majority time spent during this operation is on traveling (Kofler 2015, John J. Bartholdi 2019). Traveling is also the most time-consuming activity of the put-way operation (Kofler 2015, John J. Bartholdi 2019). Consequently, a reduction in travel time will lead to a more efficient warehouse operation.

The *storage location assignment problem* (hereafter, SLAP) decision is to assign incoming SKUs to storage locations in the storage areas or zones, to reduce material handling costs and improve space utilization (Gu, Goetschalckx et al. 2007, Faber, de Koster et al. 2013). There are several storage policies for performing SLAP. The most used policies are*; dedicated storage*, *random storage*, and *class-based storage* (Hausman, Schwarz et al. 1976, Reyes, Solano-Charris et al. 2019).

To coordinate warehouse operations, practitioners usually use an information system (Faber, de Koster et al. 2013). Warehouse management systems (Hereafter, WMS) is a complex and specific software that assists the coordination of managing operations within warehouses (John J. Bartholdi 2019). Actions that a WMS typically assist is to manage inventory, storage locations assignment, and workforce, to ensure an efficient picking, packing, and shipping of orders (John J. Bartholdi 2019)

1.2. Problem statement

The literature contains principles and policies on how SLAP can be conducted in the various constellation of warehouses. However, there is limited literature on how practitioners in the industry can adapt these principles into practical use in their physical environment (Gu, Goetschalckx et al. 2007, Bahrami, Piri et al. 2019). The version of the SLAP problem studied in the literature is often static, i.e., it assumes that the incoming and outgoing material flow patterns are stationary over the time horizon. In reality, the material flow changes dynamically due to factors such as seasonality and the lifecycles of products (Gu, Goetschalckx et al. 2007). Faber, de Koster et al. (2013) claims that, although changes in products may be unpredictable for the production environment, the warehouses should be able to cope with this due to information sharing between the production and distribution. Therefore, warehouses should be able to cope with variations in the product portfolios. However, 3PL providers have a fluctuating client base, usually signing contracts in for 1-5 years at a time. Furthermore, this reduces the opportunity of trustworthy partnerships, hence prohibits information and data sharing (Baruffaldi, Accorsi et al. 2019b)

1.3. Research objective and scope

The purpose of this study was to investigate scientific methods reducing internal travel time in a small-medium-sized 3PL (Hereafter SME-3PL) warehouse. As explained in the introduction, the internal travel time is the large nonvalue added operation in a warehouse, and therefore is reducing the internal travel time results in a more efficient warehouse operation. The research was scoped to investigate existing storage policies for solving SLAP and evaluate which of these storage policies that are most suited for an SME-3PL with multiple clients.

RQ1: *Which storage policies exist for solving the storage location assignment problem (SLAP)?*

The purpose of this RQ is to investigate which storage policies that exist for SLAP. Further, to describe when to use different policies.

RQ2: *Which storage policies for SLAP are most applicable for SME-3PL providers with multiple clients?*

The purpose of this RQ is to investigate the typical characteristics of an SME-3PL and evaluate which of the storage policies that are most applicable for SME-3PL providers.

The objectives of the study are to:

1. Conduct a literature study of storage policies for performing SLAP to identify the existing policies and the research conducted with these principles. Further, the objective of the literature study is to describe the characteristics of SME-3PL providers and typical industry challenges.
2. Conduct a case study of an SME-3PL provider. The objective of the case study is further divided into these sub-objectives:
    a. Describe AS-IS situation for the SME-3PL provider
    b. Identify and analyze challenges that increase internal travel time for the SME-3PL provider.
    c. Provide improvement suggestions that reduce the internal travel time at the SME-3PL provider

Furthermore, the scope of the objective is narrowed down. The SLAP methods considered in this study are methods that can be used in warehouses without extensive mathematical approaches. The reason is that these mathematical approaches require ICT competence, which is a limiting factor for SME-3PL providers (Evangelista, McKinnon et al. 2013). As specified in the research objective, the focus of the study is to investigate the existing storage policies for SLAP. SLAP is a broader term that also covers exact optimization methods, simulation methods, heuristic methods, meta-heuristic methods, information and technology methods, and multi-criteria methods for assigning SKUs (Reyes, Solano-Charris et al. 2019). Moreover, this thesis scope is focused on information sharing between the client and the 3PL. This is because the information sharing between grocery wholesalers are limited for the upstream part of the supply chain, due to fierce competition among the grocery wholesalers. Further, the thesis will not look at specific technology to implement a new information flow because the implementation of new technology is outside the scientific background of the author. Warehousing is the only 3PL operation considered in this thesis because no other operation affects the storage policies to a large extent. This thesis will mainly focus on literature that studies SLAP on manual picking system or pickers-to parts system as these methods are most used among 3PLs (Selviaridis and Spring 2007, Davarzani and Norrman 2015).

1.4. Structure of the thesis

Table 1 shows the structure of the thesis, and the purpose of the table is to give the reader an overview of the different chapters.

Table 1: Thesis structure

Chapter	Description
Introduction	Describes the research topic, problem statement, research objective, and scope.
Methodology	This chapter describes the methodologies used in the study. It also describes how information was gathered and why.
Theoretical background	Investigates the existing literature, describing key theoretical perspectives in the study. The first part of the theoretical background describes warehousing. Next, this chapter aims to investigate storage policies for performing SLAP. Last, the typical challenges for 3PL providers were described.
Case Study	The case study investigates measures to improve operational efficiency by reducing internal travel time at an SME- 3PL provider. The first current situation is mapped before challenges are identified and investigated. Next, a suggestion to improve the situation is suggested.
Discussion	This chapter discusses the findings in the case study against the findings in the literature study. 5.1 discusses the different storage policies for SLAP hence answer RQ1. Further, a discussion of which of these storage policies that are appropriate for SME-3PL providers. Moreover, this chapter discusses the results from the case study and evaluates the generalizability of the results. Last, the weaknesses of the study are evaluated.
Conclusion	This chapter contains a short summary of the most important findings in the literature study and the case study. Further, it describes the contribution to knowledge. Last it contains suggestions to further work within the research topic.

2. Methodology

The purpose of this chapter is to describe the research process, the research design, the data collection, and the analysis performed. The research consists of both a literature study and a case study.

2.1. Literature study

The purpose of the theoretical background is to get an overview of the topics relevant to the research objective. First, warehouse management books (i.e. John J. Bartholdi (2019), Stephen N.Chapman (2017), and Frazelle (2002)) were read to attain relevant search words. These books were also used to describe the topics as they cover parts of the theoretical background. Further, the search words and "literature review" were added to find stated articles within the topic. By reading through the literature review on SLAP Reyes, Solano-Charris et al. (2019), and (Gu, Goetschalckx et al. 2007), a broad knowledge of the topic was obtained. By using the references of these literature reviews, articles related to the topic were found. Also, the literature review provides more in-depth knowledge of the storage policies, i.e., dedicated storage, random storage, and class-based storage. These storage policies are well research and did not require an extensive literature search to be covered. When searching for literature on 3PL providers, “warehouse” was added on to the additional search word to remove all literature regarding 3PL transportation, which is not relevant for this study.

Another aim of the literature study was to identify already existing literature on the research topic and create a solid foundation for further research (Ridley 2012). Consequently, a literature search was conducted to check if any research has investigated the same topic earlier. Both 3PL providers and storage policies are well covered in the literature. However, after conducting a literature search to find articles that address the correlation between these topics, no relevant articles were found. Thus, to investigate the correlation, separate literature studies where made on each topic before the correlation between them was discussed. The search engines for the survey were Scopus and Web of Science. So, to the best of the author's knowledge, researching the correlation between these is not covered in the literature and the search used. To check for existing literature, the search was:

TITLE-ABS.KEY (“storage polic*” OR “storage method*” OR “storage strateg*” OR “storage princip*) AND (“3PL” OR “third-party logistic*” OR “TPL” OR “outsourced logistic*”)

The topic/search words used for the literature study are shown in Table 2. To add recent articles that were not cited in the literature reviews, additional searches were done.

Table 2: Search words

Main search words	Additional search words
SLAP Storage location assignment problem Storage allocation problem Slotting	Literature review
Storage	Policies Methods Principles Strategies
Third-party logistic providers 3PL Outsourced logistics TPL	Warehouse Challenges Small and medium size

The search engines used for the literature search were Scopus and Google Scholar. Scopus was mainly used to find relevant articles. Meanwhile, Google scholar was used if relevant articles were not found on Scopus.

To limit the literature search, the most cited article was prioritized, the number of citations is an implication of the validity and quality of the article. Further, the abstract was read to check for relevance to the research. Next, relevant articles were checked for useful references that contributed to the research objective. However, for new articles posted after 2019, this criterion was not applied as the citation criteria are more relevant for older articles that have existed over a period.

2.2. Case study

To achieve the research objectives, a case study of an SME-3PL provider from Norway, namely Leman A/S department Vestby, was conducted. The case study is limited to analyzing the warehouse operations Leman performs for one of their clients, Brynild Gruppen A/S. The reason including Brynild Gruppen in the project is the availability of data and the encouragement of the project from key personnel at Brynild Gruppen.

The case study was based on a single case. The main advantage of a single case study is the possibility to achieve research depth (Voss, Tsikriktsis et al. 2002). Further, case studies allow the holistic and meaningful characteristics of real-life events, such as organizational and managerial processes that must be considered (Yin 2011). However, with one case, there are limits to generalizability of the conclusion drawn. Further, single case studies have biases such as misjudging of the validity of single events and exaggerating easily available data (Voss, Tsikriktsis et al. 2002). According to Yin (2011), the reliability and validity of the research will be enhanced by a well-designed case study protocol. A case study protocol is added to Appendix A. The case study protocol is a structured scheme that presents the different stages of the case study, the information gathered, which method that is used, and where the information originates from.

The data collection of the case study consists of both primary and secondary data. The primary data is interviews with key personnel at Leman and the Supply Chain Director at Brynild. The interviews have been in various formats. Some were conducted while observing the processes in the warehouse, while other interviews were more structured. Table 3 shows different interviews and formats. In addition to the displayed interview, email correspondence and phone calls have also been conducted to clarify uncertainties as well.

Secondary data was collected by sending requests for information to key personnel in Leman and Brynild. The secondary data consist of both quantitative data and a functional description of lemans WMS. Table 4 shows how the secondary data were collected and what the secondary data contain

These data were crucial to creating a *warehouse activity profile.* A warehouse activity profile is carefully measurement and analysis of warehouses operations and is the necessary initial step into any warehouse project: understanding customer order, which drives the warehouse system (John J. Bartholdi 2019). The warehouse activity profile is a part of describing the AS-IS situation at Leman. Observations and interviews have been used to identify challenges in Leman's warehouse operations. Next, semi-structured interviews and meetings have been used to verify these observations. Moreover, qualitative data has been used to validate a second time. The qualitative data has further been used to analyze the magnitude of the challenges and suggested new improvements. The suggested improvements have then been validated by both Brynilds Supply Chain Director and the Activity Manager through interviews.

Table 3: Gathering of qualitative information

Format	Actors	Description	Date
Skype Meeting	Supply Chain Director, Brynild-Gruppen	Introduction to the supply chain	31/01.2020
Meeting	Warehouse Manager, Activity Manager, Logistics Coordinator & Supply Chain Director Brynild	Introduction to Leman's operations and discussion of problem statements	13/02.2020
Observation	Warehouse operators	Observing and interviewing warehouse operators to find possible problems during a company visit	25/02.2020
Observations	Logistics coordinators Logistics coordinators	Gather information on warehouse policies and WMS functionality	25/02.2020
Semi-structured interview	Logistics coordinator	Gather information on WMS configuration, WMS transaction data, and SLAP policies	15/05.2020
Semi-structured interview	Activity manager	Verification of operational challenges	11/06.2020
Semi-structured interview	Brynilds Supply Chain Director	Routines for information sharing and verification of challenges	12/06.2020

Table 4: Gathering secondary data

Format	Received from	Content	Date received
KPI report	Brynilds Supply Chain Director	Brynild measures of KPIs from Lemans warehouse	31/02.2020
Functional description of WMS(Consafe 2020)	Activity Manager	Description of WMS functions and logic	03/04.2020
Warehouse layout	Activity Manager	The physical layout of lemans warehouse	06/05.2020
Transaction data from the WMS	Logistics Coordinator	Every transaction in the warehouse from June 2018 until May 2020 (screenshot added to Appendix C.1	08/05.2020
Sales data from Brynild	Brynilds Supply Chain Director	Sales data from January 2018 to May 2020	25.05.2020
Current classification of SKUs	Logistics Coordinator	Classification of SKUs at 03/06 2020	03/06.2020

3. Theoretical background

This chapter presents the necessary background of the key theoretical perspectives in this thesis. It starts with an introduction of warehouses and their different physical operations before it scopes down to storage strategies within the warehouse. Then an introduction to warehouse management systems (WMS) will also be given due to its importance in coordinating the operations. The storage location assignment problem (SLAP) is described, together with different storage strategies, to perform SLAP. Lastly, a description of third-party logistics (3PL) providers is given to describe different challenges in the industry.

3.1. Warehousing

Warehousing is an essential part of any supply chain. The major role of a warehouse includes buffering material flow through the supply chain to accommodate variability in demand, merging of SKUs from various suppliers for combined delivery to customers, and value-added tasks as pricing, labeling, and product customization (Gu, Goetschalckx et al. 2007). Warehouse management has two vital resources: time (labor hours) and space. These resources are the major cost drivers in warehouse management (John J. Bartholdi 2019). The key is to reduce these resources as much as possible without it affecting the service level (John J. Bartholdi 2019). According to Stephen N.Chapman (2017) there are four objectives of warehouse management:

- Provide timely customer service
- To keep control over the inventory so products can be retrieved efficiently and correctly
- Minimize the total physical effort and thereby reduce the cost of moving goods into and out of storage
- Provide communication links with customers

The warehouse system is characterized by the SKUs stored and picked within the warehouse(Faber, de Koster et al. 2013). Faber, de Koster et al. (2013) states that the complexity of warehouse management is dependent on these factors:

- The number of different SKUs handled in the warehouse
- The number and variety of the processes carried out by the warehouse
- The number of order lines processed by the warehouse per day

3.1.1. Physical warehouse operations

Warehouse operation can be divided into four main categories; receiving, storage/put away, order picking, and shipping (Gu, Goetschalckx et al. 2007, Bahrami, Piri et al. 2019, John J. Bartholdi 2019).

John J. Bartholdi (2019) further divides them into inbound and outbound operations. The interfaces of the warehouse are inbound with receiving of pallets with goods (Hereafter, unit-load) from e.g., production and suppliers, and outbound is the shipping of outgoing products to customers (Gu, Goetschalckx et al. 2007). The storage operations are concerned with storing unit-loads to utilize the warehouse space and operators' time to maintain efficient material handling (Gu, Goetschalckx et al. 2007). Figure 1 illustrates the sequence of warehouse operations is performed. A further description of the different physical operations is given below.

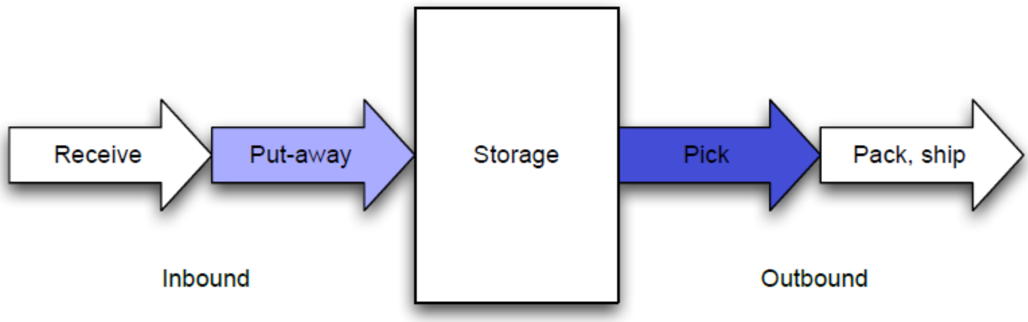

Figure 1: Warehouse operations, adapted from page 24 (John J. Bartholdi 2019)

Receiving

The receiving stage starts with the notification of incoming goods. The notice gives the operators time to coordinate the efficient handling of the incoming goods. When the goods arrive, it is unloaded and registered. Further, the incoming goods are inspected to detect discrepancies and check for damaged unit-loads. When the goods are inspected, the warehouse operator registers the goods as received, and then they are ready for put-away to the storage area (John J. Bartholdi 2019). Rough estimates indicate that the receiving stage account for 10% of the total operation cost in a typical warehouse (Kofler 2015, John J. Bartholdi 2019).

Put-away

Put-way is the operation where the operator transports the incoming unit-loads from the in-and outbound area (I/O-area) to its storage location. First, the unit-load must be assigned to a storage location. The assigned storage location has to be available and fulfill the physical aspects required by the unit-load (John J. Bartholdi 2019). A more detailed description criterion that influences the storage location assignment is given in Subchapter 3.2. When the unit-load arrives at its location, the operators scan the barcode to register the exact location of the unit-load. The order-pickers use this information to retrieve the unit-load for future orders. Typically, the put-away activity accounts for 15% of warehouse expenses, due to the labor intensity of transporting the unit-load from the I/O area to the storage area(John J. Bartholdi 2019).

Storage

Storage is the physical containment of merchandise during its awaiting demand. (Frazelle 2002) Storage directly affects one of the most expensive operations within a warehouse, namely order picking. Each different storage location has a unique address within the warehouse. These storage locations are costly because they occupy valuable space, which is the basis of fixed costs such as rent, heating, security, and investments in physical equipment as racks and shelves. Therefore storage space must be efficiently utilized to reduce cost (John J. Bartholdi 2019).

Order picking

Customer orders trigger the order picking process and the outbound process of the warehouse. The warehouse must check and verify that the inventory is available to ship the ordered goods and produces a picking-list to guide the order picker. Further shipping documentation and shipping schedule is added. To manage all these operations in a warehouse, WMS is commonly used (John J. Bartholdi 2019). WMS is described in Subchapter 3.1.3.

The order line consists of several picking lines, and each pick-line represents a storage location visited in the sequence of the order picking. The picking lines are further organized to picking lists. These picking lists are organized to reduce the travel time by letting one order picker concentrate on a specific area. Picking list comes in various forms, e-g, physical paper, light, voice transmission, or digital sheets. When the order picker receives the picking list, the physical picking is initiated(John J. Bartholdi 2019).

Order picking is the most complex and time consuming of the warehouse operations. Hence it is the most important cost-driving operation in the warehouse (John J. Bartholdi 2019). Literature typically states that order picking is estimated to account for 55% of the time spent in warehouse operations (Kofler 2015). Further broken-down traveling equals 50% of this process, searching 20%, picking 10%, and paperwork and other support activities 15% (Kofler 2015, John J. Bartholdi 2019). Figure 2 illustrates the time spent on order picking and the warehouse expenses distributed among warehouse operations. Thus, traveling within the warehouse is the most expensive part of warehouse operations. Therefore, much effort should be invested to reduce unproductive time in the order picking process (Frazelle 2002).

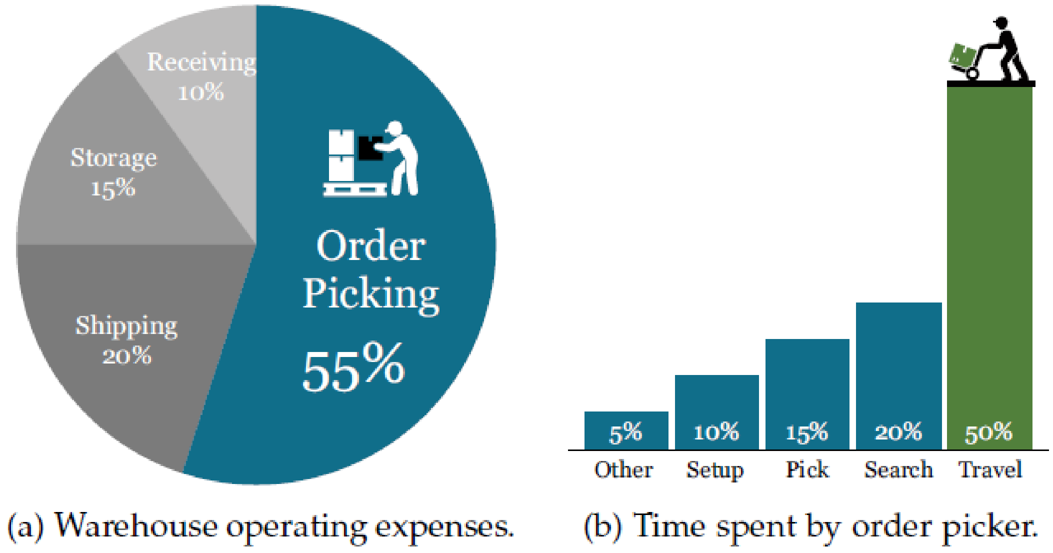

Figure 2: Warehouse expenses and times spent by the order picker, adapted from (Kofler 2015) which adapted from (Tompkins, White et al. 2010)

Shipping

Shipping is concerned with several activities among checking orders for completeness, packaging merchandise in appropriate shipping containers, preparing shipping documents, accumulating orders by the outbound carrier, and loading trucks (Frazelle 2002).

3.1.2. Warehouse performance

Warehouse performance is measured by warehouse key performance indicators (KPI). Such KPIs can be; productivity, shipping accuracy, inventory accuracy, dock-to-stock time, warehouse order cycle time, storage density, and level of automation (Frazelle 2002). Table 5 illustrates the different KPI's for each warehouse operation performed in the warehouse and how they influence the total performance of the warehouse.

The highest cost in warehouse management is the cost of warehouse personnel (Frazelle 2002). Thus labor productivity is a crucial measurement. Labor productivity is highly dependent on the type of material handling equipment, warehouse layout, *stock location system*, and order picking system used (Stephen N.Chapman 2017). As mentioned, order picking is considered as the most labor-intensive warehouse operation (Le-Duc * and De Koster 2005). According to Le-Duc * and De Koster (2005), the performance and efficiency of the order picking affected by these factors:

- The demand patterns
- The configuration of the warehouse
- *The storage strategy, how to allocate SKUs within the warehouse*
- The batching method: how to group orders and divide order among pickers

- The routing and sorting, how to determine the SKUs to be picked and how to consolidate

We will look further into the storage strategy, i.e SLAP, in Subchapter 3.2.

Table 5: Warehouse Key Performance Indicators adapted from (Frazelle 2002) page 56

	Financial	**Productivity**	**Utilization**	**Quality**	**Cycle time**
Receiving	Receiving cost per receiving line	Receipts per man-hour	% dock utilization	% Receipts processed accurately	Receipt processing time per receipt
Put-away	Put-away cost per putaway line	Put-away per man-hour	%Utilzation	%perfect put-aways	Putaway cycle time
Storage	Storage space cost	Inventory square foot	%Locations and cube occupied	% Locations without inventory discrepancies	Inventory day on hand
Order picking	Picking cost per order line	Order lines per picked per man-hour	% Utilization of picking and labor equipment	%perfect picking lines	Ordering picking cycle time (per order)
Shipping	Shipment cost per customer order	Orders prepared for shipment per man-hour	%Utilization rate	% of perfect shipments	Warehouse order cycle time
Total	Total cost per order, line, and item	Total lines shipped per total man-hour	% utilization of total throughput and storage capacity	% of perfect warehouse orders	Total warehouse cycle time = Dock-to-stock time + warehouse order cycle time

3.1.3. Warehouse management systems (WMS)

Information systems support most warehouses, and some warehouses are supported by a wide range of functionality (e.g., an ERP-system), meanwhile others utilize specific software for managing warehouses (Faber, de Koster et al. 2013). WMS is a complex and specific software that assists the coordination of managing operations within warehouses (John J. Bartholdi 2019). Actions that a WMS typically assist is to manage inventory, storage locations, and workforce, to ensure an efficient picking, packing, and shipping of orders (John J. Bartholdi 2019). The WMS contains information of each SKU and its physical dimensions, also the physical boundaries within the warehouse, including every storage location (John J. Bartholdi 2019). With this information, the WMS orchestrates the flow of products, people, and machines within the warehouse (John J. Bartholdi 2019). The WMS system is connected to the warehouse operations with Auto ID Data Capture Technology, such as barcode scanning and RFID, which monitor the material flow in the warehouse(John J. Bartholdi 2019). The WMS extracts this information in real-time. Consequently, the WMS utilizes this information to coordinate the operations and create useful reports on the status of the inventory (Frazelle 2002). Another important feature with WMS is the recording of out and ingoing goods from the warehouse, and these records can be used as a basis for invoicing and payments (John J. Bartholdi 2019). Figure 3 shows how the different modules in the WMS systems support different warehouse operations. Stock locator systems are also a major asset to WMS. It allows tracking of all storage locations, including the forks of a forklift (John J. Bartholdi 2019).

The literature distinguishes between three types of WMS, basic WMS, Advanced WMS, and Complex WMS (Ramaa, Subramanya et al. 2012, John J. Bartholdi 2019):

- Basic WMS contains simple information mainly focused on throughput in the warehouse. Further, it supports storage control and location. Also, it provides storing and picking instructions for warehouse operators
- Advanced WMS, this includes all features from the basic WMS. Additionally, the advanced version offers tools to plan resources and operations and synchronize these to include functionalities as stock and capacity analyses

- Complex WMS, it includes all features of the advanced WMS. Additionally, the complex WMS system offers functionalities as transportation, dock door and added logistics planning which helps to optimize the warehouse operations further

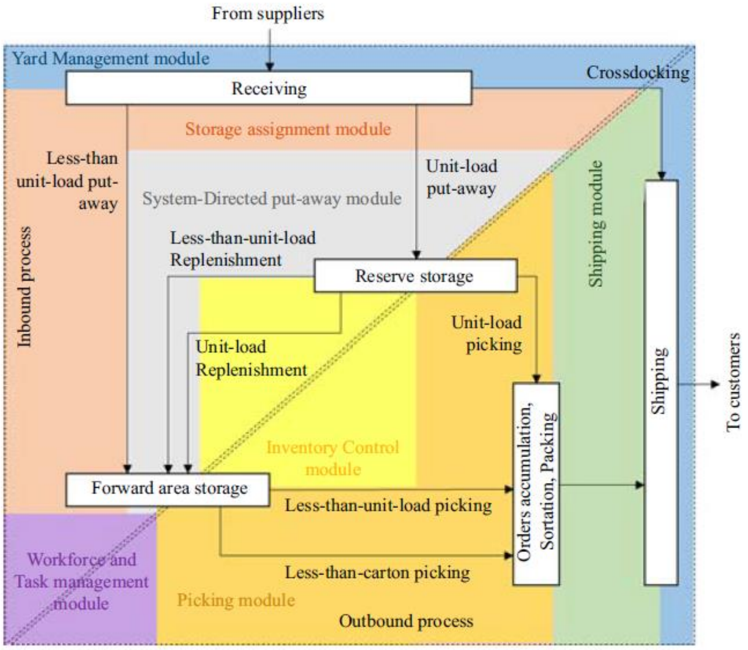

Figure 3: The warehouse operations and the associated WMS modules, adapted from (Baruffaldi, Accorsi et al. 2019b)

3.2. Storage location assignment problem (SLAP)

The *storage location assignment problem* (SLAP) is to assign incoming unit loads to storage locations in the storage areas/zones to reduce material handling costs and improve space utilization (Gu, Goetschalckx et al. 2007, Reyes, Solano-Charris et al. 2019). SLAP is dependent on several parameters as a storage area design, storage space availability, warehouse storage capacity, product characteristics, arrival time, and demand pattern (Reyes, Solano-Charris et al. 2019). A trend of increasing product varieties causes warehouses to take on a larger number of different SKUs, thus complicating the SLAP (Choy, Ho et al. 2017). According to Frazelle (2002), SLAP affects warehouse KPI's as productivity, shipping accuracy, inventory accuracy, dock-to-stock time, warehouse order cycle time, storage density, and level of automation. Further, Frazelle (2002) states that SLAP is one of the most important decisions within in warehouse management. Choy, Ho et al. (2017) argues that the outcomes of unsystematic SLAP yields higher material handling costs and lower space utilization. The version of the SLAP problem studied in the literature is often static, i.e., it assumes that the incoming and outgoing material flow patterns are stationary over the time horizon. (Gu, Goetschalckx et al. 2007) In reality, the material flow changes dynamically due to factors such as seasonality and the lifecycles of products. (Gu, Goetschalckx et al. 2007)

Gu, Goetschalckx et al. (2007) introduced different SLAP models. These are based on the amount of available data, i.e., *Item information, product information, and no information*. Kofler (2015) constructed Figure 4, which shows the hierarchy of the SLAP models.

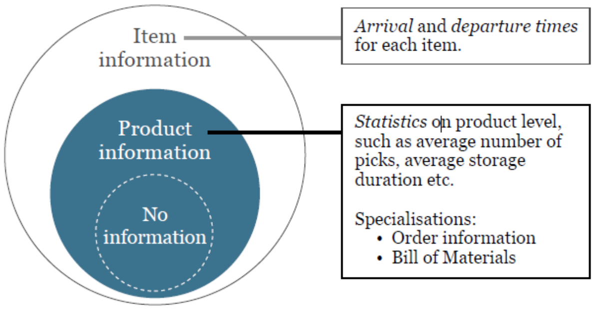

Figure 4: Hierarchy of SLAP models, adapted from (Kofler 2015)

SLAP models with *no information* are available on the characteristics of arriving SKUs. Only the simplest storage policies can be applied, i.e., closest open location, random location, farthest open location, or longest open location (Gu, Goetschalckx et al. 2007). SLAP models with *product information* can apply more detailed methods, which is based on product information as to size and usage rate (Gu, Goetschalckx et al. 2007). Historic order data can be used to retrieve general data as picking frequency, demand, delivery quantities, and intervals (Kofler 2015). Further, this formation can be used to divide SKUs into classes (Gu, Goetschalckx et al. 2007). With SLAP models having *item information*, arrival-and departures times are known before the item enters the warehouse (Kofler 2015). Hence decision-makers can place the item with the shortest duration of stay (DOS) to the storage locations with the shortest travel distance (Gu, Goetschalckx et al. 2007).

Different warehouse departments might use different SLAP policies depending on the department-specific SKU profiles and storage technology (Gu, Goetschalckx et al. 2007). Fontana and Cavalcante (2014) studied the optimal tradeoffs between order picking distance and storage space requirement when choosing a SLAP policy. By performing the Pareto Approach (described in Subchapter 3.2.3.), they introduce the Pareto curve or the efficient frontier, which illustrates the optimum between storage space utilization and order picking distance, as shown in Figure 5. Fontana and Cavalcante (2014) also state that instances with a high turnover rate, the focus should be on efficient order picking and not space utilization, and the other way around for warehouses with a low turnover rate.

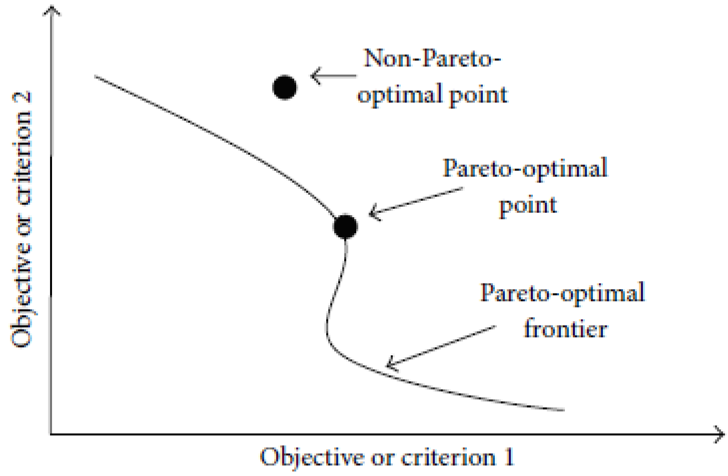

Figure 5: Pareto optimal points and Pareto optimal frontier, adapted from (Fontana and Cavalcante 2014)

Figure 6, adapted from Bahrami, Piri et al. (2019), shows various storage policies to assign a location for incoming unit-loads. There are three main policies for storing products *dedicated storage, random storage, and class-based storage (*Bahrami*, Piri et al. 2019)*. Shared storage means that SKUs do not have fixed storage locations. Further, these will be described below and broken down to the different criterion that exists.

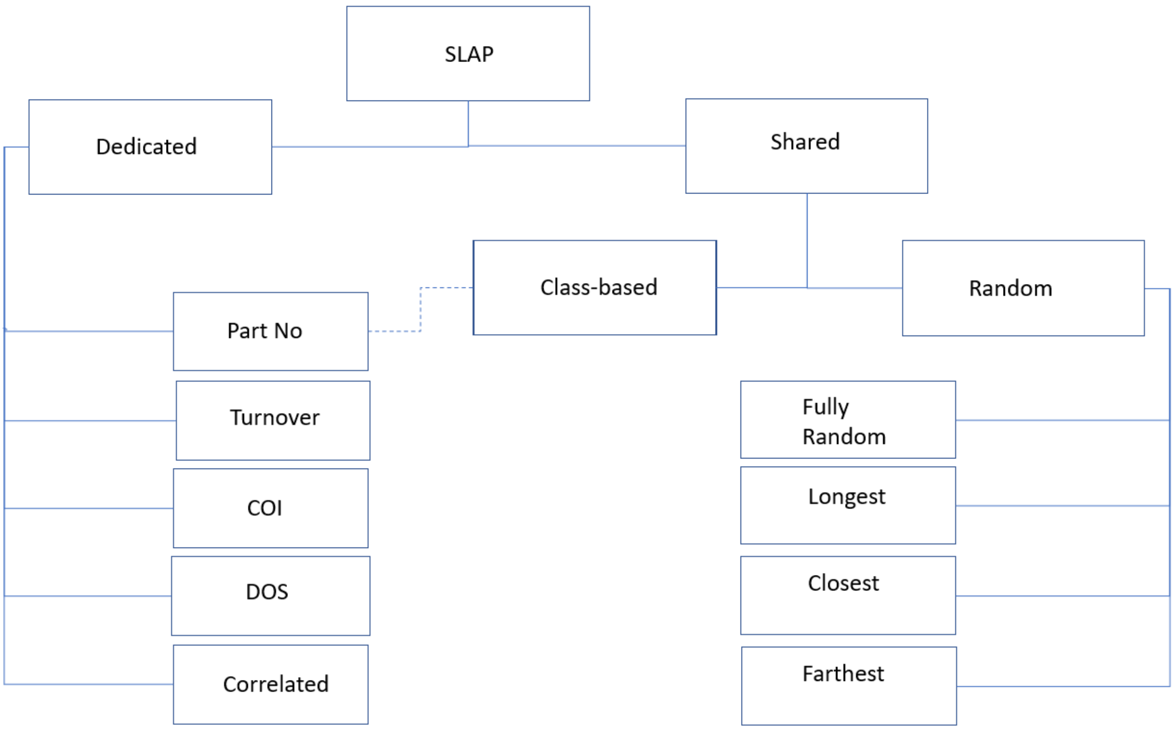

Figure 6: Storage policies, adapted from (Bahrami, Piri et al. 2019)

3.2.1. Dedicated Storage

Dedicated storage or fix location system is a policy where the number of classes equals the number of SKU identical to classes (Gu, Goetschalckx et al. 2007). With this policy, every SKU has a designated location, meaning it is not possible to store other SKUs in that exact storage location. This policy is ideal for small warehouses with no or little use of digital tools, where dedicated storage provides a simple solution where manual control is feasible (Stephen N.Chapman 2017). Before the implementation of WMS became widespread, dedicated storage was considered the most practical policy to organize the warehouse (Kofler 2015). Since the storage location of the SKU does not change, one can store the most popular products in the most convenient locations and store the slow movers on more remote storage locations (de Koster, Le-Duc et al. 2007). Consequently, operators can learn the layout and perform order picking more efficiently (John J. Bartholdi 2019). The disadvantage of this method of storing SKUs is the reduced utilization of space within the system (de Koster, Le-Duc et al. 2007, Fontana and Cavalcante 2014). When a warehouse contains up to ten-thousand storage locations, the utilization rate becomes an issue. Since every SKU has a designated location where no other SKUs are stored (Stephen N.Chapman 2017). Additionally, this policy is not flexible to changes in volume or product portfolio (Stephen N.Chapman 2017). As displayed in Figure 6, there are different subcategories for a dedicated storage policy (Bahrami, Piri et al. 2019):

Part Number: An old-fashioned policy where SKUs were stored after their product number. This was more used before information systems were available to systemize the storage locations. However, this is rarely used today.

Full Turnover: With a turnover, popularity, or a picking frequency-based policy, the most desired products are stored in the most convenient storage locations, namely the once closest or most accessible from the I/O area. Accordingly are the slow movers assigned to the storage locations farthest away from the I/O area (de Koster, Le-Duc et al. 2007). The downside with this policy is that the turnover rate of SKUS and the product portfolio is fluctuation, leads to many relocations of SKUs to maintain the advantage of using this method (Roodbergen and Vis 2009). This criterion is often mistaken for unit sales, which is incorrect; it is the number of times an SKU is requested (Frazelle 2002). This indicator is important because it measures the number of times operators pick the SKU (Kofler 2015).

Cube per order index (COI) is defined as the ratio between the space requirement and the demand for an SKU (Kofler 2015). SKUs with a low COI value is assigned to the most desirable storage locations, which is located closer to the I/O area. COI performs best with simple warehouse constellations (Kofler 2015) and especially in warehouses with single retrievals i.e, full pallet picking (Bahrami, Piri et al.

2019). However, for larger orders, the COI is only performing well if there are no statistical dependencies between SKUs, which is not the scenario for most warehouses (Gu, Goetschalckx et al. 2007).

Duration of stay (DOS): DOS is the expected time a specific unit-loads is spending in a warehouse (Gu, Goetschalckx et al. 2007). By having the DOS in every single unit-load, one can store the unit-loads with the shortest expected DOS to be placed in the storage locations closest to the I/O area(Gu, Goetschalckx et al. 2007). However, this method requires item-specific information (Gu, Goetschalckx et al. 2007). Consequently, DOS requires the most information of all the storage policies for SLAP (Goetschalckx and Ratliff 1990).

Correlation or affiliation: Correlation-based or affinity-based is when SKUs that usually are picked together are stored next to each other to reduce the travel time between picking the SKUs, resulting in shorter picking tours (Kofler 2015). A lack of accurate data to calculate the correlation index between SKUs limited the accuracy of correlated storage applications (Bahrami, Piri et al. 2019). The interrelationship between SKUs is complex for distribution warehouses to utilize compared to production warehouses since distribution warehouses do not have the opportunity to operate with BOM (bill of materials) as in production environments (Bahrami, Piri et al. 2019).

3.2.2. Random Storage

The direct opposite of dedicated storage, we have random storage. With the random storage policy, SKUs are stored in a random position within the warehouse (Gu, Goetschalckx et al. 2007). When a storage location becomes empty, it is available for other SKUs. The benefit of this solution method is that the space within the warehouse is utilized to a higher degree, compared to dedicated storage (Bahrami, Piri et al. 2019). However, this is at the expense of increase travel times (Sharp, Il-Choe et al. 1991). Since this storage policy utilizes the whole storage area, congestion of order-pickers is less likely (Petersen and Aase 2004, Kofler 2015). The random storage policy frequently is used because of its simplicity and immunity to demand and assortment fluctuations (Bahrami, Piri et al. 2019). However, in the long run, the performance declines because random storage policies do not utilize the product information available (Chiang, Lin et al. 2011). Random storage policies can be divided into subgroups also , as shown in Figure 6 (Bahrami, Piri et al. 2019):

Fully random: A random available storage location is selected. However, if the warehouse operator selects the most convenient storage location, this policy usually leads to the closest location strategy. Since operators rather put-away the Unit-load at a close storage location than to travel further(de Koster, Le-Duc et al. 2007).

Closest location: Chooses the first available storage location from the inbound area.

Farthest location: Assigns the Unit-load to the farthest away from the inbound area.

Longest available: Assigns the Unit-load to the storage location, which has been available for the longest time.

A disadvantage to this policy is that it requires "real-time" information on each single storage location in the warehouse to suggest an available storage location for an SKU and enhance an effective retrieving of SKUs (Stephen N.Chapman 2017). Thus, order pickers are not able to learn the storage locates of SKU. Therefore, the random storage policy will only work in a computer-controlled environment (Stephen N.Chapman 2017). Also, the accuracy of the information is critical. Incorrect information can lead to much waste of time since warehouse personnel has to locate the SKU without knowing where to look (Stephen N.Chapman 2017). With shared storage locations, order pickers can cause discrepancies in the inventory record. E.g., order pickers might be tempted to pick products from a convenient storage location, rather than pick from storage location suggested by the WMS. (John J. Bartholdi 2019).

3.2.3. Class-Based Storage

The idea of class-based storage is to reduce handling time by assigning the most frequently requested SKUs to the best storage zones (John J. Bartholdi 2019). Class-based storage is also referred to as ABC-storage (Kofler 2015). Class-based storage is a two-stage process; first, SKUs is divided into groups based on product information; second, product classes are assigned to storage zones (Kofler 2015, Bahrami, Piri et al. 2019). Each class is assigned to a dedicated area of the warehouse, and further, when an SKU of a class arrives, a specific storage location chosen by a random storage policy (de Koster, Le-Duc et al. 2007). Class-based storage is popular among practitioners, due to simple implementation and its flexibility to variations in product mix and demand (Le-Duc * and De Koster 2005). However, Petersen and Aase (2004) conclude that classes based storage requires periodic reviews of SKUs to represent the demand pattern through time. Both Petersen and Aase (2004), and Gu, Goetschalckx et al. (2007) states that class-based storage is an alternative to random storage and dedicated storage that provides the benefit of the other two policies. Further, Gu, Goetschalckx et al. (2007) stresses that implementation of class-based storage requires careful consideration of; how many classes, the assignment of SKUs to these classes, and the storage location of each class. These have a significant impact on the utilization of storage space and the material handling cost of a warehouse (Gu, Goetschalckx et al. 2007).

The criteria for being assigned to a class are based on dedicated storage policies, as displayed in Figure 6 (Bahrami, Piri et al. 2019). However, Gu, Goetschalckx et al. (2007) states that picking frequency, and COI is frequently used criteria:

Picking frequency: Uses the same calculations as for **Turnover** in dedicated storage. SKUs are ranked after their picking frequency, where the SKUs with the highest rank are located in the storage zone with the most convenient storage locations(Gu, Goetschalckx et al. 2007).

COI: Uses the same calculation as for **COI** in dedicated storage. It considers both the picking frequency of the SKU and its storage requirements. Further classes are divided by the COI value, where the lowest COI values are located in the most convenient storage zone, while SKUs high COI value is located in less convenient storage zones.

The policy for assignment within the storage zone is based on random policies. The most frequently used is often based on **Closest location** or **Fully random** (Gu, Goetschalckx et al. 2007, Kofler 2015)

Research indicates that picking frequency is traditionally used as the criteria for assigning SKUs to classes (Ming-Huang Chiang, Lin et al. 2014). Where class A is for the fast-moving SKUs, and the medium-popular SKUS are B and C SKUs are the least popular (de Koster, Le-Duc et al. 2007). The storage locations for class A is located in the most convenient areas of the warehouse, while storage locations for class C are located at the least convenient storage locations (Kofler 2015). The assignment of SKUs for class-based storage is commonly based on the Pareto Approach, where 20% of most picked SKUs account for 80 % of the total amount of picks (Kofler 2015). These 20% are categorized as A SKUs, while 15% are categorized as B SKUs, and the last 65% are categorized as C SKUs (Kofler 2015).

Further, the implementation of the storage zones to the needs to be spread over the storage area. Several methods exist to perform these spreads, for manual pickers-to-parts systems, the methods in Figure 7 is commonly used (de Koster, Le-Duc et al. 2007). Petersen and Aase (2004) illustrate that *within the aisle method* has a higher performance than other storage implementation strategies. However, de Koster, Le-Duc et al. (2007) argue that the optimal implementation of storage zones is fully dependent on the routing policy applied and further states that there is no firm rule optimal to divide the storage areas into storage zones.

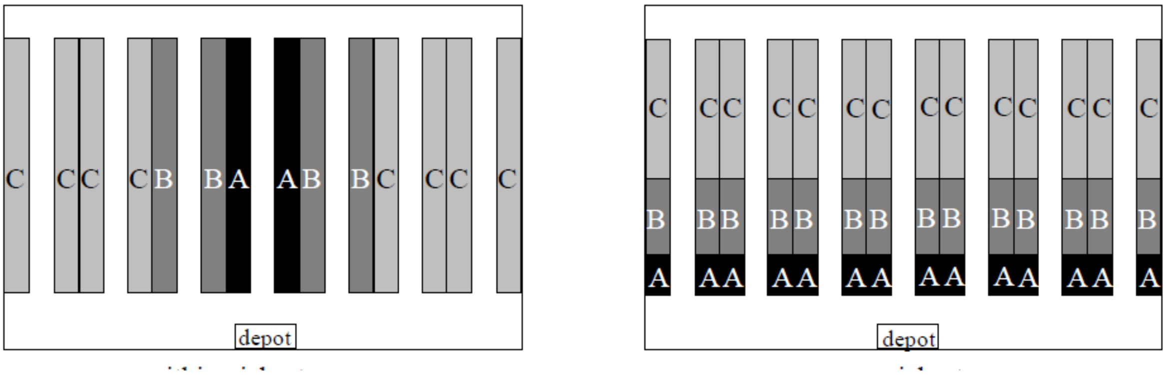

Figure 7: Two popular methods to divide classes inside a storage area, the left-most shows the within in aisle method, and the right illustrates a cross aisles method, adapted from (de Koster, Le-Duc et al. 2007)

3.2.4. Forward picking area

A particularly convenient area within a warehouse is known as a forward picking area or fast-pick area (John J. Bartholdi 2019). The purpose of forward picking areas is to store the most popular SKUs in a concentrated zone of the warehouse, to reduce the non-value-added travel time of order-pickers (Bartholdi and Hackman 2008). Dedicated storage is used in the forward picking area to support an efficient order picking. Thus the storage locations can be assigned based on activity and not just availability (John J. Bartholdi 2019). Even though the dedicated storage does not utilize the storage space very efficiently, this would not lead to significant loss of storage space since the forward picking area accounts for a relatively small part of the total storage area (John J. Bartholdi 2019). The problem regarding the forward picking area is to choose which SKUs and what quantities. This problem is known as *forward reserve problem* (Van den Berg, Sharp et al. 1998). Further, John J. Bartholdi (2019) states that the SKUs with the highest labor savings per pallet has the priority of being stored in the forward picking area.

3.3. Third-Party logistic providers

Third-party logistics (3PL) providers offer physical distribution services to buyers and suppliers of goods. They perform operations like warehousing, electronic data interchange (EDI), packaging, freight tracking, order processing, product tracking, and delivery (John J. Bartholdi 2019). 3PL providers stores SKUs for multiple clients, allowing them to merge different items in size and turnover, resulting in saving storage space and increasing efficiency in handling operations (Shi, Zhang et al. 2016). Thus, 3PL providers can provide these services to a lower economic cost, due to the economies of scale and the pre-existing infrastructure they possess from other clients (John J. Bartholdi 2019). 3PL providers also allow clients to focus on their core capabilities and outsource problems regarding logistics (Stephen N.Chapman 2017). Further 3PL providers react well to fluctuating volumes, due to the number of customers provides flexibility to "loan" space for other clients (Stephen N.Chapman 2017).

3PL providers strive to control and improve their performance to gain a competitive advantage (Baruffaldi, Accorsi et al. 2019a). 3PL provider operates a fierce environment affected by a large variety in types and number of clients, product portfolios, and demand patterns that must be met (Baruffaldi, Accorsi et al. 2019a). Thus, to handle this complexity, 3PLs providers require an in-depth understanding of the dynamics of warehouse operations and the client's product characteristics (Baruffaldi, Accorsi et al. 2019a). Further, the service level and the flexibility to cope with different processes are crucial for 3PL providers to maintain lasting relationships with clients (Hamdan and Rogers 2008). As more automation is used, the less flexible is the warehouse; therefore, a high degree of atomization discouraged for 3PL providers (Selviaridis and Spring 2007, Davarzani and Norrman 2015). Moreover, 3PL providers must continuously review their processes to meet the clients' requirements, especially in warehousing, where it is increasingly difficult to maintain the high service level and efficiency due to large inventory mix and multiple clients (Hilmola and Lorentz 2011).

Although information sharing is important for supply chains (Zhou and Benton 2007, Chopra and Meindl 2016), 3PL providers usually make decisions to reduce the visibility of the clients' processes, especially for new clients (Baruffaldi, Accorsi et al. 2019b). Due to competition among 3PL provider and high turnover of a client, reduces the opportunity for the long term and trust-based partnerships, which further discourage data and information sharing (Baruffaldi, Accorsi et al. 2019b). The information which is usually unknown for 3PLs is the schedule of incoming deliveries, the content of the deliveries, changes in the product portfolio, and forecast of expected orders (Accorsi, Baruffaldi et al. 2018). Further, the use of criteria as COI or Picking frequency contributes to reduced traveling during order picking. However, these require information provided by the client, i.e., the number of incoming orders of all SKUs (de Koster, Le-Duc et al. 2007, Baruffaldi, Accorsi et al. 2019b).

Evangelista, McKinnon et al. (2013) investigated the use of information and communication technology at SME-3PL providers. They found that the strategic importance of supply chain integration 3PL, which requires appropriate investments to improve the integration of their warehouse operation with clients and other parties in the supply chain. Another finding for the article indicates that a lack of technology skills in the workforce is a considerable constraint for implementing ICT and the exploration of ICT potential. Therefore, managers of SME- 3PL providers should use to devote more resources to training staff when investing in ICT systems (Vehovar and Lesjak 2007). Consequently, SME-3PL providers need technical support from client companies (Gunasekaran and Ngai 2003).

Gunasekaran and Ngai (2003) stresses that SME-3PLs are especially flexible and innovative in their logistics processes. Due to the necessity of strategic partnerships. SME-3PL has less capital to invest in technology and ICT skills. Further, the article states that SME-3PL providers must form long term strategic partnerships with companies that are dependent on their core competence and market opportunities.

3.4. Summary of the theoretical background

Key information from the theoretical background:

- Warehouse complexity is affected by characteristics of the SKU it stores
- The major cost divers in warehousing are labor cost and warehouse space
- The most expensive resource in warehouse management is labor (time), and internal transportation occupies the largest share of it. Order picking is the most time-consuming activity, and the storage location of SKUs influences the time used on order picking
- WMS is used to support operations within the warehouse
- The storage location assignment problem (SLAP) is concerned with the locating storage locations for incoming unit-loads.
- SLAP has different policies, dedicated storage, random storage, and class-based storage. Where class-based storage is the most frequently uses among practitioners, due to flexibility and simple configuration.
- 3PL providers are subjected to other challenges than in-house warehousing, as information barriers, flexibility to adapt to changes, increased complexity, and low degree of atomization
- SME-3PLs needs strategic partnerships to compensate for lacking ICT capabilities

4. Case study: Leman A/S

This chapter contains a description of Leman A/S in Vestby. First, a general introduction to the case company and its distribution chain is given and followed by a specific description of the demand pattern, warehouse operations, warehouse layout, and warehouse principles. Further, a description of Lemans WMS is conducted and a description of how the WMS performs SLAP. Next, an analysis of the challenges Leman faces in their operations and the need for improvements. Last, an analysis of the performance of the current SLAP policy is conducted, and a suggested process improvement proposed.

4.1. Case introduction.

4.1.1. Leman

Leman A/S is a Danish 3PL provider with global departments in six countries, among these are Norway, where Leman has two departments, Leman-Drammen and Leman-Vestby. Leman-Vestby (herby Leman) is the case company for this case study. Leman has today 25 full-time employees, which characterize them as a small-medium sized enterprise (SME). Leman acquired Dan Cargo AS in 2014, having two facilities, one in Moss and another one in Vestby. These facilities were later merged in 2018 to a larger facility at Vestby, where they are situated today.

Leman performed several services for customers, and each customer has different requirements. The core operation is warehousing. Additionally, they offer services like transportation and customs clearance. Leman has multiple clients, among the largest, are Brynild Gruppen A/S, Jensen A/S, Nutricia A/S, and Kavli AS. All the customers have SKUs stored separated storage area within the warehouse. Lemans' business strategy is to form long term contracts with their clients and integrate into their businesses to form mutually beneficial relationships. With each client, Leman signs five years of contracts, matching the leasing of the current facilities, and this makes it possible for Leman to adjust the facility to match the space need for their clients.

4.1.2. Brynild

Brynild Gruppen A/S (herby, Brynild) is a Norwegian family-owned snack and confectionery manufacturer founded in 1895. Brynild operates in the fast-moving consumer goods segment. Today Brynild has a broad product portfolio, including Den Lille Nøttefabrkken (Nuts), Brynild (Confectionary), Minde (Chocolate), Dent (Hard candy). Besides the production and distribution of their own SKUs, Brynild also distributes NIVEA SKUs in Norway for Beiersdorf AS.

4.1.3. Distribution chain

Brynild Gruppen has one production facility located in Fredrikstad. In addition, they outsource the production of several SKUs to foreign suppliers. Further, all the Brynilds SKUs are stored in Leman's facility in Vestby, where they are stored until requested by the customers. Brynilds largest customers are the Norwegian grocery wholesalers, namely "Reitan-Gruppen", "COOP AS," and "Norges-Gruppen", which contribute to approximately 90% of Brynilds sales. These wholesalers have regional and central distribution centers that order Brynild SKUs. Next, the grocery wholesaler distributes Brynilds SKUs to grocery stores and kiosks, where end customers purchase them. Figure 8 shows a simplified overview of the distribution chain.

On request from the wholesalers, Leman has 1-2-day lead time to prepare orders before the wholesaler's transport arrives. Brynilds SKUs are sold as either full pallets or mixed picking pallets consisting of cartons. Also, Brynild offers sales solutions, which is a sales display filled with a pre-defined SKU. Further, the wholesaler distributes Brynild SKUs to grocery stores, where it is available for end customers.

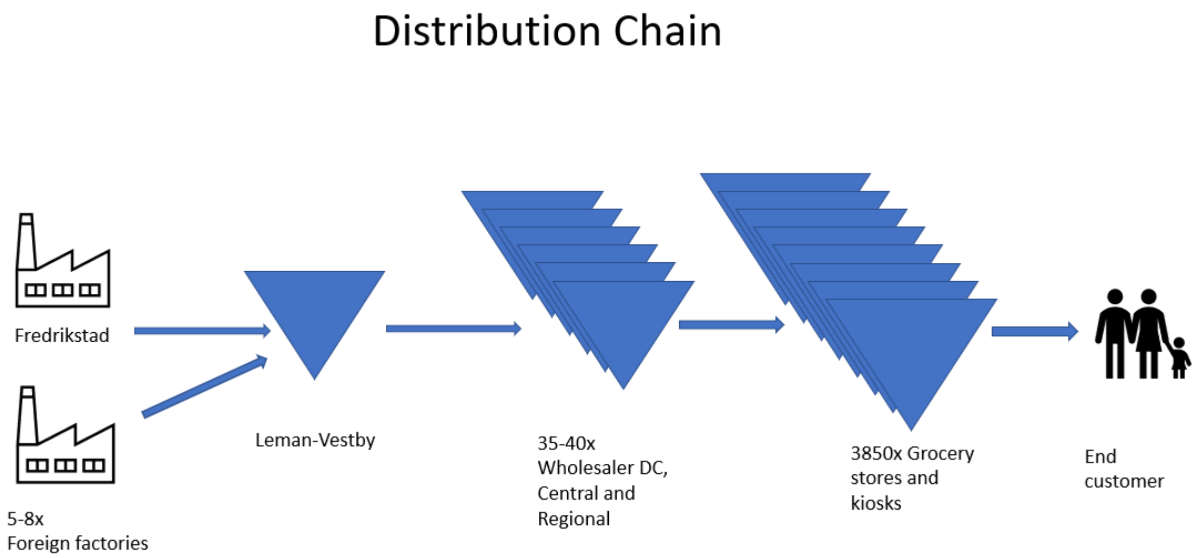

Figure 8: Simplified overview of the distribution chain

4.2. Current situation

The purpose of this subchapter is to describe the AS-IS of Leman, which lays the foundation for the investigation of challenges.

4.2.1. Product characteristics and demand pattern

As mentioned in the general description of Brynild, they have a broad portfolio of fast-moving consumer goods where each category of goods has different demand patterns. According to the transaction data from Lemans, WMS stores 695 different SKUs. Table 6 shows the distribution of SKUs.

Table 6: Number of different SKUs stored at Leman

Description of SKUs	Number of SKUs
Brynilds consumer goods	367
Brynilds packaging	8
Beiersdorf consumers goods	320
Total	695

Brynilds SKUs are subjected to high variability in demand. Brynhild's Supply Chain Director mentions that several reasons for high variation in demand, among them are seasonality, promotions, and high service level requirements from the customers. Appendix E. shows a period from 2012 to 2014, which exemplifies the high variation in demand for one of their SKUs. Brynhild's demand pattern can be categorized into:

1. **Regular demand** that consists of standard demand for SKUs, which is not affected by promotion or seasons. Regular demand is forecasted based on historical data and other currently available information, providing one forecast per SKU
2. **The introduction of new products** which is demand forecasted based on qualitative knowledge. Brynild supply chain must be filled with the SKU for approximately two months.
3. **Campaign demand** agreed upon between Brynild and the grocery chains. The campaign demand is confirmed 4 to 8 weeks in advance of the campaign
4. **Seasonal demand***,* i.e., extra sales of seasonal and regular SKUs during Halloween, Christmas, Easter, and Summer. This volume is forecasted based on previous seasons and added to the forecast for regular demand. The volume for each season is determined four months in advance, to ensure that the production capacity is sufficient

In terms of seasonality, SKUs can be divided into three main categories:

- All season SKUs relatively stable demand, e.g., nuts, and hard candy
- All season SKUs with seasonal fluctuations, e.g., confectionery and candy
- Seasonal SKUs which is only sold during specific seasons, e.g., Easter and Christmas chocolate

4.2.2. Warehouse operations

Leman's warehouse operations deviate from conventional warehousing operations. Including the operations found in the literature (Receiving, Put-away, Storing, Order picking, and Shipping). Figure 9 shows the different physical warehouse operations at Leman.

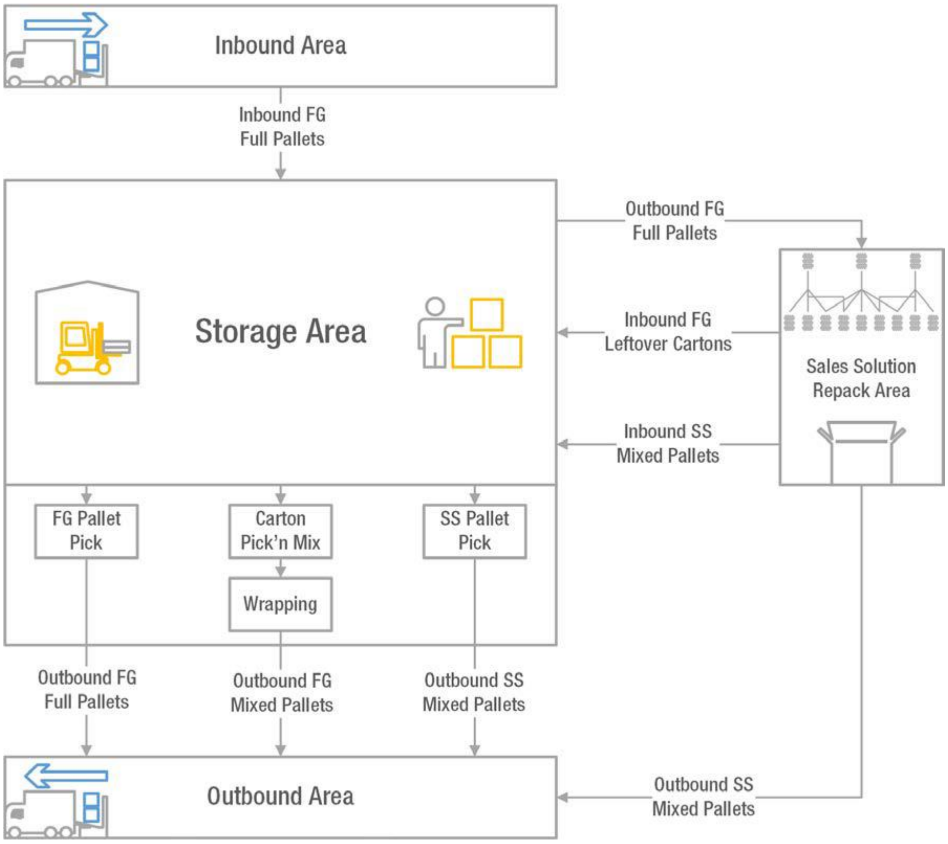

Figure 9: Physical operations (SS= Sales solution, FG= Finished goods), adapted from (AUU-students 2019)

The inbound process is conventional, i.e., as described in the theoretical background. Leman receives a truckload of shipments approximately 3- 4 times a day from Brynild. The truckload is unloaded in the in-and outbound area (Hereafter, I/O area). Further, the warehouse operator scans the barcode to confirm the arrival of the unit-load, Electronical data exchange (EDI), then transfers the information of the unit-load from Brynilds ERP system to Lemans WMS. Next, the WMS assign a storage location to the unit-load based on the integrated logic (described in Subchapter 4.2.5), product information, and warehouse status. Then the operator transports the unit-load to the assigned storage location. One warehouse operator is responsible for the receiving and put-away of Brynilds SKUs.

For Leman, order picking can be divided into two groups, picking a full pallet, or picking a mixed pallet. First, customer orders are translated to an order line, which consists of pick lines, the order office structures the pick lines into picking lists and releases the order. Next, an order picker is assigned to a pick list. The picking list either consists of full pallets or mixed pallets. The operation of picking full pallets only requires the order picker to transport the unit-load from its storage location to the I/O area where it awaits transportation. However, the picking of mixed-pallets more complicated. The order pickers then pick cartons from the different storage locations and assemble it to a

Figure 10: Mixed pallets, picture taken during a company visit

mixed pallet. Since Brynilds largest customers (Norwegian grocery wholesalers) require pallets between each different SKU and production batch, resulting in pallets as in Figure 10. According to Lemans Warehouse Manager, the reason for these extra pallets in between each SKU is due to the use of automated storage systems at the grocery wholesaler's distribution centers. Consequently, the order picker must return to certain locations in the warehouse to retrieve an extra pallet after picking one SKU. Additionally, new labels and plastic wrapping must be attached to the pallet before it is placed in the I/O area and awaits transportation. Thus, picking of mixed pallets is more labor-intensive than the picking of full pallets. Last, the replenishment of the carton picking area is also performed, the full pallet area usually replenishes it. However, if the SKU is stocked out, it might be directly replenished by an incoming unit-load.

The operations above are conventional and recognizable in theory. In addition to delivering pallets with standard cartons, Brynild offers sales solutions to grocery stores. Sales solutions are cardboard displays that carry a selection of given SKUs. These sales solution is placed in a secondary location in the grocery stores, as shown in Figure 11. The repacking of these sales solutions is performed in Leman's facility. Both Leman and non-profit organizations collaborate to execute this operation. First, Leman places all the required unit-loads on the mezzanine (Shown in the warehouse layout, Appendix C2) by using forklifts. The Warehouse Manager controls that all cardboard displays and requested SKUs are placed on the mezzanine. Later, past regular working hours, non-profit organizations enter the mezzanine to repack the SKUs into the displays. Further, the display is packed back on pallets. The next day, warehouse personnel transport the repacked pallets to the I/O area to await transportation or to the storage area if an order is scheduled for a later date.

Figure 11: Sales solution, taken from presentation by Brynilds Supply Chain Director

The warehouse operators also perform other operations, e.g., restacking SKUs on to other pallets, which is placed on pallet types customer does not desire. According to the Warehouse Manager, this is a frequent operation due to different customer requirements. The customer requirements are often due to automatization at the customer's DC, which cannot handle certain pallets. Also, Leman handles imported Brynild SKU's and raw material, and this requires Leman to quality check the deliveries and check for discrepancies from suppliers on behalf of Brynild.

Each warehouse operator is assigned to a specific storage client and has clear operational responsibilities. For Brynilds SKUs, there are three to four operators (one part-time operator), one operator is responsible for the receiving and put-away operation, one operator is responsible for picking full pallets, and the last operators are assigned to carton picking.

The average number of picking lines shipped from Leman each month is shown in Table 7. One can see that the number of pick-lines for full pallet picking and mixed pallets is even distributed. However, a picking line for full pallet picking equals one full pallet, meanwhile picking line for mixed pallets equals one pick of an SKU. Hence one full mixed pallet consists of several picking lines, depending on the number of different SKUs.

Table 7: Picking lines, based on KPI report, received from Brynilds Supply Chain Director

Number of picking lines	Full pallets	Mixed pallets
June 2018-April 2020	82071	82087
Average per month	3568	3569
Average per day	162	162

The number of units per full pallet is irrelevant since it requires the same amount of work regardless of the number of cartons. While for mixed pallets, the cartons do relevant since it requires extra work. According to the KPI report, the average of 32 cartons picked per picking line, due to different physical sizes of SKUs and the requirements of pallets in between each SKU, the number of picking lines per mixed pallet is highly variable.

Leman's turnover originates from two sources; handling and storage of SKUs. The storage income is defined as the income of storing one pallet per day. While the turnover generated by handling SKUs is more complex, as this is based on which operations Leman conducts for the client. E.g., handling is put-away of incoming Unit-loads (cost per pallet), picking of mixed pallets (cost per carton + cost of wrapping), picking of full pallets (cost per pallet). The income is based on the transaction data of Lemans WMS. Leman also provides other services that require operators to manual register time used and the operation performed. These operations are printing new labels, support non-profit organizations in assisting the non-profit organization in creating sales solutions, restacking unit-loads, etc. These operations are registered directly from operators the display to the WMS.

4.2.3. The layout of the warehouse and equipment

Lemans' facility consists of 16 000 m^2 were they store SKUs for many different clients with different needs. Each client has a designated storage area within the warehouse. Brynilds designated storage area consists of a rack system with 15 wide aisles (forklifts can turn within the aisle). Each aisle consists of 22 racks with up to eight shelves in height and three pallet locations on each shelf, adding up to approximately 7800 storage locations. Brynild designated storage area is further divided into four storage areas, where Brynilds own SKUs are stored from aisle 25 to 36, and Beiersdorf's SKUs from aisle 21 to 24. Both are divided into a storage area for full pallet picking and carton picking. The carton picking area consists of the bottom shelves in each aisle, while the full pallet picking area consists of the remaining shelves. Some of the bottom shelves are equipped with deep storage locations used for the order picking of cartons. The storage areas are further divided into zones, A+, A, B, and C, as shown in Figure 12 and Figure 13. Each storage location is assigned into one zone based on the time the operator uses from the I/O to the location, including the time to place it on the storage position. Leading to storage locations located on the top shelves is less favorable than the once on the bottom, as shown in Figure 12. The A+ zone, or commonly known as the forward picking area, consists of twelve storage locations. These are the most convenient storage locations in the warehouse. Thus, the purpose is to store the SKUs with the highest carton picking frequency in these storage locations.

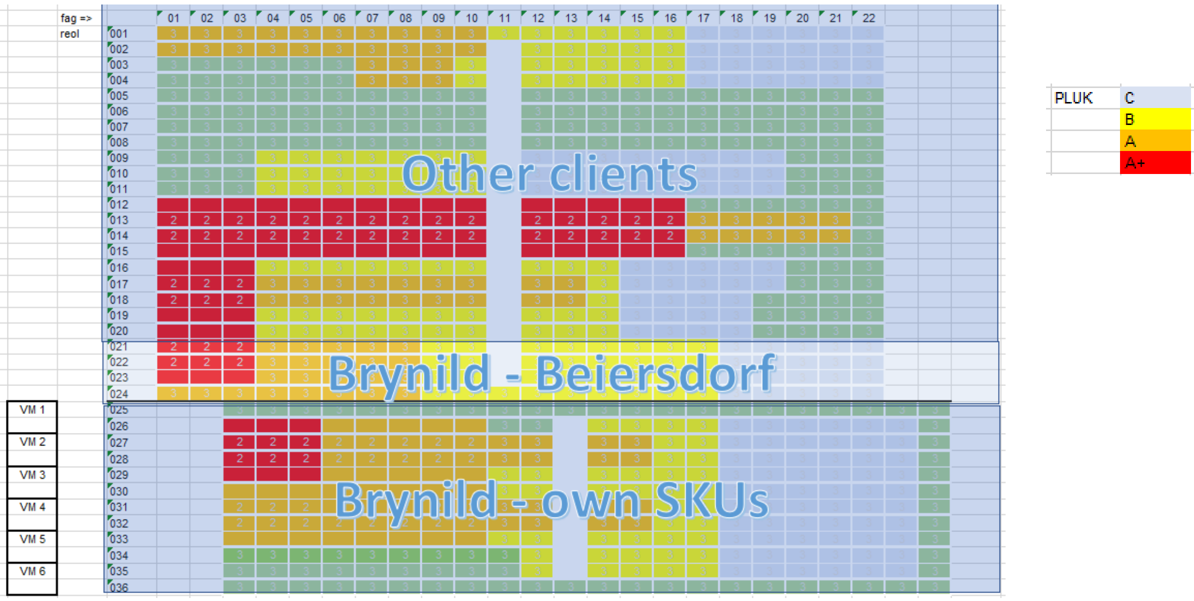

Figure 12: Layout including storage areas and storage zones for the bottom shelf, provided by the Logistics Coordinator

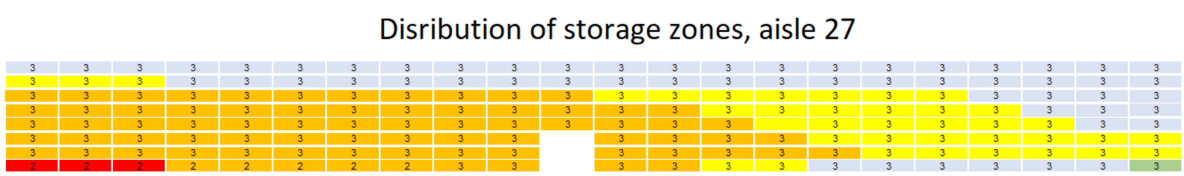

Figure 13: An example of Storage zones within an aisle (aisle 27), showing the vertical distribution of storage zones

Brynilds storage area also consists of six lanes for incoming and outgoing pallets (I/O-area). This is where incoming deliveries are stored while the warehouse operators perform the put way operation. The second purpose it serves it the pre-pick outgoing order in advance of shipping. VM1-VM5 is used for outgoing orders, while VM6 is used for incoming pallets, displayed in Figure 12. Within the I/O area, there is also a small area for packing of mixed pallets (packing area) This is in front of aisle 25.

To ensure traceability in the warehouse, every storage location has a unique identification number and a barcode. Warehouse operators are equipped with forklifts, which are both used for order picking, replenishment of carton picking area, and put way operation. The forklift has supportive tools, like a barcode scanner and a display linked to the WMS. Barcode scanners and the operator screen are the interfaces between the WMS and the warehouse operations. Figure 14 shows the operator screen.

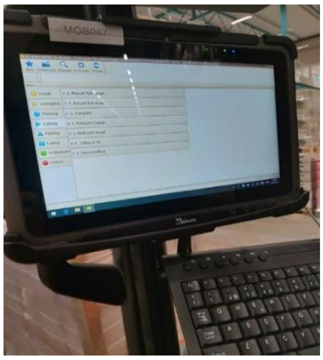

Figure 14: Operator screen, picture taken during the company visit

4.2.4. Warehouse principles

As mentioned in the previous chapter, the warehouse is divided into storage zones. Accordingly, SKUs are assigned to these classes, the parameter which the SKUs is measured by is picking frequency. Hence, they use a class-based storage policy. Where SKUs are assigned to either to the A, B, or C zone. Where A zone is located closer to the inbound and outbound area, B is further away, and C products are located furthest away. The height of the location is a parameter which also considered, at the closest location, only the highest location classified as C and B; further away, these classes are located lower in shelves, illustrated in Figures 12 and 13. SKUs are assigned to two classes, one for the storing of full pallets and one for the carton picking area. Initially, when a new product is introduced, the Logistics Coordinator assigns the SKU to class A. The WMS automatically tracks the picking frequency of each SKU. If an SKU exceeds or is less than the given threshold value of the assigned class, the Logistics Coordinator must manually change the class of the SKU. According to the Logistics Coordinator, this is typically performed every second week. However, the threshold values are not established or systematically used.

The order picking of cartons can be distinguished as a single order picking where the order picker must return to the packing area after retrieving one picking line, due to the mentioned requirement of pallets in between each SKU. However, the order pickers have, in some cases, stacked pallets in arbitrary locations in the storage area to avoid going back and forth to the packing area.

The warehouse operates with a FEFO (first-expire-first-out) principle. Thus, the unit-load with the closest expiry date is picked first to avoid expired SKUs. Also, each order line has a batch requirement, meaning that one picking line can only be fulfilled by one production batch, to achieve traceability in the supply chain.

Leman's operators can overrule principles if they want to. Here are scenarios where the operators usually overrule the principles:

- Pallets are perceived as unstable by operators if WMS assigns these pallets to a location with high altitude, the operator will see this as a hazard and instead put the unit-load on a lower shelf to avoid the unpleasant risk
- Operators put-way two unit-loads at once, where they place the second unit-load close to the first, regardless of the suggestions from the WMS
- Operators find discrepancies in the storage, e.g., arrives at a full location, when putting away a unit-load. And therefore, places the unit-load in another location

4.2.5. Lemans WMS

In this subchapter, a more detailed description is given to show how the storage location logic of Lemans WMS is functioning and how Leman has configured their WMS to perform the storage location search. The functionality of the WMS is adapted from the functional description of Lemans WMS, namely Consafe (2020). Currently, Lemans uses a basic WMS. Thus, advanced/additional features in Consafe (2020) are not considered when searching for functionalities in their current WMS. Storage location search is applicable for the following functions: Put-away, replenishment of nearby buffer, and replenishment of carton picking storage location.

General description of the WMS location search:

The storage location logic is initiated by the operator when the unit-load is entered into the WMS. Further, the WMS automatically suggests a storage location based on underlying logic, the information of the unit-load, and the status of the storage area (i.e., available and unavailable locations). However, warehouse operators can always override a suggested location and instead select a location manually. The automatic location selection is set upon each storage area, where each storage area can choose among three alternatives:

- *"Location automatic"*: The suggestion is usually based on the SKU definitions and an algorithm defined by the location spread logic and the location search logic.
- *"Auto, prompt rack"*: In the put functionality, instead of verification of the suggested location, the operator can press next to be requested a new rack to get a new search
- *"Auto, same aisles as pick area":* the location is searched from the same aisle where the picking location is to reduce the travel time when the picking location is empty

The "*location automatic*" requires a set of logic to work. The basic of this alternative is defined by these factors:

- Preferred storage zone
- Preferred pick storage zone

Within the preferred storage zone, these factors influence where to start to search for storage locations:

- The rack where to start searching for a free location
- The X or Y coordinate where to start searching for a free location
- The load carrier type suggested by the system when creating a unit-load
- The zone where to search for a free location

Further, each storage area has a logic that determines the spread of unit-loads. The different configurations are shown in Table 8.

Table 8: WMS location spread logic, adapted from (Consafe 2020)

Spread Logic	**Description**
Near last location	The system searches for a new storage location close to the last one used for the put-away of the same SKU
Even over the rack	The system spread unit-loads over the rack
Even over the aisles	The system spread unit-loads evenly over aisles
Defined location of the SKU	The predetermined location suggested for each SKU
The first free location	The system search from the first storage location in the storage area
Against the location of a defined SKU	The search starts from a specified location and searching forward. The system searches all available storage location in the storage area but always starts from a defined X and Y coordinate. The search will never check for storage locations before the defined X and Y coordinates.

However, if no storage locations were available by applying the first logic, the system will conduct a second search with a changed criterion. Some alternatives are shown in Table 9. However, more combinations are available, as any of the criteria can be combined. Again, if no appropriate storage locations after the second search, the warehouse operator must manually find an alternative storage location.

Table 9:Second location search, adapted from (Consafe 2020)

Second Search Logic	Description
Rack+	The system will increase the rack number (search in next rack, and next, and so on until all racks in the storage area have been searched)
Location type+	The system will search in the current rack and look for a location of the alternative location type(s)
Zone +	The system searches for location in the current zone after it searches in the next zone if no location was found in the first. This is repeated until a storage location is found. Note: If it starts to search from zone B, it will not search in zone A.
Zone +, location type+, rack+	First, if no storage location is found by the initial search, the system will first conduct zone+, then location type+ and last rack+

The WMS also considers these factors when searching for storage locations; weight restriction, i.e., on single storage locations maximum and maximum weight of a section to prevent hazards.

Leman's configuration of the storage location logic:

The warehouse is divided into storage areas, firstly by the clients. Within the Brynild storage area, it is further broken down into two areas, one for storage of carton picking and one storage area for the replenishment of carton picking and full pallet picking. The storage area for picking of full pallets is called VBP10 and the Storage area for picking of cartons VBH10. Accordingly, the storage zone for Beiersdorf divided in the same manner, with storage are VBP08 for full pallets and VBH08 for carton picking area.

The logic used for SLAP is for storage area VBP10:

Location search → Location automatic → Preferred storage zone→ Starts searching in rack 01 placed on Ailes 25 → Spread logic → The first free location

If the logic does not find a storage location, it initiates a second search: "Zone +, location type+, Rack+". If no location is found by the second search, the operator must manually find a storage location in another storage area, because the given storage is full. The storage area that Leman uses when Brynilds storage area is full is located at the other side of the warehouse, at aisle 6.

The logic used for replenishing the carton picking area from the full pallet area is based on the FEFO principle. The full unit-load, which is closest to its expiry date, replenishes the storage location. If many unit-loads has the same expiry date, the WMS chooses a random of the qualified unit-loads.

The storage locations of the carton picking area are partially dedicated storage and class-based storage. Twelve storage location is dedicated, this zone is called A+ or *forward picking area,* which is reserved for the fast movers. The remaining storage locations are divided as full pallet area into zones.

4.3. Challenges and initial analyses

The purpose of this subchapter is to describe the challenges that Leman faces. They are initially investigated before one challenge is selected for further analysis.

During the first company visit, Leman introduced two specific problem statements. The first problem statement includes workload estimation and capacity planning at Leman, while the second problem statement was in the direction of the operational efficiency of the warehouse. After an introduction to the two problem statements, it became apparent that Leman's management wanted the project to focus on operational efficiency. Since AUU-students (2019) investigated workload estimation and capacity planning at Leman in 2019, it was assumed by the management that Leman would gain more efficiency improvements by an investigation of their physical operations.

The second company visit was dedicated to getting an overall overview of the operations within Leman. Further, the objective of the visit was to find out why or if the operational efficiency at Leman was suboptimal. As described in the theoretical background, internal travel time is one of the largest prohibitions for operational efficiency. Thus, the focus was to identify the causes of unnecessary travel time within the warehouse.

4.3.1. Challenges

By observing and interviewing the warehouse operations and Logistics Coordinator, some non-verified reflections were made, and with possible methods to investigate the challenge. Further, an initial investigation of the mentioned challenges was conducted to understand why these challenges occur and to select problems that can be solved by research. Possible solutions to some of them are suggested. However, not all of them are analyzed in-depth. These are left for further research.

Challenge 1:

Initial finding

Operators load two unit-loads from the inbound area to reduce the travel time of the put-away operation. First, the operator scans the upper unit-load and puts it in the storage location suggested by the WMS. Then the operator scans the second unit-load. Further, the WMS assigns a storage location for that unit-load. WMS does not consider the first movement of the unit-load. Hence, the WMS still believes that the operator is in the I/O area. This can lead to additional travel time from the location the operator left the first unit-load to where it suggested transporting the second unit-load.

Operators are then tempted to overrule the WMS and place the second unit-load in a storage location close to the first storage location, rather than move it to a location that the WMS suggests. If the WMS understood where the operator scanned the second pallet, it might be able to suggest a storage location closer to the operator. At the same time, it makes sure that the pallet is placed in the correct storage zone.

Here an investigation of the WMS and its functionality could provide useful information. To find out if the WMS supports the transportation of multiple pallets in one operation.

Initial investigation

By surveying through the functional description, Consafe (2020), no function or configuration mentioned the possibility of transporting multiple unit-loads at the same time. Further, the Activity Manager at Leman confirmed that there is no possibility for the WMS to support the transportation of multiple unit-loads. Therefore, Leman must consider the tradeoff between the efficiency of driving two pallets into the storage area versus the discrepancies it causes due to misplacements.

Challenge 2:

Initial finding

The order pickers experience that the replenishment of the carton picking locations requires an unnecessary amount of travel time. Since the replenishment is often situated in another aisle than the carton picking location, also, not all the order-pickers is equipped with forklifts that cannot retrieve pallets above the bottom shelf. Therefore, they must interrupt colleagues and ask them for assistance, which leads to further inefficiency.

This indicates a mismatch between the operations and the WMS. Here some questions are critical to answer. First, an investigation of why the WMS assigns an operator with "low reach" forklift to tasks that requires a "high reach" forklift. Second, what are the reasons Leman uses "low reach" forklifts if the order-picker must replenish the carton picking area. Third, regarding the travel distance for replenishment, one can investigate if there is any correlation between the carton pick storage location and the SLAP of full pallets.

Initial investigation

Regarding the replenishment of the carton, the picking area has been analyzed more in-depth. Operators choose the function in which he will operate in after logging in to the system, where the functions are either; put-away, moving of full pallets to the I/O area (picking of full pallets), carton picking, or replenishing the carton picking area. When a storage location is picked empty, an order is placed by the WMS to replenish this storage location. However, this order is given to an operator that is logged into the replenishment function. In a larger warehouse, some operators might be assigned to this function at any time. Leman has no operators assigned to this function and requires another operator to login to the replenishing function and replenish the picking locations. Consequently, if the order picker is equipped with a "low reaching" forklift, he must ask a colleague to replenish the storage location. So, to conclude, there is a mismatch between the system and the operations because it is the scale of the warehouse that does not require anyone that is solely assigned to replenish the picking area. Still, the order-pickers should be equipped with "high reaching" forklifts to avoid interrupting other operators, and one can rather say that there is a mismatch between the equipment and the operation. The Activity Manager explained that they have five-year lease contracts on their forklifts, which is aligned with the leasing of the warehouse space, and the contracts with their clients. Further, an analysis of the return of investment of just leasing "high reaching" forklifts can be compared to the time wasted on waiting for replenishment by other warehouse operators.

As mentioned in the previous subchapter, the searching for replenishment follows the FEFO principle. Further, the logic of the WMS searches for the replenishment closest to the current storage location. However, SLAP for full pallets does not consider where the carton picking area for the given SKU is located. That is why the order picker experience unnecessary long travel distances when replenishing carton picking storage locations. If the WMS was configured as *"Auto, same aisles as pick area "the* replenishment would be located in the same aisle. However, this logic is not applied. Further investigation could evaluate the trade-off between the current configuration against the "*Auto, same aisles as pick area."*

Challenge 3:

Initial finding

The warehouse operators experience that the WMS suggested suboptimal storage locations, as they various travel distances when the put-away the same SKU.

To investigate this challenge, an overview of the procedure of SLAP must be conducted. Further, an investigation of the WMS configurations that Leman is currently using. Next, by analyzing the transaction data that the WMS record, the pattern of how SKUs are placed can be shown. Another factor that can influence the performance of the SLAP is the fill rate of the warehouse.

Initial investigation

The operators experienced variable transportation distances for the of the put-away function. By surveying the logics, the WMS uses for the SLAP, and interviewing the Logistics Coordinator to retrieve the configuration they use, some reasons for unnecessary travel time were found. The WMS logic for SLAP and the configuration of the WMS in Subchapter 4.2.5. One of the reasons for additional travel time WMS starts its storage location search in aisle 25, even though this is the aisle that is furthest away from Brynilds lane for incoming unit-loads (VM6). It can partially explain why the operator experiences longer travel distances than expected. According to the Logistics Coordinator, they have attempted to change this configuration in the WMS. However, they experienced that other WMS configurations had other complications. To solve this issue, an investigation of the different configurations could be initiated, where the performance of the configurations is measured over a period. This could result in a list of the advantages and disadvantages of each configuration and then testing to determine the most feasible configuration.

By comparing the KPI report of Leman with the layout of the warehouse, an average fill rate per month is shown in Figure 15. This average warehouse fill rate shows that Leman has an average fill rate of approximately 90% from September to April 2020. This high fill rate can influence the efficiency of warehouse operations. The Activity Manager states: "*If the storage has a high average fill level, it generates a lot of turnover for us because we get paid for every pallet per day. However, if the fill level gets too high, we get problems regarding the efficiency*". Therefore, Leman is investing an additional aisle, next to aisle 36, which will give them approximately 500 new storage locations. Further, an investigation of the correlation between the performance of SLAP could be conducted.

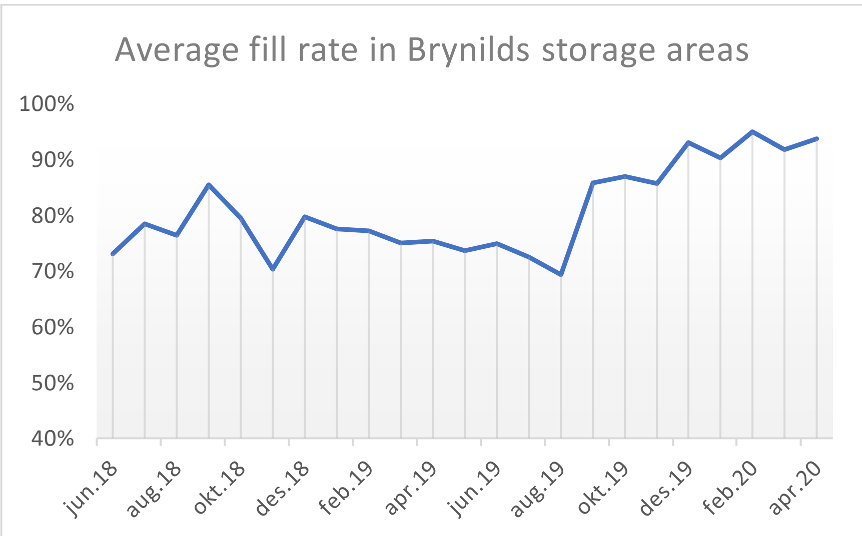

Figure 15: Average fill rate of Brynilds designated storage areas

Last, a lack of systematic approach for assigning SKUs to classes can be vital. If SKUs are assigned to the wrong class, it causes unit-loads to be misplaced within the storage area. Moreover, this is leading to both fast-moving SKUs to be placed in less convenient storage locations and slow-moving SKUs to occupy the most convenient storage locations. An analysis of the transaction data from Lemans WMS could be conducted to show the mismatch between structured theoretical approaches and the current placement of SKUs.

Challenge 4

Initial finding

Logistic Coordinator has a limited overview of the demand pattern of Brynild SKUs. By both observing and interviewing the Logistic Coordinator at Leman, it was noticed that they classified all new products as A products because they did not receive any forecast or pre-orders on new products. This could lead to misplacement of SKUs as they could be wrongfully assigned to class A, hence occupies the most convenient storage locations. Moreover, they have no information on whether the new product is a seasonal SKU or a new standard SKU. As these product types have a clear difference in demand pattern, it is crucial for the storage location assignment.

An investigation of the information flow between Brynild and Leman could be useful. First, an AS-IS that show the information sharing between Leman and Brynild today, what information does Leman receive. Further, investigate if Leman utilizes the available information they receive to improve the SLAP. If Leman lacks the appropriate information from Brynild, an investigation could be conducted on what information they should share and how they should share it.

Initial investigation

The WMS base the classification of SKU by analyzing historical data (Consafe 2020). However, WMS is to slow to react to seasonal changes and promotions. Consequently, these variations must be manually accounted for by the Logistic Coordinator. Besides, Logistic Coordinators have limited information to support decision making. By interviewing the Supply Chain Director at Brynild, it was made clear that the only systematic information flow between Leman and Brynild was of incoming customer orders. Further, he mentioned that the barrier for sharing more information with Leman because they do not have a forecast that is suited for Leman's operations. The forecast that the Brynild possess is based on expected sales of cartons. However, this does not indicate if the SKUs will be sold as full pallets or carton picks, which is what Leman desire. Therefore, he further states that they need a transition model to calculate the forecast into useful information for Leman. According to the Logistics Coordinator, they would prefer a tool as the Brynilds Supply Chain Director describes. However, the most crucial for them is when they do not receive any information regarding promotions or introductions of new SKUs.

Challenge 5

Initial findings

Beiersdorf SKUs and Brynild SKUs have their own storage areas. Hence, impose an extra constraint on the storage system. Brynild distributes all Beiersdorf's SKUs in the Norwegian market, and Beiersdorf SKUs mainly sold to the same customers as Brynilds own SKUs. In addition, Nivea (Beiersdorf brand) includes sun lotions, which has high seasonality in summer months hence complement Brynilds low demand in these periods.

Interviews with both Brynild and Leman must be conducted to find out why these storage areas are separated. An investigation of the AS-IS performance of the current separate storage area and further compare this to the merged storage area where both Beiersdorf and Brynilds SKUs are stored together.

Initial investigation

Lemans Activity Manager stresses that they receive indications from Brynild that suggests that they what to separate the handling of the SKUs and to store Beiersdorf SKUs from their own. Also, he states that Beiersdorf and Brynilds SKUs have separate order processes, and therefore merging the areas would not be feasible. As an example, he states that the Beiersdorf SKUs do not have the same order picking a policy, as there is no batch requirement on Beiersdorf SKUs.

From Brynilds' perspective, Brynilds Supply Chain Director states: "The reason for these storage areas being separated is random, and it has been this way since Leman was hired to store our SKUs." Further, he states: "The only barrier for us is the invoicing of Beiersdorf for our distribution of their products. It makes it easier for us to send sales reports without separating our and their SKUs, but this can also be done in other ways". Regarding the benefits of merging the areas, he discusses: "*For us, there are no direct benefits, but for Leman, I believe that enhance an improved efficiency of their handling, and this can indirectly reduce the cost for us. In addition, the grocery wholesalers will benefit from this since they could optimize their transport with one less constraint*". We can then conclude Brynild does not have any requirements of separate storage areas for these SKUs. Further investigations should be conducted to identify the qualitative benefits of merging these areas and the WMS barrier of differentiated order picking policies in the same storage area.

Challenge 6:

Initial findings

A Combination of FEFO and batch requirements cause inefficient occurrences. According to the order-pickers, if a customer orders a full pallet of an SKU, and the carton picking area contains a half-full pallet of the first expiring batch. The order picker must pick the half pallet and then place a second pallet in between before he picks another half-full pallet from another batch.

Interviews can prove useful information about why these principles are used, first with Leman and then with Brynild. An investigation of how much extra labor this creates for Leman and how much this cost Brynild.

Initial investigations

Regarding the combination of batch requirements and the FEFO principle, an interview with both Brynild and Leman was conducted. Leman follows the two principles regardless of the inefficiency it causes because they are specifically told to comply with the principles, even though this leads to extra work. According to Brynild Supply Chain Director, Brynild is not aware that extra expenses are caused by these policies. A further investigation could analyze when to follow both principles, and when not to follow them. E.g., for fast-moving SKUs where the chance of expiry is next to zero, orders of full pallets should be served solely from the full pallet area. Whilst for slow-moving SKUs, the chance of expiry is significant and should always follow the FEFO policy.

4.3.2. Selection of challenge(s)

From the initial start of the project, Leman wanted to investigate how they could improve operational efficiency, thus reducing the travel time within the warehouse. After the initial analysis of demand patterns, warehouse operations, warehouse layout, and warehouse management system, several challenges were revealed that influence Lemans' operational efficiency by reducing internal travel time. However, not all of them could be documented, proven, or improved. After a meeting with Leman, all these challenges were verified. Further, we discussed which of these challenges that were most interesting to investigate further. One of the challenges that could be proven to have a significant influence on operational efficiency is the non-structured policy to assign SKUs to classes. Further, a lack of information to Leman's Logistics Coordinator, forcing them to assign SKUs to classes without any provided information. The priory of the challenges was discussed with Leman to verify that this selection of the challenge benefits the case company. Thus, the challenge that has been processed with is **Challenge 3.** Further, **Challenge 4** is also relevant as it also affects **Challenge 3.** These are further discussed in Subchapter 5.3. The next subchapter is dedicated to analyzing the performance of Leman's assignment of classes to SKUs.

4.4. Analysis of Lemans SLAP

This subchapter investigates the consequences of Lemans' approach assigning SKUs to classes. First, an overall analysis is conducted to illustrate the problems with Lemans' current policy. Further, the *current policy comparing the current approach to the Pareto approach. Next, a sample of SKUs is analyzed to investigate why and when SKUs storage locations are misaligned. Further, an analysis conducted to illustrate Leman's use of their forward picking area to investigate how much time travel time can be reduced only by small adjustments of storage location assignment. Last, a recommendation of changing the routines for assigning SKUs classes is implemented*

4.4.1. An overall analysis of classifications

As previously mentioned, Leman applies a class-based storage policy for their SLAP.SKUs are assigned to classes based on picking frequency. Figure 16 shows an overview of the picking of full pallets from each storage zone for all Brynhild's SKUs. This figure illustrates the distribution of which storage zones SKUs have been retrieved from each month. By analyzing Figure 16, we can see some findings which are remarkable. The distribution of B and C SKUs proportional, which is unfavorable since B SKUs typically should have a higher picking frequency. A less remarkable finding is that the peak season is in autumn and spring when the Brynild has increased sales due to Christmas and Easter. An interesting finding from these high seasons is that the distributions of pickings from B and C zones increase compared to the A zone. This can indicate that the A zone is full in these periods.

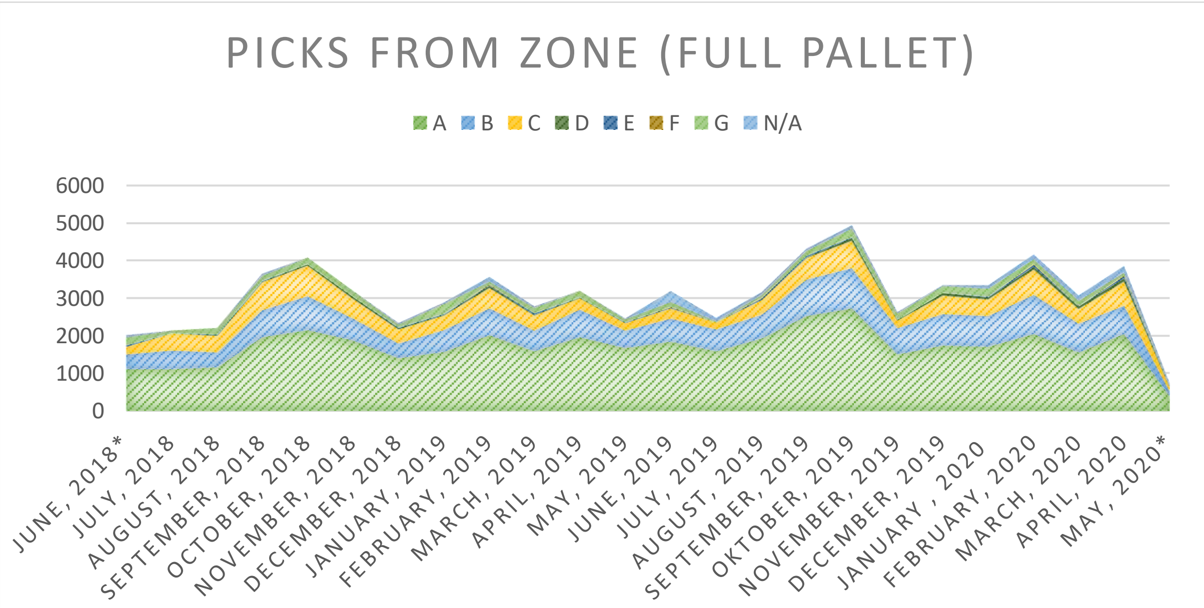

Figure 16: Picks from zone (Full pallets)

Figure 17 shows the picking frequency of cartons from storage zones. The results show similar trends as the full pallet picking, with peak seasons in spring and autumn. However, the picking frequency of B and C products is more differentiated.

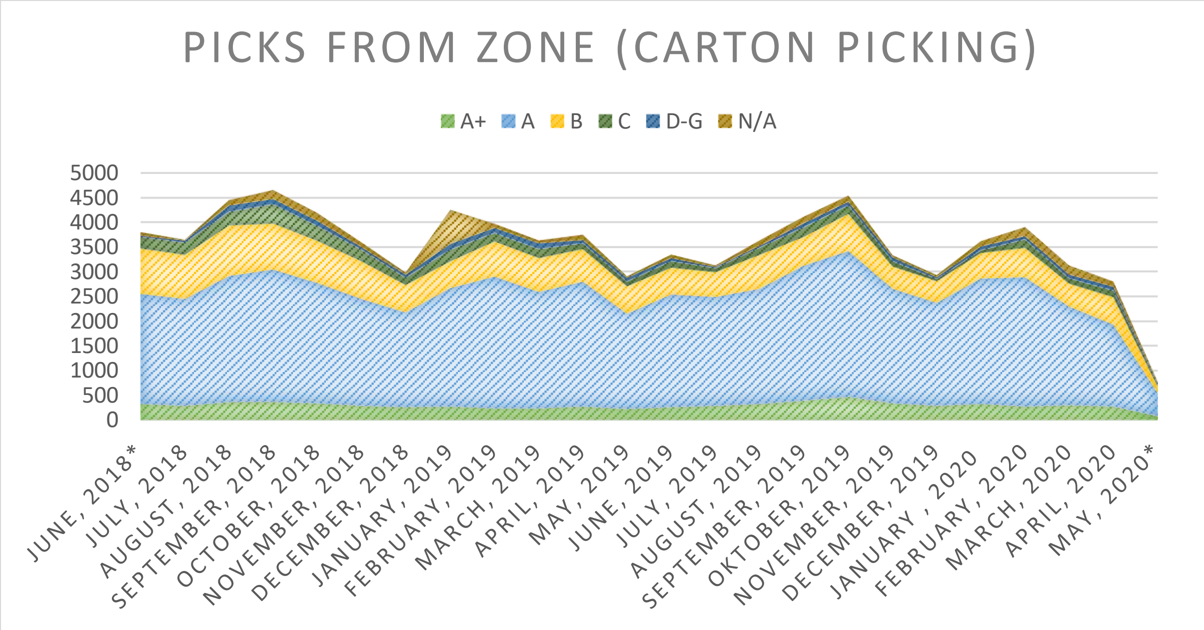

Figure 17: Picks from zone (carton picking)

Although SKUs are picked from a storage zone, it does not necessarily mean that the SKUs class is aligned with the zone it is picked from. Further, by analyzing how many SKUs which is assigned to each class each month, we could establish the appropriateness of the current process. An assumption here is that if an SKU is picked for an A storage location during a month is must be classified as an A SKU. The reason for this is the WMS logic (*Zone+, location type + Rack+*, explained in Subchapter 4.2.5) that Leman uses that make it impossible for B and C SKU to be assigned to A storage locations. As mentioned earlier, operators can override the suggested storage location and is, therefore, a source of possible deviations. Figure 19 and 20 shows the distribution of A, B, and C SKUs every month. The reason for a high number of C SKUs is that they do not have any turnover in the given month, e.g., seasonal SKUs. By analyzing the figures, a significantly higher number of SKUs is assigned to class A compared to class B, this is better illustrated in Appendix D3 and D4, where class C is excluded. According to Kofler (2015), the classes should be divided into by the Pareto approach, where 80% of the cumulative picks are from 20% of the SKUs, and the cumulative picks from 80% to 95% are B SKUs while the remaining is C SKUs. The Pareto approach is based on the same data set as the current policy. Figure 18 shows the result popularity distribution of the SKUs, and it shows that fewer SKUs account for a higher picking frequency among full pallet picking than for carton picking. Hence, they should have a different distribution of classes. Full pallet pick is aligned with the Pareto approach, whilst for carton picking, 30% of the SKUs account for 80% of the cumulative volume.

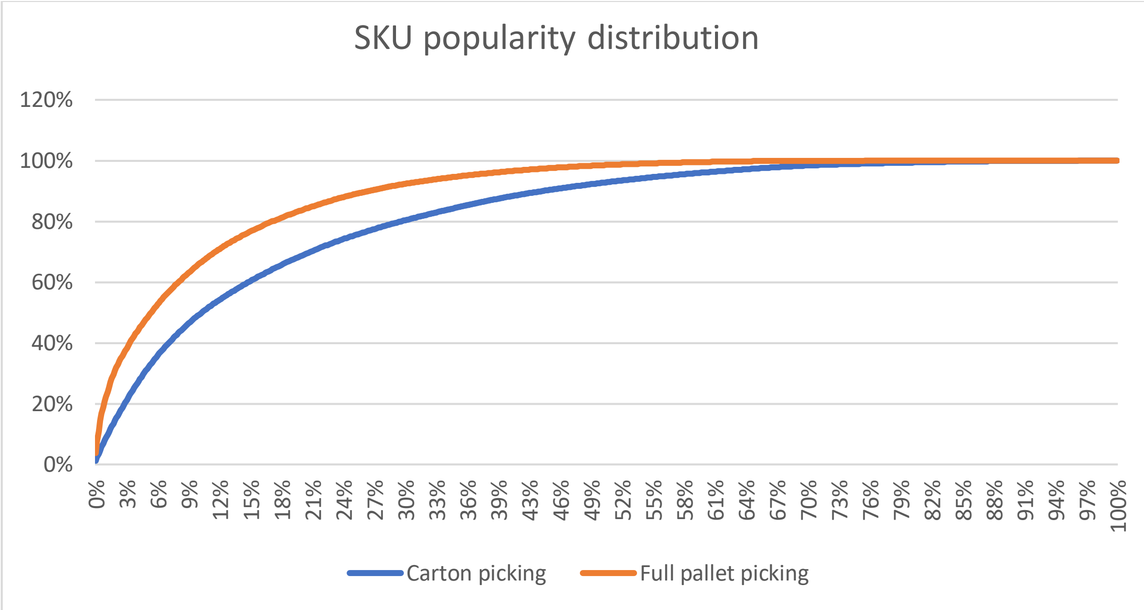

Figure 18: SKU popularity distribution for carton picking and full pallet picking

To measure the current policy from assigning SKUs to classes, an analysis of a Pareto approach is conducted. Each SKU has one class for full pallets and one for carton picking. The method used to divide the SKUs into class by analyzing the content of the WMS transaction data:

1. Separate carton picking and full pallet picking from each other
2. Select the given increments of time to analyze (e.g months, weeks)
3. Extract the picking lines from the increment of time
4. Count the number of picking lines per SKU
5. Classify SKUs with 80% of the cumulative picking frequency as A, 95% of the cumulative volume as B, and the remaining as C. For carton picking, the SKUs with 20 with the highest picking frequency are added to class A+
6. Repeat from step 2 for each period to analyze

To clarify: this approach is used to measure the correctness of the current approach. Thus, it is not applicable to use for a forecast, since it measures the actual picks for an amount not the expected number of picks for the next period.

Figure 19 shows the comparison between the Pareto approach and actual class SKUs is assigned to for full pallet picking. It shows a decrease in the number of A SKUs compared to the current policy, on average, a decrease of approximately 50%. Also, an increase of SKUs classified as B products by using the Pareto approach. Figure 20 shows an interesting result; the number of SKUs assigned to class A/A+ is more stable for carton picking compared to full pallet picking. However, the distribution of A SKUs is also significantly higher for the actual classes compared to the Pareto approach.

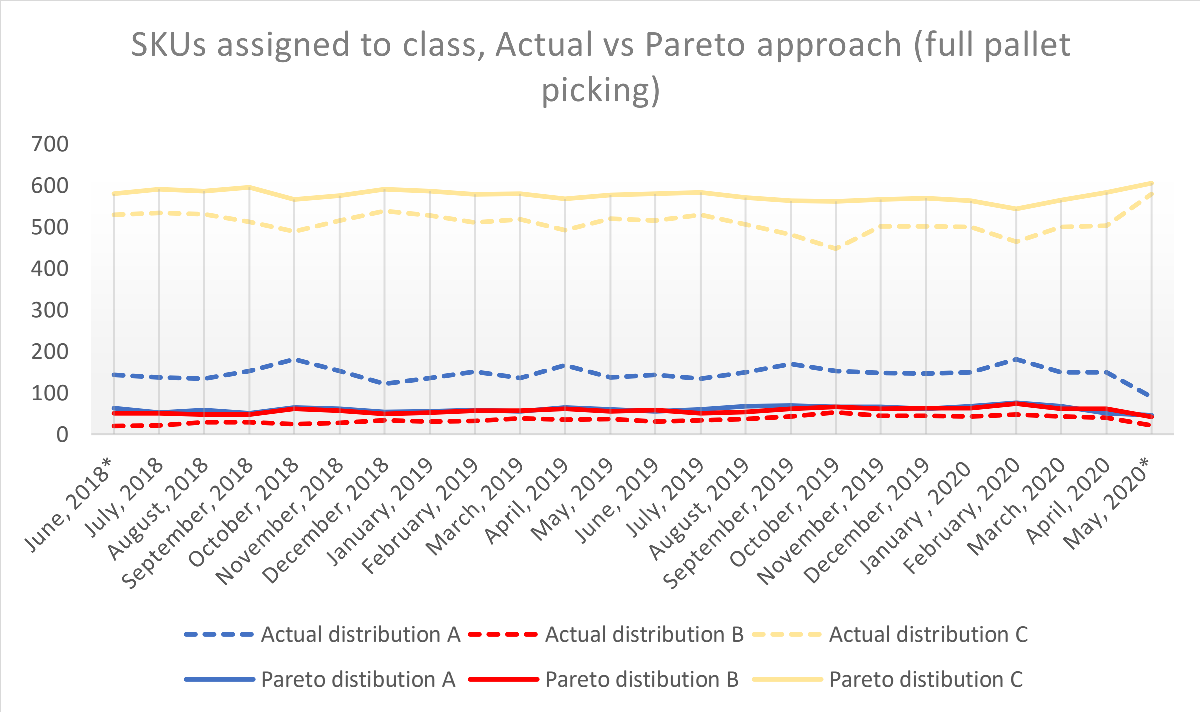

Figure 19: Number of SKUs assigned to each class in the full pallet picking area, comparison between the current approach and the Pareto approach

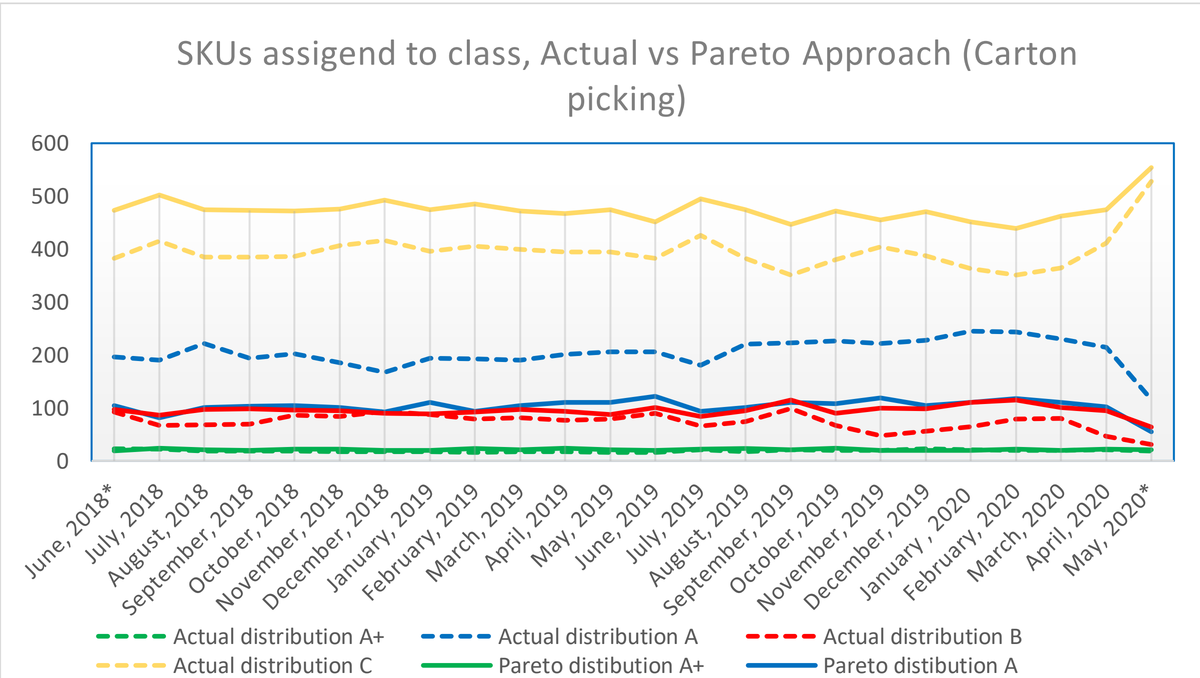

Figure 20: Number of SKUs assigned to each class in the carton picking area, comparison between the current approach and the Pareto approach

Further, based on the Pareto approach, threshold values are established. These threshold values show the criteria for being assigned to a class each month. Figure 22 shows the threshold values for full pallet picking. While Figure 21 shows the threshold values for carton picking, one can observe that threshold values between the different classes change dynamically. However, some threshold values are stable, namely, class A of carton picking with an average picking frequency of nine. Also, the threshold values for the B classes are stable. Consequently, the threshold values for A+ carton picking and A full pallet picking are subjected to the highest fluctuations.

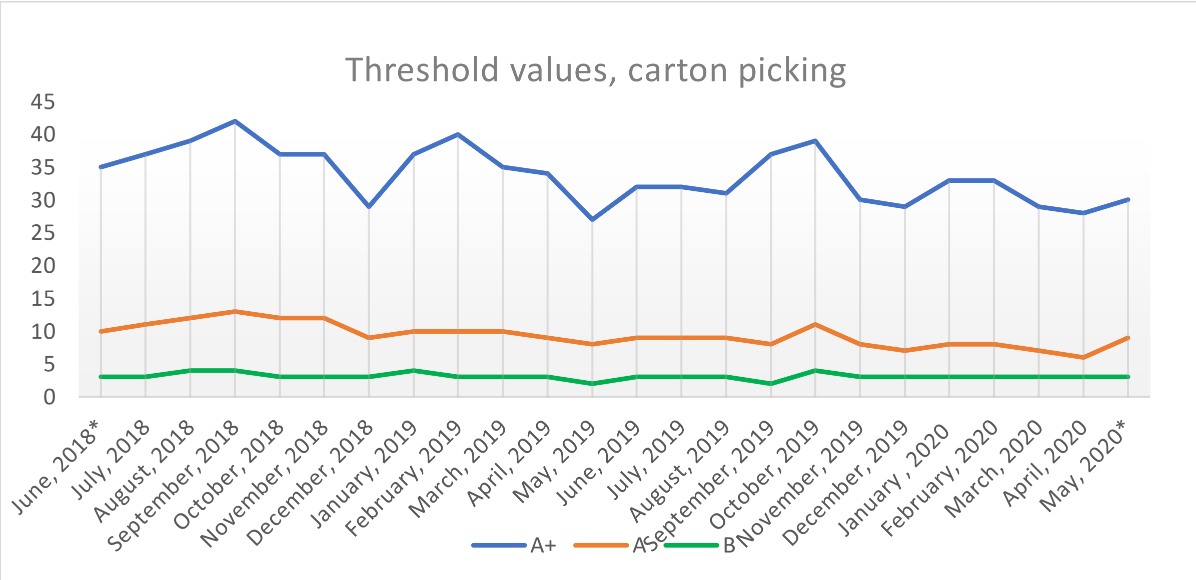

Figure 21: Threshold values, carton picking

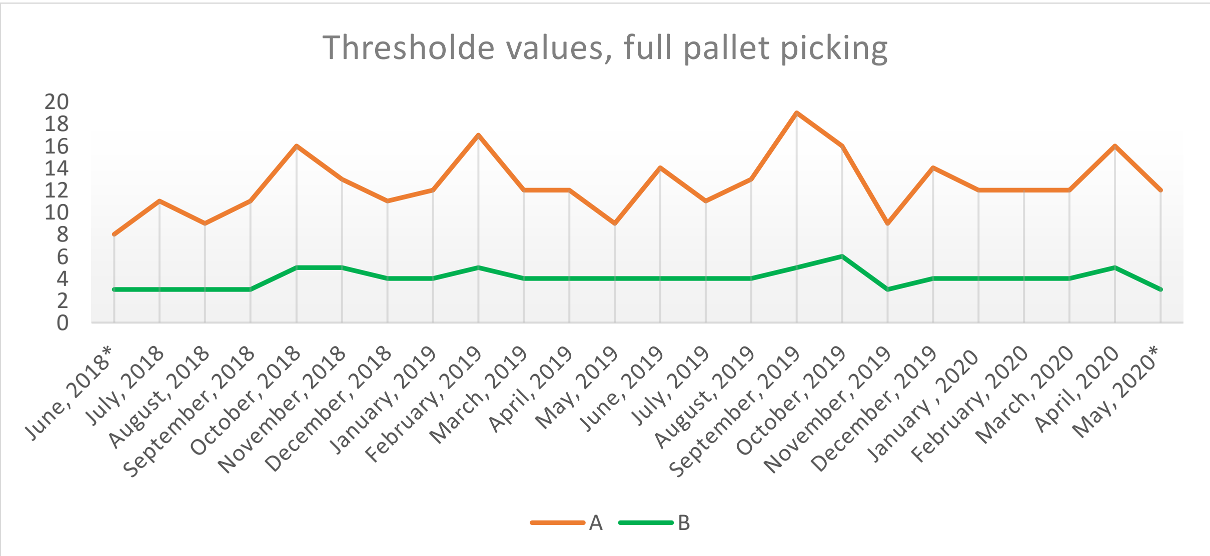

Figure 22: Threshold values, full pallet picking

The threshold values are further used to check to what degree the actual picks of SKUs is appropriate. By comparing which zone SKUs have been picked from and where the Pareto approach classifies the SKU, we get the alignment curve showed in Figure 23. It shows that under 50% of the picks are aligned with the suggested class of the Pareto approach for carton picking and that 50% is aligned for full pallet picking.

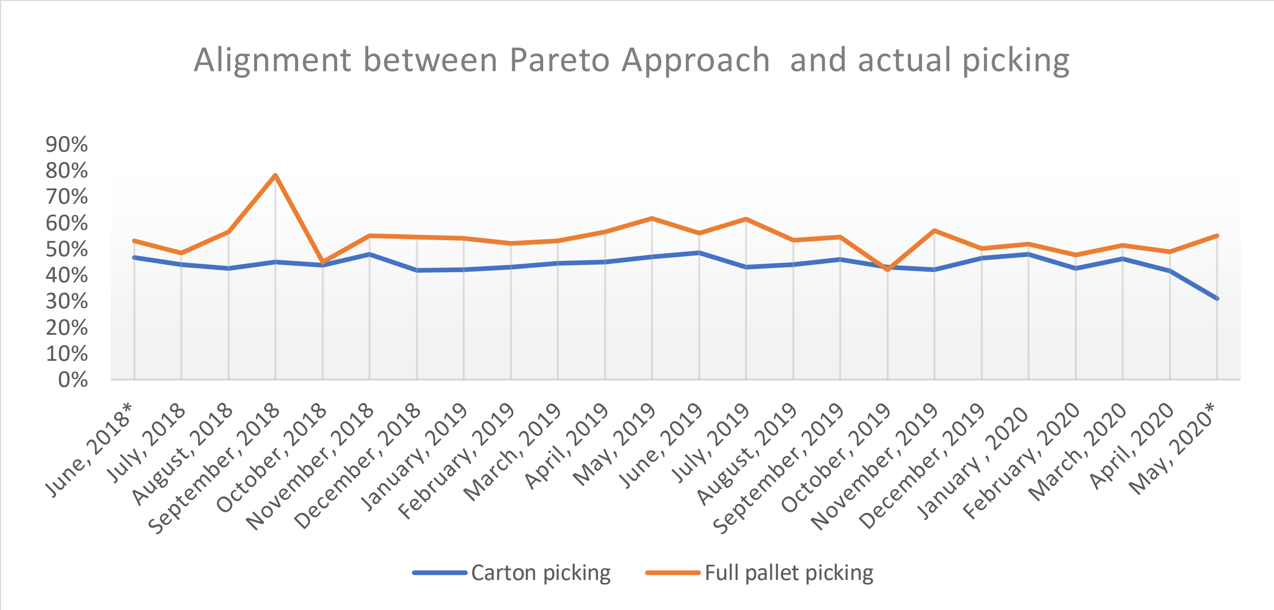

Figure 23: Alignment between threshold values and actual picking

4.4.2. Sampled SKU analysis

The transaction data received for Leman contained over 200 000 transactions with several hundred SKUs. Consequently, get a more in-depth analysis of a sample of SKUs is more feasible to analyze. The sample of the SKUs was chosen to analyze the challenges Leman faces in an assigning SKUs to appropriate storage zones. The sample of SKUs consists of three groups: fast movers with high picking frequency (X SKUs), fast movers with a low physical volume (Z SKUs), and seasonal SKUs (Y SKUs). Graphs showing the zones in which each SKU is picked from each month are added to Appendix B1, B.2, and B.3. Some selected graphs are added to the text to illustrate the challenges. Fast movers have the highest pick frequency throughout the period and, therefore, should always be placed in convenient storage locations, i.e., A zone or A+ carton picking. The purpose of this subchapter is to analyze when and why deviations occur. Five SKUs were chosen from each category to validate trends. Table 8 shows the zones which the fast movers are picked from, Table 9 shows the zone which the seasonal SKUs is picked from, and Table 10 shows the zones which the fast movers with low physical volumes are picked from.

From Table 10, we can establish that A SKUs are not always put in the A storage zone, 25% of full pallet pick of SKU X1 is picked for the B and C zone, this also applies for the other fast movers. Figure 24 further illustrates that SKU X1 has a significant amount of the picks from zone B and C in October, November, March, and April, i.e., during the months with the highest total picking frequency. This indicates that zone A is full during these periods since every SKU shows the same trend in these months. However, Figure 24 also illustrates that a small but significant amount is picked from other zones throughout the period. This can be a result of the warehouse operators overriding the WMS. A correlation between the fill rate of the warehouse and the misplacement of SKUs can also be seen in the graphs of the sampled SKUs. In the initial analyses of **Challenge 3**, it was shown that the storage areas had an average fill rate of 90% from September 2019 until April 20. Consequently, we see that the fast movers have a significant increase of misplacement in this period.

Table 10: Fast movers high volume, X SKUs

SKU nr of stable fast-movers	Year introduced	Storage period	Pallet type		Full pallet picked from zone			Carton picked from zone			
			Full	Mixed	A	B	C	A+	A	B	C
SKU X1	2015	All year	2515	790	1885	427	201	0	690	76	15
SKU X2	2015	All year	2368	963	1579	438	346	0	829	106	27
SKU X3	2015	All year	2554	751	1756	559	232	0	673	51	27
SKU X4	2015	All year	944	854	579	244	124	237	526	68	17
SKU X5	2016	All year	539	194	348	67	124	0	134	22	38

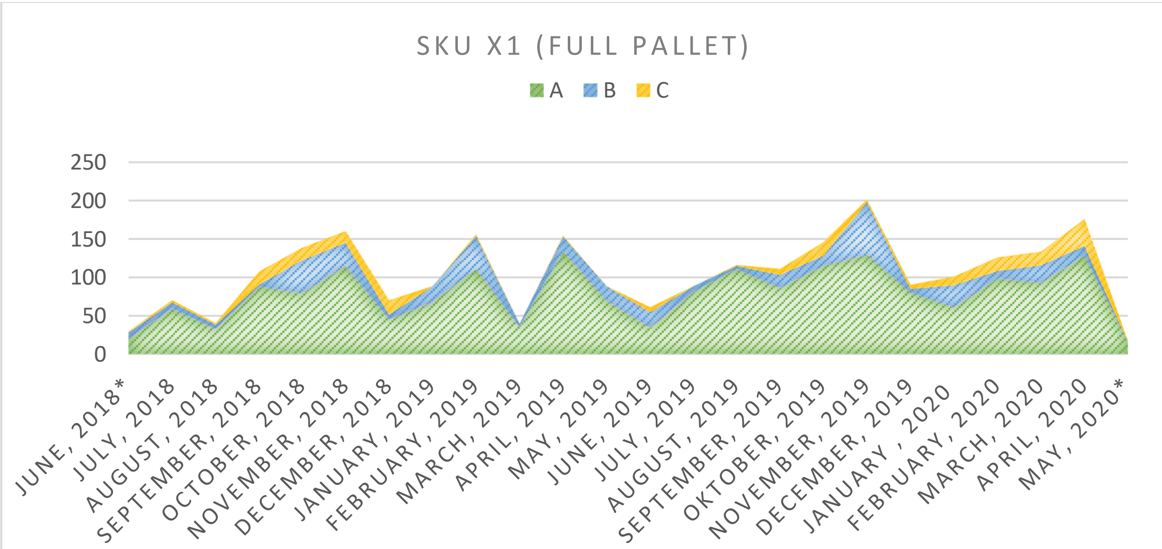

Figure 24: Full pallet picking of SKU X1

Table 9 shows the picks of seasonal SKUs. However, these SKUs are only stored in given periods each year. Hence, the yearly volume accumulated in a shorter period. Brynild produces these SKUs in advance on the season. Therefore, Leman must store these SKUs for a period before orders arrive were the first arrivals of pallets is incoming in mid-August. When the orders arrive, the picking frequency increases fast, as illustrated in Figure 25 for SKU Y2. The picking frequency of SKU Y2 rapidly in September. Likewise, it decreases as rapid after October. Further, Figure 25 illustrates that SKU Y2 is classified as a C when the demand arrives, which leads to long travel distance for the order picker. Further, Figure 26 illustrates that the classification of the SKU is changed when Leman notices that the picking frequency of the SKU is increasing. According to the Logistic Coordinator, this is common, as they do not have any information regarding the new SKUs. As shown in Table 9, the seasonal SKUs are recently introduced, which means that Leman has no information on these SKUs the first week/days before orders arrive. Moreover, Figure 25 illustrates that the assignment of the class is more evenly distributed the second year, which indicates that the Logistics Coordinator has utilized the data from the prior year.

Table 11: Seasonal SKUs, Y SKUs

SKU nr of seasonal SKUs	Year introduced	Storage period	Pallet type		Full pallet picked from zone			Carton picked from zone			
			Full	Mixed	A	B	C	A+	A	B	C
SKU Y1	2018	16.aug- 03.dec	345	192	214	45	87		134	22	38
SKU Y2	2018	16.aug-15.nov	264	93	100	36	128		62	17	14
SKU Y3	2019	13.dec-29.mar	416	263	253	116	47		253	8	4
SKU Y4	2019	8.jan-19. mar	213	193	141	19	53		177	10	1
SKU Y5	2018	15.aug-15 nov	44	32	10	8	23		28	0	4

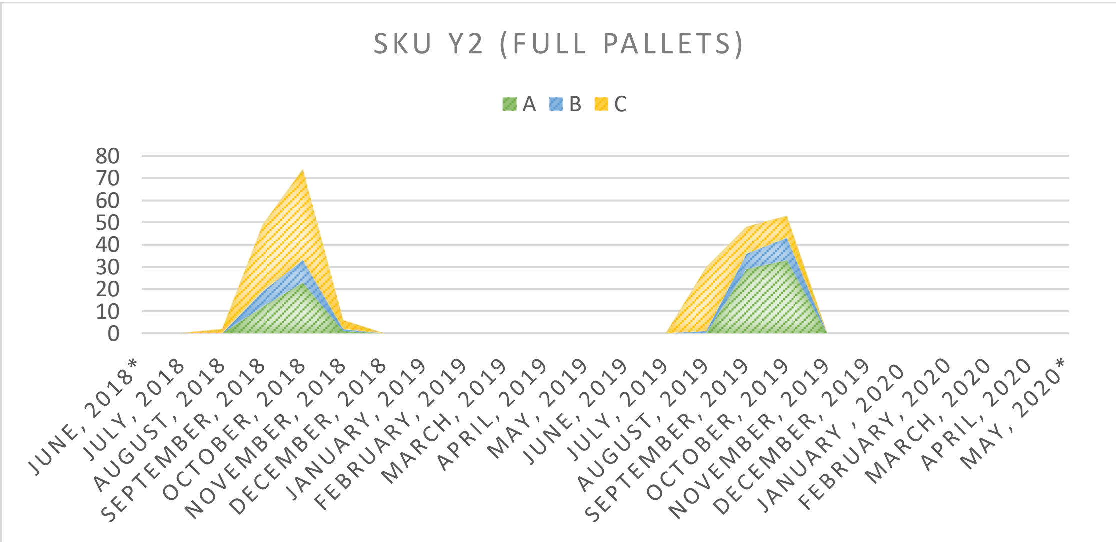

Figure 25: Full pallet picking SKU Y2

From Table 12, one of the findings shows that the carton picking frequency of SKU Z2 is higher than other SKUs, it has a lower distribution of A+ pickings. The same applies to SKU Z1 that also has a significantly higher picking frequency than other SKUs but still almost none picking from A+ zone. Additionally, some SKUs from group X also has significantly higher picking frequency of cartons as SKU X2, which has 963 picks during the period and still is not picked from zone A+. Consequently, an investigation of which SKUs that is classed as A+, is analyzed in the next subchapter

Further, Figure 26 shows the distribution of picks for SKU Z5. Even though the picking frequency is significantly lower than for SKU X5, the distribution of zones picked from is the same. This indicates that too many SKUs are classed as A when the high seasons arrive. Therefor is the A zone full and prohibits the fast movers from being store in most convenient storage locations.

Table 12: Fast movers with low physical volume, Z SKUs

SKU nr of fast movers with low physical volume	Year introduced	Storage period	Pallet type		Full pallet picked from zone			Carton picked from zone			
			Full	Mixed	A	B	C	A+	A	B	C
SKU Z1	2013	All year	199	908	74	14	111	9	817	75	7
SKU Z2	2019	All year	64	749	45	4	4	10	667	70	1
SKU Z3	2017	All year	140	770	116	11	11	667	67	28	7
SKU Z4	2012	All year	325	698	235	47	42	598	61	17	8
SKU Z5	2015	All year	167	406	124	35	12	20	350	36	0

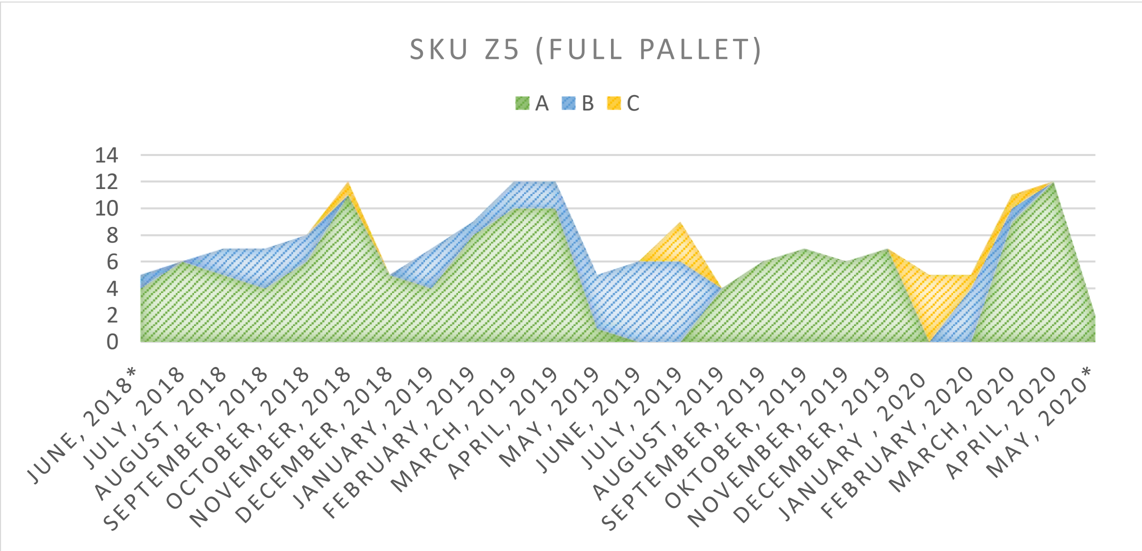

Figure 26: Full pallet picking SKU Z5

4.4.3. Analysis of forward picking area

As shown in Figure 22 (Alignment between Pareto approach and actual picks), cartons are more often picked from a storage location, which is not aligned with their picking frequency. Further, the previous subchapter showed that SKUs with the highest carton picking frequency was not necessarily picked from zone A+. This gave reasons to look deeper into the storage location for carton picking. By sorting the transaction data for carton picking, it identified that SKUs that were picked from the forward picking area did not qualify according to the threshold values set by the Pareto approach.

According to the Logistics Coordinator at Leman, SKUs are assigned given to forward storage locations, i.e., these storage locations are dedicated to these SKUs. The forward storage locations consist of twelve storage locations in the storage area for Brynilds own area (not including Beiersdorf's SKUs). By ranking the total picking frequency over a period, shows that some of these SKUs have a significantly lower picking frequency than the threshold value suggested by using Pareto Approach. Table 13 shows the current SKU located at the forward picking area and their respective picking frequency, further all SKUs are ranked after the picking frequency. The rankings show that some of the SKUs in the forward picking area have a significantly higher rank than they should have. Accordingly, In Appendix D.1, it is shown that these SKUs are below the threshold values set by the Pareto approach most of the given months.

Table 13: Current SKUs in the forward picking area

Current SKUs in the forward picking area

SKU	Total carton picks	Ranking	Mean picking frequency per month	STD
SKU C1	653	25	27	10
SKU C2	203	117	8	4
SKU C3	678	19	28	7
SKU C4	516	37	21	7
SKU C5	854	6	36	11
SKU C6	654	23	27	12
SKU C7	608	28	25	10
SKU C8	545	36	23	5
SKU C9	639	26	27	10
SKU C10	770	10	32	5
SKU C11	492	42	31	10
SKU C12	235	99	25	11

To compare with the current SKUs located in the forward picking area, the twelve most picked SKUs have been listed in Table 14. Accordingly, as shown in Appendix D.2, these SKUs stay above the given threshold value to a more significant extent than the current SKUs. However, we can see that also these SKUs drop below the threshold value. This is due to the seasonal fluctuation of these SKUs and promotions/seasonality on other SKUs.

Table 14: Suggested SKUs for the forward picking area

Suggested SKUs for forward picking area

SKU	Total cartons picks	Ranking	Mean picking frequency per month	STD
SKU S1	963	1	40	17
SKU S2	937	2	39	6
SKU S3	908	5	38	11
SKU S4	854	6	36	11
SKU S5	811	7	34	9
SKU S6	790	8	33	12
SKU S7	772	9	32	8
SKU S8	770	10	32	5
SKU S9	751	12	31	10
SKU S10	749	13	31	13
SKU S11	685	18	29	7
SKU S12	678	19	28	7

The threshold value is set to be the lowest picking frequency for each mouth that still qualifies for the forward picking area. Further, the average value has been calculated to illustrate the threshold value. So, it is more fluctuation than shown in Appendix D2 and Appendix D1. Figure 21 in (Subchapter 4.4.1.) shows the variations in the threshold values for A+ storage locations. Also, seasonal SKUs and promotions affect this value as the quality for the forward picking areas in short periods.

By assuming that the travel distance for retrieving SKUs from the forward area is half of the travel distance by picking SKUs from other zones, one can estimate the reduced travel time of changing the SKUs from Table 13 to the SKUs in Table 14. Table 15 shows the results:

Table 15: Reduction of travel time by changing SKUs in the forward picking area

	Picking of SKU in FPA	Picking from other zones	Total travel time (min)	Total travel time(hours)
Current SKUs in FPA	6847	17628	24475	408
Suggested SKUs in FPA	9668	13694	23362	389
			Reduction in travel time	19

The results show that just by reducing by small changes in the storage location assignment can reduce the travel time of picking these SKUs with 5%.

4.5. TO-BE process for classification of SKUs

For Leman to improve their classification of SKU, they need to apply a more structured approach to assign SKUs. By not using a strict distribution, it has been proven that a too a high number of SKUs has been assigned to class A. This has led to a full storage zone A, during high seasons. Consequently, SKUs, which are fast movers, must be stored in less convenient storage locations. By comparing the current classification of the SKUs with the Pareto analysis showed, a significant discrepancy was identified. The future state must ensure that the fast movers are always stored in the most convenient storage location.

The transaction data used for calculation of the Pareto approach and the threshold values are based purely on historical data. Hence, it can only evaluate the correctness of the classification in retrospect, but not ensure that its classification is correct for the forthcoming period. To estimate an appropriate class of each SKU, a forecast for the next period is needed. Today, Leman receives no forecasts from Brynild on their SKUs. Consequently, Leman must classify SKUs based on historical data from their own WMS. This has implications, as they do not have information about SKUs regarding promotions, the seasonal forecasts of SKUs, or a forecast of new SKUs. Brynild has forecast on these types of demand, but these volumes are giving in estimated sales of cartons. This information is also stored in many different formats and originates from different sources. Consequently, this will require much work for Brynild as well to share this information. Additionally, these estimates must be transformed into picking frequency of each SKU, before being used in a calculation of storage classes. Figure 27 shows the sequence of the possible prosses of a TO-BE. The TO-BE describes the possibility of an automated process and not necessarily the future solution.

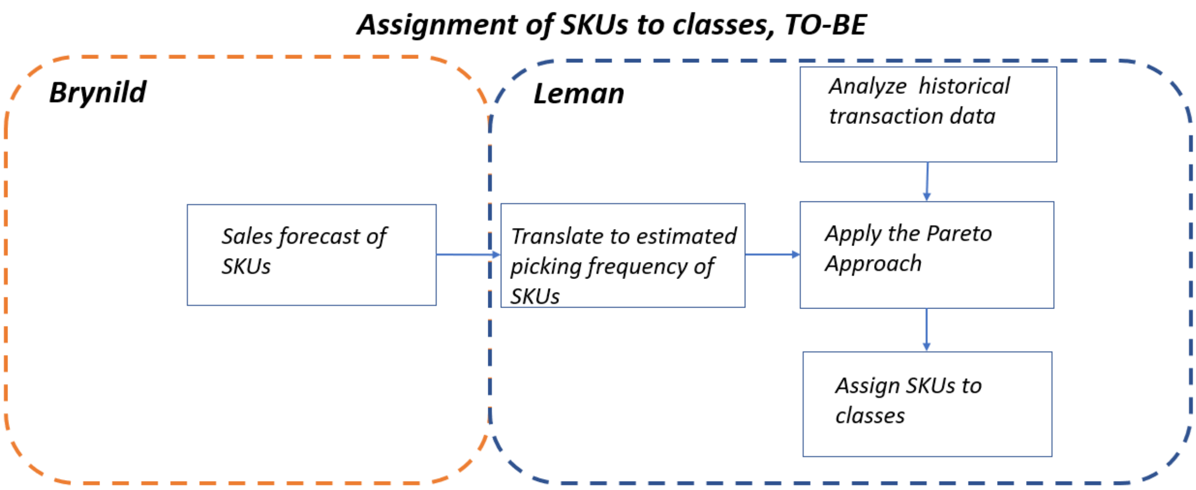

Figure 27: TO-BE prosses for assigning SKUs to classes

The proposed TO-BE process of classifying SKUs consists of:

1. **Sales forecast of SKUs:** Information sharing between Brynild and Leman, to provide Leman with estimates of promotions, seasonality, and introduction of new SKUs. Brynild has access to all this

information today. However, sharing this data with manual routines requires a lot of work. This information sharing should automatically be shared with Leman, to avoid extra time-consuming work for Logistics Coordinators at both Leman and Brynild

2. **Translate to estimated picking frequency of SKUs:** A translation of Brynilds sales forecasts into picking frequency for both full pallets and carton picking. For Leman to utilize the information from Brynild, they need a translator of the forecast, that differentiates between full pallet picking and carton picking. With such a translation Leman could receive improved information quality. Also, this step should be performed automatically, to avoid extra time-consuming work for Logistics Coordinators at Leman or/and Brynild
3. **Analyze historical transaction data:** Analyze the performance of the previous period to evaluate the distribution of the Pareto Approach. E.g., was the SKUs picked from the correct class, if not, why. If too many SKUs were picked from the wrong zone, it indicates that too many SKUs are assigned to one class. If the utilization rate of the most convenient zones were low, it indicates that the too few SKUs is assigned to those zones
4. **Apply a Pareto Approach:** Conduct Pareto analysis of historical transaction data, also, add forecasted pick seasonal SKUs, SKUs with incoming promotions and new SKUs. This should be performed every second week to ensure that all these uncertainties are accounted for. Additionally, this should be performed every time a season starts/ends because these periods are subjected to the highest fluctuations in demand
5. **Assign SKUs to new classes**. This step should consider some qualitative knowledge. E.g., If the picking frequency of an SKU expected to exceed or decrease for a short period of time, it might be reasonable not to change the classification to avoid relocations

The benefits of the TO-BE is that Leman can classify SKUs with much more knowledge of the demand pattern, which increases their flexibility to change classes for SKUs that have significant demand fluctuations. Also, this TO-BE emphasizing that automation is a key factor, as Leman does not have the capacity to conduct manually periodic reviews of the classifications. The feasibility of suggested TO-BE of assigning SKUs is discussed further in the next chapter.

5. Discussion

The purpose of the discussion is to tie the thesis together. First, to answer RQ1, the findings from the literature study of storage policies for SLAP is discussed. Then the findings in RQ1 are used to compare the literature study on 3PL providers and insights from the case study to answers RQ2. Further, the case study is discussed against the literature study to examine the generalizability of the findings. Last, an evaluation of the weaknesses in the research is described.

5.1. Existing storage policies for SLAP

RQ1: *Which storage policies exist for solving the storage location assignment problem (SLAP)?*

The purpose of this research question is to investigate which storage policies that exist for solving SLAP. Further, to describe when to use different policies.

In the literature study, it was identified three main storage policies used for SLAP; *dedicated storage policy, random storage policy*, and *class-based storage policy* (Hausman, Schwarz et al. 1976, Gu, Goetschalckx et al. 2007). The main storage policies have subcategories that are characterized by the criteria used to assign SKUs to storage locations. Each of the different storage policies is discussed:

Dedicated storage:

The advantage of a dedicated storage policy is that order-pickers can memorize the storage location of SKUs, making order picking more efficient (Stephen N.Chapman 2017). SKUs can be stored to reduce the average travel time. E.g., by ranking SKUs according to **picking frequency** or **COI**, so that the most picked SKUs is stored in the most convenient storage locations (Bahrami, Piri et al. 2019). Another criterion that also reduces travel time is the **correlation** between SKUs. If SKUs that are usually picked together are stored next to each other, one reduces the travel time between each picking location (Kofler 2015).

The main drawback with dedicated storage is the space utilization rate (de Koster, Le-Duc et al. 2007, Fontana and Cavalcante 2014). As SKUs have fixed locations, no other SKUs can be stored in the same storage location even when it is available. This causes many storage locations to be unutilized (John J. Bartholdi 2019). Since warehouse space is one of the highest costs in warehousing, the utilization rate important performance indicator (John J. Bartholdi 2019). Another drawback with dedicated storage policy is lack of performance in dynamic environments, as the ranking of SKU changes due to fluctuations in demand and product portfolio (Baruffaldi, Accorsi et al. 2019b). As a consequence, dedicated storage needs continuous updates and relocation of unit-loads to maintain the "correctness" in dynamic environments (Tompkins, White et al. 2010, Bahrami, Piri et al. 2019). There are also some challenges for dedicated storage policies regarding available information. Some of the criteria require high amounts of data, e.g., **correlation** and **DOS,** which also must be processed to be used. These criteria require a certain degree of technical and mathematical competence. Thus, **DOS** is considered as too complicated for real-life use due to its requirement of item information (Goetschalckx and Ratliff 1990)

There are circumstances where dedicated storage policies are the most applicable option. E.g., in forward picking areas, where SKUs that are frequently picked can be stored in fixed positions to ensure a higher order picking efficiency of the fast movers. The forward picking area is typically a small area within a warehouse. Consequently, the space utilization for forward picking areas is not that critical as for other storage area in the warehouse (John J. Bartholdi 2019). Another circumstance where dedicated storage is applicable is in warehouses with a low degree of technical applications, to avoid manual searching for SKUs (Stephen N.Chapman 2017). Fontana and Cavalcante (2014) state that the efficiency of material handling (reduction in internal travel time) is a more vital performance indicator than space utilization for warehouses with a high turnover rate. Thus, dedicated storage is more applicable in warehouses with a high turnover rate. Last, warehouse environments with stable demand patterns and little changes in the product portfolios are also suited for a dedicated storage policy.

Random storage:

The main advantage of random storage policy is the utilization of storage space, where every storage location is available for all SKUs (Petersen and Aase 2004, John J. Bartholdi 2019). Further, random storage strategies are rather simple to implement (Gu, Goetschalckx et al. 2007). The next advantage is that random storage policies are not affected by any changes to the product portfolio and demand fluctuations (Bahrami, Piri et al. 2019). Last, random storage does not require any information or analysis (Gu, Goetschalckx et al. 2007).

The most significant drawback of random storage is internal travel time (Sharp, Il-Choe et al. 1991, Kofler 2015). Another drawback is the dependence on an ICT system that tracks the exact locations of every unit-load. Without an ICT system that tracks every unit-load, it can be very challenging for order pickers to locate the correct unit-load (Stephen N.Chapman 2017).

The different criteria for random storage are not as diverse as for dedicated storage. Only two criteria are usually applied practices, either **closest** or **fully random,** where both have approximately the same performance according to (Hausman, Schwarz et al. 1976).

If we compare dedicated storage with random storage, random storage performs better in dynamic environments, because it is unaffected by changes in product portfolios and demand fluctuations (Bahrami, Piri et al. 2019). Also, in warehouses where storage utilization is more important than the order picking efficiency, e.g., small warehouses, random storage could be beneficial. In warehouses with a low turnover rate, storage utilization is more vital that operational efficiency (Fontana and Cavalcante 2014).

Class-based storage:

The advantage of class-based storage is that it utilizes the logic of dedicated storage while avoiding its side effects (Petersen and Aase 2004, Gu, Goetschalckx et al. 2007). Class-based storage is popular among practitioners, due to simple implementation and its flexibility to variations in product mix and demand (Le-Duc * and De Koster 2005). It does not require as much data and analysis as dedicated storage to stay updated. It utilizes storage space more efficiently than dedicated storage. Simultaneously, it only performs 1% worse when measuring the handling efficiency, according to Petersen and Aase (2004).

Drawbacks of class-based storage require careful consideration of the number of classes, assigning storage locations, and products to class (Gu, Goetschalckx et al. 2007). This further requires periodical reviews to account for changes to the product portfolio as well as fluctuations in demand (Petersen and Aase 2004, Kofler 2015). Another drawback of the class-based storage that has been proven in the case study is that the periodical reviews require information on future picking frequencies, which is difficult to account for without forecasts of expected picks.

The criterion for dedicated storage applied for class-based storage as well. However, Gu, Goetschalckx et al. (2007) points out that **picking frequency** and **COI** as the most frequently used to assign SKUs to classes. After SKUs are assigned to classes, **Closest** or **fully random** is used to assign incoming unit-loads to their exact locations.

Class-based storage has an overall higher performance than dedicated and random storage. Class-based storage utilizes both the advantages of random storage and dedicated storage while limiting their disadvantages (Petersen and Aase 2004, Gu, Goetschalckx et al. 2007). Class-based storage is not as difficult to maintain as dedicated storage, and at the same time, it utilizes some of the available product information to ensure efficient material handling (Gu, Goetschalckx et al. 2007). Random storage requires the least maintenance of the three policies. However, it does not utilize easily accessible information of SKUs and yields longer travel distance for order pickers (Chiang, Lin et al. 2011). To summarize, if the warehouse environment is complex with fluctuations, but at the same time, product information is available, one could adopt a class-based storage policy. If the environment is stable, one could apply a dedicated storage policy to utilize **correlations** and **COI/picking frequency**. If the environment is complex, and no information is available, a random storage policy is recommended.

5.2. Applicability for SME-3PL providers

The previous subchapter discussed the three main storage strategies for performing SLAP. In this subchapter, the applicability of these policies 3PL providers is evaluated. The challenges that SME-3PL providers face when conducting SLAP is also discussed to answer RQ2 answer:

***RQ2:** Which storage policies for SLAP are most applicable for SME-3PL providers with multiple clients?*

The purpose of this research question is to evaluate which of the policies are most applicable to SME-3PL providers that serve multiple clients. An investigation of the characteristics of SME-3PL providers must also be conducted to evaluate how applicable the different storage policies are.

3PL providers have multiple clients with hundreds of different SKUs each. To manage their warehouse is, therefore, more challenging than managing in-house storage, where only one company is considered. Faber, de Koster et al. (2013) claims that, although changes in SKUs may be unpredictable for the production environment, the warehouses should be able to cope with this due to information sharing between the production and distribution. However, 3PL provider usually makes decisions with reduced visibility of their clients' process (Baruffaldi, Accorsi et al. 2019b). 3PL providers then have a complex environment with multiple clients and little transparency due to reduced information sharing (Baruffaldi, Accorsi et al. 2019b). According to the discussed storage policies, random storage policy fits in complicated environments with limited information, due to its immunity to changes in product portfolios and changes in demand patterns (Bahrami, Piri et al. 2019). To utilize matrixes as COI and to pick frequency for reducing order picking time, 3PLs requires information on changes in product portfolios and forecast of expected orders (Accorsi, Baruffaldi et al. 2018). Warehouses usually have WMS or other software that supports their operations (Faber, de Koster et al. 2013). These software solutions eventually record transactions internally in the warehouse and generate data, which can be utilized to support more complex storage policies than random storage policies to reduce the internal travel time.

To access more data from their clients, 3PLs must aim to integrate with them to form mutually beneficial relations or strategic partnerships. This is according Gunasekaran and Ngai (2003), the key for SME-3PL providers. With a strategic partnership with its client, the SME-3PL providers will receive more trust, and the client will no longer be as reluctant to share information. Another challenge regarding 3PL, especially SMEs, is lacking ICT competence (Evangelista, McKinnon et al. 2013), which can lead to both miss configurations of WMS and lack of utilization of available data. Consequently, it is essential to invest much training of personnel when implementing a new ICT system (Evangelista, McKinnon et al. 2013). From the case study, we learned that the Supply Chain Manager of Brynild was not reluctant to share data with Leman. However, the doubt was rather if Leman has the capacity to utilize the information for any purpose. Also, by investigating the challenges, it was identified that Leman faces some ICT issues. Consequently, we can confirm the statement regarding that SME-3PL lacking ICT competence could be an issue.

For SME-3PLs providers, the capacity to assign employees to analyze the information is also an important consideration. As Leman stresses in the case, they do not have resources to analyze the product portfolio of each client periodically. They also state that they are dependent on clients to provide accurate analyses instead for them to analyze the client’s product portfolio with limited information. This supports Gunasekaran and Ngai (2003), which states that clients must assist their 3PL providers for them to be more efficient. Accorsi, Baruffaldi et al. (2018) states that 3PLs usually lack information regarding the schedule of incoming deliveries, the content of deliveries, changes to product portfolio, and forecasts of expected orders. This is also true for this case, but as already mentioned, this is a question of whether the SME-3PL providers could utilized this information to become more efficient.

In addition, SME-3PLs have to be flexible to changes both in product portfolios and clients (Hamdan and Rogers 2008). This further leads to a limited degree of automatization, hence a significant degree of manual labor (Selviaridis and Spring 2007, Davarzani and Norrman 2015). The case study indicates the same, and Leman must stay flexible to adapt to new customer requirements and possible new client relationships. Hence Leman has a low degree of automation in their physical operation. This further supports the importance of reduced travel times within the SME-3PL providers' warehouses since increased travel time in manual warehouses directly affects the labor cost.

To summarize the challenges that SME-3PL warehousing is:

- A large variety of SKUs and clients, leading to many different requirements
- Limited information of the SKUs stored in the warehouse
- Limited ICT capacity
- A limited degree of automatization, hence a significant degree of manual labor

Baruffaldi, Accorsi et al. (2019b) states: "*Dedicated storage is indeed not suitable in 3PL warehouses since the inventory mix changes continuously with demand seasonality and the clients' portfolio".* However, the use of forward picking areas, which is dedicated storage, can still be feasible in some circumstances, where the 3PL locate "stable" fast movers among the client's product portfolio. This use dedicated storage locations to reduce the overall internal travel time. Apart from forward picking areas, dedicated storage is likely to be suboptimal for 3PL due to the information barrier, variation in the product portfolio, and fluctuations in demand. These three factors would regularly cause SKUs to be misplaced with a dedicated storage policy.

Further random storage policies are an applicable option in complex environments, and we can consider 3PL warehousing as a complex environment. However, since 3PLs uses WMS that record transaction, it could be utilized for more advanced policies. In the long run, 3PLs could lose a lot of valuable time in choosing not to utilize the available information in the WMS.

By utilizing the available information, 3PLs can apply class-based storage policies. Class-based policies require 3PLs to know how to utilize the information they possess, which requires training of personnel. For the SME-3PL providers to utilized information regarding complicated criteria as **Correlations** and **DOS** are considered as unfeasible. Due to the lack of accurate data and lack of ICT capacity, which these criteria require. Performing periodical updated class-based storage is considered as within the scope of the ICT competence of SME-3PL providers. This does not require complicated algorithms, nor is it too time-consuming to perform. However, getting the classification correct requires frequent updates and information sharing from clients, which is not always possible. Thus, to achieve a high performance of the class-based storage, Gu, Goetschalckx et al. (2007) state that careful considerations have taken on a number of classes, assignment of classes to SKUS and the storage locations of each class, as these have a significant impact of the required storage space and order picking cost. Regardless of these considerations, class-based storage is fitting the complex environment of SME-3PL providers. However, it has some implications that must be addressed to be as efficient as possible. Some of these implications are addressed in the next subchapter.

5.3. Case study discussion

The case study is discussed against the literature study to examine the generalizability of the finding.

5.3.1. Assigning SKUs to classes

Leman applies a class-based storage policy to assign a storage location to incoming SKUs. The SKUs are assigned to either class A, B, or C, based on the picking frequency of the specific SKU. The Logistics Coordinator, periodically (every 2-3 weeks) retrieves data from the WMS and updates the classes of the SKUs. However, there is no set threshold value or distribution that must be met to qualify for each class. Approaches for assigning SKUs to classes are already suggested in the literature, where it is stated that SKUs should be divided after their picking frequency (or other criteria) to ensure that the most popular SKUs are placed in the most convenient storage locations. Next, according to literature, the distribution classes of these should follow a systematic distribution, e.g., the Pareto approach, that is updated periodically (Kofler 2015). However, in practice, shown through the case study, this is a challenge due to the time spent on performing these updates. The Activity Manager from Leman states: "*We are dependent on our clients to provide information about their products. We do not have the capacity to let one of our employees spend considerable time analyzing which SKU that belongs to each class".* This indicates that SME-3PL providers have limited resources to perform support activities as assigning classes to SKUs. Further, it is common for 3PL to be dependent on information from their clients to understand the demand pattern of the SKUs (Baruffaldi, Accorsi et al. 2019b). However, to analyze the SKUs in the with the Pareto approach used in the case study, could be an effective option to perform periodic updates of classifications, as transaction data is easily extracted, automatically counted, and analyzed by the spreadsheet. A significant limitation of this approach is that it is based solely on historical data. Consequently, if a season starts in the next period, the historical data from the last period is less relevant. Thus, the classification should be based on the coming period. This requires information sharing from the client, which is further discussed in the next subchapter.

The Pareto Approach is just a rule of thumb for the distribution of SKUs to classes. Consequently, the proposed distribution is most likely not the optimum solution for assigning SKUs to class in every warehouse at every given demand pattern. However, it provides useful indicators of how companies should prioritize their SKUs and are more likely to perform better than a non-structured approach. In Leman instance, the Pareto curve matches the 80:20 distribution for full pallet picking, where 20% SKUs account for 80% of the cumulative pickings. Thus, we can assume that it was appropriate to use in the case study.

5.3.2. Routines for information sharing

The analysis of Leman's assignment of SKUs is based on historical data. However, Leman needs to predict the future to implement the exact threshold values. Currently, they have limited information on future estimated picking frequency on SKUs. The only indicators Leman has on future orders is the WMS transaction data and qualitative knowledge. Consequently, Leman needs information sharing from Brynild to be able to set the correct classification of SKUs prior to a given period. Literature states that 3PL providers have limited access to information on clients due to the unwillingness of the clients (Baruffaldi, Accorsi et al. 2019b). The relationship between Brynild and Leman also lacks information. However, this is not due to the unwillingness to share information. According to the Activity Manager at Leman, the reason for the lack of information is the process of sharing and analyzing the data is too time-consuming. Brynild has available data that Leman could process regarding promotions, seasonality, and new products. However, this data is given in cartons sold and must "translated" to picks of pallets and cartons to be used by Leman.

The TO-BE in Subchapter 4.5 in suggests a new possible process for Leman to assign classes to SKUs. This involves increased information sharing between Leman and Brynild. However, due to the limitations of resources to process this data, information sharing must be automatically shared and processed. Therefore, further work in this topic could be to design a software solution or a software integration between Brynild and Leman that provides Leman with processed information that is directly integrated into the WMS. With such a solution, Leman could improve their SLAP due to the knowledge of the forthcoming picking frequency of SKUs. This would further lead to an increase in the accuracy of the assignment of classes.

Such a solution is not realistic on a short horizon, as it requires time to research and implement. In the meantime, Leman needs some information to classify new SKUs, because as of now, these SKUs have no information attached to them. For Leman to use a class-based storage policy without information on SKUs is not recommended by the literature (Gu, Goetschalckx et al. 2007). As Gu, Goetschalckx et al. (2007) state that SLAP without any information should be performed by a random storage policy. Brynild, on the other hand, has the information on these new SKUs and knows how much they will produce in a period. Meanwhile, Leman does not know if newly introduced SKUs are seasonal SKUs or regular SKUs with sales throughout the year. This is critical since these SKUs have very different demand patterns, as shown in the analyses of sampled SKUs (Subchapter 4.4.2). If Leman received this information, they could at least make some estimates on which class to assign the new SKU, thus improve the SLAP of new SKUs. Chopra (2013) states about the quality of information sharing: "*is not say that all information must be 100 percent correct, but rather that the data available paint a picture that is at least directionally correct*." By Brynild sharing information on sales data on new SKUs would give a direction of the estimates for a short horizon of time, later Lemans WMS has to gather information on the SKU. Consequently, Leman would have available information on every SKU.

However, this intermediate solution requires that Brynild has the available capacity to share the data manually, which may not be feasible.

5.3.3. Storage utilization vs. handling efficiency

Including the already discussed factors of non-structured routines for classifications of SKUs and lack of information sharing, Lemans SLAP is also subjected to other challenges. The fill rate of the warehouse has an average fill rate of Brynilds storage areas of 90% in the last months of the sampled period. With such a high average fill rate, Brynilds storage areas are complete/almost full in some periods. Consequently, the WMS is not able to find suitable storage locations for SKUs. The Activity Manager stated: "*If the storage has a high average fill level, it generates a lot of turnover for us, because we get paid for every pallet we store per day. However, if the fill level gets too high, we get problems regarding efficiency*.".

Fontana and Cavalcante (2014) discussed this trade-off with a bi-objective study of reduction in order picking time and storage utilization. The result gave an efficiency frontier that displays the correlation between the cost of warehouse space and the cost of order picking distances (Figure 5, Subchapter 3.2). Fontana and Cavalcante (2014) conclude that if one factor is close to optimal, the cost of the other is high. The article also states that in some instances with a high turnover rate, the focus should be on efficient order picking and not space utilization, and the other way around for warehouses with a low turnover rate.

The turnover rate cannot be considered as low in the Brynilds storage area, as Brynilds offers fast-moving consumer goods. Consequently, a 90% fill rate is most likely too high. The operators at Leman experience that the travel time for the put-away of Unit-loads deviates significantly for the same SKUs. Thus, the fill rate of the warehouse is affecting the internal travel distance of the warehouse.

5.4. Limitations of the research

One of the original objectives of the case study was to a comparison of travel time of the Pareto approach compared to the travel time with the current situation, thus comparing the AS-IS with the TO-BE. Due to the restrictions described in the preface, the comparison does not cover the whole of Brynilds storage areas. Therefore, a sample was done for the forward picking area. It showed that by relocating a few SKUs, gave a 5% reduction in travel time for order picking of these SKUs. This result is an indicator of how appropriate SLAP can reduce the travel time by small adjustments, as stated by Gu, Goetschalckx et al. (2007).

The Pareto approach is not necessarily an optimal solution for how to assign SKUs to classes, but it is significant deviations can be assumed to be a source of inefficiency. By analyzing single SKUs, shown that the current distribution fills the most convenient storage zones. This indicates that too many SKUs are assigned to class A, and the warehouse fill rate is too high. The research has not considered the zones of the storage areas or how many classes that should be applied. The size of the difference zones affects how many SKUs are picked from the wrong zone. Of course, expanding zone A would result in more SKUs being picked from the correct zone in this case study. At the same time, one would get an average longer travel time at each pick from zone A from doing this.

Six challenges were identified in the case study. However, only one of them was further analyzed. Some of them were dead ends, where either customer requirement or other barrier prohibits changes. Some of the challenges were related to software issues, as the WMS did not match Leman's operations, e.g., driving two unit-loads into the storage area at once. Some of the challenges also required on-site testing, e.g., testing of alternative WMS configurations to reduce internal travel time. These challenges can be further investigated by other scholars or internally by Leman.

Since the case study was limited to one case, there are limits to the generalizability of the conclusion drawn. Single case studies have biases such as misjudging of the validity of single events and exaggerating easily available data (Voss, Tsikriktsis et al. 2002). Therefore, the case company was interviewed to ensure that the found challenges in the case study were correct, and further qualitative data were used to get a second verification. For some challenges that discovered at Leman, achieving verification was difficult as qualitative data were missing. Thus, these challenges were left open and not concluded upon at this point, due to the lack of qualitative data.

6. Conclusion

The first objective of the study was to conduct a literature study to investigate the existing storage policies for SLAP. The findings showed that there are three main storage policies for SLAP; *dedicated storage, random storage*, and *class-based storage*. The main storage policies have subcategories that are characterized by the criteria used to assign SKUs to storage locations. The advantages and disadvantages were discussed for each storage policy to argue when each of them is applicable. The result of the discussions indicates that a random storage policy could be applied when the turnover rate of a warehouse is low, the complexity of the environment is significant, and little information is available. Dedicate storage is most suitable in stable environments with significant information available and a high turnover rate. Class-based storage is the most flexible of the three and is applicable in complex environments with some available information and can be adjusted to fit both high and low turnover rates.

The second objective was to describe the environment of an SME-3PL provider and discuss which of the storage policies that are most applicable to this business. SME-3PL environments were found to be subjected to several factors that complicate the warehouse environment among them:

- A large variety of SKUs and clients, leading to many different requirements
- Limited information of the SKUs stored in the warehouse
- Limited ICT capacity
- A limited degree of automatization, hence a significant degree of manual labor

The identified challenges in literature are recognized in the case company, such as limited information sharing. Thus, we can conclude that the SME-3PL environment is complex and that information is limited. However, 3PLs usually support their warehouse operations with software, e.g., a WMS. These systems record transactions within the warehouse. One can argue that this information is enough to apply a class-based storage policy. However, the class-based storage policy also requires more information to increase its performance.

The third objective was to conduct a case study of an SME-3PL provider, Leman, to investigate challenges that lead to a reduction of internal travel time and suggest improvements to reduce internal travel time. Several challenges were identified in Leman's physical operations. All the challenges were initially investigated. After a selection process, one of the challenges was selected for further research; *the lack of a systematic approach of assigning SKUs to classes in their class-based storage policy*. Analysis of the current assignment of classes showed significant deviations from methods suggested in the literature. By implementing a more structured approach, Leman could potentially achieve a reduction in internal travel time. Causes for not implementing a structured approach earlier is due to limited capacity to perform such activities among SME-3PL providers. As an example of a potential saving, the results of rearranging only parts of the Lemans warehouse show a reduction of 5% of the internal travel time of picking the rearranged SKUs. Last, the case study also suggests a TO-BE process for the classification of SKUs. The TO-BE also includes information sharing between Leman and one of its clients, as this is one of the causes of misclassification of SKUs.

Generalizable results from the case study are that SME-3PL providers have a limited capacity to conduct an analysis of the client's SKUs, which is one of the root causes of this challenge analyzed in the case study. The case study supports the other challenges for 3PLs found in the literature study. Another significant result is that all clients are not reluctant to share information due to trust; It is instead ICT capacity that is the most significant barrier.

In further work, it is recommended to measure the performance of the whole warehouse by implementing a structured process for assigning SKUs to class and by implementing the suggested TO-BE.

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8. Appendix

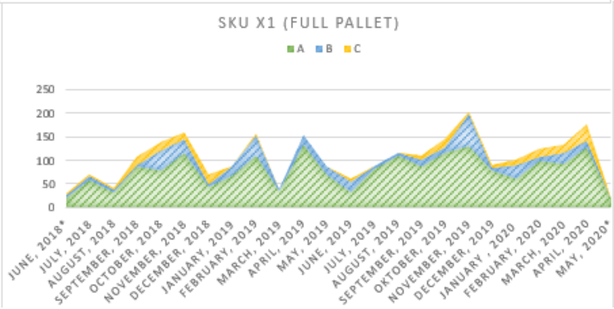
A. Case study protocol

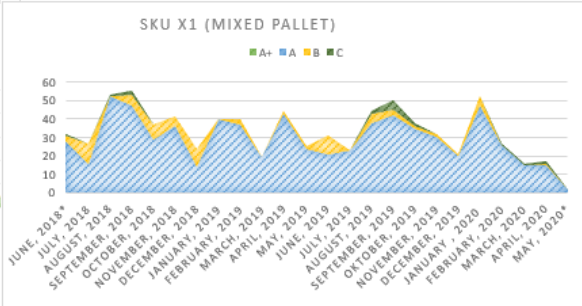
Major Area	Context Area	Questions	Information sources
General information of the industry	Introduction to the case study	Which factors are essential in this supply chain? Which operation does the case company perform?	Skype presentation (Supply Chain Director)
Initial problems at Leman-Vestby	Initial problem description	Which overall challenges does Leman have? Which areas does Leman want to improve? How is the current performance of Leman today?	Company visit(Leman executives) Secondhand data (KPI report, received for Brynild)
Warehouse information	Operations	Which operations does Leman conduct? How are they performed? Which challenges does Leman have in their physical operation?	Company visit Leman Vestby Interview /observation order office Interview/observation Logistics Coordinators Interview/observation warehouse operators
	Configurations	How is the warehouse organized? In regards to layout, workforce, customers, picking areas, and storage areas	Interview (Warehouse Manager) Observation (Company visit) Second hand data (physical layout) Interview/ meeting(Activity manager)
	Policies	Which policies are used to manage the material flow warehouse	Interview Warehouse manager and Logistic Coordinator
		What is the procedure for SLAP?	Interview Logistics Coordinator

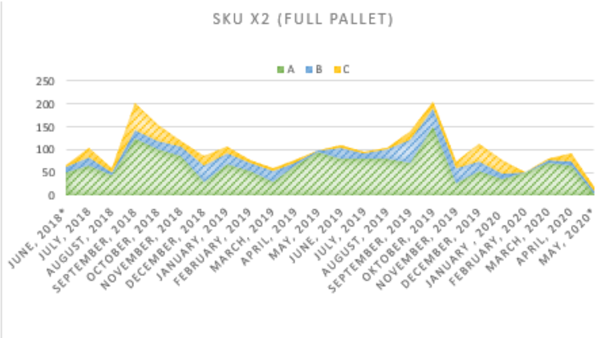
Storage location assignment problem (SLAP)	Procedure for SLAP	Which factors are influencing this decision? Could improved coordination between the actors result in improved?	Second-hand data(Data transaction out-and inbound SKUs) Interview /observation warehouse operators Second-hand data (Current classification of SKUs)
Warehouse management system	Utilization of the WMS	What functionalities does Leman have access to in their WMS? How do they configure the WMS to solve SLAP? Which logic is used? Do any discrepancies between their configuration and their operations?	Secondhand data, (Functional description of the WMS) Semi-structured interview 15/05 (Skype interview with the logistics coordinator
Information sharing	Procedures for information sharing	What information does Leman receive from Brynild today? What information does Leman desire? How do/can they utilize that information? What are the reasons for limited information sharing?	Interview/meeting 10/06 Activity Manager Semi-structured interview Supply Chain Director

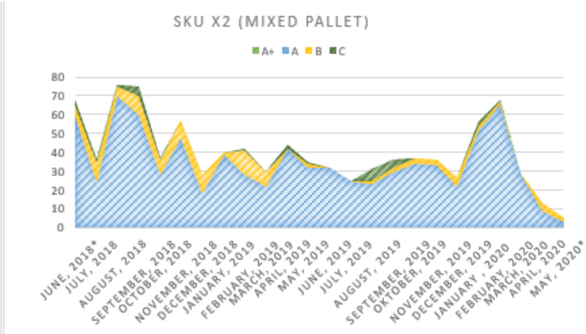
B. Sample SKUs distribution

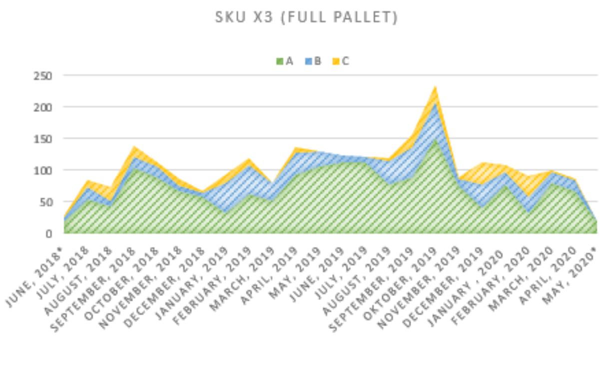
B.1. SKU X1-X5

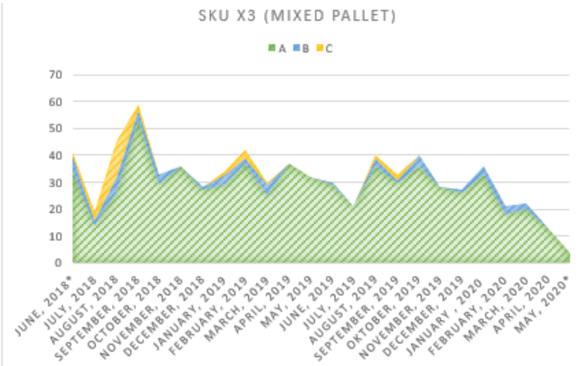


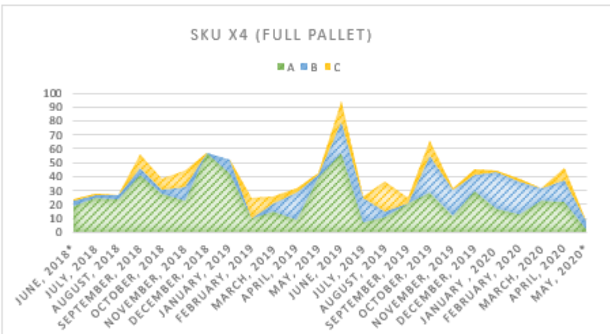


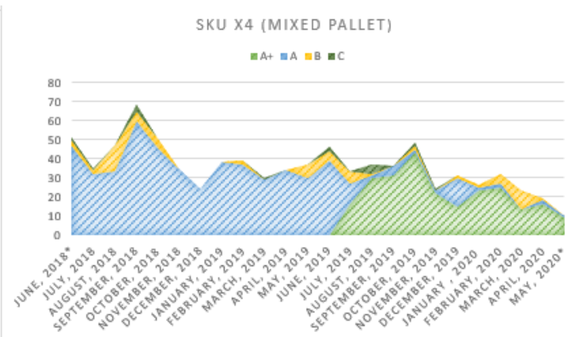


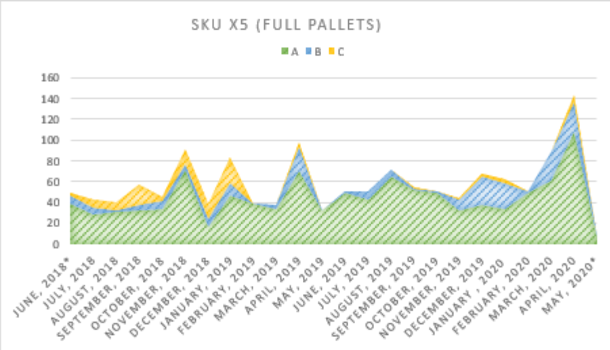








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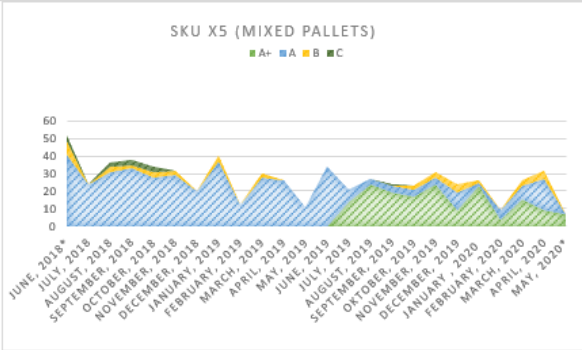
A B C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A+ A B C

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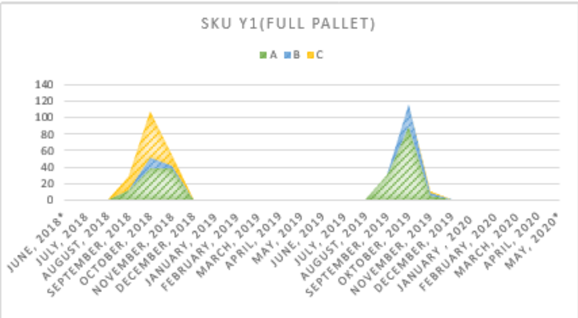
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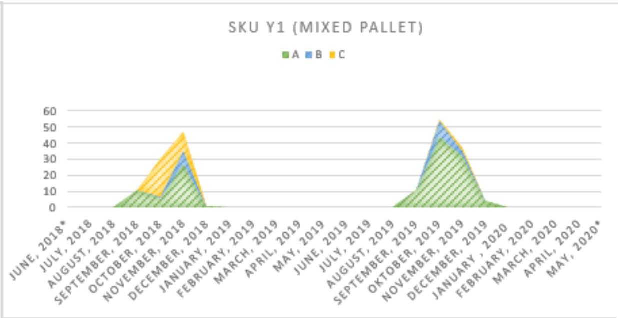
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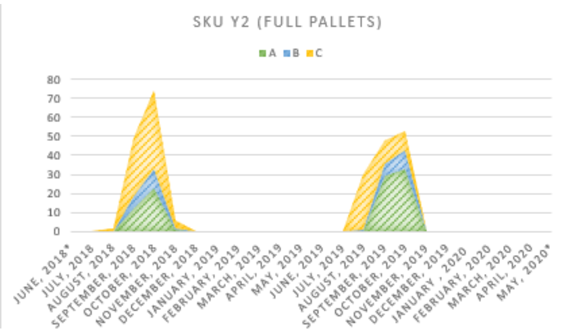
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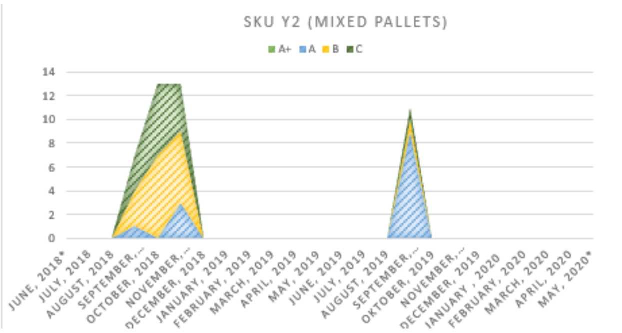
A B C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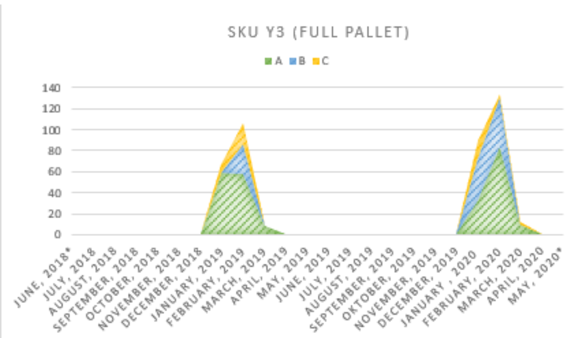
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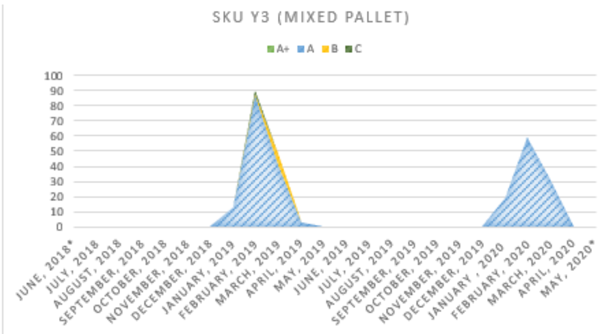
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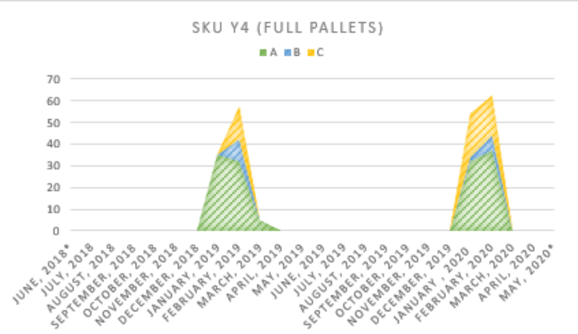
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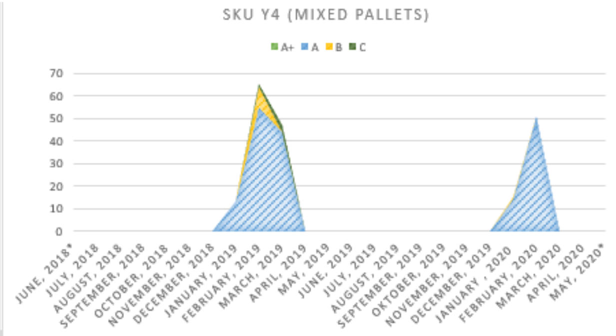
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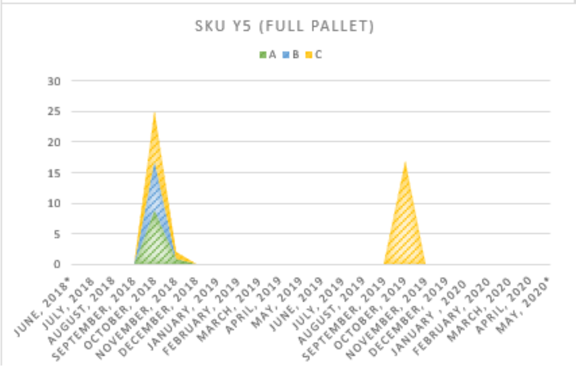
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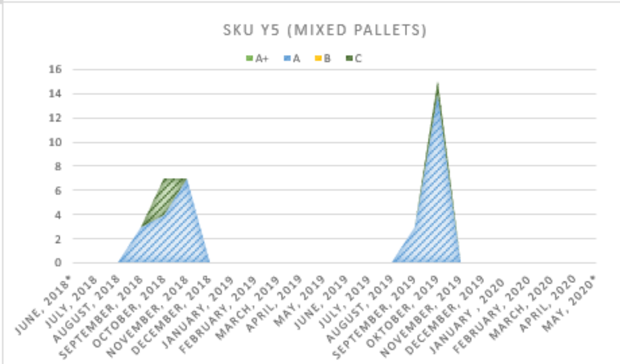
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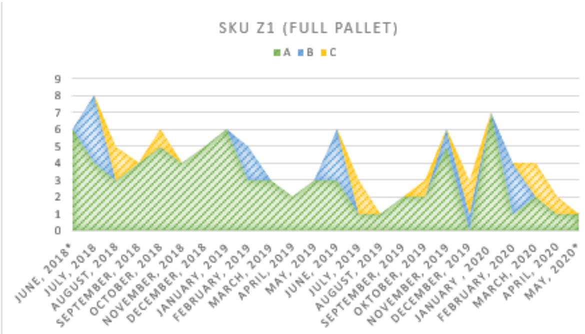
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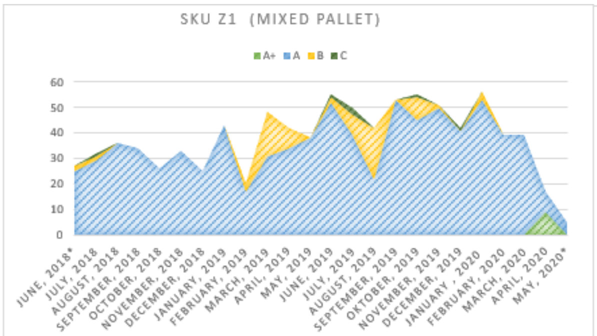
A B C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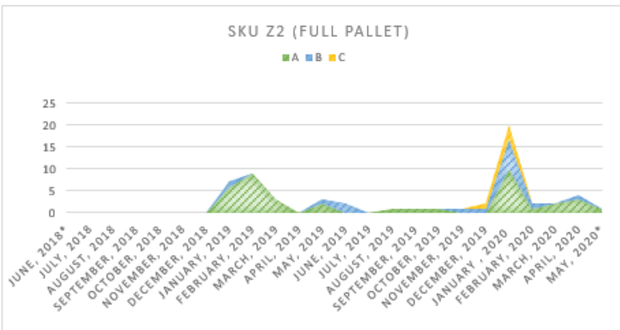
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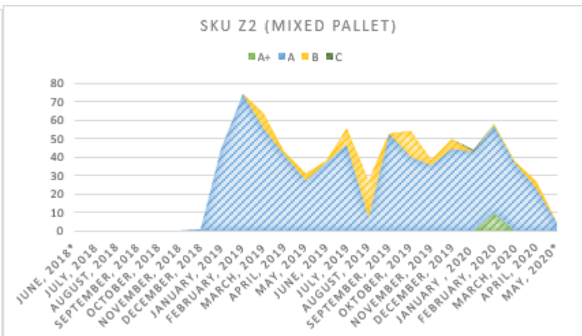
A B C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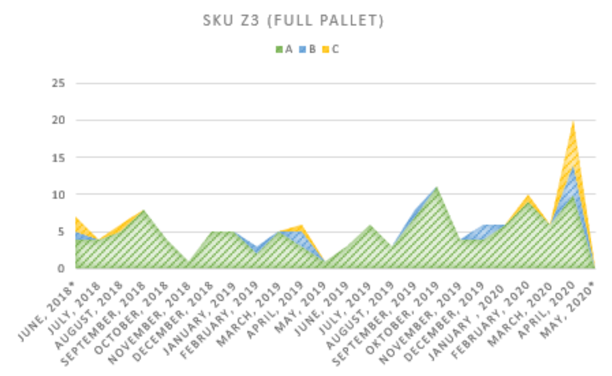

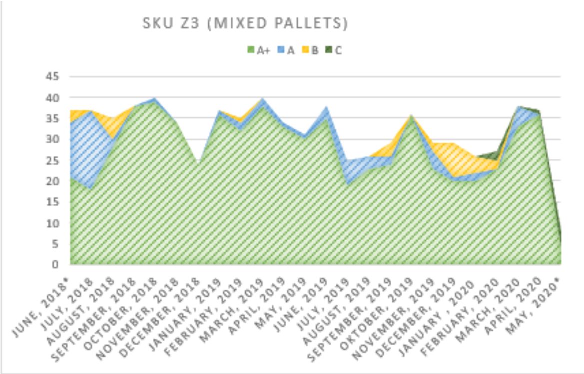

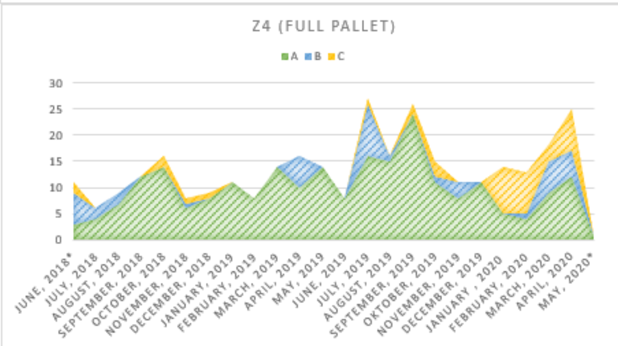

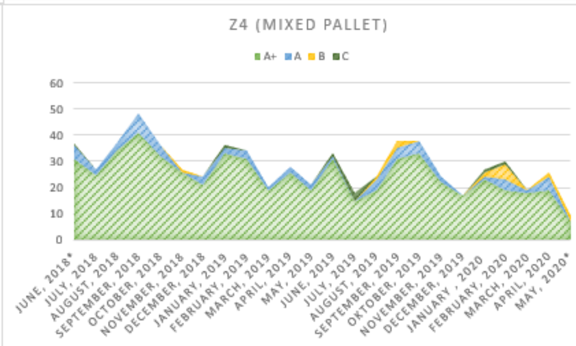

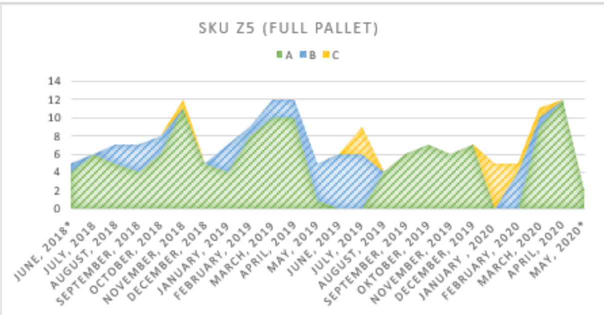

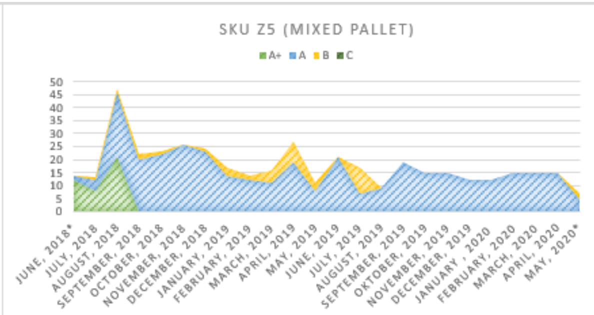

C. Data inquiries

C.1. Transaction data (sample)

Reg-dato	Lc	Fur	Flytte-ty	Bruk	M	Kø	Divis		Prod-batch	Innleverar	Antal	Vekt	Volum	Fra-Ml	Fra-hyll	Fra-X	Fra-Y	So	Plå	Tillg	Best før-dato	Kollinr	Las	Reg-dato	Artikkelnr	Ordre
04-06-2018 12:49:14	4	7	0	DSO	212	BP10	101413		8099	279185	1,00	1,23	4,07	VBP10	028	061	001	A	L13	6992,00	08-04-2020 00:00	373111110000021216	E12	16-04-2018 00:00	113005	0080272884
04-06-2018 12:49:40	4	7	0	DSO	212	BP10	101413		100014857	279216	1,00	0,87	1,54	VBP10	028	091	001	A	L13	2506,00	29-04-2019 00:00	370411100016893811	E12	07-05-2018 00:00	113174	0080272884
04-06-2018 12:50:13	4	7	0	DSO	212	BP10	101413		100014844	279217	1,00	0,87	1,54	VBP10	029	101	001	B	L13	1209,00	28-04-2019 00:00	370411100016888848	E12	08-05-2018 00:00	113176	0080272884
04-06-2018 12:50:35	4	7	0	DSO	212	BP10	101413		800050324	279233	1,00	0,95	2,99	VBP10	029	082	001	B	L13	195,00	20-11-2018 00:00	370036873040456354	E12	26-03-2018 00:00	113277	0080272884
04-06-2018 12:51:02	4	7	0	DSO	212	BP10	101413		100014411	279088	2,00	3,64	13,50	VBP10	029	061	001	B	L13	821,00	03-11-2018 00:00	370411100016766399	E12	09-03-2018 00:00	111587	0080272884
04-06-2018 12:51:42	4	7	0	DSO	212	BP10	101413		800050322	279232	1,00	0,95	2,99	VBP10	031	103	001	A	L13	195,00	20-11-2018 00:00	370036873040456316	E12	26-03-2018 00:00	113276	0080272884
04-06-2018 13:00:28	4	7	0	DSO	212	BP10	101413		100014704	279215	1,00	0,87	1,54	VBP10	031	021	001	A	L13	5361,00	12-04-2019 00:00	370411100016847173	E12	18-04-2018 00:00	113173	0080272884
04-06-2018 13:20:34	4	7	0	DSO	212	BP10	101413		100013999	279250	2,00	3,46	13,50	VBP10	026	121	001	B	L13	650,00	21-11-2018 00:00	370411100016641511	E12	26-01-2018 00:00	113366	0080272884
04-06-2018 13:23:49	4	7	0	DSO	212	BP10	101413		100014454	283977	2,00	3,98	11,78	VBP10	027	162	001	C	L13	138,00	10-11-2018 00:00	370411100016777685	E12	15-03-2018 00:00	113360	0080272884
04-06-2018 13:57:06	18	8	0	RSU	220	HP027	101413		100014849	282036	48,00	184,32	1036,80	VBH10	027	012	002	A	L13	610,00	30-12-2018 00:00	370411100016892456	E12	07-05-2018 00:00	112626	0080272853
04-06-2018 14:12:55	18	8	0	RSU	220	HP028	101413			280170	16,00	96,00	0,16	VBH10	028	051	004	A	L13	2434,00		370036873040059265	E12	12-01-2018 00:00	110727	0080272853
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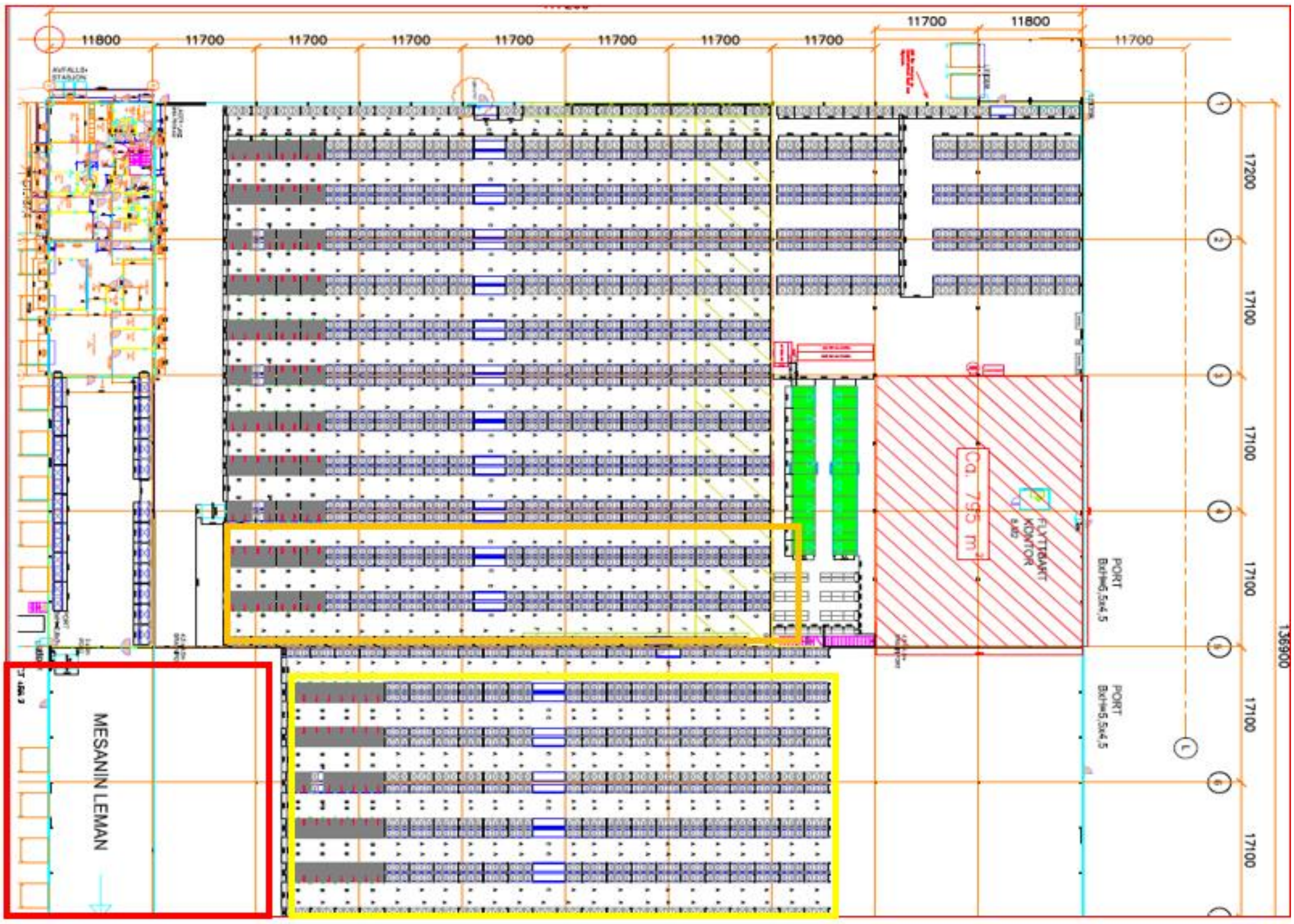
04-06-2018 14:24:49	18	8	0	RSU	220	HP031	101413		100014716	281729	48,00	213,12	1065,60	VBH10	031	161	003	B	L13	1737,00	14-12-2018 00:00	370411100016850654	E12	19-04-2018 00:00	112487	0080272853
04-06-2018 14:33:07	18	8	0	RSU	220	HP027	101413		100014851	279781	240,00	345,60	2,40	VBH10	027	011	002	A	L13	170,00	29-01-2019 00:00	370411100016891145	E12	07-05-2018 00:00	105637	0020065802

C.2. Warehouse layout

Yellow area = Storage area for Brynild own SKUs

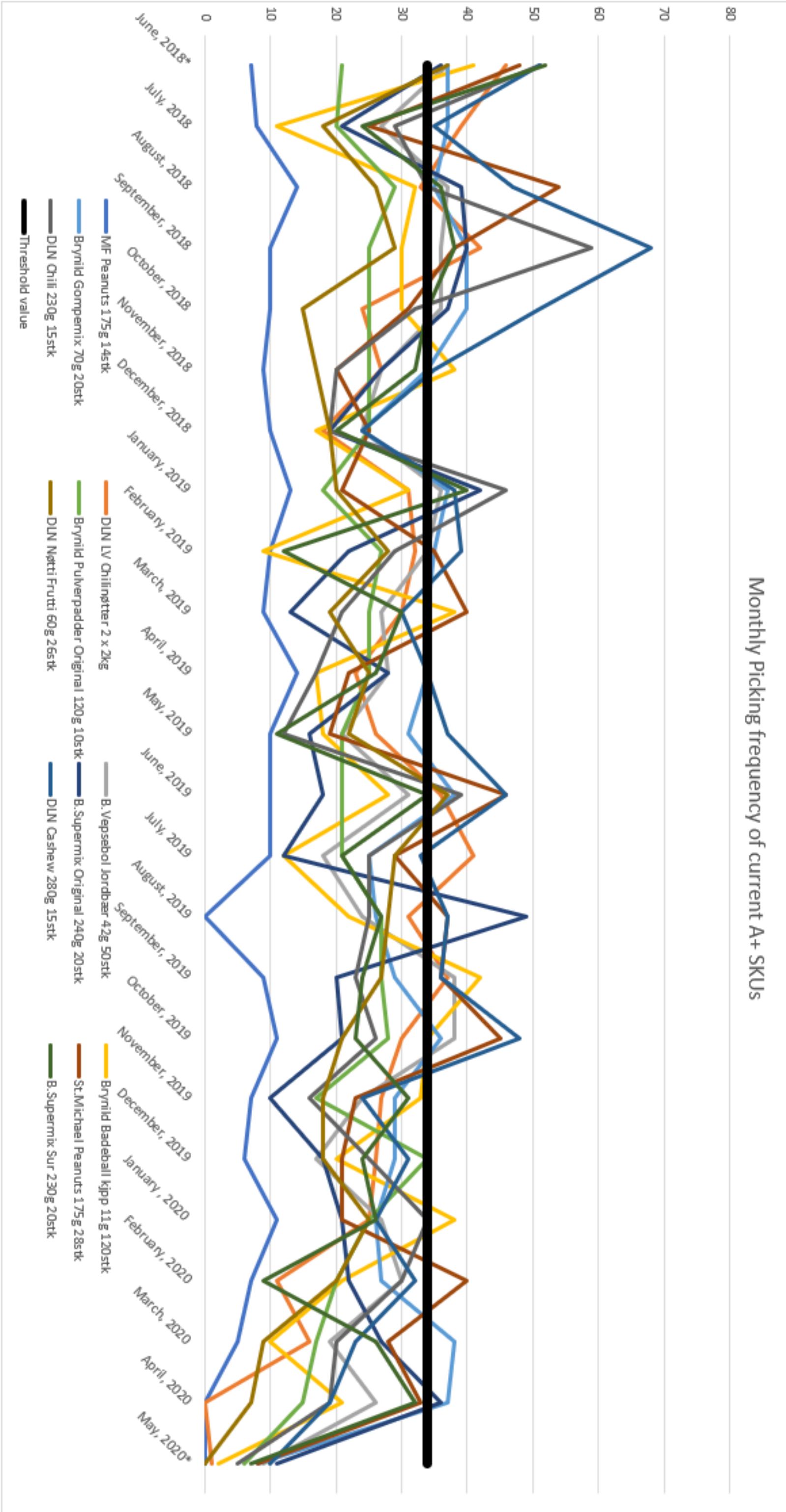
Orange area =Beiersdorf's SKUs

Red area = Mezzanine, used for creating sales solutions

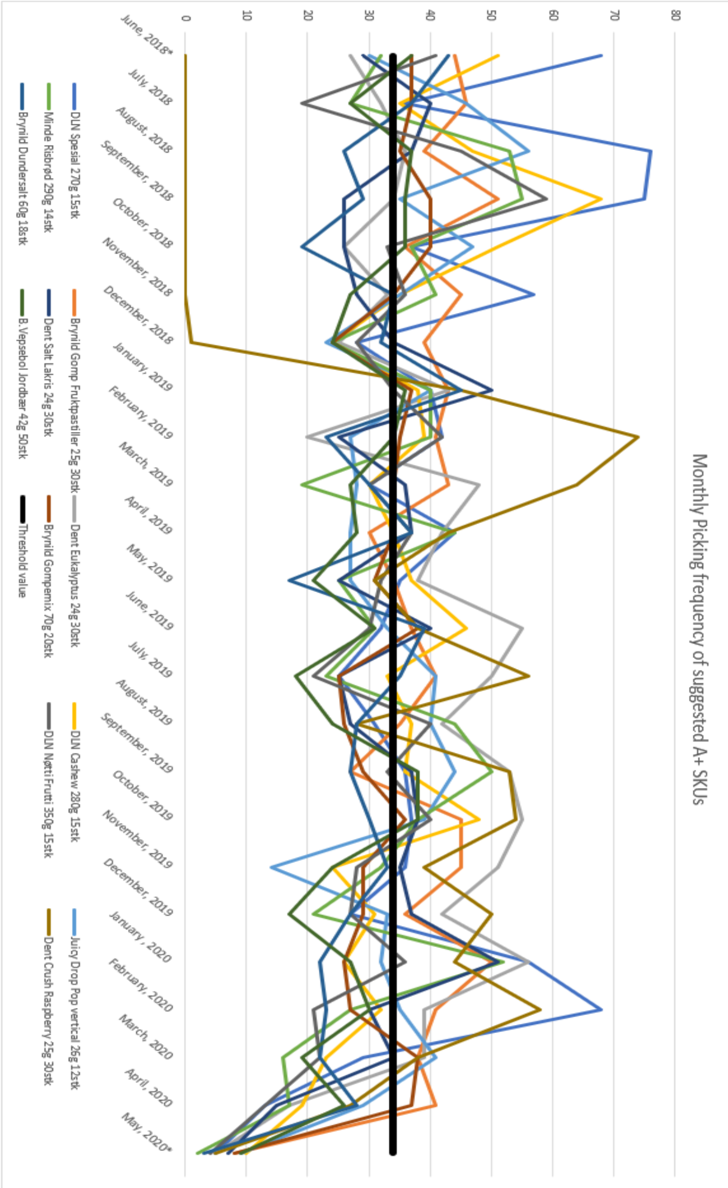


D. SLAP graphs

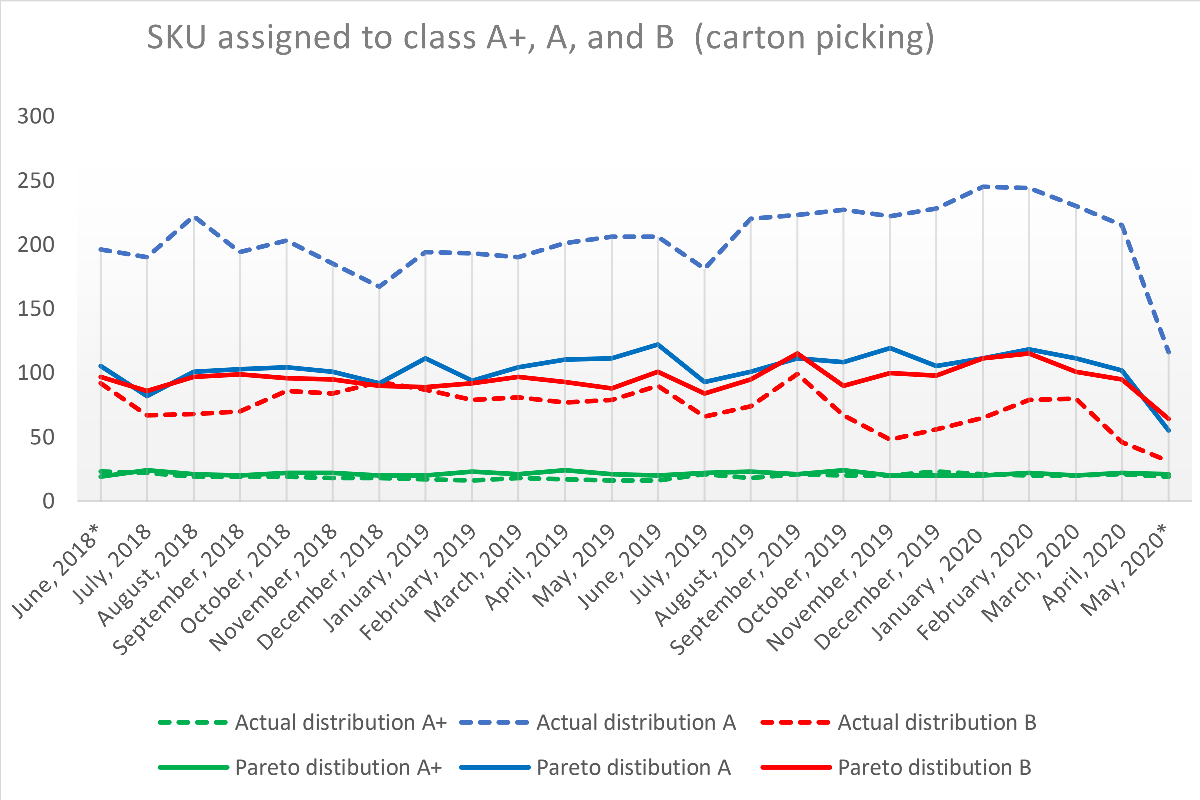
D.1. Current SKUs in the forward picking area



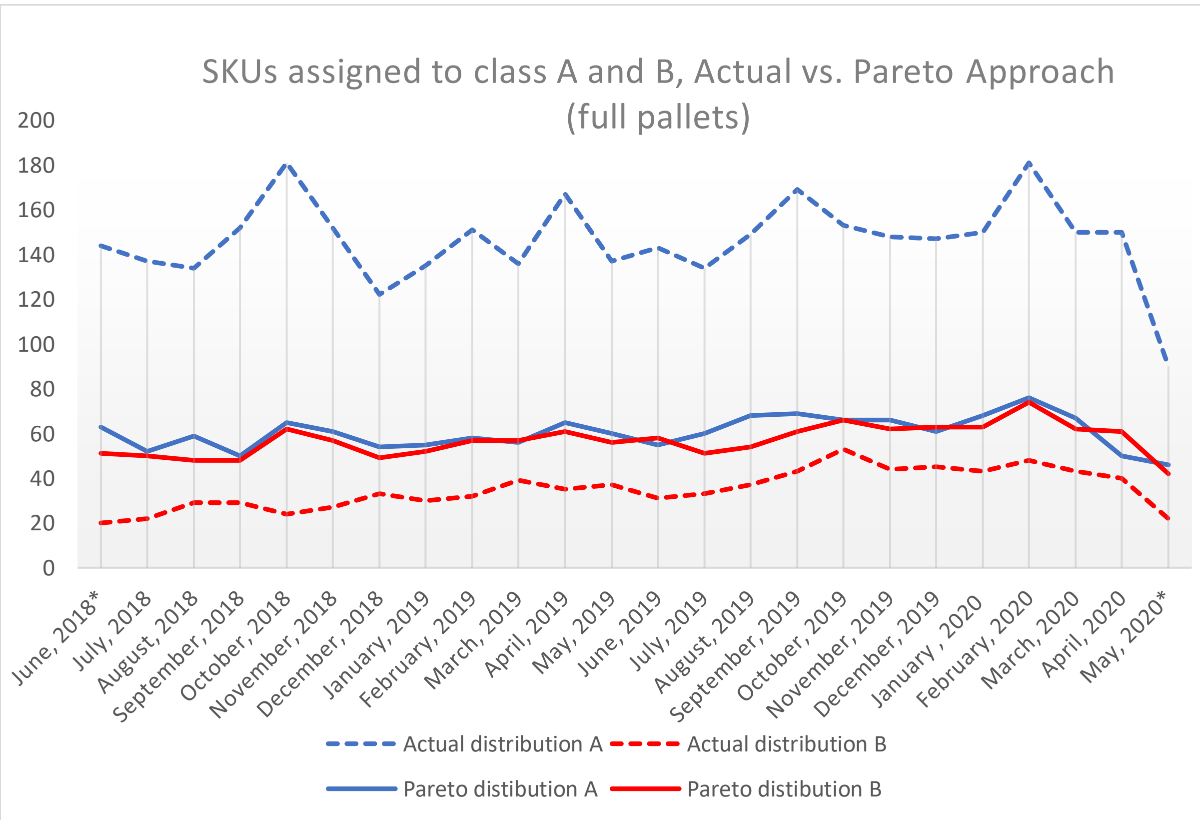
D.2. Suggested SKUs in the forward picking area


Monthly Picking frequency of suggested A+ SKUs
0
10
20
30
40
50
60
70
80
June, 2018*
July, 2018
August, 2018
September, 2018
October, 2018
November, 2018
December, 2018
January, 2019
February, 2019
March, 2019
April, 2019
May, 2019
June, 2019
July, 2019
August, 2019
September, 2019
October, 2019
November, 2019
December, 2019
January, 2020
February, 2020
March, 2020
April, 2020
May, 2020*
DUN Spesial 270g 15stk
Brynild Gomp Fruktpastiller 25g 30stk
Dent Eukalyptus 24g 30stk
DUN Cashew 280g 15stk
Juicy Drop Pop vertical 26g 12stk
Minde Risbrød 290g 14stk
Dent Salt Lakris 24g 30stk
Brynild Gompemix 70g 20stk
DUN Nøtt Frutti 350g 15stk
Dent Crush Raspberry 25g 30stk
Brynild Dundersalt 60g 18stk
B.Vepsebol Jordbær 42g 50stk
Threshold value

D.3. SKUs assigned to a class, Actual vs. Pareto Approach (carton picking)



D.4. SKUs assigned to a class, Actual vs. Pareto Approach (full pallets)



E. Demand variations