Unattended Collection and Delivery Points: Exploring the Concept and Physical Dimensioning

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Abstract

The unattended collection and delivery point (UCDP) is one of several solutions to address the delivery issues arisen by increasing online retail sales. There are four solutions of the UCDP concept: the traditional parcel locker, the automated box design, the automated pillar design and the cart design. Moreover, the physical dimensioning of a UCDP mainly needs to consider the number of orders, order composition and the customers' mean times to retrieve their orders.

This Master thesis project has been conducted in collaboration with Inter IKEA System Services AB (IISSAB) to examine the existing solutions of the UCDP concept, as well as how certain factors affect the physical dimensioning of a UCDP. This thesis will provide answers to the following research questions:

- *Which solutions exist for the UCDP concept and what are their characteristics?*
- *How do the number of orders, order composition, customer behaviour, UCDP localization and schedules of the UCDP service provider affect the utilization and dimensioning of storage containers of the UCDP?*

To provide the answers, a simulation study was conducted in combination with reviewing both academic and non-academic sources. Aside for contributing to the research field of UCDPs, this thesis has the following additional contributions:

- It suggests that UCDPs should be used together with other delivery solutions.
- It suggests that an increase or decrease in number of orders does not generate the same proportionate adjustment of utilization of storage containers of the UCDP.
- It has provided a simulation tool to dimension a UCDP.
- It presents recommendations and managerial guidelines when implementing UCDPs.

Keywords: unattended collection and delivery point (UCDP), simulation study, last mile delivery solutions, e-commerce and physical dimensioning.

Sammanfattning

Obemannade samlings- och leveranspunkter (UCDP) är en av flera lösningar för att komma till rätta med de leveransproblem som uppstått till följd av ökade köp via detaljhandeln online. Det finns fyra lösningar till UCDP konceptet: den traditionella paketautomaten, den automatiserade paketautomatdesignen, den automatiserade pelardesignen och vagndesignen. Vidare så måste den fysiska dimensioneringen av en UCDP huvudsakligen ta i beaktning antalet beställningar, beställningarnas sammansättning och kundernas medeltid för att hämta ut sin beställning.

Detta examensarbete has genomförts i samarbete med Inter IKEA System Services AB (IISSAB) för att undersöka de existerande lösningarna för UCDP-konceptet samt hur vissa faktorer påverkar den fysiska dimensioneringen av en UCDP. Examensarbetet ska förse svaren till följande forskningsfrågor:

- *Vilka lösningar existerar för UCDP konceptet och vilka är deras egenskaper?*
- *Hur påverkar antalet beställningar, beställningarnas sammansättning, kundernas beteende, platsen för UCDP:n och scheman hos UCDP:ns tjänsteleverantör utnyttjandet och dimensioneringen av förvaringsplatser hos UCDP:n?*

För att finna svaren genomfördes en simuleringsstudie i kombination med en granskning av både akademiska och icke-akademiska källor. Bortsett från att bidra till forskningsområdet om UCDP:s så bidrar examensarbetet även med följande:

- Det föreslår att UCDP:s ska användas tillsammans med andra leveranslösningar.
- Det föreslår att en ökning eller minskning av antalet beställningar inte leder till en lika proportionerlig ändring av utnyttjandet av förvaringsplatser hos UCDP:n.
- Det har bidragit med ett simuleringsverktyg för att dimensionera en UCDP.
- Det presenterar rekommendationer och riktlinjer för ledningen vid implementering av UCDP:s.

Nyckelord: obemannade samlings- och leveranspunkter (UCDP), simuleringsstudie, lösningar på det slutgiltiga leveranssegmentet, e-handel och fysisk dimensionering.

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I would further like to show my appreciation to my family: mom, dad and sister. Your support and understanding throughout this thesis have been invaluable to me. I love all of you.

Sara, my girlfriend, you have been by my side every day of this journey. You have brought me so much love, happiness and support, both in times of joy and difficult times. I will support you the same when you will write your thesis. I love you.

To all my friends who have been part of my journey of this thesis project: thank you for your understanding and support, as well as all the joyful moments I have shared with you in the past and during this thesis project, as well will share with you in the future.

Lund, June 2018

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List of Acronyms and Abbreviations

ADS	Automatic delivery station
APS	Automatic parcel station
B2B	Business-to-business
B2C	Business-to-consumer
C2C	Consumer-to-consumer
CDF	Cumulative distribution function
CDP	Collection and delivery point
DA	Data assumptions
IISSAB	Inter IKEA Systems Service AB
LTH	The Technical Faculty of Engineering at Lund University
MA	Model assumptions
NOC	Number of occupied containers
PDF	Probability distribution function
PP	Pick-up point
RQ	Research question
SC	Simulation configuration
TRIA	Triangular random distribution
UCDP	Unattended collection and delivery point
UNIF	Uniform distribution
V&V	Verification and validation

1 Introduction

This introductory chapter of the thesis project is structured as follows. First, the background of the project is presented followed by a problem formulation and the research questions this thesis will answer. Then, the purpose and objectives of the thesis are presented. The introductory chapter concludes with presenting the scope and delimitations of the thesis project as well as a structure of the report.

1.1 Background

The growth of e-commerce has led to issues in the last mile delivery. To solve these problems, several solutions for the last mile delivery have been proposed. The cause-and-effect relationship as well as one of the solutions will be further explored in the following sub-sections.

1.1.1 **The Rise of E-commerce**

With the rapid technological advancement and development, the Internet and Web technologies have changed the way of conducting business, and thus also has changed the traditional way of commerce. The result is e-commerce, short for electronic commerce (Khurana, 2017). In general terms, e-commerce is the buying and selling of information, products and services through the means of computer networks (Stafford & Gillenson, 2003, p. 33). There are commonly three mentioned types of E-commerce transactions: business-to-consumer (B2C) transactions, business-to-business (B2B) transactions (Maamar, 2003, p. 252) and consumer-to-consumer (C2C) transactions (Khurana, 2017).

E-commerce has grown significantly throughout the years and will continue doing so the coming years. Future projections show that the worldwide online retail sales is projected to grow from 1,34 trillion US dollars in 2014 to 4,48 trillion US dollars in 2021 ("Retail e-commerce sales worldwide from 2014 to 2021 (in billion U.S. dollars)," 2017). This is an average increase with 19,2 percent per year over the five-year period. Not only does the projection for the online retail sales show a significant increase, but so does the share of online retail sales of the total retail sales. This figure globally is expected to increase from 7,4 percent to 15,5 percent from 2015 to 2021 ("E-commerce share of total global retail sales from 2015 to 2021," 2016). The projections for both the worldwide retail e-commerce sales and e-commerce share of total global retail sales are presented in Figure 1 below.

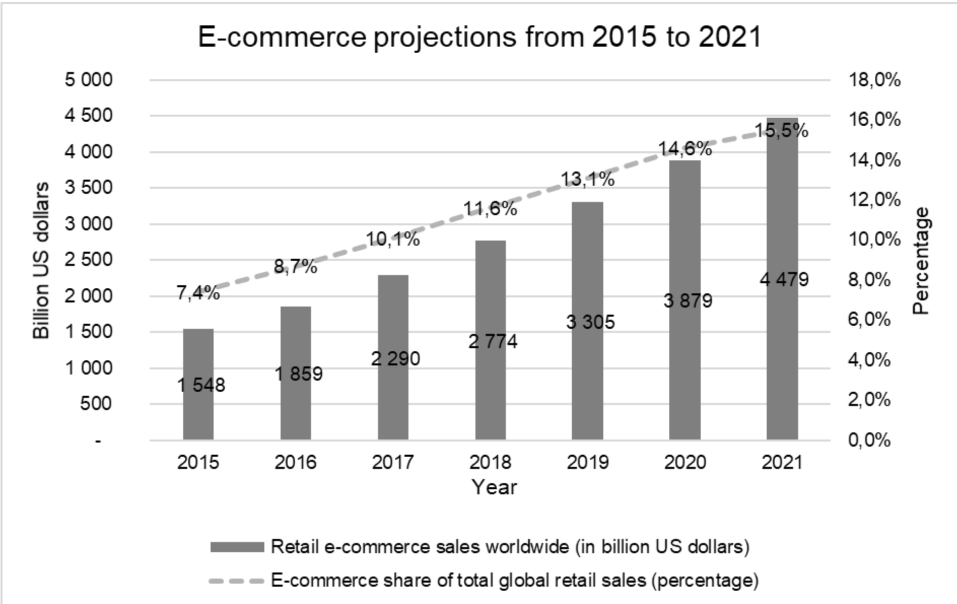

Figure 1 The projections of the e-commerce retail sales worldwide (in billion US dollars) and e-commerce share of total global retail sales (in percentage) between 2015 to 2021 (based on eMarketer (2016, 2017)).

Because of increased online retail sales, shipped parcel volumes worldwide have increased. Between 2014 and 2015, the parcel volume increased with 9,4 percent and 7,6 percent in Europe and North America respectively. At the same time, it decreased with 0,4 percent in the Asia Pacific ("Global parcel volume trend between 2014 and 2015, by region," n.d.). 20 percent increase in global parcel shipping is expected by 2018, with an annual growth rate between five to seven percent. 31 billion parcels were shipped in 2014, which was an increase with 2,4 percent compared to the previous year ("Pitney Bowes Parcel Shipping Index forecasts 20 percent industry growth by 2018," n.d.).

1.1.2 The Last Mile Delivery Problem

The growth of e-commerce has caused issues in the so called last mile. The last mile is mentioned as being the final segment of the supply chain (Morganti, Seidel, Blanquart, Dablanc, & Lenz, 2014, p. 182) or the last segment of movement from the last upstream distribution centre, local warehouse or consolidation point to the final destination (Z. Xiao, Wang, Lenzer, & Sun, 2017, p. 985). The last mile delivery problem is thus the logistics problem of e-commerce directed towards retail recipients concentrated on the last stage of the delivery (Moroz & Polkowski, 2016a, p. 381).

Although e-commerce offers several advantages, it poses many challenges to the supply chain, mostly due to the online shopping behaviour and preferences of the customers. The causes for the last mile delivery problem are several:

- Because of e-commerce, there has been an increasing fragmentation of orders (Lemke, Iwan, & Korczak, 2016, p. 273) and shipments (Morganti, Seidel, et al., 2014, p. 182) in the last mile delivery. The fragmentation is due to that online shoppers usually buy in small amounts (Lemke et al., 2016, p. 273), but at the same time they do it relatively often (Moroz & Polkowski, 2016a, p. 379).
- The customers, which is often a wide dispersion of recipients, expect fast deliveries and deliveries within a particular time window (Z. Xiao et al., 2017, p. 986). To satisfy the customers' need, the companies provide the delivery services regardless of the fill rate in the transport vehicles (Lemke et al., 2016, p. 273).
- Many parcels do not fit in the mail- or letterboxes or require a consignee signature. The customer is hence required to be at home once the parcel is delivered, which is often not the case. This leads to an increase in redelivered or returned parcels to the sender. As home deliveries increase, so does the number of failed deliveries (Weltevreden, 2008, p. 639). This also causes an increase in pollution emissions (de Oliveira, Morganti, Dablanc, & de Oliveira, 2017, p. 35) .

The cost of the last mile delivery problem is considered high, although this varies. Wang, Yuen, Wong, and Teo (n.d., p. 3) states that 28 percent of the total transportation costs is due to the last mile delivery, while Z. P. Xiao, Wang, and Liu (2018, p. 4) instead present a range of 30 percent up to 50 percent. Z. Xiao et al. (2017, p. 386) present the number 53 percent as the cost of last mile deliveries in proportion to total logistics costs. According to the same source, the proportion can reach as high as 75 percent. Although there is no exact number on how much the last mile delivery problem costs in proportion to total transportation or logistics costs, it is implied that it is a high cost which needs to be addressed.

1.1.3 Brief Introduction to the Unattended Collection and Delivery Point

One of the solutions to tackle the last mile delivery issue is the unattended collection and delivery point (UCDP). The “parcel locker” (Vakulenko, Hellström, & Hjort, 2017b, p. 1) is one of the more commonly known solutions to the UCDP concept. An example of a parcel locker is seen in Figure 2. A UCDP in brief is a stationary online retail distribution point which requires no attendance by service personnel.

Figure 2 An example of a parcel locker, one solution of the UCDP concept ("The EGG Smart Locker System/Package Delivery System," 2018).

1.2 Problem Description

The research which has been conducted in the field of unattended collection and delivery points have been focusing mostly on the consumers’ preferences regarding various aspects of the UCDP. In addition, some research has examined the economic benefits of properly locating UCDPs but has also compared the economic benefits of UCDPs to other last mile delivery solutions.

However, no identified research examines the available solutions of the UCDP concept. Furthermore, the identified research does not examine the storage containers of the UCDP and the impact of factors such as the number of orders, order composition, customer behaviour, the location of the UCDP and the schedules of the UCDP service provider regarding utilization and dimensioning.

1.3 Research Questions

Considering the background and problem description of the thesis presented in the previous two sections, the following research questions (RQ) are proposed for the thesis:

RQ1: Which solutions exist for the UCDP concept and what are their characteristics?

RQ2: How do the number of orders, order composition, customer behaviour, UCDP localization and schedules of the UCDP service provider affect the utilization and dimensioning of storage containers of the UCDP?

1.4 Project Purpose

The purpose of this thesis is to gain an insight into which available solutions exist for UCDPs, their distinct features and characteristics. In addition to this, factors that affect the dimensioning and utilization of storage containers of the UCDP will also be examined. The thesis is done in collaboration with Inter IKEA System Services AB (IISSAB).

1.5 Project Objectives

The objectives of the project are threefold:

1. Present the reader to different solutions to the UCDP concept and make a comparison of these.
2. Develop a generic simulation tool for dimensioning a UCDP by IISSAB.
3. Present managerial guidelines and recommendations to IISSAB to consider when implementing a UCDP.

1.6 Project Scope and Delimitations

The first delimitation of this thesis is that the study is limited to the B2C-side of e-commerce sales. As a second delimitation, the thesis only includes UCDP solutions which are available to retrieve information about for the researcher.

1.7 Structure of the Report

Following this introductory chapter to the thesis, the next chapter presents the methodology used to find the answers for the proposed research questions. The third chapter presents the frame of reference, which is a synthesis of the available research which has been conducted in the field. The fourth chapter presents the developed simulation study in more detail, while chapter five presents the results of it. An analysis and discussion regarding the identified UCDP solutions and the findings from the simulation study is conducted in chapter six. The concluding chapter is chapter seven, which presents the conclusions and contributions of this thesis project.

In addition, the report has one appendix. This appendix briefly introduces the reader to the developed simulation model.

2 Research Methodology

This chapter presents the different methodologies used in the thesis. First, the research strategy in general is presented, followed by a description regarding each of the methodologies used: literature review and simulation study. Only the theoretical approach to the simulation study will be presented. The concluding section summarizes the chapter.

2.1 Research Strategy

Applying a proper research strategy is at the core of any thesis. The essence in conducting research is to gain knowledge and insights to questions formulated in advance in a deliberate and systematic manner.

There are two different types of research. Scientific research aims to increase the general knowledge in a particular field (Jonker & Pennink, 2010, p. 9). The proposed research questions and purpose of this thesis are presented in a general setting (see 1.3 Research Questions and 1.4 Project Purpose), categorizing it as a scientific research. The other type of research is applied research, with the goal to solve and improve on a particular issue (Jonker & Pennink, 2010, p. 9).

The research strategy which will be used in this thesis project mainly consists of two methodologies: a literature review and a simulation approach. In addition to these, information was gathered through several personal conversations with the supervisor of IISSAB. Research methodology is defined as the way the researcher conducts the research, the way the researcher chooses to examine the research questions at hand (Jonker & Pennink, 2010, p. 17). The literature review will present what research has been conducted in the field of UCDPs and give an understanding of the existing knowledge in the field. The literature review will result in a frame of reference. Conversely, the literature review will uncover what research has not been done regarding UCDPs.

The second method employed in the thesis is to develop a simulation study in collaboration with IISSAB. The simulation approach is suitable according to Banks (2010a, p. 22), because it can be used with input data from a real-world system to study the behaviour of the system over time.

While the literature review is of a more qualitative manner, the simulation approach is of a quantitative manner. Combining qualitative and quantitative research methodologies is called the “multi-method” approach (Jonker & Pennink, 2010, p. 92) and the combination is a preferred method to increase the legitimacy of the research (Jonker & Pennink, 2010, p. 95).

2.2 Literature Review

As a first methodology used in this thesis project, an extensive literature review regarding the research questions (see 1.3 Research Questions) will be conducted. In its essence, a literature review is the systematic search and evaluation of the available literature with regards to the research subject or question ("What is a literature review?," 2018). The goal of the literature review is to examine the current knowledge of UCDPs in academic research leading to a frame of reference.

Two types of literature reviews were conducted: one based on academic sources and the other based on non-academic sources.

2.2.1 **Identifying a Suitable Literature Review Method**

There are several different types of literature reviews. Grant and Booth (2009b) present 14 different taxonomies on reviews. A description of the 14 different review types are presented in Table 1 below.

Table 1 The main review types (fraction of table by Grant and Booth (2009a)).

Taxonomy of review	***Description***
Critical review	Aims to demonstrate that the writer has extensively researched the literature and critically evaluated its quality. Goes beyond mere description to include degree of analysis and conceptual innovation. Typically results in hypothesis or model.
Literature review	Generic term: published materials that provide examination of recent or current literature. Can cover wide range of subjects at various levels of completeness and comprehensiveness. May include research findings.
Mapping review/ systematic map	Map out and categorize existing literature from which to commission further reviews and/or primary research by identifying gaps in research literature.
Meta-analysis	Technique that statistically combines the results of quantitative studies to provide a more precise effect of the results.
Mixed studies review/mixed methods review	Refers to any combination of methods where one significant component is a literature review (usually systematic). Within a review context it refers to a combination of review approaches for example combining quantitative with qualitative research or outcome with process studies.
Overview	Generic term: summary of the literature that attempts to survey the literature and describe its characteristics.
Qualitative systematic review/qualitative evidence synthesis	Method for integrating or comparing the findings from qualitative studies. It looks for ‘themes’ or ‘constructs’ that lie in or across individual qualitative studies.
Rapid review	Assessment of what is already known about a policy or practice issue, by using systematic review methods to search and critically appraise existing research.
Scoping review	Preliminary assessment of potential size and scope of available research literature. Aims to identify nature and extent of research evidence (usually including ongoing research).
State-of-the-art review	Tend to address more current matters in contrast to other combined retrospective and current approaches. May offer new perspectives on issue or point out areas for further research.
Systematic review	Seeks to systematically search for, appraise and synthesize research evidence, often adhering to guidelines on the conduct of a review.
Systematic search and review	Combines strengths of critical review with a comprehensive search process. Typically addresses broad questions to produce ‘best evidence synthesis’.
Systematized review	Attempt to include elements of systematic review process while stopping short of systematic review. Typically conducted as postgraduate student assignment.
Umbrella review	Specifically refers to review compiling evidence from multiple reviews into one accessible and usable document. Focuses on broad condition or problem for which there are competing interventions and highlights reviews that address these interventions and their results.

Although the difference between the several taxonomies presented above are vague, the goal of the frame of reference as an outcome of the literature review, is to provide analysis and in conclusion answers to the first RQ (see 1.3 Research Questions). Thus, choosing amongst the proposed 14 taxonomies in

Table 1, the review used in this thesis is systematized review as this also is typically done in postgraduate student assignments.

2.2.2 Conducting the Academic Literature Review

The academic literature review is an important part of many academic documents, as it seeks to synthesize the findings to the related topic (Neill, 2017, p. 1). According to Lingard (2018, p. 47), the purpose of a literature review is to identify what remains unknown rather than to identify what is already known. An alternative formulation of the purpose of the literature review is that it provides a framework of the available related findings to previous findings (Randolph, 2009, p. 2).

The approach to conduct a literature review is first to establish a research question followed by searching for articles to determine what has already been discovered about the research question. By using keywords in a search engine database and using multiple databases, an exhaustive search can be reached. Next, the identified literature should be analysed (Neill, 2017, pp. 1-2), through extraction and evaluation of the information (Randolph, 2009, p. 7), and compiled systematically into related sections of the report (Neill, 2017, p. 2). A similar step-by-step approach, including the steps problem formulation, data collection, data evaluation, analysis and interpretation and public presentation, is presented by Randolph (2009, p. 4).

Using the presented theoretical approach to conduct an academic literature review, the first RQ stated in 1.3 Research Questions were used as the foundation for the literature review. The main search engine database employed in the literature search of academic literature was LUBSearch, the library of Lund University which is one of the largest digital databases in Sweden containing 320 000 e-books, around 200 databases and more than 78 000 e-journals ("LUBSearch & Electronic Resources: Home," 2018). This database was complemented by other databases and search engines, such as Emerald Insights, Web of Science and Google Scholar. In addition to the digital search engine databases, non-digital literature was acquired from the library at the Technical Faculty of Engineering at Lund University (LTH) and other related university libraries.

The keywords which were used in the literature search were identified at the start of this thesis through the research questions and topic. The following keywords gave fruitful results in the initial search of the search engine databases: *last mile delivery solutions, parcel lockers* and *e-fulfilment solutions*. However, the literature identification is an iterative process, and through the initial results of literature, the following keywords were used to identify further literature: *last mile distribution, parcel station, automated parcel station, collection and delivery point, customer parcel collection point, automated delivery station, e-commerce final delivery, automated parcel delivery terminal, locker solutions, reception box, unattended collection and delivery point* and *simulation*. After the second search, the literature collection process had reached saturation and the process was stopped. This is suggested by Randolph (2009, p. 7).

Each identified literature was first screened by its title, abstract and keywords, as suggested by Randolph (2009, p. 7) to decide whether it contributed to the topic of the thesis or not. If deemed acceptable, a summary of the literature was written, consisting of mainly the problem formulation and findings from the literature. Keywords and references were also taken note of to identify further relevant literature. For each literature, a short reflection about how it could potentially contribute to the thesis was written. The findings of the literature review will be presented in the frame of reference in the next chapter of this report.

2.2.3 Conducting the Non-Academic Review

Non-academic resources were also used in the thesis. The identified academic literature did not bring any potential answers to RQ1 (see 1.3 Research Questions). Instead, non-academic sources provided fruitful results.

There is much value to be found in the non-academic resources (Candice, 2009, p. 156). However, the difference between an academic and non-academic resource needs to be defined first. The definition of both of these distinct resources are derived from an evaluation using four criteria (Candice, 2009, p. 156):

- *Authority:* The authority of an academic resource is derived from peer review, the name of the author(s) and academic affiliation of the author. This is seldomly applied to non-academic resources.
- *Accuracy:* The accuracy of an academic resource is determined by double-checking facts in other sources and by knowing if an editor has been involved. Non-academic resources are self-edited, and the content may be unique.
- *Coverage:* The coverage of a topic in an academic resource is often in depth. This often does not apply to non-academic resources.
- *Objectivity of the source:* This is an evaluation category and in academic resources, this category is used to uncover unstated agendas and bias.

These criteria are suitable to distinguish academic resources from non-academic resources. Yet, the criteria are unable to identify which non-academic resources which are valuable and which are not (Candice, 2009, p. 156). To remedy this issue, Candice (2009, p. 160) proposes the following guidelines to distinguish between valuable and non-valuable non-academic resources:

- The researcher must determine if the non-academic resource is presented at the level of scholarship or learning appropriate to the task at hand.
- The non-academic resource supports an argument, either by example or by evidence.
- The non-academic resource adds value.

- The non-academic resource presents legitimate information.

With the four guidelines to assess the value of non-academic resources kept in mind, the following restrictions were set for the search process. As a first limitation to the search, only UCDP manufacturers or the first-tier supplier of the UCDP and not UCDP service providers were sought. The difference is that the product of a UCDP manufacturer or first-tier supplier can be used by several UCDP service providers. This also means that UCDP retailers and organizations integrating or using a third-party UCDP are excluded. The second limitation was that primarily technical data regarding the UCDP was sought. The third limitation was that the goal of the search process was to identify different solutions to the UCDP concept and to distinguish which solution belong to the UCDP concept or which does not, the following key criteria for a UCDP needed to be fulfilled (see 3.4 Identified Themes in the Literature):

1. A UCDP requires the customer to fulfil the last mile delivery, meaning the customer has to cover a distance to fulfil the delivery.
2. A UCDP handles both parcel collection and sometimes returns.
3. A UCDP can store several parcels at a time.
4. A UCDP is unmanned, unattended and electronic.
5. A UCDP is a stationary last mile delivery solution.

The search engine used in this search process was Google and was conducted by using several keywords. In the first iteration of searching for non-academic sources, the keyword *parcel locker* was used. In the second iteration of the search *parcel locker manufacturer, parcel locker provider, smart lockers, parcel station, package delivery system, self-service parcel pick up, intelligent courier locker* and *automated locker system* were used. Once the search had reached saturation, a total of 18 UCDP manufacturers had been identified.

2.3 Theoretical Approach of Simulation Studies

2.3.1 **Introduction to Simulation Studies**

To provide answers for RQ2 (see 1.3 Research Questions), the literature review will be complemented by a simulation model developed with IISSAB to identify how certain factors affect the physical dimensioning of a UCDP.

As defined by Banks (2010a, p. 21), simulation is the imitation of a real-world process or system over time. A simulation model can be created to study the behaviour of the real-world system as it develops over time. By using data observed in the real world, the simulation model can generate data of the performance of the system. Simulation is nowadays a widely used and accepted tool in operations research and system analysis, because of the computing capabilities decreasing the cost per operation and advancement in simulation methodologies (Banks, 2010a, p. 22).

Simulation as a tool has both its advantages and disadvantages. The advantages mentioned by Banks (2010a, pp. 23-24) are:

1. The simulation can be used to evaluate different setups of the real-world system without interrupting the real-world system.
2. A real-world system can be tested before being implemented, and thus cost savings can be realized.
3. Simulation can be used for hypothesis testing.
4. The simulation, being run over time, can either be speed-up or slowed-down so that more detailed observation of a phenomenon in the system can occur.
5. Insights about the internal interactions of variables, and their importance to the performance of the system, can be observed as well.
6. It helps individuals understand how the system operates in an objective manner.
7. Different scenarios can be tested and thus answers can be provided to “What if”-questions.

By applying a simulation approach in the context of this thesis, IISSAB can test their system before it is implemented in the real-world, analyse how various factors interact with each other and the output as well as test different scenarios.

However, as also being mentioned by Banks (2010a, p. 24), the disadvantages of using simulation are that it requires special training, simulation results can be difficult to interpret, developing a simulation model can be time consuming and expensive, especially if analytical solutions are possible substitutive methodologies.

Even though simulation has both its advantages and disadvantages, it is not always an appropriate tool. This is true if the problem can be solved by common sense or analytically but also if the costs of performing direct experiments is lower than using simulation or if the savings are lower than the expected costs. Another circumstance when simulation is not appropriate is when the required resources are unavailable or when there is restricted time to perform the simulation (Banks, 2010a, pp. 22-23). With regards to the second RQ, a simulation model was deemed as an appropriate approach to examine how the physical dimensioning of IISSAB’s UCDP and hence no other approaches were suggested. This is because of the following reasons:

- The flow of orders to and from the UCDP is complex in the real world. Furthermore, the flow is affected by many behavioural and stochastic variations in the real world.
- It is costly to perform experiments in the real world with various type of settings and especially type of UCDP.

- Other methods can be used to study aggregated values, but a simulation model can examine how certain factors are affected over time, which is important when studying how various factors affect the physical dimensioning of a UCDP.

2.3.2 The Structured Process of Developing a Simulation Study

When performing a simulation study, it is important follow a structured process in how to develop the simulation model. Banks (2010a, p. 35) has constructed a theoretical structured process when creating a simulation model, which is illustrated in Figure 3. This process will be adopted when creating and developing the simulation model in this thesis. The structured process consists of in total twelve steps, which are presented in the following sub-sections. Robinson (1999, p. 6) similarly proposes the same steps, although these are not necessarily performed in the sequential manner as presented below and that iteration among the steps are necessary. Furthermore, verification and validation should be performed continuously and iteratively throughout the simulation study (Robinson, 1999, p. 7).

For each of the following sub-sections, a brief description of the simulation step from the literature is presented.

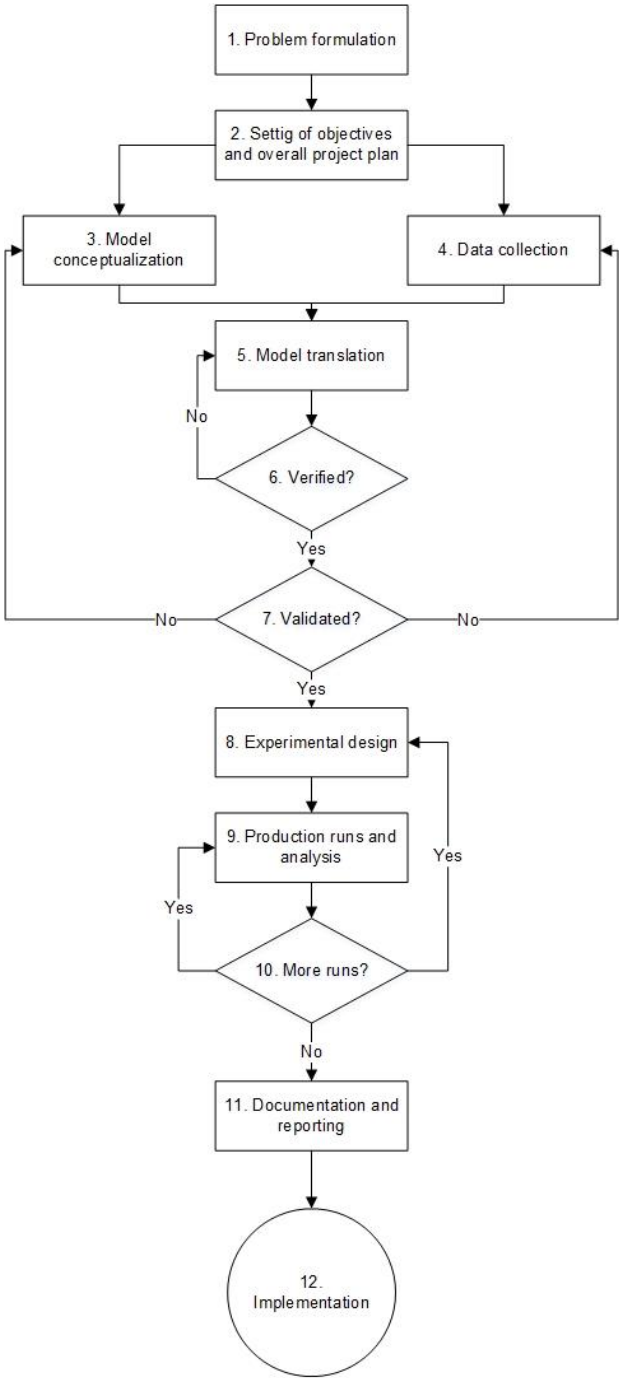

Figure 3 Steps in a simulation study (Banks, 2010b).

Problem Formulation, Setting of Objectives and Overall Project Plan

The first and most important step when developing a simulation model is to create an understanding of the real world to state the problem which the simulation model should analyse (Robinson, 1999, p. 5). Although this is the first step in the process, this step might be revisited if the problem statement needs to be reformulated (Banks, 2010a, p. 34).

By using the stated problems, it is necessary to also check if simulation is an appropriate tool. If simulation is deemed as appropriate, then the problem formulation should be translated into objectives by stating questions to be answered by the simulation (Banks, 2010a, p. 36).

Model Conceptualization

The simulation model is an abstraction of a real-world system, and thus the model should abstract the essential features of the problem by selecting and modifying assumptions that characterize the system. At first, a simple model should be developed which then later till become more complex as the process progresses (Banks, 2010a, p. 36). Model conceptualization revolves around recognizing the internal interactions within the system before developing the simulation model in a software.

Data Collection

Data collection should be performed as early as possible, as it is one of the most time-consuming steps in a simulation process. Data collection is also closely interlinked with the construction of the model; thus, this is an iterative step. This is because as the complexity of the model changes, new data might be identified as being necessary. Furthermore, the data required is also closely linked to the objectives of the simulation model (Banks, 2010a, p. 36).

Model Translation

This step uses the acquired data and the model conceptualization to program the model in a simulation software (Banks, 2010a, pp. 36-37), or alternatively expressed by Robinson (1999, p. 5), to develop a computer model of the conceptual model.

Verification and Validation

Verification and validation (V&V) are maybe the most important steps in a simulation study. V&V are concerned with trying to prove that a simulation model is incorrect. When it cannot be proved that a model is incorrect, it increases the confidence that the simulation model and its results are accepted. It is however, not possible to prove that a simulation model is correct (Robinson, 1999, p. 23). Without a thorough V&V, there are no grounds to place confidence in the results of the simulation model (Robinson, 1999, p. 3). As mentioned previously, V&V should be carried out during the whole simulation study, in an iterative manner. However, every aspect of the simulation model cannot be verified and validated, as there is not enough time to do this (Robinson, 1999, p. 11).

The meaning of verification and validation as well as different methods of V&V are presented below.

Verification

As described by Sargent (2007, p. 124), model verification is “ensuring that the computer program of the computerized model and its implementation are correct”. An alternative formulation of model verification is given by Banks (2010a, p. 407), which states that verification is concerned that the model built has been built correctly. Model verification is a comparison of the conceptual model and the computerized model to see if the computerized model represents the conceptual model correctly. A third definition of the term verification is proposed by Robinson (1999, p. 4). Model verification ensures that the model is built right, so that the conceptual model has been translated to a computer model with sufficient accuracy. Verification is also a micro check of the simulation model (Robinson, 1999, p. 15).

Several methods to verify a simulation model are presented in the literature by Banks (2010a, p. 407):

- The simulation model should be checked by someone who is an expert in the simulation software and is not the developer of the simulation model.
- Examine the inputs and outputs of the simulation model post running it.
- Make the simulation model as self-documenting as possible.
- If animation is applied in the simulation model, study the animation to see if it imitates the actual system.
- Use the built-in debugging tool in the simulation software to identify any errors.

Further verification methods are proposed by Robinson (1999, pp. 15-17):

- The modeller should read through the code of the simulation model to check whether the correct data and logic have been applied.
- Study the visual display of the simulation model to check how the elements of the simulation model are affected by the model’s logic and the behaviour against the real-world system. The visual display check can be done by stepping through the model event by event, force certain conditions to take place and tracing a specific item throughout the flow of the simulation model.

Validation

The term validation has several formulations depending on the literature. In one article, validation is building the correct model, to ensure that the model is sufficiently accurate for the purpose of the simulation study (Robinson, 1999, p. 4). Another definition of validation is: to answer the question whether the correct model has been built, that is, if the computerized model is a correct representation of the real-world system (Banks, 2010a, p. 407). Sargent (2007, p. 124) gives a likewise definition of model validation, which is "substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model". Validation is considered to be the most crucial step among the twelve steps of the simulation study process, because implementing an invalid model could lead to erroneous results which could be both costly and dangerous (Banks, 2010a, p. 39).

However, there are several problems in validating a simulation model. First, it is impossible to prove a model to be completely valid. Instead, validation should be thought of terms of confidence which can be put in the simulation model. Second, the purpose of the simulation study is the focal point of validation. One model may be validated for one purpose, while being invalid for another purpose. In its essence, the only model which is valid, is the real-world "model". Third, since a simulation study can be developed for systems which have not been implemented in the real-world, the consequence is that there is no real-world system to validate the simulation model against. Fourth, different people have different views of the real-world system. The consequence of this is that a model may be valid for one person, but invalid for another. Lastly, if data proves to be inaccurate, this creates problem in determining if the simulation model results are correct. However, even though data from the real-world data does exist, it is only a sample, which creates inaccuracies. Furthermore, to validate every aspect of a simulation model is too time consuming (Robinson, 1999, pp. 9-11).

Although there exists several difficulties with validation, Robinson (1999, pp. 12-21) proposes several concepts and methods which can be used for validation:

- *Conceptual model validation:* The modeller of the simulation study needs to acquire an in-depth understanding of the real-world system through interaction with the people who has the knowledge of the system. Furthermore, the modeller needs to understand the problem at hand. The modeller then needs to interpret the information and develop a consensus with the people involved in the project. If any changes or errors are identified, these should be incorporated in the simulation model. However, no formal methods for validating a conceptual model exist.
- *Data validation:* The simulation study modeller should analyse the data used for the simulation model and assess its reliability and identify any inconsistencies. If erroneous data or unavailable data is identified, collecting or estimating the data is necessary, as well as to perform a sensitivity analysis of the inaccuracies in the data.
- *White-box validation:* The white-box validation is practically the same as verifying the simulation model, but the validation method ensures that the developed simulation model is a correct representation of the real-world system. White-box validation can be done by checking the data and logic of

every element of the simulation model, by checking the simulation model's visual flow and comparing the simulation's output to the actual results.

- *Black-box validation:* This approach studies if the overall behaviour of the simulation model represents the real-world system. While white-box validation is a micro check of the simulation model, the black-box validation is instead a macro check. The black-box validation can either be implemented by comparing the simulation model to the real-world system or, if there exists no real-world system, to compare the model to other models.
- *Experimentation validation:* By using the simulation model to perform experiments of the real-world system, these experiments require significant validation of various facets of the simulation model. Some of these facets are: to remove any initialisation bias, run the simulation model for a sufficient amount of time to obtain results which are sufficiently accurate and to consider the thoroughness of the experiments. However, there must be a compromise between accuracy and experimentation time.
- *Solution validation*: If the aim of the simulation model is to assure validity of a final solution, the simulation model can be validated by comparing the results with the real-world system once this has been properly implemented. If the purpose of the simulation model is to understand a phenomenon occurring in the real-world, then this validation method is not possible to use.

Experimental Design

Performing scenario analysis is the essence of simulation. This is the eighth step in the structured process in developing a simulation model. As stated previously, simulation can evaluate different alternatives of the real-world system. In this step, these alternatives need to be determined, usually as a function of runs that have been completed and analysed (Banks, 2010a, p. 37).

The Concluding Steps

The concluding steps in Banks (2010a, p. 35) model of a structured process when developing a simulation study are *Production Runs and Analysis*, *More Runs?*, *Documentation and Reporting* and finally *Implementation*.

Production Runs and Analysis regards to estimate the measure of performance for the various simulation designs, production runs and their analysis. This step is followed by *More Runs?*, in which additional simulation runs and experiments or scenarios need to be considered if the previous runs give imprecise answers to the objectives of the simulation study (Banks, 2010a, p. 37).

The penultimate step in the structured process in developing a simulation study is *Documentation and Reporting*. According to Banks (2010a, pp. 37-38), two types of documentation are required: program documentation and progress documentation. The purpose of the program documentation is to enhance the ability to use the simulation model by either the same user or different users. Banks (2010a) further refers to Musselman (1998) about progress reports, which are the important, written history in chronological order of a simulation project. Musselman (1998) suggests frequent project reports and deliverables and that a project log is conducted. In the final report, the result of the analysis should be clearly and concisely presented.

The concluding step is *Implementation.* According to Banks (2010a, p. 38) If the previous eleven steps have been performed thoroughly and with much care, then the chances for a successful implementation is higher.

2.4 Chapter Summary

To summarize this chapter, two main methodologies were used in this thesis project. The first methodology constituted of two types of reviews. The first literature review regarded a systemized review of academic sources, while the other type of literature review regarded a review of non-academic sources. The academic sources provided material for the frame of reference but failed to provide information regarding the available UCDP concepts. In contrast, the non-academic review provided fruitful results regarding available UCDP concepts.

The second methodology used in this thesis was to develop a simulation study together with IISSAB. First, an introduction to simulation studies was given. A simulation study can abstract real-world system over time in a simulation model. The simulation model can further be used to test difference configurations of the real-world system. This is especially important when analysing how various factors affect the physical dimensioning of a UCDP. After this, the outline of the rest of the chapter followed and described the twelve steps in the structured process in developing a simulation study as proposed by Banks (2010a).

3 Frame of Reference

> *« To contribute with new knowledge to a field of study, students must first establish a comprehensive understanding of existing knowledge. « -Blair (2016)*

To establish a foundation for the rest of this thesis, an outline regarding the current knowledge and research which has been conducted in the field of last mile delivery solutions and UCDPs need to be presented. Furthermore, the UCDP concepts implemented in practice are presented. These sections in this chapter create together a frame of reference. The concluding section summarizes the chapter.

3.1 Last Mile Delivery Solutions

To face the challenges the last mile delivery poses, several solutions have been developed. In contrast to the traditional home delivery method, other solutions such as delivery boxes, reception boxes, collection and delivery points as well as controlled access systems exist. The relationship between these solutions are seen in Figure 4 below. The first distinction is made whether the organization or the customer fulfils the last mile delivery. The second distinction is whether the solution is attended by service personnel, or if its unattended through the presence of an automated, electronic system.

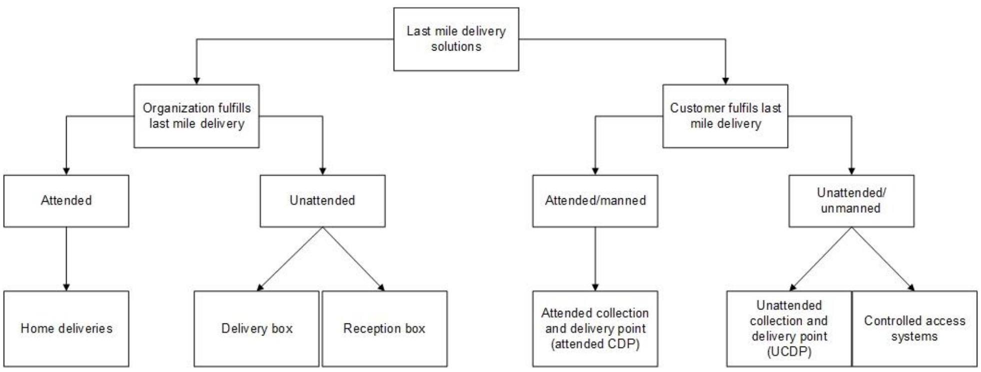

Figure 4 The different identified last mile delivery solutions and their relationships.

3.1.1 **Home Delivery**

Home delivery is considered to be the most common delivery method to the customers in e-commerce retailing (Kedia, Kusumastuti, & Nicholson, 2017, p. 587) and is also the key feature of e-commerce (Iwan, Kijewska, & Lemke, 2016, p. 645; Moroz & Polkowski, 2016b, p. 381). The main concept of home delivery is that the goods are directly delivered to the customer, which requires that the customer is present and personally receives the parcel if a signature is needed (Otter, Watzl, Schwarz, & Priess, 2017, p. 462).

The main advantage of home delivery is its convenience to the customer (Iwan et al., 2016, p. 645). However, many of the disadvantages of home delivery are directly linked to the last mile delivery issue (see 1.1.2 The Last Mile Delivery Problem). The issues lie in that the customer orders are fragmented and at the same time, the customers expect quick and timely deliveries. This increases home deliveries with less-than-full truckloads, which incurs greater costs. Furthermore, unattended reception along with the parcels delivered may not fit in the mail- or letterbox, results in failed deliveries, which generate higher costs and higher vehicle pollution emissions.

3.1.2 **Delivery Box**

The delivery box is an unattended last mile delivery solution which requires the organization to fulfil the last mile delivery. The delivery box, which is owned by the retailer or delivery company (Iwan et al., 2016, p. 646; Lemke et al., 2016, p. 273), is an insulated box containing the goods. The box is delivered to the customer and temporarily attached in a secure locking device bolted on the building wall. Once the goods have been collected by the customer, the empty delivery box is retrieved by the delivery company on the following day or later (Punakivi, Yrjölä, & Holmström, 2001, pp. 428-429). This can be done in a separate round or as part of the next delivery (Iwan et al., 2016, p. 646; Lemke et al., 2016, p. 273).

Advantages of the delivery box are independence of delivery time windows, elimination of redelivery costs, short delivery time by the door and regulation of temperature (Punakivi et al., 2001, p. 434).

There are however some disadvantages to the delivery box. Delivery boxes can only regulate the temperature for a certain time period (Punakivi et al., 2001, p. 434) and costs are incurred once the delivery boxes need to be recollected by the service provider (Punakivi et al., 2001, p. 429). Furthermore, the utilization rate of the delivery box is low (Punakivi & Tanskanen, 2002b, p. 500).

3.1.3 Reception Box

A reception box also requires the organization to fulfil the last mile delivery and is also an unattended solution. A reception box is permanently installed at the customer's home (Iwan et al., 2016, p. 646; Lemke et al., 2016, p. 273), often the garage or the home yard (Punakivi et al., 2001, p. 434). It is often used for parcels, but food can be delivered as well if the boxes are temperature regulated (Iwan et al., 2016, p. 646; Lemke et al., 2016, p. 273). Access to the reception box is gained through a key or electronic code and the customer is notified of the delivery by mobile phone or email (Iwan et al., 2016, p. 646; Lemke et al., 2016, p. 273). This way, the delivery of goods can be done without the reception of the customer and is thus a solution for unattended reception.

The advantages of the reception box are several. First, it eliminates of specific delivery time windows and redelivery costs for failed home deliveries. This creates convenience for the customer (Punakivi et al., 2001, p. 434). Another advantage is the ability of temperature regulation, which is an issue for B2C e-grocers (Punakivi et al., 2001, p. 427).

The reception box also has some disadvantages. These are the investment cost and the issue of finding space to install the reception box at the customer-specific location, which is often scare around buildings especially in the city centres. The investment cost of the reception box is expected to be larger than that of the delivery box (Punakivi et al., 2001, p. 434). According to Punakivi and Tanskanen (2002b, p. 500), another disadvantage of unattended reception solutions such as the reception box is its low utilization rate.

3.1.4 Collection and Delivery Point (CDP)

The literature is unanimous regarding the definition of collection and delivery point (CDP). However, one common theme identified in the literature is that the goods are not delivered directly to the customer's home. Thus, the customer has to cover the last mile for order fulfilment (Iwan et al., 2016, p. 646; Kedia et al., 2017, p. 588; Lemke et al., 2016, p. 273; Weltevreden, 2008, p. 639). CDPs are further characterized as a location where customers can collect and return their online orders (Weltevreden, 2008, p. 639).

The general benefits of CDPs are numerous. First, since the goods are delivered to a CDP instead of the customer's home, there is no risk for a failed delivery or risk of theft of goods. Another result of this is that freight transport in residential areas may be reduced. Second, if the CDP is located near a residential area or areas that already generate consumer trips, then little extra travel is incurred to the customer. Third, a CDP may increase the attractiveness of shops and shopping centres in which they are located in or at (Weltevreden, 2008, p. 639). Finally, CDPs allow for more consolidated deliveries, resulting in higher utilization of delivery vehicles, lower traffic volume and efficient delivery scheduling (Wang et al., n.d., pp. 3-4).

There are two types of the CDP. The difference between these two types is how the CDP and parcels are handled: either by staff (attended/manned) or using electronic technology (unmanned/unattended) (Moroz & Polkowski, 2016a, p. 382; Wang et al., n.d., p. 3; Weltevreden, 2008, p. 640). A CDP which is manned by staff are further on called attended CDP, while an unattended CDP is called unattended CDP (UCDP).

Attended Collection and Delivery Point (attended CDP)

Attended CDPs are a sort of shop-in-shop concept, where parcels are delivered to the location. In the attended CDP concept, customers can pay, collect and return their parcel. The store personnel manage the parcel related activities (Weltevreden, 2008, p. 640). An attended CDP is generally attended six days a week and during the opening hours of the host business (Morganti, Dablanc, & Fortin, 2014, p. 24). A network of attended CDPs usually make use of IT tools for tracking parcels and managing returns. International partnerships are also set up for cross-border deliveries (Morganti, Dablanc, et al., 2014, p. 24). An attended CDP is commonly located in a store, petrol station, post office (Weltevreden, 2008, p. 640), dry cleaners, florists (Morganti, Dablanc, et al., 2014, p. 24) or convenience stores (Iwan et al., 2016, p. 273; Lemke et al., 2016, p. 646).

Unattended Collection and Delivery Point (UCDP)

In contrast to the attended CDP, the UCDP is an unmanned, electronic solution. A UCDP can be located in several places, such as shopping malls, public transport stations, within stores and business centres, residential areas (de Oliveira et al., 2017, p. 35) car parks, work places (Iwan et al., 2016, p. 646; Lemke et al., 2016, p. 273) and gas stations (Morganti, Dablanc, et al., 2014, p. 24). Furthermore, they can be located in a public area where the customers can gain access to them through short-distance trips (de Oliveira et al., 2017, p. 35). The UCDP is located to make the customers' travel to the UCDP as short as possible places (Iwan et al., 2016, p. 646; Lemke et al., 2016, p. 273). A UCDP uses luggage locker technology (Weltevreden, 2008, p. 640) and often has camera surveillance (Wang et al., n.d., p. 3). At the UCDP, the customer can withdraw packages 24 h a day from locker boxes (Morganti, Dablanc, et al., 2014, p. 24). The courier or delivery person can at any time manually place the customer's packages into one of the lockers of the UCDP, also around the clock. Once this has been done, the backstage system will send a notification to the customer with information regarding the locker number and location, as well as a verification code, PIN or access code. This code can then be used by the customer to gain access to the dedicated locker and thus retrieve the package (Chen, Yu, Yang, & Wei, n.d., p. 4; Iwan et al., 2016, p. 646; Lemke et al., 2016, p. 273; Wang et al., n.d., p. 3; Weltevreden, 2008, p. 640). In order to optimize the usage of the UCDP, the customers are usually not assigned a specific locker.

Furthermore, it can be dedicated by either one delivery company or shared by many delivery companies (Iwan et al., 2016, p. 646; Lemke et al., 2016, p. 273).

Using the findings from the literature, the following themes are identified to define a UCDP:

1. A UCDP requires the customer to fulfil the last mile delivery, meaning the customer must cover a distance to fulfil the delivery.
2. A UCDP handles both parcel collection and sometimes returns.
3. A UCDP can store several parcels at a time.
4. A UCDP is unmanned, unattended and electronic.
5. A UCDP is a stationary last mile delivery solution.

A Comparison of the Two CDP Types

Weltevreden (2008, pp. 640-641) presents a thorough comparison of strengths and weaknesses of the two different types of CDPs. By using a UCDP, the retrieval process of the parcel can be done anonymously and efficiently without having to wait for store personnel to collect the parcel as compared to an attended CDP. The opening hours of a UCDP are not bound to store opening hours but can be sensitive to theft and vandalism. In order to establish a UCDP at a public site, often a permit from the local authorities is required. Since the UCDP is using an electronic locker system, it often requires knowledge on how to operate it. At an attended CDP, the parcel collection is managed by the staff. Maybe the most compelling argument to use an attended CDP instead of a UCDP is the size of the parcels. Some of the parcels cannot be delivered to the UCDP because of their sizes and the fact that the UCDP often have fixed sizes for its lockers. An attended CDP has a shared storage area for the goods and can thus accommodate larger parcels. Furthermore, an attended CDP often offers several other payment options than the UCDP and an attended CDP can offer retailers a revenue increase since the customers can combine the parcel collection with other activities, such as shopping. However, the author of this thesis does not agree on this point, because UCDPs according to the literature review can also be located in places where the customers can perform other activities such as shopping centres, stores, supermarkets and gas stations. This is supported by Iwan et al. (2016, p. 648).

Many of the aspects of this comparison is also addressed by Iwan et al. (2016, pp. 646-647) and there are many similarities between them. Iwan et al. (2016, pp. 646-647) complements the above mentioned comparison as it mentions that UCDPs can handle groceries as well, but an attended CDP has lower investment costs than a UCDP.

An aggregated comparison of the two comparisons made above is presented in Table 2. It presents the strengths and weaknesses of both the UCDP and attended CDP.

Table 2 A comparison of the strengths (+) and weaknesses (-) of UCDP and attended CDP.

Aspect	***UCDP***	***Attended CDP***
Opening hours	+	-
Parcel retrieval time	+	-
Ease of use of the service	-	+
Retrieval process anonymity	+	-
Storage possibilities	-	+
Goods characteristics	+	-
Sensitivity to crime and vandalism	-	+
Use of public space	+	+
Possibility to combine parcel collection with other activities	+	+
Investment cost	-	+

3.1.5 **Controlled Access Systems**

A controlled access system delivers the goods to the customer through a locked area. The delivery driver gains access to this area through a key which is accessible to the driver through an access code. Once the key has been retrieved, the delivery driver can enter the locked area and leave the goods there (Iwan et al., 2016, p. 646; Lemke et al., 2016, p. 273).

3.2 UCDP Solutions in Practice

The non-academic resources gave a significant number of results regarding which UCDP solutions that are currently used in practice. A total of 18 UCDP manufacturers were identified and together they provide 36 different products for the UCDP concept. All of these products met the search requirements. Although the identified UCDP products had different brandings, a review of each of the products showed that there are few variations to the physical appearance and functions of the products. The following sub-sections present the different categories of UCDP solutions identified from the non-academic review.

3.2.1 **The Traditional Parcel Locker**

A significant majority of the UCDP products (32 out of the 36 identified products) have the appearance of a “typical” parcel locker (see Figure 5). These are thus categorized as the traditional parcel locker. The characteristics of these are that the UCDP arrangement contains several slots, lockers or storage containers and in one or numerous sizes. The interior of the slot is formed by a rectangular or cubic space where the articles to be delivered or retrieved can be stored. However, these slot sizes cannot be adjusted and are thus fixed. The slots are mostly accessed from the front, or in some cases, rear access is possible as well such as the Click n Collect Parcel Locker ("Parcel Lockers," n.d.).

While the storage slot outline is more or less the same for the UCDP products, some specific configuration to the storage slots exist. Most of the UCDP products are designed for ordinary parcels with no specific storage requirements. However, some of the UCDP products have slots designed for parcels requiring temperature regulation, such as groceries, or parcels which cannot or ought to not be rotated in certain ways, such as textiles. For instance, the storage slots of Click n Collect's Grocery Lockers can be temperature regulated in three modes (chiller, freezer or ambient) to adapt to the requirements set by the products ("Grocery Lockers," n.d.). Another example is the Laundry Locker by Click n Collect, whose storage slots are equipped with hangers or flat beds to be able to store parcels which impose requirements regarding the way the parcels are stored. These are typically used by laundry providers for drop-off of clothes by the customers and delivery of cleaned clothes by the laundry service ("Laundry Lockers," n.d.).

The arrangement furthermore has several slots of different sizes and control consoles as well used for human interaction with the UCDP solutions. Slots and control consoles can either be added or removed and the traditional parcel locker thus features modularity to its capacity.

The longest dimension of the UCDP arrangement is usually its width, while the depth and height are restricted. The height is restricted so that the customers are able to retrieve their parcels in the top-most storage slots. Furthermore, load-in and retrieval has to be done manually by the customer or the parcel courier. Additionally, the products can be placed indoors and outdoors.

Figure 5 A sample of the identified products categorized as the traditional parcel locker. Explanation from the top-left: ActiveBuilding's The EGG Smart Locker ("The EGG Smart Locker System/Package Delivery System," 2018), American Locker's i-Collect ("American Locker i-Collect," 2018), Cleveron's Cleverbox ("The CleverBox," 2017) and Cleveron's SnapLocker ("The SnapLocker," 2018). From the bottom-left: InPost's Cooling Locker ("InPost Portfolio," 2016), Click n Collect's Grocery Locker ("Grocery Locker," n.d.), InPost's Laundry Locker ("InPost Portfolio," 2016) and Click n Collect's Laundry Locker ("Laundry Locker," n.d.).

3.2.2 **The Automated Box Design**

A solution which is distinct from the previous design is Cleveron's CleverFlex (see Figure 6). This solution is named the automated box design. The main alignment of this UCDP solution is horizontal. However, it does not contain several slots accessible for the customer or the parcel courier on the exterior for parcel retrieval or insertion. Instead, there is only one opening and initially one console. The opening is used both for retrieving or inserting a parcel and the console consists of a touchscreen only. The placement of the console can be changed, but also the number of consoles can be adjusted. The UCDP arrangement is used indoors and can either be placed externally adjacent to a wall or be integrated into a wall or facade. Initially, the capacity of this product is up to 2 000 parcels, but this can be extended with extra modules, to increase its width or height ("CleverFlex: self-learning robotics based parcel terminal," 2017).

The uniqueness of this design lies behind the exterior, in the storage process. All the parcels which are either inserted or extracted from the one opening of the UCDP product are done so by using a type of AS/RS[1] solution equipped with trays ("Inditex click and collect in-store pickup location solution in Spain," 2017). Thus, this is a

[1] An automated storage-and-retrieval (AS/RS) device uses robotic, which can move horizontally and vertically, to convey a product to or from storage (Bartholdi & Hackman, 2006, p. 186).

fully automated process. The system is also self-learning, as it can predict the user activity based on past data and in doing so optimizing its work flow. For instance, during peak times, it can position parcels to leave shelves around the console empty for the peak periods. However, the limitation is that the parcels which can be stored in this UCDP can have a maximum dimension of 60 x 40 x 40 cm ("CleverFlex: self-learning robotics based parcel terminal," 2017).

Figure 6 An example of the automated box design, CleverFlex by Cleveron ("The CleverFlex," 2017).

3.2.3 The Automated Pillar Design

An additional identified design which is different from the previous mentioned ones is where the UCDP is formed into a pillar and thus stores all the parcels on its height. This solution is thus named the automated pillar design. Once such instance is the PackRobot by Cleveron (see Figure 7). It resembles a large octagonal pillar covering an area of six square meters and can be installed both indoors and outdoors ("PackRobot: robotics based parcel terminal," 2017). Its exterior consists of a control console which can be used both by the customer and parcel courier for inserting and retrieving parcels. Furthermore, the exterior features one opening, called gateway, in which the parcels can be inserted. As with the CleverFlex, the interior is equipped with a modification of an AS/RS in the form of a parcel lift which is rotatable. The parcel lift is on the form of trays to store the parcels on, which can hold parcels up to 60 x 40 x 40 cm ("PackRobot: robotics based parcel terminal," 2017).

Figure 7 An example of the automated pillar design. Cleveron's PackRobot, the exterior (left) and the interior (right) ("The PackRobot," 2017). Left-side picture number explanation: 1. Control console, 2. Parcel gateway, 3. 3D parcel lift, 4. Eight columns of parcel trays, 5. Weatherproof and insulated outer shell, 6. Facade and 7. One-size trays for all parcels

IISSAB in collaboration with another company is currently developing a similar concept which can be categorized into the automated pillar design. The exterior is similar, with a control console and an opening or gateway and the concept also uses an AS/RS to retrieve the order. The difference lies in that IISSAB's concept can store larger orders consisting of several parcels of different sizes and weights, since the carriage inside the system is a cart which larger than the trays of the PackRobot. Because of this, the gateway of this design is larger than that of the PackRobot.

3.2.4 **The Cart Design**

A UCDP with a cart design is featured in Bell and Howell's BH QuickCart (see Figure 8). This system can accommodate large shopping carts, flatbeds and even full pallets. Because of this, large product mix can be stored, including large and heavy products. It can be used both indoors and outdoors. Furthermore, it can be integrated into the existing physical infrastructure of the environment and a refrigeration option is also available for perishable goods ("BH QuickCart," 2018).

Figure 8 An example of the cart design, the BH QuickCart by Bell and Howell ("The BH QuickCart," 2018).

3.2.5 Summarizing the Identified UCDP Solutions

Table 3 below summarizes the key features of each of the identified UCDP solutions.

Table 3 A summary of the key features of the identified UCDP solutions.

Factor	***The traditional parcel locker***	***The automated box design***	***The automated pillar design***	***The cart design***
Number of storage classes	Variable	One	One	Variable
Storage classes special configuration	Yes	No	No	Yes
Container access	Front/rear	Through gateway	Through gateway	Front
Modularity feature	Yes	Yes (capacity increase)	No	Yes
Type of retrieval process	Manual	Automated	Automated	Manual
Retrieval flow optimization	No	Yes	No	No
Placement	Indoors and outdoors	Indoors	Indoors and outdoors	Indoors and outdoors
Integration possibilities	Through its aesthetics	Full integration	Through its aesthetics	Full integration
Product dimension main alignment	Horizontal	Horizontal	Vertical	Horizontal

3.3 UCDP Terminologies and the Research Field

The terminology used for the UCDP concept varies among the identified literature from the academic resources. Among 13 identified research articles, 19 different terms were used interchangeably for the UCDP concept (see Table 4). This means that there is no standardized term for the UCDP concept.

Table 4 Identified alternative names for UCDPs.

Name for UCDP	***Mentioned in the following research papers***
Automated CDPs	Otter et al. (2017, p. 462)
Automated locker systems	Wang et al. (n.d., p. 3)
Automated lockers	de Oliveira et al. (2017, p. 35); Morganti, Dablanc, et al. (2014, p. 24); Vakulenko et al. (2017b, p. 1)
Automated parcel station (APS)	Morganti, Dablanc, et al. (2014, p. 23); Morganti, Seidel, et al. (2014, p. 184); Wang et al. (n.d., p. 1); Z. P. Xiao et al. (2018, p. 3)
Automatic deliver station (ADS)	de Oliveira et al. (2017, p. 35)
Communal reception point	Weltevreden (2008, p. 640)
Group of reception box units	Iwan et al. (2016, p. 646); Lemke et al. (2016, p. 273)
Intelligent lockers	Vakulenko et al. (2017b, p. 1)
Locker boxes	Vakulenko et al. (2017b, p. 1)
Locker points	Weltevreden (2008, p. 640)
Locker-banks	Iwan et al. (2016, p. 646); Lemke et al. (2016, p. 273)
Lockers	Iwan et al. (2016, p. 646); Lemke et al. (2016, p. 273)
Parcel kiosks	Vakulenko et al. (2017b, p. 1)
Parcel lockers	Iwan et al. (2016, p. 646); Lemke et al. (2016, p. 273); Vakulenko et al. (2017b, p. 1)
Parcel machines	Moroz and Polkowski (2016a, p. 379)
Self-service delivery lockers	Vakulenko et al. (2017b, p. 1)
Self-service parcel pickup machine	Chen et al. (n.d., p. 4)
Shared reception boxes	Punakivi and Tanskanen (2002b, p. 499)
Smart lockers	Z. Xiao et al. (2017, p. 988)

The existing UCDP research sample was relatively small. There were in total 17 identified research articles conducting research on last mile delivery solutions, but only ten of these focused on UCDPs. Vikingsson and Bengtsson (2015, p. 18) states that there is limited research on parcel lockers (another name for UCDP) and customer interaction by 2015. Of the identified ten articles, eight of these were published between 2015 and 2018. The oldest paper originates from 2002 by Punakivi and Tanskanen (2002b).

The identified literature regarding UCDPs have been conducted in several countries, having different perspectives and environmental settings. The countries in which the identified UCDP literature were conducted in were in total of six countries: Brazil (one article), China (two articles), Finland (one article), Poland (three articles), Singapore (one article) and Sweden (two articles). However, the research which has been conducted on UCDPs usually takes one of two perspectives: either the customer perspective or organizational perspective (from the UCDP operator's perspective). Punakivi and Tanskanen (2002b) analyse the UCDP from an organizational perspective, while Chen et al. (n.d.); de Oliveira et al. (2017); Lemke et al. (2016); Moroz and Polkowski (2016a); Vakulenko et al. (2017b); Wang et al. (n.d.); Vikingsson and Bengtsson (2015); Z. P. Xiao et al. (2018) analyse UCDPs from a customer's perspective in different environments and settings. The article by Iwan et al. (2016), although the main research objective regards the customer perspective, also includes another research from an organizational perspective. Among the research articles focusing on the customer perspective, there are two environmental settings: the first being that the UCDP has been implemented in a large scale and is thus largely known to the customer, while the second being that the UCDP has not been implemented and customers have little or no knowledge regarding what a UCDP is. A summary of the identified UCDP research is seen in Table 5.

Table 5 Summary of the UCDP research and identified themes.

Author	Chen et al. (n.d.)	de Oliveira et al. (2017)	Iwan et al. (2016)	Lemke et al. (2016)	<Moroz and Polkowski (2016a)	Punakivi and Tanskanen (2002)	Vakulenko et al. (2017)	Vikingsson and Bengtsson (2015)	Wang et al. (n.d.)	Z. P. Xiao et al. (2018)
Country	China	Brazil	Poland	Poland	Poland	Finland	Sweden	Sweden	Singapore	China
UCDP implemented	Yes	No	Yes	Yes	Yes	No	No	No	Yes	Yes
Data collection method	Questionnaire survey	Preference surveys	Meta-analysis	Online survey	Questionnaire survey	Simulation	Group interviews	Interviews	Questionnaire survey	Meta-analysis
Perspective	Customer	Customer	Both	Customer	Customer	Organizational	Customer	Customer	Customer	Customer
Access times		X								
Transportation		X		X						
Localization		X	X	X		X		X		
Environment		X		X				X		
Customers' initial adoption								X	X	
Reasons and intentions	X		X	X	X					
Context of utilization				X						
Features		X						X		
Customer value and behaviour							X			X
Sustainability		X			X					
Operational cost						X				
Pay-back investment						X				

3.4 Identified Themes in the Literature

The identified articles from the academic review cover several themes and topics related to the UCDP concept. These are summarized in Figure 9. The following sub-sections are structured according to the two perspectives and identified themes and will present the findings in each of the themes from the literature.

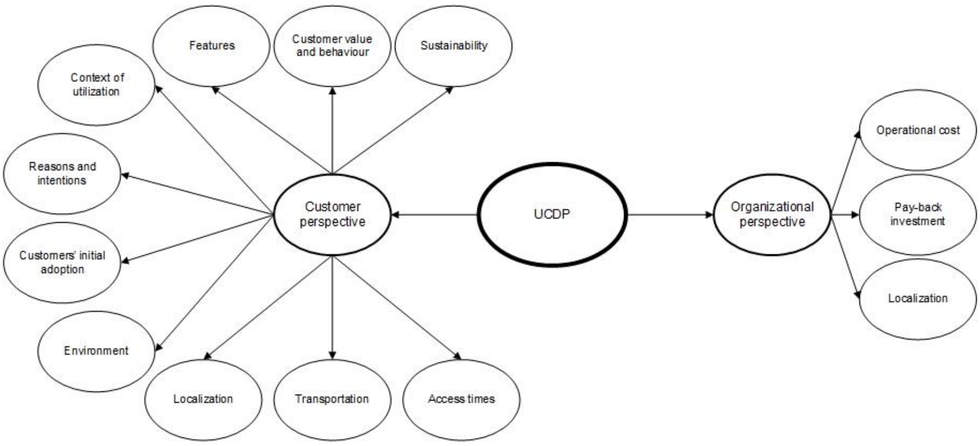

Figure 9 Identified themes related to the UCDP concept identified in the literature review.

3.4.1 The Customer Perspective

As mentioned earlier, most of the research which has been conducted about the topic UCDP focuses on one or several aspects of the customer perspective. The identified themes from the customer perspective are:

- Access times for the UCDP
- Transportation to and from the UCDP
- The localization of the UCDP
- The environment of the UCDP
- Customer's initial adoption of the UCDP
- Reasons and intentions to use the UCDP
- Contexts of using the UCDP
- Features of the UCDP
- Customer value and behaviour towards the UCDP
- Sustainability context of the UCDP

All these themes are explored in the following sub-sections.

Access times of the UCDP

The preferred access times of a UCDP from the customer's perspective has only been studied limited. The access time of a UCDP is defined as the time during the day a customer is able to pick up its delivery from the UCDP. The results from a revealed preference survey and stated preference survey show that customers prefer to access the UCDP between 18.00-24.00, corresponding to 24 percent of the respondents of the survey. 19 percent of the respondents preferred access time between 20.00-00.00, followed by 14.00-18.00 (16 percent of the respondents). This was followed by access times of anytime during the day in decreasing order, 12.00-14.00, 08.00-12.00 and 06.00-08.00 (de Oliveira et al., 2017, pp. 40-41).

Transportation to and from the UCDP

Another discussed aspect of the customer perspective of using the UCDP is how the customers transport themselves to and from the UCDP and which mode of transportation is used. The results from both Lemke et al. (2016, p. 282) and de Oliveira et al. (2017) suggest that the most common transportation mode used to reach the UCDP is by car or private vehicle. The travel time was in between 15 to 30 minutes (de Oliveira et al., 2017) and most customers did not need a detour to reach the UCDP, while some needed to cover an extra distance between one to five kilometres. The second mentioned transportation mode to the UCDP was by foot (Lemke et al., 2016, p. 282).

The localization of the UCDP

The proper localization of a UCDP is its most important criterion for efficient utilization (Iwan et al., 2016, p. 650). Localization in this context means the geographical position of the UCDP. This aspect of the customer perspective has been examined by Iwan et al. (2016), Lemke et al. (2016, p. 282), de Oliveira et al. (2017, p. 40) and Vikingsson and Bengtsson (2015, p. 44). The number of respondents in each of the studies varies significantly and two of them were conducted in Poland, one in Brazil and one in Sweden. The results from each of the studies are presented in Table 6. As can be seen, the customers' preferences regarding the localization of UCDPs varies between the studies.

Table 6 Results regarding the localization of the UCDP.

Ranking (in decreasing favourability)	*Author*			
	Iwan et al. (2016)	***Lemke et al. (2016, p. 282)***	***de Oliveira et al. (2017, p. 40)***	***Vikingsson and Bengtsson (2015, p. 44),***
1	Close to the home	Vicinity of the home	Close to supermarkets	Nearby shopping area
2	On the way to work	On the way to work	Close to shops	Nearby home
3	Parking spaces	Parking spaces	Close to shopping centers	Nearby transportation
4	Safety	Close to shopping centers	Gas station	Nearby school/job
5	Close to shopping centers	Close to bus/tram stops	Pharmacy	
6	Close to public transport stops		Bakery	
7			Public transportation	
8			Lottery house	
9			Newsstand	
10			Academy	

The environment of the UCDP

The environment of the UCDP, meaning the surroundings of the UCDP and not its localization (geographical position), is also examined in the literature. Safety and security of the environment is one aspect of the UCDP environment. de Oliveira et al. (2017, p. 40) found in their survey that security issues and safety of the location of the UCDP were valued as being important to the respondents of their survey (54 percent), while it was necessary for 45 percent of the respondents. As also has been presented in the previous sub-section, in the study Lemke et al. (2016, p. 282) found that safety was one of the factors of the expectations of the UCDP localization. In contrast to this, 18 percent of the participants in the study by Vikingsson and Bengtsson (2015, p. 45) had absence of security as the reason to not use the UCDP again. In line with the security aspect of the UCDP environment, 22 percent of the participants favoured placing the UCDP indoors compared to outdoors. However, placing the UCDP indoors, for instance in shops and malls, could impose restrictions to the access time of the UCDP. However, an advantage to locate the UCDP within another business is increased terms of service such as cleaning services around the UCDP. Furthermore, this could affect the customers' preconception of the UCDP through the preconception of the business. Instead of placing the UCDP inside a business, the UCDP could be located in a restricted indoor area, for instance rooms for ATM-machines (Vikingsson & Bengtsson, 2015, p. 60).

Customer's initial adoption of the UCDP

The drivers for customers to adopt the UCDP concept initially is also a mentioned theme in the literature, although it is limited. Wang et al. (n.d., pp. 7-18) studies customer initial adoption of UCDPs by developing a conceptual framework using theoretical insights from innovation diffusion literature and attitude theories. Five terms in the study were defined as dimensions of the consumer's perception:

1. Perceived relative advantage is the degree to which an innovation is perceived as being better than its precursor.
2. Perceived compatibility is the degree to which an innovation is perceived as being consistent with the existing values, needs and past experiences of potential adopters.
3. Perceived complexity assesses the degree to which an innovation is perceived as being difficult to use.
4. Perceived observability is the degree to which the results of an innovation are perceived as observable to others.
5. Perceived trialability refers to the degree of which the innovation is perceived to be trailable before adoption.

The results of the hypothesis testing showed that consumers' perceived compatibility, perceived complexity and perceived trialability of UCDPs is positively related to the consumers attitude toward initial adoption of UCDPs, while perceived complexity had a negative relationship. Furthermore, the results suggested that perceived compatibility and perceived trialability had a positive impact on the consumers' attitude toward using UCDPs. In addition to this, perceived observability is not a significant predictor of consumers' attitude towards UCDP-adoption. The results further showed that perceived relative advantage is directly associated with consumers' initial intention of UCDP-adoption, while attitude toward initial adoption of UCDPs is the strongest predictor of consumers' adopting intention.

An interpretation is also given to the findings. Wang et al. (n.d.) mean that simplicity, compatibility and trialability of a UCDP are perceived as attractive attribute that contribute to the consumers being in favour for the system. However, these are not sufficiently strong to invoke consumers' adoption intention. On the other hand, what determines the consumers' adoption intention is the overall favourable attitude toward UCDPs, which is formed on the overall perception. The consumers' positive attitude towards UCDPs and perception of these as a better alternative to other last mile distribution solutions motivate the consumers to adopt UCDPs. In contrast to the hypothesis, perceived observability of UCDPs does not turn out to be a significant predictor of consumers' attitude or consumers' adoption intention. An explanation to this could be that the hypothesis itself was not constructed appropriately, or that the consumers avoid observing other users of the UCDPs due to social norms, such as privacy.

Reasons and intentions to use the UCDP

The reasons or intentions to use a UCDP from the customer perspective is a further aspect of investigation in the literature. Three studies were conducted in Poland, while one was conducted in Brazil and one in Singapore. The three studies from Poland and the one study from Brazil revealed the following reasons and intentions to use the UCDP from the customers' point of view. These are summarized in Table 7. The findings show that although the reasons and intentions of using the UCDP varies in ranks in the different studies, there are some shared aspects, such as availability 24/7, the price of the service and the localization of the UCDP.

Table 7 Summary of the findings regarding the reasons and intentions to use the UCDP from the customers' perspective.

Ranking (in decreasing favourability)	***Author***			
	Iwan et al. (2016, pp. 652-653)	***Lemke et al. (2016, p. 281)***	***Moroz and Polkowski (2016a, pp. 385-391)***	***de Oliveira et al. (2017)***
1	Price of deliveries	Availability 24/7	Availability 24/7	Parcel information and traceability
2	UCDP's availability	Price of the service	Lower delivery costs compared to other delivery modes	The delivery time
3	Localization of the UCDP	The convenient location of UCDPS	Speed of delivery compared to other delivery modes	Transportation cost
4	Time	Time to use the UCDP	Brand confidence	Localization of the UCDP
5	The ability to track the parcel	Possibility of parcel tracking	Environmental considerations	
6		Complexity of the offer		
7		Other		

Chen et al. (n.d.) also studies the consumers' intention to use UCDPs, but instead using a three-factor model. The developed three-factor model contained situational, individual and socialized factors. Situational factors explain how the consumers behave when facing physical or social environment. The factors used to study the situational factors affecting the consumers' intention to use UCDPs in this article are location convenience and perceived time pressure. Individual factors have a strong explanatory power to the acceptance of self-service technologies, and the two factors being studied are innovativeness and optimism. For the socialized factors, the factor "need for human interaction" is being used. Using these different factors, five hypotheses were formulated, and using a survey to collect the data, the following results were acquired.

The different proposed factors affect the consumers' intention to use the UCDP differently according to the results. Among the different proposed factors, location convenience, which is a situational factor, significantly affects a consumer's intention to use UCDPs according to the results. The second situational factor, perceived time pressure, did not have a significant correlation with consumer's intention to use UCDPs (Chen et al., n.d., p. 16). This in contrast to what is as being mentioned by Vikingsson and Bengtsson (2015, p. 58), where the time saving aspect of using a UCDP is an important factor. The results further show that there was a strong correlation between individual factors and the consumers' behavioural intention. Thus, both innovativeness and optimism showed a positive effect on a consumer's intention to use UCDPs. The factor "need for human interaction", which was proposed as a socialized factor, positively influences a consumer's intention to use UCDPs according to the results (Chen et al., n.d., p. 16).

Context of using the UCDP

Another mentioned topic in the literature regards which other errands the customers run while using the UCDP. This is defined as context of using the UCDP.

The following results were obtained from a Polish study regarding the context of using the UCDP. Lemke et al. (2016, pp. 283-284) in their study present that 45,9 percent of the respondents of their survey answered that they would run other errands while using the UCDP, while 29,4 percent answered that they never did, and 24,6 percent used the UCDP often while running other errands. Regarding the question which errands customers would run while visiting the UCDP, the results were:

1. 42,3 percent answered that they picked up a parcel from a UCDP on the way to or from work or school.
2. 37,6 percent usually go or drive to the UCDP solely to pick up the parcel.
3. 18,0 percent picked up the parcel from the UCDP while doing shopping.
4. 1,4 percent picked up the parcel from the UCDP while refuelling the car.

Features of the UCDP

The features of a UCDP is also important to the customer. What defines the feature of a UCDP is its software, hardware and aesthetics. This has been heavily studied in Vikingsson and Bengtsson (2015).

UCDP Software

Regarding the UCDP software, two studies examined this aspect. The results of the study in de Oliveira et al. (2017, p. 40) show that a significant majority (83 percent of the survey respondents) would like to receive a security code to accomplish the parcel pick-up process. Furthermore, several features to the software of the UCDP is suggested in Vikingsson and Bengtsson (2015, pp. 56-58):

- *Sounds:* The UCDP should incorporate sounds in its collect and return process, to give more clear instructions to the customer but also aid customers with bad sight in their collect and return process.
- *Written instructions:* First, the UCDP should provide several languages so that customers with different nationalities are able to operate the UCDP. Second, a map over the containers of the UCDP should be provided in the UCDP software, to give clear instructions to the customer of which container the order is stored in. Third, the written instructions should provide reminders to the customer of closing the container door after having retrieved its order, but also to warn customers if a container door is in immediate risk of hitting the customer due to it being opened.
- *Comfort zone:* The comfort zone of the UCDP is an area of containers where customers with physical restrictions, such as elderly customers or customers in a wheelchair, can access a container. The software needs to specify clearly to the customer if the order can be reached or returned in the specified comfort zone. A picture of the comfort zone should be provided as well in the software.
- *Capacity:* If a UCDP can handle return processes as well, the customers need to be notified in advanced if a specific UCDP has free capacity to store the returned order.

UCDP Hardware

Vikingsson and Bengtsson (2015, pp. 58-59) examines the hardware configuration of the UCDP. The hardware configuration in this context means the functions of the hardware rather than the physical dimensions of the UCDP:

- *Speakers:* The UCDP should be installed with speakers to be able to erect instructing sounds during the collect and return process, as was presented in the previous sub-section.
- *Video surveillance:* The environment of the UCDP presented that security and safety in the environment of the UCDP is regarded as important to the customers. In order to improve the security of the UCDP, it is suggested to install video surveillance
- *Plastic bag machine:* A participant of the study suggested that a plastic bag machine should be installed in the UCDP to make it easier for the customer to carry the collected parcel on the way home. However, the authors argue that this hardware configuration would be difficult to install in the UCDP, since it imposes considerable adjustments to the hardware, software and functionality of the UCDP.
- *Scale:* The storage container of a UCDP can only hold a certain weight of the parcels. Thus, for the return process, and potentially customer-to-customer (C2C) transactions through the UCDP, a scale is suggested to be installed.

- *Payment function:* Participants also suggested that the UCDP should be able to handle payment functions as well.
- *Service phone:* A service phone is suggested to be installed by the participants, to be able to complement the instructions provided by the software if an error would occur, or if guidance in the return and collect process is needed. However, the authors perceive that this service phone could be misused by others.

UCDP Aesthetics

The aesthetics of the UCDP is another aspect of the feature of the UCDP. Vikingsson and Bengtsson (2015, pp. 58-59) suggest that the UCDP could be used for advertisement. However, both advantages and disadvantages of this idea are discussed. The colour of the UCDP should also be in line with the colour the UCDP operator uses, to enhance the ability to recognize what the UCDP is used for. To enhance this ability even further, several and large signs should decorate the UCDP. However, this could in some cases be victim of vandalism. As is also suggested by de Oliveira et al. (2017, p. 42), the UCDP needs to be design with regards to the architecture characteristics of the surroundings of the UCDP in mind, so that is does not contribute in an unappealing way to the environment.

Customer value and behaviour towards the UCDP

Vakulenko et al. (2017b) studies the customer value with regards to UCDPs using a focus group of in total 26 e-consumers in Sweden. The findings of the study revealed that customer value could be classified using four different elements:

1. *Functional value:* This was the most frequently mentioned value in the focus groups and relates to the functional aspects of the UCDPs. The functional value is divided into functional, utilitarian or physical service attributes. The results showed that functional value could be created through the customer, where the location and time access were dominant functions. However, the functional value could also be prevented in being created at the same time, since the service provider is in control of the functional value elements.
2. *Emotional value:* Using a UCDP could trigger both positive and negative emotions. Emotional values are distinguished through the customers' experiences, feelings and emotions.
3. *Social value:* The social value refers to the human interaction while using the UCDP, which is on a low level according to previous findings. However, the results of the study showed that there was no consensus regarding the absence of human interaction.
4. *Financial value:* Traditionally, the financial value has been associated with transaction cost. In the context of UCDP, the financial value is linked to the cost the UCDP services (both delivery and returns). The financial value was one of the most commonly mentioned values among the participants.

The results of the study were summarized in a framework for customer value creation with UCDPs, see Figure 10. The framework starts with the customer using the UCDP. The results presented that the customer is included in the value creation process and thus the input for the value creation is both the UCDP and the customer. Using the UCDP creates or destroys functional value, emotional value, social value and financial value (Func. V, Em. V, Soc. V and Fin. V in Figure 10). The results from the study suggested that functional, emotional and social customer value was affected by both customer value creation and destruction, while financial customer value only was affected by value destruction or played no role in the value process. The sum of the four customer value types creates an output, which can either be positive or negative. The output is positive if the customer value creation (V_{CR} in Figure 10) is larger than the customer value destruction (V_{DES} in Figure 10), and negative if the relationship is opposite. The service value output has a direct effect on future customer interaction with the UCDP. Two cycles are the result of this: the virtuous cycle and the vicious cycle. The virtuous cycle results in customer retention due to the creation of customer value. In the vicious cycle, the destroyed value is more than the created value, leading to a cycle of value destruction of repetitive uses of the UCDP. The result is that the customer abandons the service.

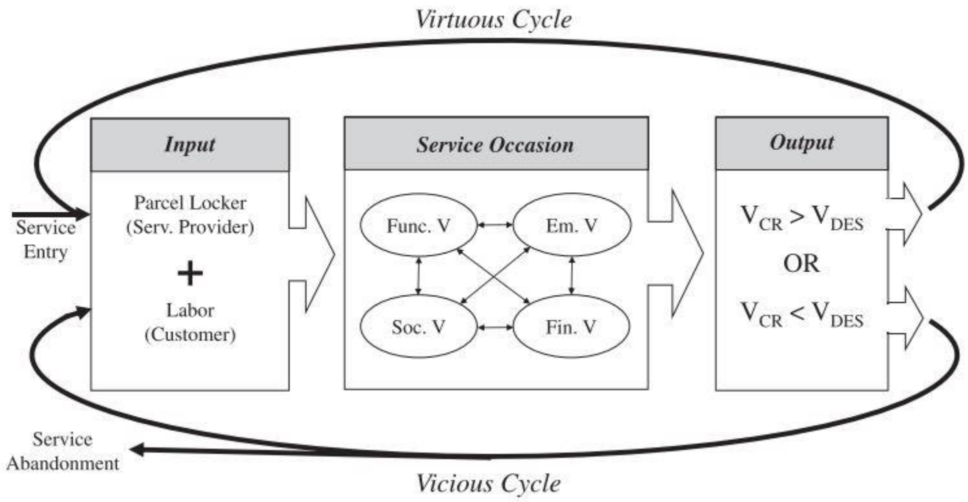

Figure 10 The customer value creation with UCDPs (Vakulenko, Hellström, & Hjort, 2017a). Explanation: Func V. = functional value, Em. V = emotional value, Soc. V = social value, Fin. V = financial value, V_{CR} = value created and V_{DES} = value destroyed.

In context of UCDP customer values, customer behaviour regarding UCDPs have also been studied. In the research by Z. Xiao et al. (2017), final delivery solutions are examined in order to assess how they affect e-shopping behaviour usage. The results of this research with regards to the UCDP concept is that the UCDPs did not show any statistically significant direct correlation with e-shopping frequency and spending. UCDPs would improve the customer satisfaction of the delivery service but would otherwise not generate online sales (Z. P. Xiao et al., 2018, p. 16).

Interpreting this result, the research suggests that the availability of UCDPs can significantly reduce the negative perception of final delivery services. At the same time, it has no impact on the frequency and spending of e-shopping (Z. P. Xiao et al., 2018, p. 17).

Sustainability context of UCDP

The UCDP concept in relation to sustainability has also been studied in the literature, although the scientific research is limited. de Oliveira et al. (2017, p. 42) and several other sources mention that UCDPs contribute to a reduction in number of delivery vehicles used but also in preventing traffic congestion caused by the delivery vehicles, resulting in overall lower vehicle emissions. However, according to the results by Moroz and Polkowski (2016a), the customers does not use the UCDP for environmental reasons, but rather for reasons of comfort, delivery time and cost. Furthermore, there is a weak relationship between people manifesting pro-ecological behaviour and the willingness to pay more for pro-ecological delivery modes. Lastly, there is no relation between the level of disposable income and tendency of customers to have an eco-friendly attitude. However, the study conducted by Moroz and Polkowski (2016a) is based on the answers of people from Generation Y[2].

3.4.2 The Organizational Perspective

Only two identified sources have conducted research from the organizational perspective. The organizational perspective is defined as the perspective of the organization which operates the UCDP, or in any means uses it for distribution. There are three distinct themes presented in the literature:

- Operational cost of the UCDP
- Payback investment of the UCDP
- Localization of the UCDP

Operational cost of the UCDP

The operational cost of the UCDP compared to other last mile delivery modes is examined in Punakivi and Tanskanen (2002b). The research method employed was a simulation approach to evaluate the operational cost difference for UCDPs in relation to four other last mile distribution solutions. These four main solutions were home deliveries, the reception box and two modes of delivery box. This was put in the context of e-grocery distribution in Finland, using real point-of-sales data. Different number of UCDPs, storage containers and utilization rate of the storage

[2] Generation Y is a collective name describing those individuals born between 1980 and 1999 (Moroz & Polkowski, 2016a, p. 384)

containers were used in the simulation model. The utilization rate in this context is defined as if a storage container in the UCDP stores one delivery per day, then the utilization is 100 percent.

The simulation results provided figures regarding the operational cost (see Figure 11). The results showed that a low operational cost could be achieved with a small amount of deliveries (40-60) per day and with a 50 percent to 75 percent utilization rates for a UCDP with 16 storage containers. The result indicates that a UCDP with 16 storage containers is already large enough to significantly increase cost efficiency in home delivery operations and that after that efficiency only increases slightly.

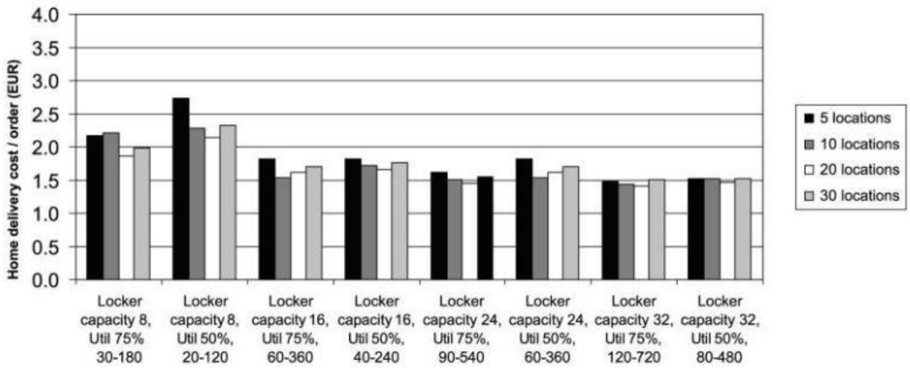

Figure 11 Home delivery costs per order in the UCDP concept (Punakivi & Tanskanen, 2002a). Locker capacity equals the number of storage containers in the UCDP.

Another result was regarding the cost savings of using UCDPs (see Figure 12). The cost savings were as much as 55 to 66 percent, with an operational efficiency that was 2,8 times higher than traditional attended home deliveries. The same operational efficiency was 1,9 times higher for the reception box concept and delivery box concept, resulting in cost savings of 44 percent to 53 percent.

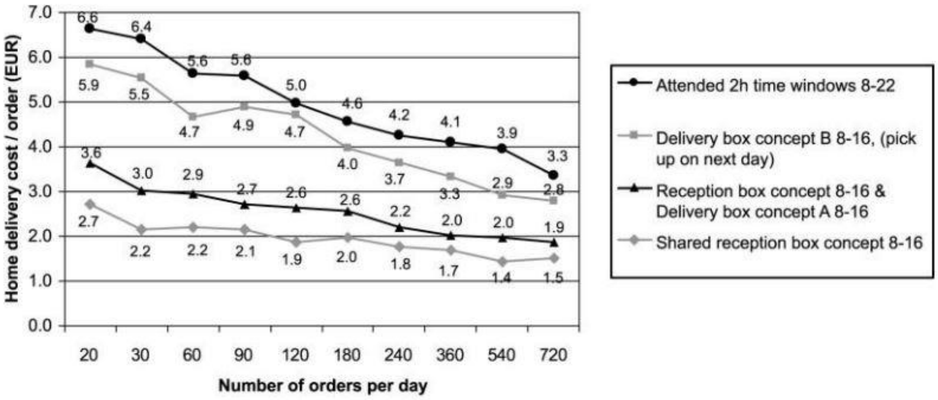

Figure 12 The operational cost levels for different last mile delivery solutions (Punakivi & Tanskanen, 2002d). The shared reception box concept is the term used for UCDP in the figure.

Payback investment of the UCDP

Another aspect covered in the research by Punakivi and Tanskanen (2002b) was the payback investment of a UCDP (see Figure 13). To analyse the payback period for the UCDP, a UCDP with 24 storage containers with the investment cost of EUR 42 000 was used as a reference in the research. With a 75 percent utilization rate of the UCDP (100 percent utilization rate equals one delivery per storage container per day), the payback period would be between two to three years, while a 50 percent utilized UCDP would have a payback period between three to five years. This means that the operational cost savings (see previous sub-section) in attended home deliveries will not cover the investment cost of EUR 42 000 if the life cycle of the equipment is less than five years or the utilization rate is lower than 50 percent. This result encourages investing in UCDPs rather that specifically designed vehicles for home deliveries. As a comparison, the payback period for a EUR 1 000 reception box was between six to 13 years when the number of daily deliveries ranged between 20 and 720. The reason for this is the economies of scale. With a high number of orders, the density of the stops is also higher, and thus the home delivery operations are more cost-effective.

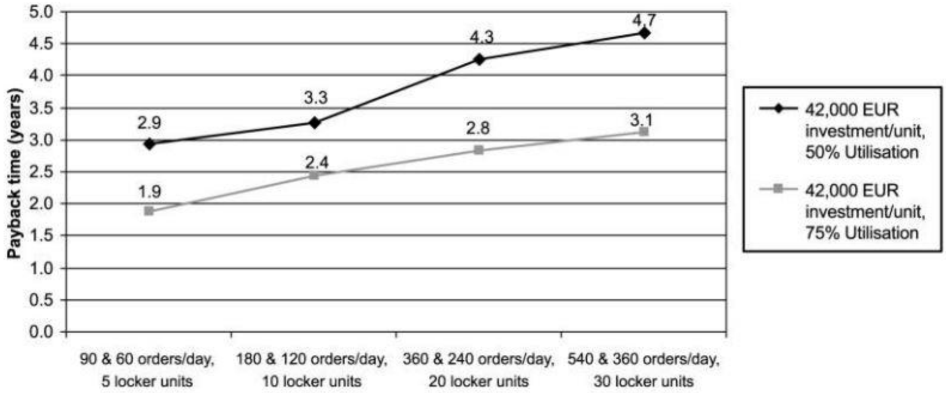

Figure 13 The payback period for the UCDP concept (Punakivi & Tanskanen, 2002e). A locker unit equals one storage container in the UCDP.

In conjunction with payback investment assessment by Punakivi and Tanskanen (2002b, the number of delivery vehicles needed for each last mile distribution concept was examined (see Figure 14). For the UCDP, with between 20 to 720 orders per day, one to five vehicles were needed. The same amount needed for attended home deliveries was between one to eleven vehicles. The number of deliveries per delivery mode varied from ten to 18 and from four to eight for the UCDP and attended home delivery respectively.

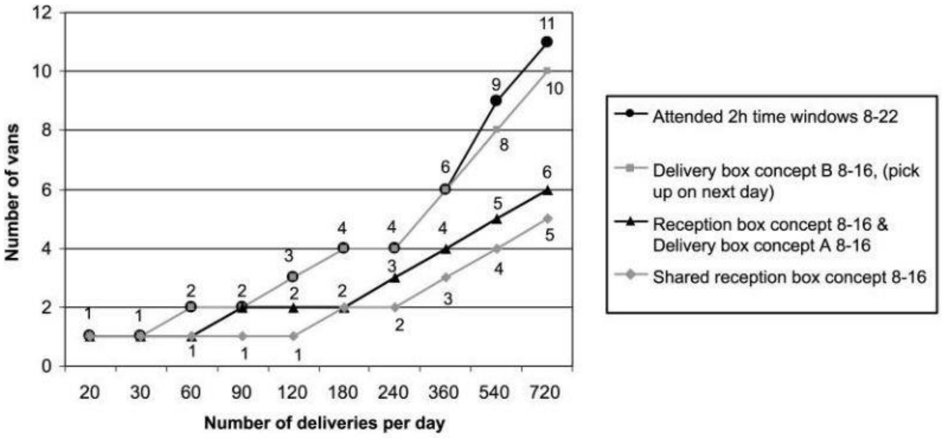

Figure 14 The number of delivery vehicles (vans) needed for the different last mile delivery concepts (Punakivi & Tanskanen, 2002c). The UCDP concept is called shared reception box concept in the figure.

Localization of the UCDP

Although the research by Iwan et al. (2016) presents findings from the customer perspective, the study also presents findings from another research from the organizational perspective. This research was conducted by the Polish UCDP provider InPost. In the Polish city of Szczecin, there were on average 335 parcels delivered per UCDP by 17 UCDPs between January 2012 to April 2013. In an experiment to assess the importance of UCDP location, InPost relocated five UCDPs since these were underperforming. In addition to this, an additional UCDP was implemented. The most important criterion in this experiment was to relocate the UCDPs to the proximity of gas stations, universities and shopping centres. The result was that the number of parcels delivered to the UCDPs increased with 32 percent, up to 443 deliveries per UCDP and month. After the relocation, only one relocated UCDP underperformed, while the most efficient growth with more than 200 parcels per month was achieved in the case of UCDPs located near the shopping centre. On average, the four successful relocations increased its deliveries with 79 parcels per month (Iwan et al., 2016, pp. 651-652). Furthermore, InPost identified the best available locations for UCDPs to be at:

1. Local hot spots with suburbs, such as convenience stores or high density of the population living in the neighbourhood
2. High traffic pedestrian areas in city centres
3. Shopping centres and supermarket car parks
4. Bus or underground stations next to local commuting hubs,
5. Petrol station forecourts
6. Service stations business centres

3.5 Chapter Summary

According to the conducted research, there exist several solutions to the last mile delivery issue. Amongst these are home deliveries, the delivery box, the reception box, attended collection and delivery points (attended CDPs), unattended collection and delivery points (UCDPs) as well as controlled access systems. Each of these solutions offer their own advantages and disadvantages.

Four distinct types of UCDP solutions were identified from non-academic sources: the traditional parcel locker, the automated box design, the automated pillar design and the cart design. These concepts have each their own distinct key features.

The research which has been conducted in the field of UCDPs showed that there is no general term for the UCDP. Furthermore, the research has focused mainly on the customer perspective of the UCDPs. The topics discussed for the customers' perspective are:

- The access times of UCDPs.
- Transportation to and from UCDPs.
- The localization and environment of UCDPs.
- The customers' initial adoption of using UCDPs.
- The reasons and intentions to use UCDPs.

- The context in which the customers’ use UCDPs.
- Features of the software, hardware and aesthetics of UCDPs.
- The customers’ values and behaviours toward UCDPs.
- Sustainability context of UCDPs.

Some identified academic sources showed research regarding the UCDPs from an organizational perspective and these discussed the following topics:

- The operational cost of UCDPs.
- Payback investment of UCDPs.
- Localization of UCDPs.

4 Developing the Simulation Study

This chapter presents the developed simulation study in more detail. The chapter starts with presenting the company which the simulation study was developed together with. The following section presents the applied practical approach of the structured process when developing a simulation study. The concluding section summarizes the chapter.

4.1 About the Company

4.1.1 Introduction to IISSAB

The simulation study will be conducted in cooperation with IISSAB. IISSAB is the subsidiary of Inter IKEA Systems B.V. and handles the immaterial rights of the IKEA business (Sörensson, 2018). The concept behind IKEA is to provide home decoration at an affordable price, through the combination of function, quality, design, product value and sustainability ("IKEA Konceptet," 2018). IKEA sells a wide range of products, from smaller products such as kitchen-ware, tealights and picture frames, to larger products such as beds, couches and whole kitchen solutions. The larger articles are often packed into several packs to make it easier for the customers to transport the products from the warehouse back home.

Currently, IISSAB has only implemented UCDPs in the form of traditional parcel lockers in Stockholm and Helsingborg (Sweden), Vienna (Austria) and Glasgow (United Kingdom). These have been implemented next to an IKEA store and these were installed during the time of this project. Furthermore, the automated pillar design concept which IISAB is developing is still currently in its development phase and hence have not been implemented in any of its worldwide stores (Sörensson, 2018).

4.1.2 IISSAB's Context in the Simulation Study

As was briefly mentioned in 1.1 Background and which was presented in chapter 3 Frame of Reference, the existing research on UCDPs have been focusing on UCDPs from either a customer perspective and organizational perspective. The physical dimensioning of the UCDP, with regards to different storage classes (storage containers' dimensioning) and the utilization of storage containers has been taken for granted as the scope of the research has not needed to take these into consideration. Only Punakivi and Tanskanen (2002b) briefly mentioned the utilization of storage containers, but from an economic perspective. Furthermore, in their research, the utilization and dimensioning of storage containers were predetermined. Another factor which was taken for granted was the size of the parcels delivered to the UCDP. The frame of reference typically does not give any suggestions on how larger parcels should be handled by a UCDP, if it would be handled by a UCDP at all.

IISSAB, and thus also IKEA, is therefore a suitable company to have as a case study. As mentioned, IKEA has a wide product assortment with different customer purchasing behaviours. Furthermore, IISSAB has and will implement different type of UCDP solutions. To study the physical dimensioning of IISSAB's UCDPS using various factors is therefore a suitable simulation study approach. Sales data from an IKEA-store will be provided by IISSAB as input for the simulation model.

4.2 The Applied Practical Approach of the Structured Simulation Study Process

In 2.3 Theoretical Approach of Simulation Studies, a theoretical approach to the structured process in developing a simulation study proposed by Banks (2010a) was presented. The following sub-sections present how some of these steps were implemented in practice when developing the simulation study with IISSAB.

4.2.1 **Purpose, Research Questions and Objectives of the Simulation Study**

The following sub-sections present the purpose, research questions and objectives of the developed simulation study.

Simulation Study Purpose

The real-world system of the UCDP is complex and thus studying the UCDP in a simulation model is appropriate. With regards to what was presented in the previous section, the purpose of the simulation study is to gain an increasing knowledge of how the physical dimensioning, meaning the utilization and dimensioning of storage containers, of the UCDP is affected by certain factors.

Simulation Research Questions

The simulation study will be used to provide answers for the second research question (RQ2). Hence, the simulation research question adopts RQ2.

Objectives of the Simulation Study

The objectives of the simulation study are:

1. Develop a simulation model of the UCDP flow, from the sales order has been placed at IKEA to when the order leaves the UCDP, which can be used for dimensioning a UCDP.
2. Introduce scenarios to analyse and provide answers for RQ2.
3. Provide thorough guidelines on how the simulation model works so that IISSAB can use it as a future tool to evaluate the physical dimensioning of UCDPs under certain conditions.

4.2.2 **Model Conceptualization**

The UCDP Order Retrieval and Order Return Conceptual Flow

The conceptual flow for order retrieval and order return for a UCDP is shown in Figure 15 below. This conceptual model has used the information from IKEA regarding the flows of the UCDP and information from the frame of reference (see 3 Frame of Reference). The processes within each flow is distinguished by which actor performs the process: either the customer, the UCDP operator or the UCDP itself.

Both the order retrieval and order return processes start with an initializing process and ends with a concluding process. In the case of the order retrieval flow, this starts with the customer placing an order which will be retrieved from a UCDP (1.1 in Figure 15). The concluding processes are either when the customer leaves the UCDP after having retrieved the order (1.12.1 in Figure 15), or if the UCDP operator needs to remove the order from the UCDP due to the customer not picking it up within the order retrieval time set by the UCDP operator (1.8.2 in Figure 15). The customer not picking up the order is further called customer order abandonment.

The customer also initiates the order return flow but does this through notifying the UCDP operator of an order return (2.1 in Figure 15). The concluding process is when the UCDP operator removes the order from the storage container(s) (2.9 in Figure 15). Note that the processes surrounded by parentheses (2.1 and 2.2) in Figure 15 are processes that occur in the real-world system but are not captured in the simulation model.

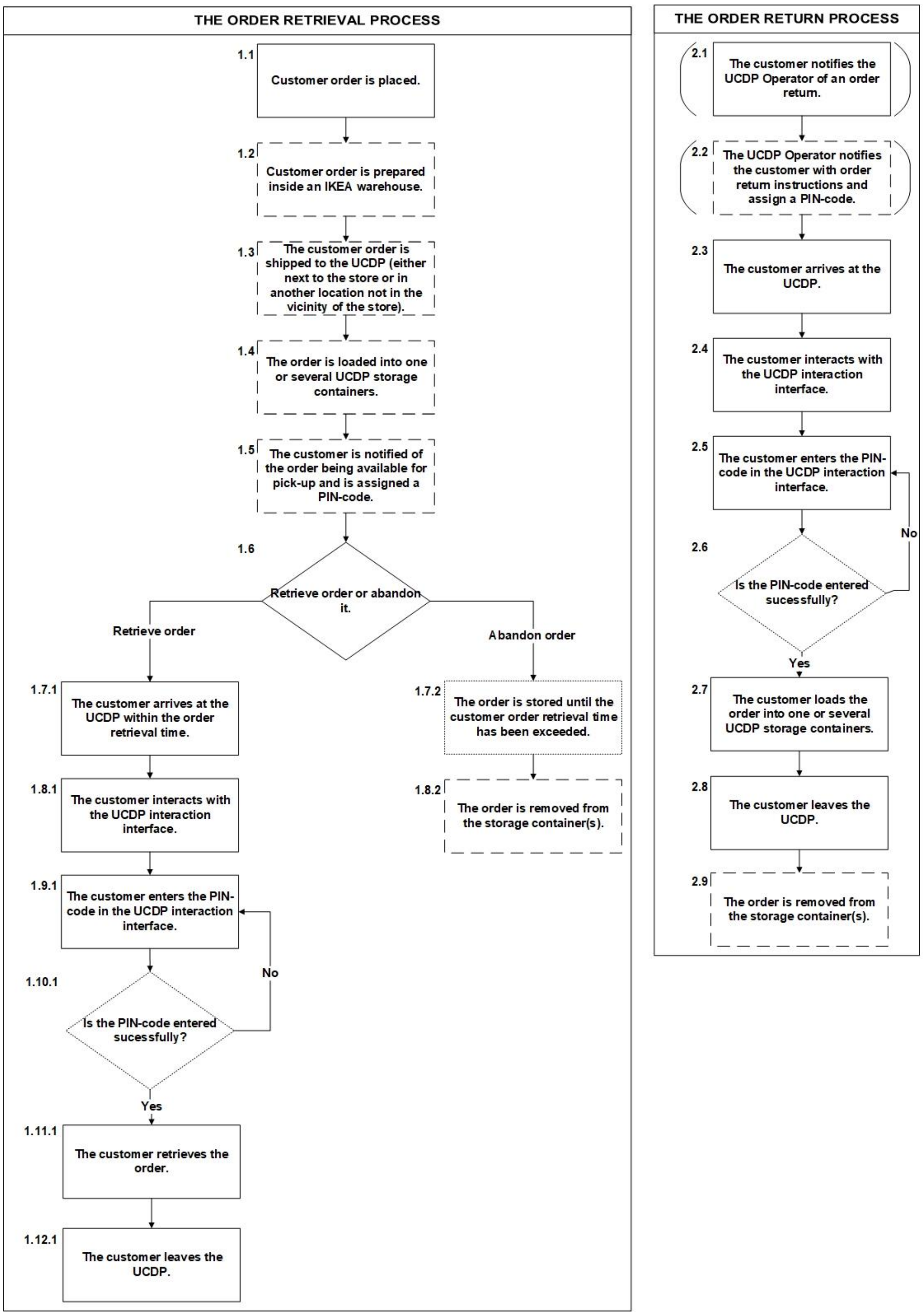

Figure 15 The conceptual flow of IKEA's UCDP order retrieval and order return processes. Filled box-outlines represent customer processes, dashed box-outlines represent UCDP operator processes and dotted box-outlines represent UCDP processes.

Factors Impacting the Simulation Model

The factors which will be studied in the scenario analysis are presented in Figure 16 below. Although the type of UCDP is not a factor of interest to answer RQ2, each type of UCDP have different storage classes with different characteristics, meaning they both have different dimensioning of the storage classes.

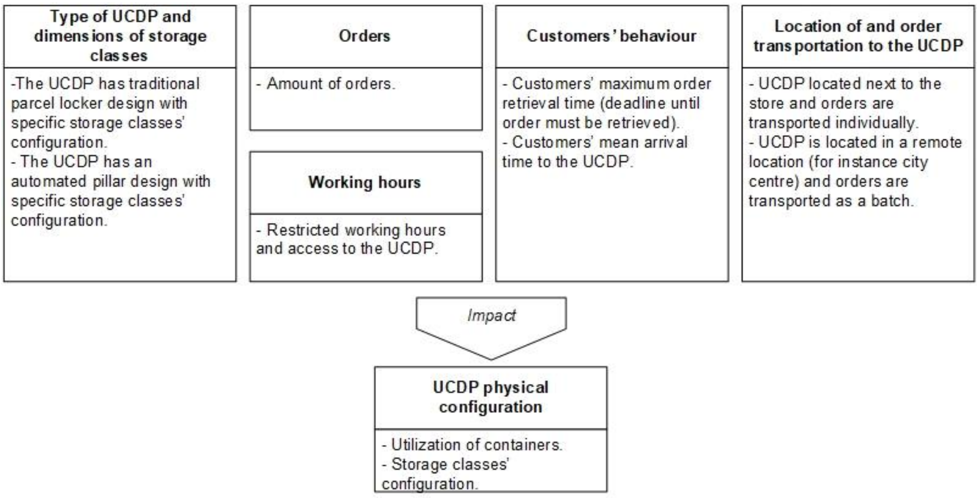

Figure 16 The various factors which will be analysed in the simulation model.

4.2.3 **Data Collection and Description**

The data sought from IISSAB for the simulation study were:

1. Sales data including:
    a. Order number
    b. Date and time of sale
    c. Article number
    d. Quantity sold per article
2. Article data including:
    a. Article number
    b. Article name
    c. Number of packs the article is divided into
    d. Dimensions of the individual packs of the article
    e. Weight of the individual packs of the article
    f. Special article storage characteristics, i.e. if it is restricted to a specific type of storage such as needs to be refrigerated.
3. Customer related data:
    a. The time until the customer arrives at the UCDP to retrieve the order.
    b. The percentage of returned orders or packs.

    c. The percentage of abandoned orders or packs.
4. IKEA UCDP working routines and policies:
    a. The time it takes to prepare an order.
    b. The time interval at which the orders are moved to the UCDP.
    c. The schedule of the order preparation employees and transportation.
    d. The time an order may be stored in the UCDP until IKEA removes it.
    e. The time until a returned or abandoned order or pack is removed from the UCDP by IKEA.

The two first data categories, sales data and article data, were given early in the thesis, where the sales data originated from an IKEA store in Glasgow. The sales did not, however, origin from purchases done by using the UCDP, but instead of in-store purchases. This, as well as the difficulty in acquiring customer related data and information regarding IKEA UCDP working routines and policies, was since IISSAB's implemented UCDPs had not been in use for a long period of time. This means that the customers' awareness of IKEA's UCDPs were low, resulting in too few orders using the UCDP. Although the sales data originates from sales in the IKEA store and not UCDP specific orders, it was deemed as still being valuable in the simulation study of the UCDPs physical dimensioning. It can also be added that the store in Glasgow has discussed in implementing a UCDP for these orders (Sörensson, 2018).

Description of the UCDP Types

Data regarding the type of UCDP and the storage classes dimensions and characteristics (storage containers' dimensioning) came from the Vienna store and from the supervisor from IISSAB. The Vienna store has implemented a UCDP of the type traditional parcel locker and IISSAB's automated pillar design is still in development. The characteristics of the two UCDP types and their storage classes characteristics are summarized in Table 8 below.

Table 8 Summary of the characteristics of the two UCDP types of IISSAB.

Type of UCDP	***Type of storage operations***	***Storage classes***	***Width (mm)***	***Height (mm)***	***Depth (mm)***	***Maximum allowed storage weight (kg)***
Traditional parcel locker (parcel locker)	Manual	Storage class 1	500	450	2100	-
		Storage class 2	330	900	2100	-
		Storage class 3	500	900	2100	-
		Storage class 4	1000	1200	2100	-
		Storage class 5	1000	2100	3000	-
Automated pillar design version 1	Automated	Storage class 1	600	815	2600	200

Furthermore, customers arrived to the UCDP at the Vienna store on average after eleven hours and 46 minutes. IKEA further has a policy that the customers should be able to retrieve the order from the UCDP after two hours from placing the order.

Description and Analysis of the Order Data

The order data used in the simulation study comes from sales data from an IKEA store in Glasgow. The sales data constitutes of in total 24 014 orders with in total 81 308 order entries, resulting in 156 460 number of packs and 5 099 distinct articles.

The order data was initially formatted to a desirable state and redundant data was removed. Following this, the sales data and article data were combined by cross-referencing the sales data to the article data. After the cross-reference, data where there occurred an unsuccessful cross-reference resulting in errors, were removed.

The sub-sections below describe the sales data in three various aspects.

The Sales Data over Time

The sales data ranges from the 1st May 2017 to 31st July 2017. Figure 17 to Figure 19 below describe the sales data over the sales period in different aspects. Figure 17 presents the total number of orders, distinct articles, order entries and packs over time for the whole sales period of the data. Figure 18 shows the total and average number of orders, distinct articles, order entries and packs but instead per weekday, while Figure 19 shows the same aspects but per hour of weekday.

Figure 17 shows that the sales data peaks every sixth or seventh day. This can also be seen in Figure 18, which also shows that the peaks are during Mondays, Saturdays and Sundays. Figure 19 shows that the first orders are registered at seven in the morning and the last orders at ten in the evening. The peak hours are around early afternoon, between 13.00 to 15.00.

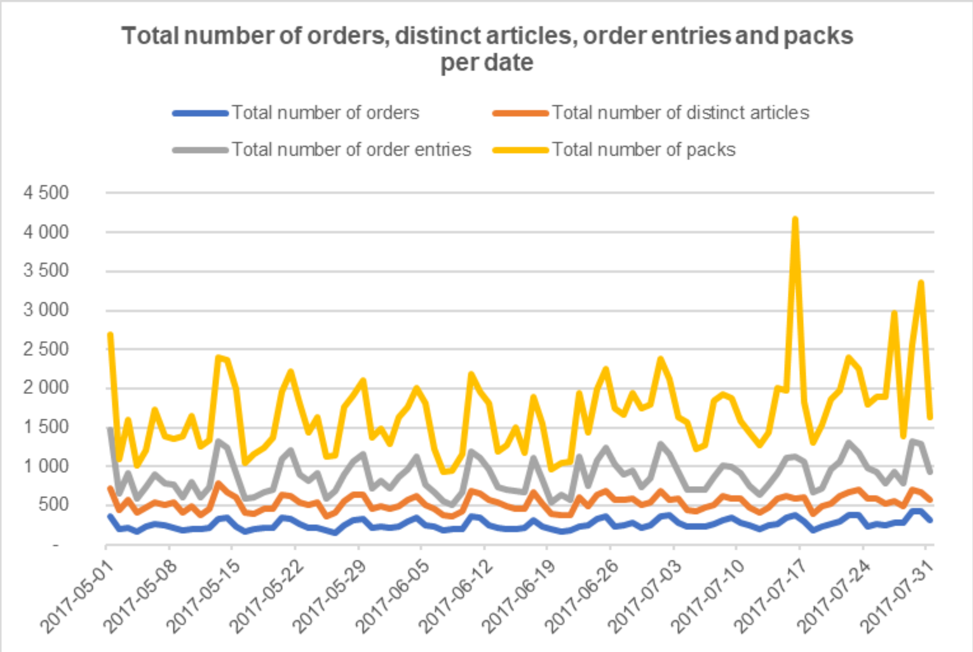

Figure 17 Total number of orders, distinct articles, order entries and packs per date registered in the sales data.

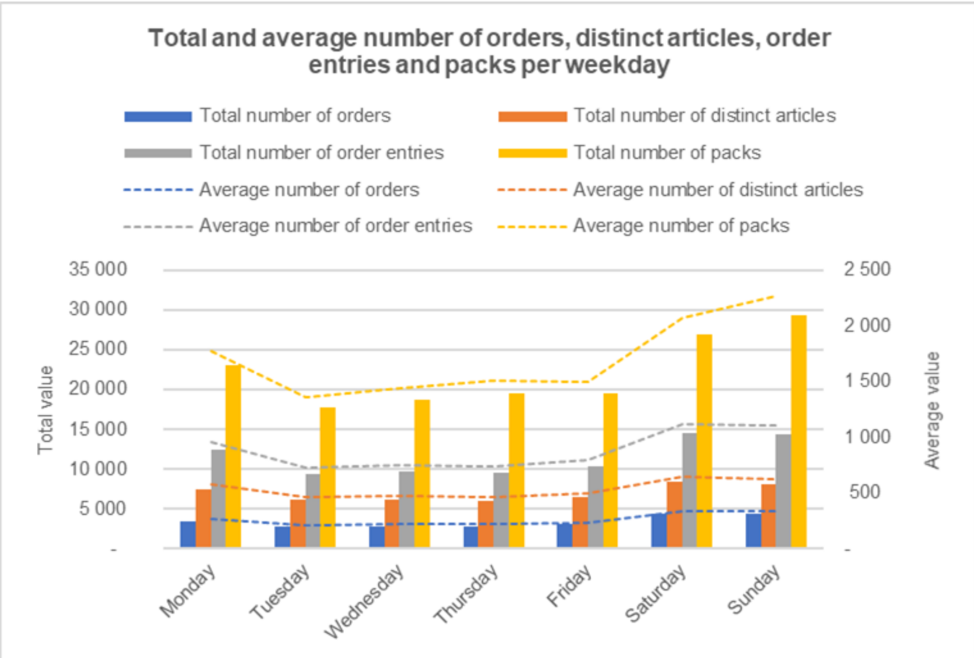

Figure 18 The total and average number of orders, distinct articles, order entries and packs per weekday registered in the sales data.

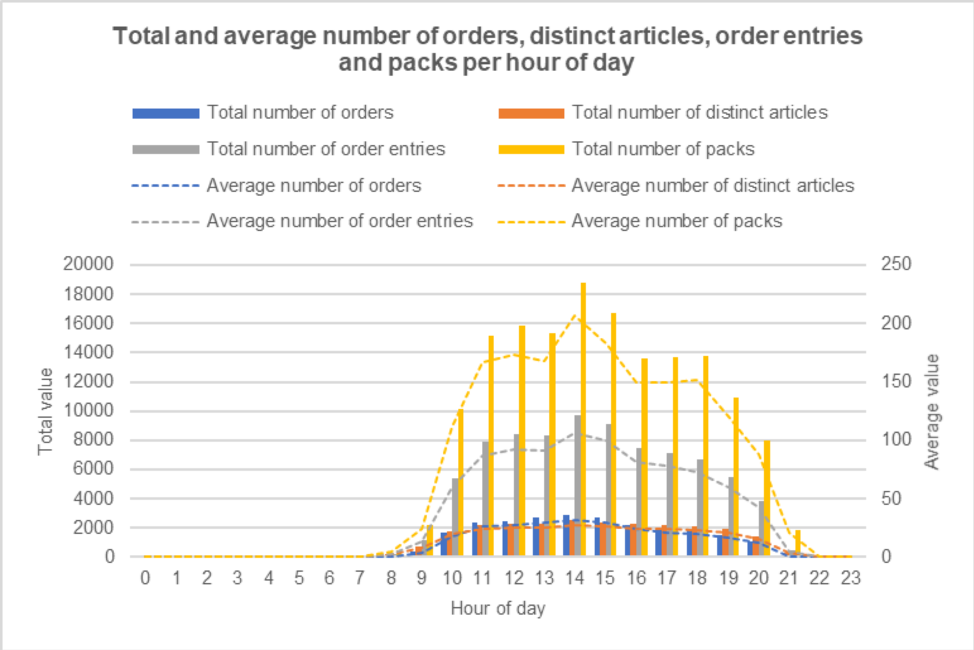

Figure 19 The total and average number of orders, distinct articles, order entries and packs sold per hour of weekday in the sales data.

The Characteristics of the Articles

At IKEA, an article may be packed into several smaller packs. In the sales data, an article could constitute of one to six separate packs. However, as Figure 20 shows, most of the articles sold only constitute of one pack.

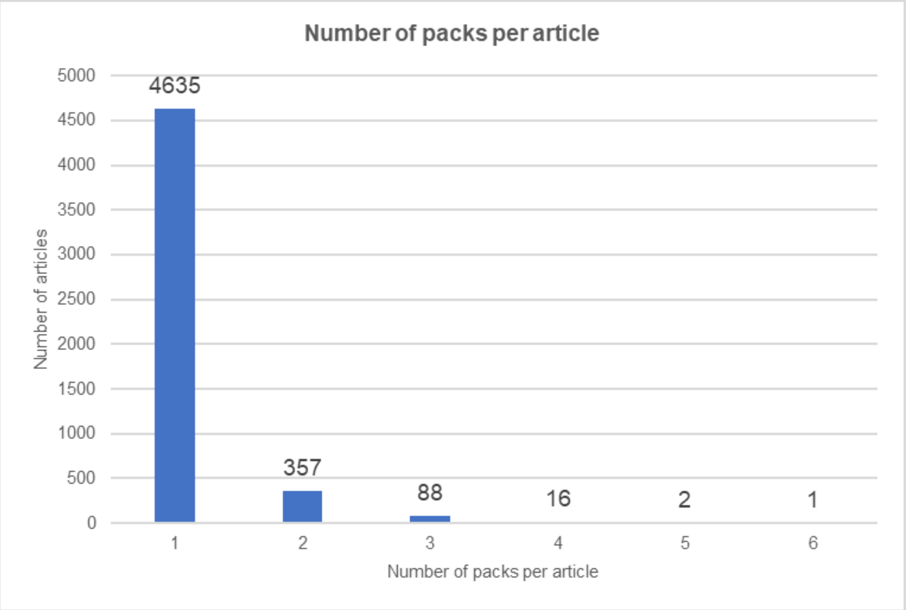

Figure 20 The number of packs an article constitutes of.

Figure 21 shows the range of all the articles' maximum, mode and minimum dimensions.

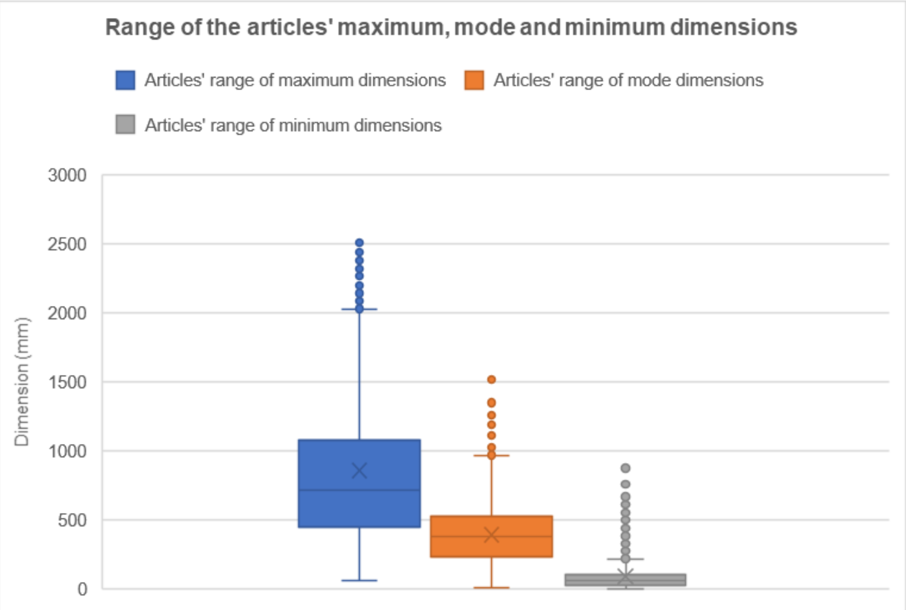

Figure 21 Ranges of the articles' maximum dimensions, mode dimensions and minimum dimensions.

Most of the weight of the articles lie in the range from approximately 500 grams to 14 000 grams. However, there are some distinct articles which are relatively heavier than the most common ones, with the heaviest article weighing around 77 000 grams. This can be seen in Figure 22.

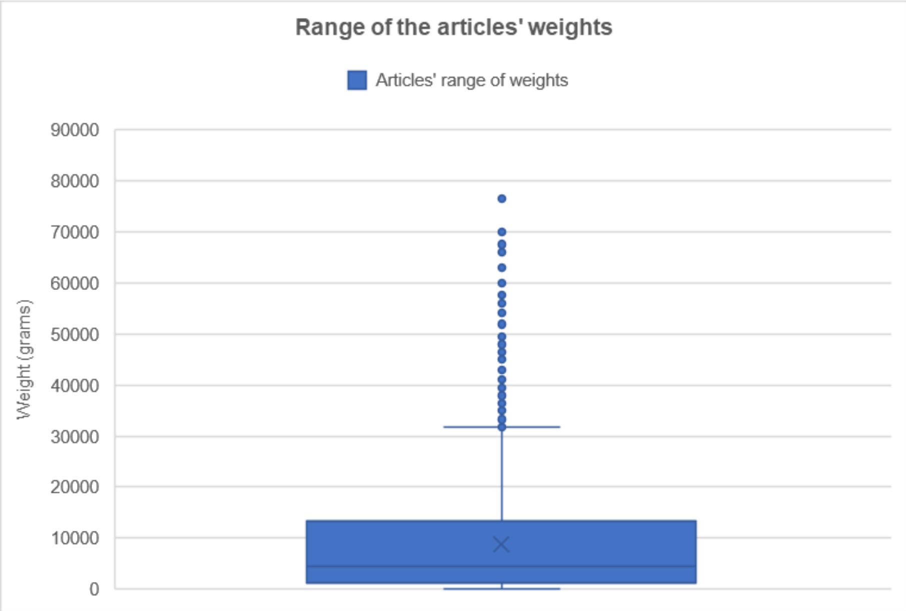

Figure 22 Range of the articles' weights.

Instead of studying the weight variation amongst the articles (see Figure 23), most of the articles have a volume of less than 40 cubic decimetres (litres), while there exist some distinct articles with volumes up to 1 360 cubic decimetres (litres).

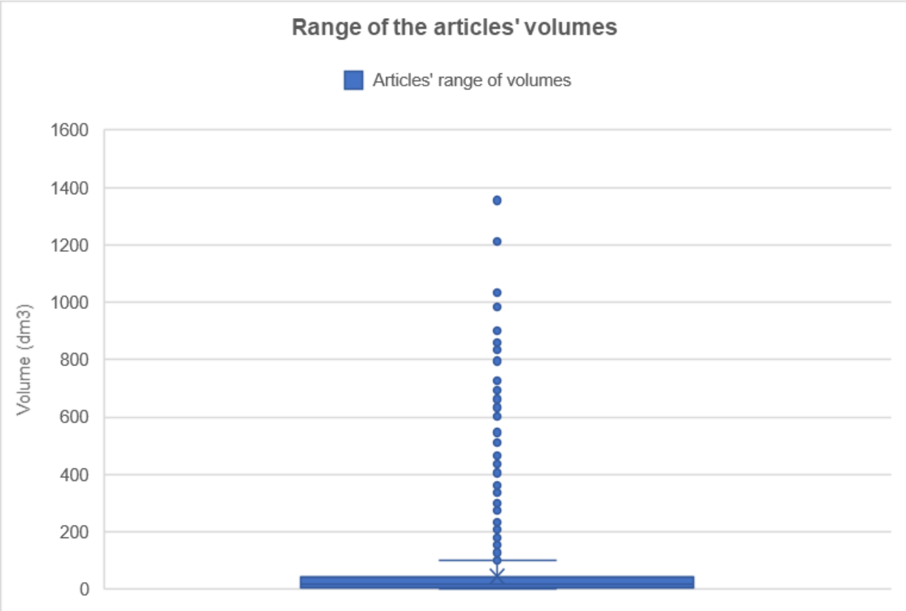

Figure 23 Range of the articles' volumes.

The Characteristics of the Orders

The previous two sub-sections have presented the sales data in two different aspects: over time and on an article level. Figure 24 to Figure 28 present various characteristics of the orders.

Figure 24 shows that on average, an order had three distinct articles, while the maximum number of distinct articles in an order was found to be 120 different articles. The figure furthermore shows that on average, an order consisted of seven packs. Some orders were however significantly larger than the other ones. Three orders constituted of over 1 000 packs, while some orders had over 80 different articles in it. One order even had 1 083 packs while another one had 120 distinct articles.

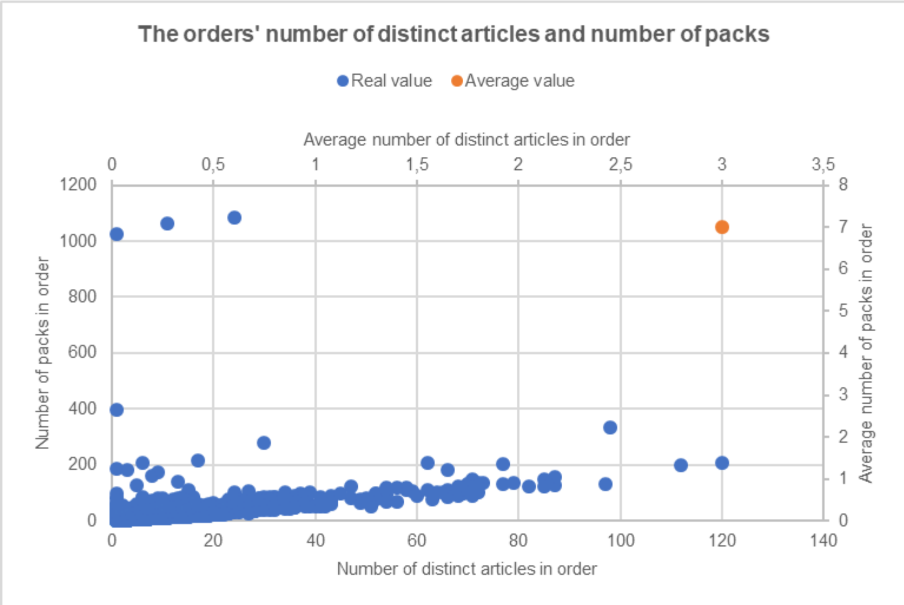

Figure 24 The number of distinct articles and number of packs in the orders.

The maximum, mode and sum of minimum dimensions are presented in Figure 25 and Figure 26. The maximum dimension of an order is defined as the largest identified dimension of all the packs in the order. The same definition is applied to an order's mode dimension but identifies instead the largest mode dimension of all the articles in the order. The sum of minimum dimensions is the sum of each pack's minimum dimension in the order. These dimensions are used in the simulation model. The maximum, mode and sum of minimum dimensions of the orders were on average and approximately 1 400 mm, 560 mm and 300 mm respectively.

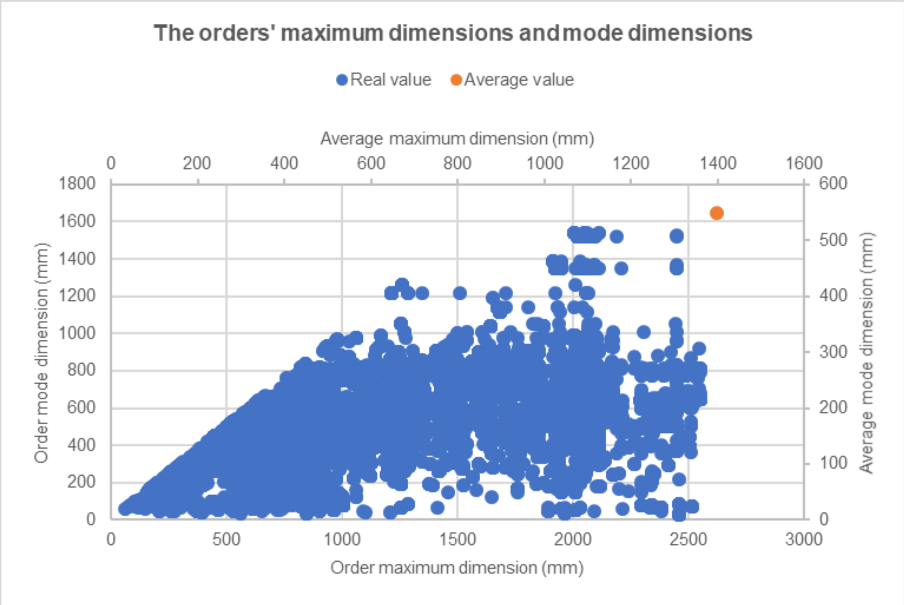

Figure 25 The maximum and mode dimensions of the orders.

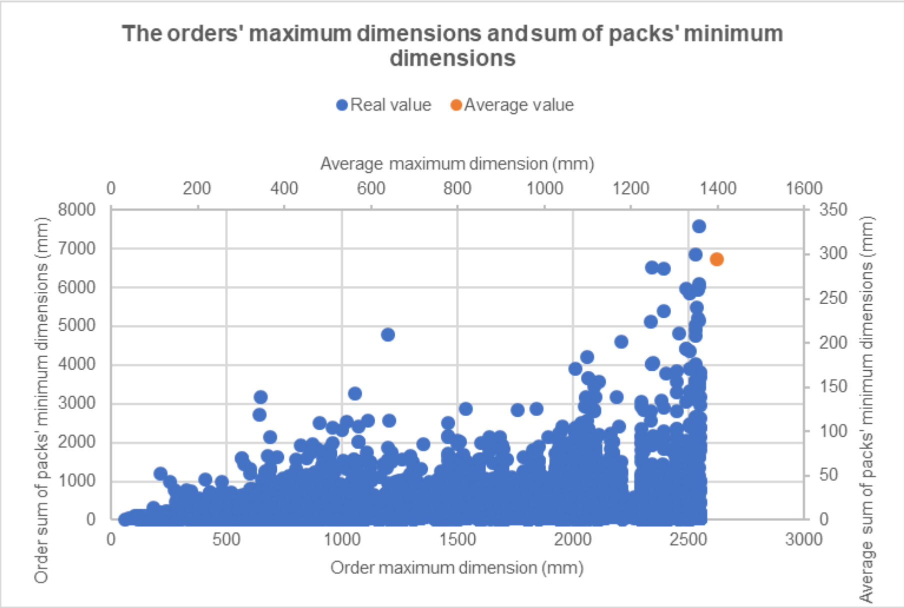

Figure 26 The maximum and sum of packs' minimum dimensions of the orders.

The volumes and weights of the different orders varied widely. This can be seen in both Figure 27 and Figure 28. The difference between these is that the former figure includes all the orders, while the latter figure excludes the 15 largest orders by volume. The wide range of the orders' volumes and weights could be explained by the fact that *assumption DA1* (see next section) is assumed. Since only the largest dimensions and weights of the packs are known from the given article data, this assumption regards that if an article consists of several packs, all the packs in this article has the dimensions and weights of the largest pack of the article. A further explanation to this phenomenon is that the customers purchases small and large quantities of a wide range of products from different HFBs. As previously shown, the articles have large variation regarding the dimensions, volumes and weights.

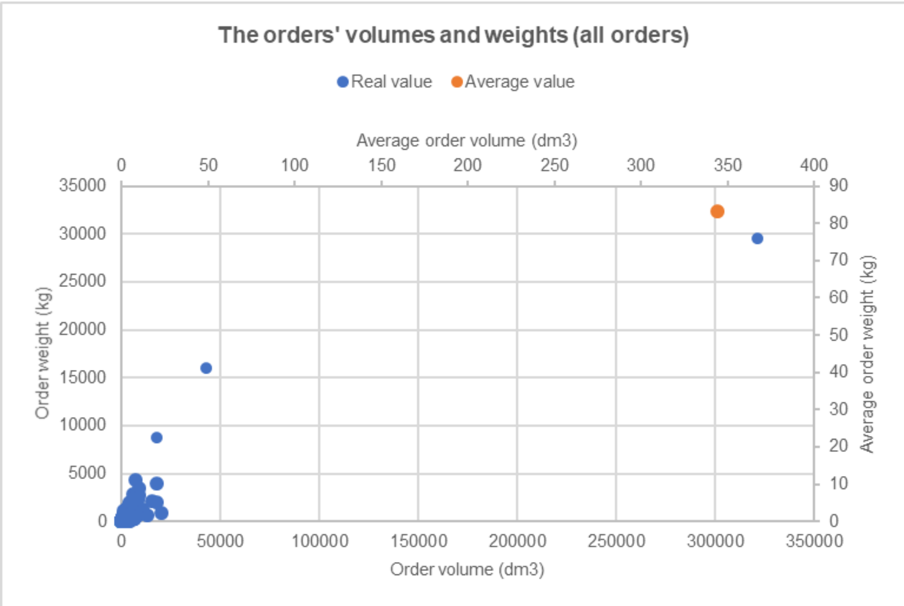

Figure 27 The volumes and weights of all the orders.

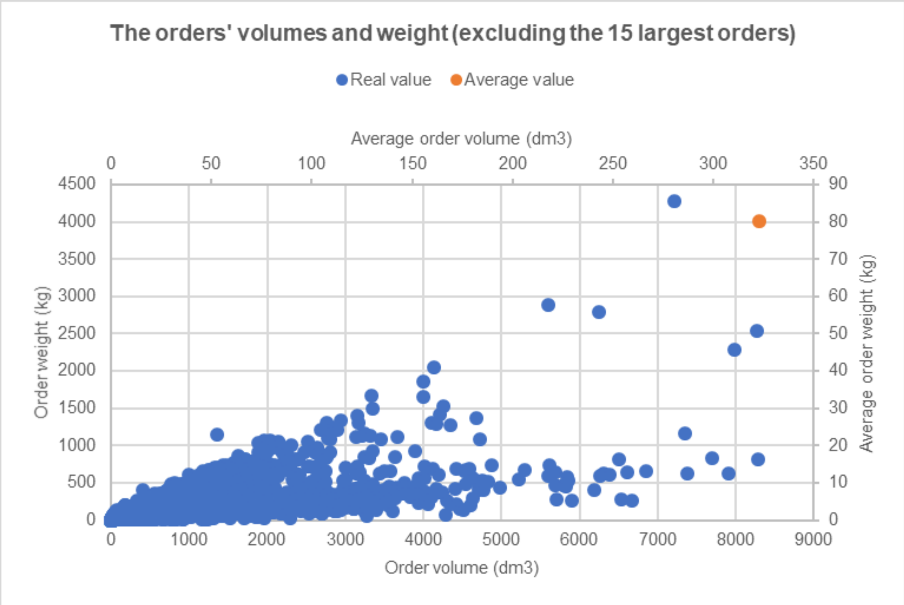

Figure 28 The volumes and weights of the orders, excluding the 15 largest orders (by volume).

4.2.4 **Model Translation**

The two computer software employed to develop the simulation model were Microsoft's Excel and Rockwell Automation's Arena. Excel was used to store the input data such as order data and user defined input. Excel was then integrated with Arena so that the input data could be used in the simulation model. The simulation model itself was developed in Arena, a discrete event simulation software which has several features flowchart modelling technology, statistical distribution options, statistical analysis and report generation, performance metrics and dashboards as well as 2D and 3D animation capabilities ("Discrete Event Simulation Software," 2018).

Features of the Developed Simulation Model

The features of the developed simulation model are several:

- The order data is connected to the simulation model. The order data creates the flow in the simulation model.
- The characteristics of the orders and articles, such as time of registration, order and article number, number of packs, dimensions, volumes and weights are used to assist the logical flow in the simulation model. The dimensions, volumes and weights are especially used in the flows where the storage container of the UCDP should be decided.

- The simulation model can optionally manipulate orders, meaning either increasing and decreasing the number of orders from the order data.
- It features an optional order preparation mode, where the orders are prepared inside the IKEA store.
- It features an optional order transportation mode, where the orders are batched together to a delivery vehicle cargo before sending the orders to a remote UCDP location.
- It decides which storage class an order should be optimally stored into according to the orders' (and inherited articles' and packs') characteristics and the characteristics of each storage class. However, if the containers in the optimal storage class are full, the simulation model chooses the next storage class which the pack will be inserted into.
- It has two storage operations modes: either manual storage operations, which means that the packs are inserted piece-by-piece, and automated storage operations, which means that all the packs which should be stored in a container are inserted at the same time. The manual storage operations should resemble the traditional parcel locker and the automated storage operations the automated pillar design.
- It has four schedules, connected to the order preparation times, order transportation times, the times when the customers have access to the UCDP for retrieval of orders and returns as well as a schedule for the UCDP operators' access to the UCDP to insert orders or retrieve returned and abandoned orders.
- The user can input specific values from an Excel-sheet regarding process times, available resources etc and can thus run several different configurations.

For further explanation of how the simulation model works, see Appendix A.

Simulation Model and Data Assumptions

A simulation model is prone to some simplifications, as phenomenon occurring in the real world sometimes are difficult to capture in a simplified manner in a simulation model. The simplifications also depend on the tool to design the simulation model, as different tools have different functionalities, design opportunities and design restrictions. Furthermore, not only the simulation model itself needs assumptions, but also the input data used. Thus, the assumptions are divided into two categories: data assumptions (DA) and model assumptions (MA):

1. Data assumptions (DA):
   - *DA1*: If an article consists of several packs, meaning the article is divided into several packs, all of those packs have the same dimensions, volume, weight and special characteristics as the largest of the packs.
   - *DA2*: A pack of an article is assumed to be rectangular.
2. Model assumptions (MA):

- *MA1:* Each pack can be stored in any rotational way within the storage container. This means that any restrictions to how a pack may be stored, for instance an oven which cannot be stored with its top against the floor, is assumed to be disregarded.
- *MA2:* A storage container can only hold articles from one specific order number at a time.
- *MA3:* If a pack is deemed unable to fit into a single container in any storage class, the order will be split into several containers. The algorithm first attempts to store the order in the largest storage class.
- *MA4:* The following four comparisons are done when deciding on if the storage container in a specific storage class is adequate to store an additional pack (see Figure 29 for an example):
    - *MA4.1:* If the sum of the minimum dimensions of all the stored packs in the storage container, plus the minimum dimension of the pack which will be inserted, is less or equal to the minimum dimension of the storage container, then the pack may be stored in the storage container.
    - *MA4.2.1:* If the order is not split according to *MA3*, then the pack may be stored in the storage container if the sum of the volume of the stored packs in the storage container, plus the volume of the pack to be inserted, is less or equal to the storage volume of the container.
    - *MA4*.2.2: If the order is split according to *MA3*, then the pack may be stored in the storage container if the relative value of the sum of the stored packs in the storage container, plus the volume of the pack to be inserted, to the storage volume of the container is less or equal to the maximum volume utilization of the container as assigned by user input.
    - *MA4.3:* If the sum of the weight of all the stored packs in the storage container, plus the weight of the pack which will be inserted, is less or equal to the allowed storage weight of the storage container, then the pack may be stored in the storage container.
- *MA5:* If a pack is unable to be inserted into a storage container due to it being over dimensioned or does not fulfil other criteria set by the storage container, such as volume, weight or special article characteristics, the pack is immediately disposed.
- *MA6:* If a pack is unable to be inserted into the UCDP due to all of the available containers in the UCDP being occupied, the pack is immediately disposed.
- *MA7:* The UCDP, its storage containers, interaction interfaces, gateways and ASRS, have no breakdowns. Furthermore, delivery

vehicles and order preparation employees also have no breakdowns.

- *MA8:* A customer or UCDP operator is equivalent to an order number.
- *MA9:* A single pack in an order can be returned.
- *MA10:* A customer is only able to abandon the whole order and all the packs it constitutes of.
- *MA11:* The customer is being notified of delivery to the UCDP after the order has been loaded into the UCDP.

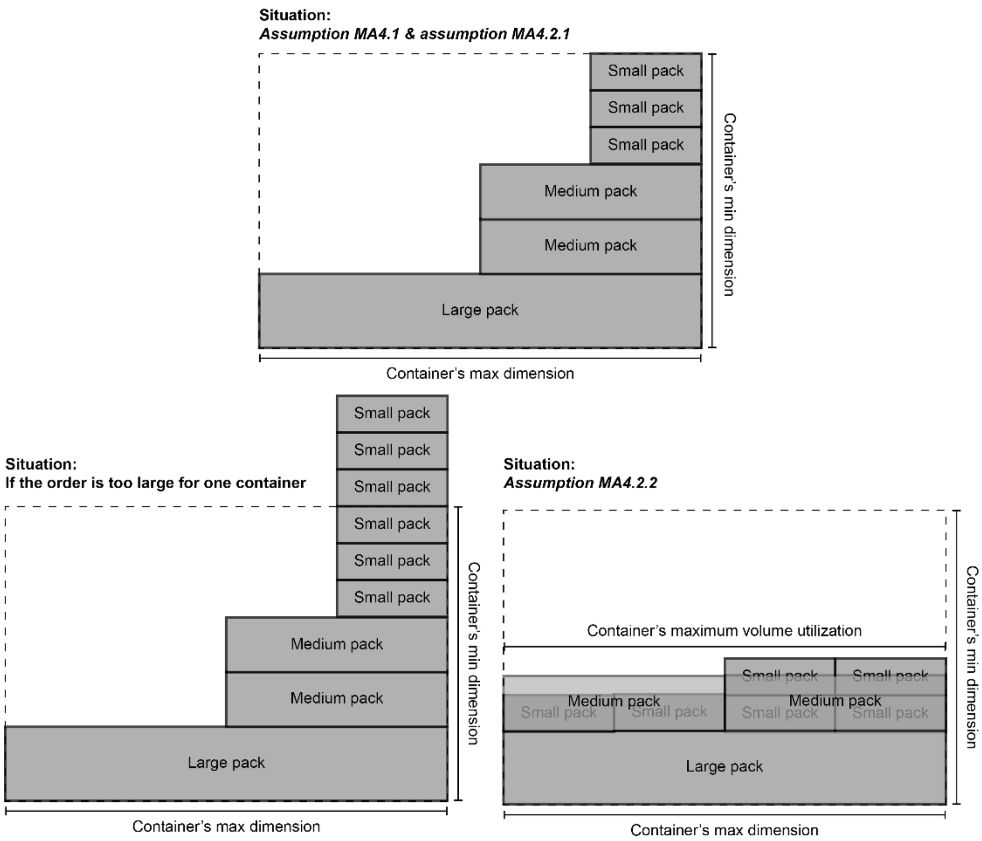

Figure 29 Example of *assumption MA4.1*, *assumption MA4.2.1* (left-side image) and *assumption MA4.2.2* (right-side image).

4.2.5 Verification and Validation

As was mentioned in 2.3 Theoretical Approach of Simulation Studies, verification and validation (V&V) is an important step in any simulation study. In the two sub-sections, the methods applied to verify and validate the developed simulation model respectively are presented.

Verification

The simulation model was verified by using several of the previously mentioned methods (see Verification and Validation in 2.3 Theoretical Approach of Simulation Studies):

- Each module in the simulation model was checked so it had the correct configuration of data and logic.
- The flow of the entities in the simulation model was carefully studied so they followed the logical design flow.
- The simulation model underwent rigorous testing, testing each feature separately and in conjunction as well as with various settings.
- The output data was processed, analysed and used to verify the model as well.
- The debugging tool was frequently used to identify errors in the model and step through the simulation model event by event.

Validation

The validation of the developed simulation study involved the following methods:

- To develop the conceptual model, both the supervisors were contacted to validate whether the conceptual model was a correct representation of the real-world system. This was a sort of conceptual model validation.
- The data used as input in the simulation model was analysed, to identify any inaccurate data and format the data according to the format required by the simulation model.
- Under two meetings with both the supervisors, validate the developed simulation study and implement any identified changes deemed as necessary.
- A white-box validation was used, in which all the elements of the model, as well as the logical flow of the simulation model, was carefully studied.
- Using an experimentation validation for validation.

4.2.6 **Experimental Design**

A feature of simulation model is that it can test a system with various settings. To provide answers for RQ2, three types of analyses will be made: scenario, factor and sensitivity analyses will be conducted. A scenario analysis considers the impact on the outcome of an analysis using assumptions regarding several independent variables and environmental factors. In the scenario analysis, many factors may be adjusted to see how the outcome is affected (Hawks, 2018). A factor analysis will be used in conjunction with the scenario analysis to study one factor at a time. For each factor, a sensitivity analysis is made. The sensitivity analysis estimates how sensitive a dependent variable (the factor) is to a change in an independent variable (the physical dimensioning of the UCDP) (Hawks, 2018).

Two scenario analyses are proposed, one for each type of UCDP. These will be called *scenario 1* and *scenario 2*. For each scenario analysis, factor analyses will be made. This means that one of the five factors presented in Figure 16 (two factors for the customers' behaviour) will be analysed. For the factor analyses, sensitivity analyses will be made. This means that the value of the factor of interest will be adjusted to see how this affect the simulation results. How the scenario, factor and sensitivity analyses are interlinked is summarized in Figure 30.

In total, 54 different simulation configurations (SC) will be constructed. The index of each configuration consists of the scenario index, factor index and sensitivity value index. For instance, the index for scenario 1, factor 2 with the sensitivity analysis index 10 (factor value 10) is *SC 1.2.10*.

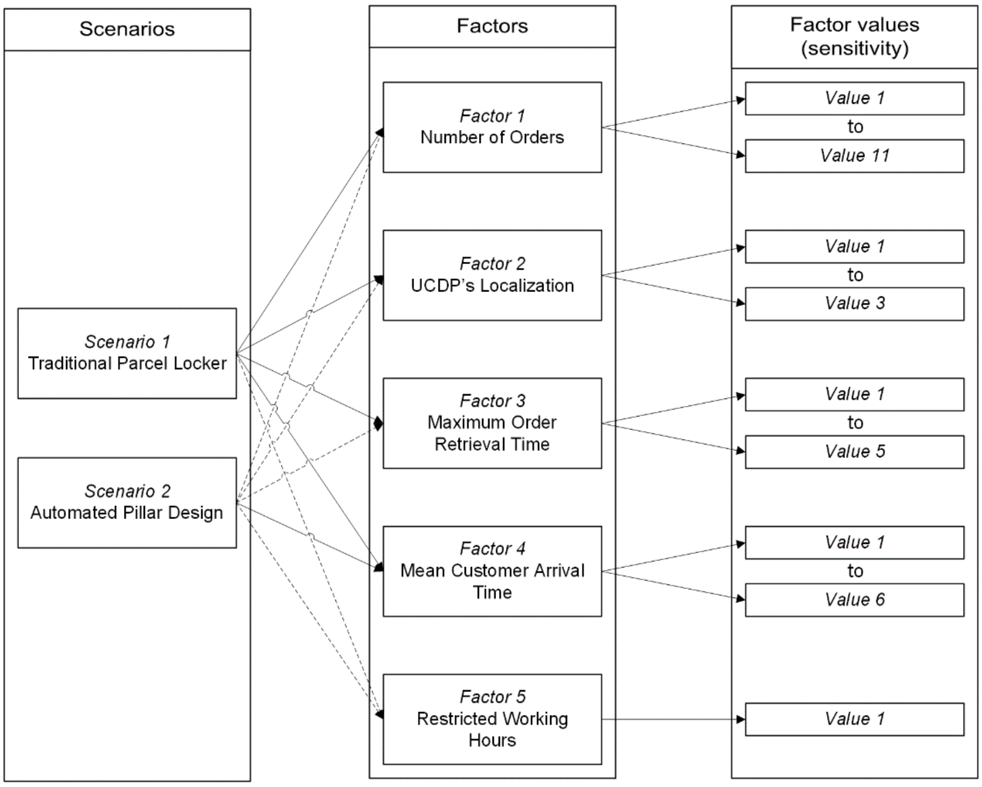

Figure 30 Overview of the scenario, factor and sensitivity analyses.

The following sub-sections will first introduce some additional assumptions to the scenarios, and present the scenario, factor and sensitivity analyses in more detail.

Scenario Assumptions

In addition to the assumptions regarding the data used and logic of the simulation model, additional assumptions for the scenarios need to be made. In the simulation model, there are several resources used for instance to prepare an order, issue the order to the UCDP, UCDP interaction interfaces as well as gateways and ASRS for the automated ASRS. Since the order data has no connection to purchases made using an UCDP, the amount of orders does not currently reflect the amount of purchases which can or will be done by the UCDP. The large amount of orders will influence the resources. A realistic amount of resources, for instance one gateway and one ASRS for the automated solution, is unable to cope with this large amount of orders. This will result in long processing times in the simulation model. Hence, the number of resources used in the scenarios will be at maximum level. This assumption is consistently introduced as well since the process times of the UCDP are not the focal point in the simulation study.

Scenarios 1 and 2

There are two scenarios, one for the traditional parcel locker design and one for the automated pillar design as described by IISSAB. The names of the two scenarios are *scenario 1* for the former UCDP design and *scenario 2* for the latter design. Respectively, these are also named *SC 1.0.0* and *SC 2.0.0*.

The configuration of the simulation model common for both scenarios are presented in the list below:

- The maximum volume utilization of a container if an order is split is set to 70 percent of the container's maximum storage volume.
- It uses the ordinary order data without any manipulation, i.e. the number of orders is neither increased or decreased.
- It takes in between 20 minutes to 30 minutes according to a triangular distribution to prepare an order.
- The UCDP is located next to the store.
- The customers arrive to the UCDP according to a beta distribution with the minimum value of two hours, up to 72 hours (three days) of the order delivery to the UCDP. This means that the maximum order retrieval time is 72 hours. The mean arrival time is nine hours. This corresponds to an alpha value of 1,5 and beta value of 13,5 used in the beta distribution (see A.2.3 Beta Distribution in Appendix A). The probability distribution function[3] (PDF) and cumulative distribution function[4] (CDF) for the beta distribution of the scenarios can be seen in Figure 31 and Figure 32 respectively.

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[3] The probability distribution function (PDF), or probability density function, shows all possible values for a stochastic or random variable for a probability function (Stephanie, 2014) .

[4] The cumulative distribution function (CDF) shows the cumulative probability associated with a probability function. The CDF can be used to find the probability that a stochastic variable is above a certain value, below a certain value or in between two values (Stephanie, 2015c).

- It takes between 20 to 60 seconds to interact with the UCDP interaction interface for load-in and retrieval, both for the customers and the UCDP operators.
- It takes between five to ten seconds to enter the assigned PIN-code into the UCDP interaction interface during retrieval. The success rate that the PIN-code is entered successfully is 99 percent.
- The probability of a pack being returned is 0,5 percent. The customers then return to the UCDP after between two days to four days. The order is stored in the UCDP for 24 hours after the returned order has been inserted until the order is removed.
- The probability of a full order being abandoned by the customer is 0,5 percent. The order is stored in the UCDP until the maximum order retrieval time has expired, at which point the order is removed from the UCDP. In the scenarios, this means that an abandoned order is stored 72 hours in the UCDP before being removed.
- The order preparation employees work around the clock, and the UCDP operators' access to the UCDP is also around the clock.
- The customers have 24/7 access to the UCDP.
- The number of order preparation employees and UCDP interaction interfaces are set to 50 respectively according to the previously mentioned scenario assumptions.

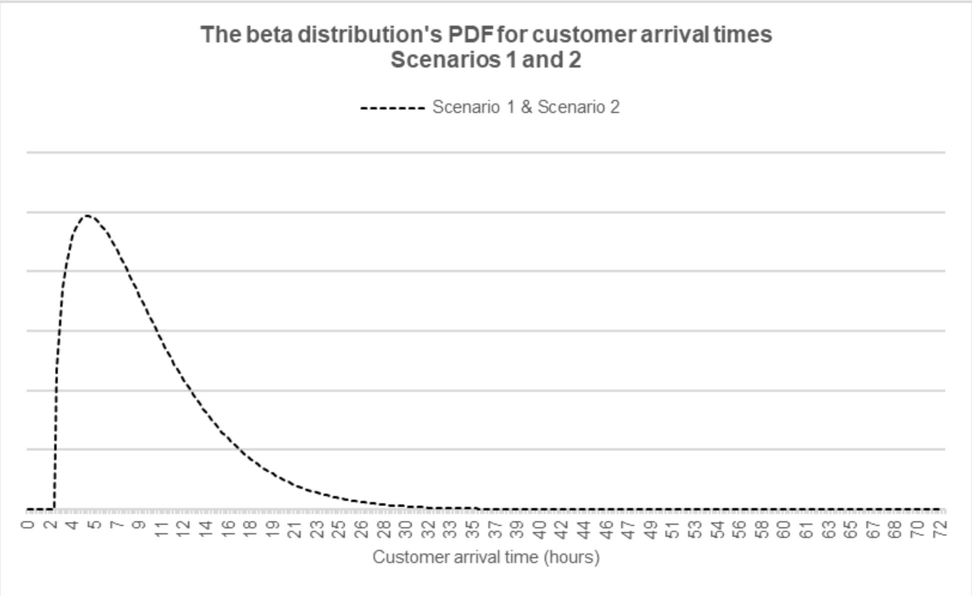

Figure 31 The PDF for the beta distribution used for *scenario 1* and *scenario 2*.

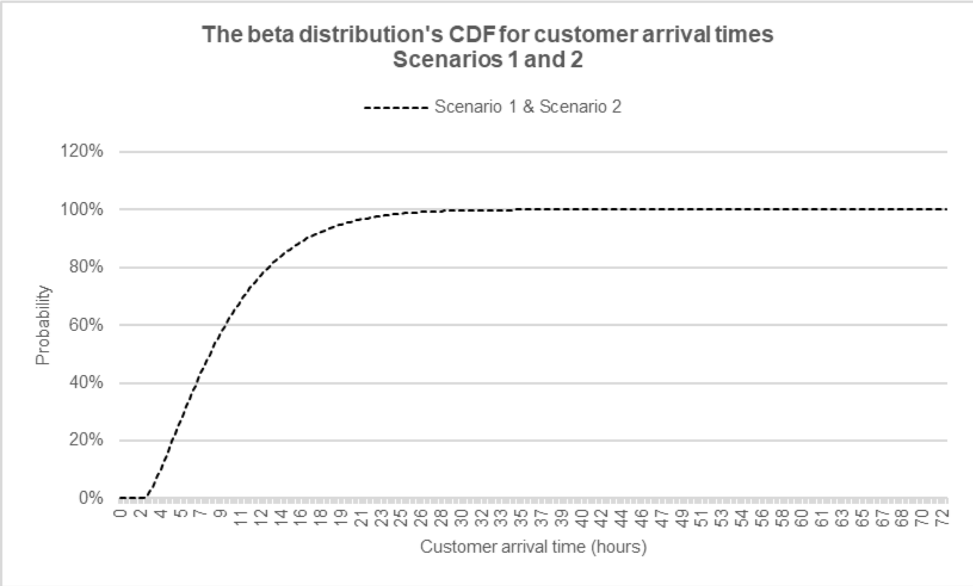

Figure 32 The CDF for the beta distribution used for *scenario 1* and *scenario 2*.

The difference between *scenario 1* and *scenario 2* is the type of UCDP used, their storage classes dimensions, type of storage operations and storage operations process times. For the storage operations process times for *scenario 1*, it takes between three to five seconds to insert or remove a pack from the UCDP. In *scenario 2,* the time to insert or remove all the packs from a container is between five to ten seconds. Note that the process times affect each pack in *scenario 1*, while it affects all the packs in a container in *scenario 2*. Since the storage operations in *scenario 2* are automated, it has 50 gateways and 50 ASRS according to the scenario assumptions. The other characteristics are summarized in Table 9. Both the scenarios have 2 500 containers, but these are equally distributed for all the storage classes in *scenario 1*, meaning that each storage class has 500 containers.

Table 9 The configuration of the UCDP for *RS 1.0* and *RS 2.0*.

Scenario name	***Type of UCDP***	***Type of storage operations***	***Storage classes index***	***Width (mm)***	***Height (mm)***	***Depth (mm)***	***Maximum allowed storage weight (kg)***
Scenario 1	**Traditional parcel locker**	**Manual**	**1**	500	450	2100	-
			2	330	900	2100	-
			3	500	900	2100	-
			4	1000	1200	2100	-
			5	1000	2100	3000	-
Scenario 2	**Automated pillar design**	**Automated**	**1**	600	815	2600	200

Sensitivity Analyses for Factor Analysis 1: Number of Orders

The first factor to be analysed regards the number of orders the UCDP should handle. To see how the number of orders affect the physical dimensioning of the UCDP, eleven sensitivity analyses are proposed. In the first ten sensitivity analyses of the factor, the number of orders is increased (*SC 1.1.1* to *SC 1.1.10* and *SC 2.1.1* to *SC 2.1.10*). The order manipulation mode is set to increase orders, and there is a chance that an order is duplicated with ten percent. The factor is incremented by ten percent for sensitivity analysis.

The duplicated orders have the same article, order entry and pack composition as the original order. However, there is a chance that the time of the order is moved to another week, but at the same day and time of day of the original order.

In the eleventh sensitivity analysis (*SC 1.1.11* and *SC 2.1.11*) of the factor the number of orders is instead decreased. The probability of an order being removed is 50 percent.

A summary of the different sensitivity analyses made for the factor number of orders is presented in Table 10.

Table 10 Summary of the sensitivity analyses for the factor number of orders.

SC index	*Order manipulation mode*	*Chance of manipulation*
1.1.1 & 2.1.1	Increase	10%
1.1.2 & 2.1.2	Increase	20%
1.1.3 & 2.1.3	Increase	30%
1.1.4 & 2.1.4	Increase	40%
1.1.5 & 2.1.5	Increase	50%
1.1.6 & 2.1.6	Increase	60%
1.1.7 & 2.1.7	Increase	70%
1.1.8 & 2.1.8	Increase	80%
1.1.9 & 2.1.9	Increase	90%
1.1.10 & 2.1.10	Increase	100%
1.1.11 & 2.1.11	Decrease	50%

Sensitivity Analyses for Factor Analysis 2: The UCDP's Localization

To analyse how a UCDP's localization, namely if it would be located in a remote location (for instance city centre), affects the UCDP's physical dimensioning, three sensitivity analyses for the factor are proposed *(SC 1.2.1* to *SC 1.2.3* and *SC 2.2.1* to *SC 2.2.3*). In each of the sensitivity analyses, there are 10 delivery vehicles available according to the scenario assumptions. Although there are several delivery vehicles available, not all of them might be utilized. The chosen number of delivery vehicles assures that all the orders arrive at the UCDP at a reasonable time after the order has been placed. Each of the delivery vehicles can further hold a cargo of up to 50 000 dm^3. Their velocity is between 70 to 90 kilometres per hour, but on average 80 kilometres per hour. The UCDP is located 30 kilometres away from the store.

The difference between the sensitivity analyses is when the departure of the delivery vehicles occurs. In the first sensitivity analysis, the delivery vehicles depart once a day at around 08.00. In the second sensitivity analysis, the delivery vehicles depart twice a day, approximately 08.00 and 16.00. Three deliveries occur at around 08.00, 12.00 and 16.00 for the third sensitivity analysis. A summary of the sensitivity analyses is presented in Table 11.

Table 11 Summary of the sensitivity analyses for the factor UCDP in a remote location.

SC index	*Delivery departure times*
1.2.1 & 2.2.1	Around 08.00
1.2.2 & 2.2.2	Around 08.00 and 16.00
1.2.3 & 2.2.3	Around 08.00, 12.00 and 16.00

Sensitivity Analyses for Factor Analysis 3: Maximum Order Retrieval Time

The sensitivity analyses for this factor adjusts the maximum time until the customer can arrive to the UCDP and still retrieve the order. This means that the maximum order retrieval time is adjusted. In correspondence, the time until an abandoned order is removed corresponds to the maximum order retrieval time. However, most of the customers still arrive at the UCDP after nine hours of being notified and the minimum arrival time is after two hours.

The five sensitivity analyses (*SC 1.3.1* to *SC 1.3.5* and *SC 2.3.1* to *SC 2.3.5*) for the factor maximum order retrieval time are summarized in Table 12. Note that since the maximum order retrieval time is adjusted, the alpha and beta values for the beta distributions of the customers' arrival times need to be adjusted accordingly.

Table 12 Summary of sensitivity analyses for the factor maximum order retrieval time, including new alpha and beta values for the beta distribution.

SC index	***Minimum arrival time***	***Mean arrival time***	***Maximum order retrieval time***	***Alpha value***	***Beta value***
1.3.1 & 2.3.1	2 hours	9 hours	96 hours (4 days)	1,5	18,64
1.3.2 & 2.3.2	2 hours	9 hours	120 hours (5 days)	1,5	23,79
1.3.3 & 2.3.3	2 hours	9 hours	144 hours (6 days)	1,5	28,93
1.3.4 & 2.3.4	2 hours	9 hours	168 hours (1 week)	1,5	34,07
1.3.5 & 2.3.5	2 hours	9 hours	336 hours (2 weeks)	1,5	70,07

Figure 33 shows the PDFs for the beta distributions used for each of the sensitivity analyses. As can be seen, the beta distributions look similar to each other. This is because the mean value is left unchanged. The difference is that there is a slight probability that the different maximum order retrieval times could occur, although this is difficult to observe in the plot. This is more clearly visible in Figure 34, which shows the CDFs for the beta distributions for the sensitivity analyses.

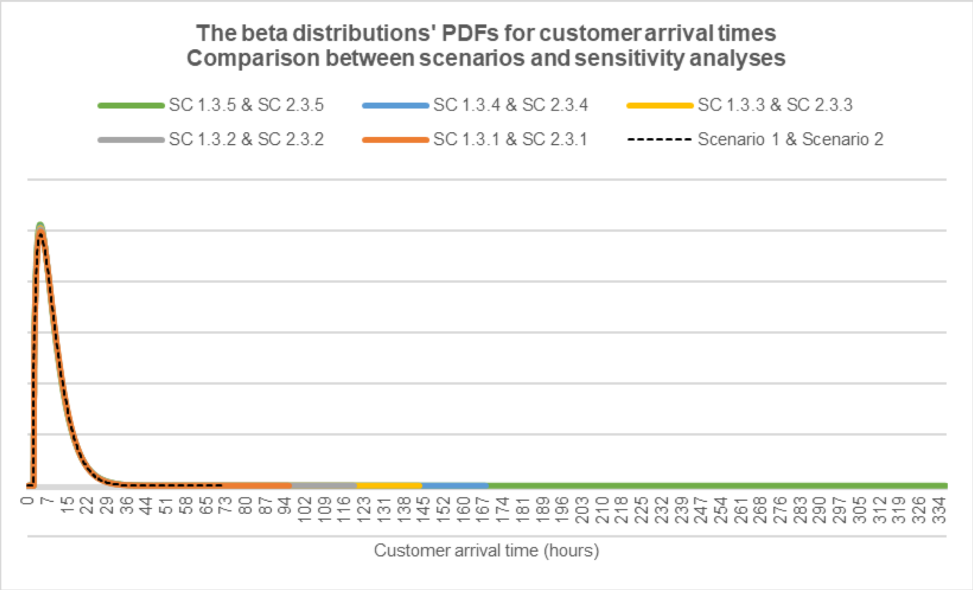

Figure 33 The PDFs for the beta distributions used for the sensitivity analyses compared to the PDF for the scenarios.

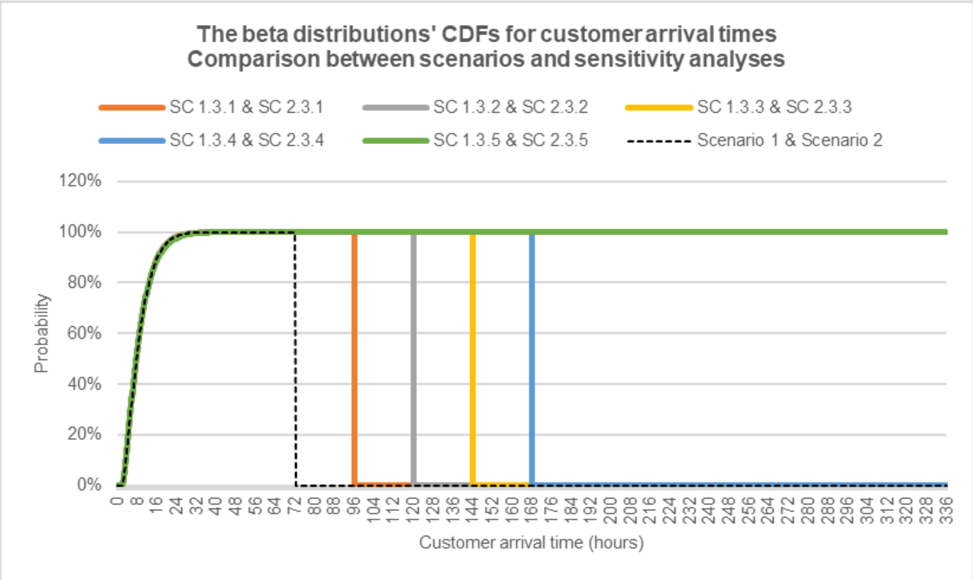

Figure 34 The CDFs for the beta distributions used for the sensitivity analyses compared to the CDF for the scenarios.

Sensitivity Analyses for Factor Analysis 4: Customer Mean Arrival Time

Six sensitivity analyses study how the factor mean customer arrival times to the UCDP affects its physical dimensioning. These contrast with the previous factor analysis, where instead the maximum order retrieval time was adjusted but the mean arrival time was the same. The minimum arrival time is still set at two hours and the maximum order retrieval time, and thus the time until an abandoned order is removed, is still set to 72 hours. A summary of the sensitivity analyses is presented in Table 13. The alpha and beta values are also adjusted accordingly.

Table 13 Summary of sensitivity analyses for the factor customers' mean arrival times, including new alpha and beta values for the beta distribution.

SC index	*Minimum arrival time*	*Mean arrival time*	*Maximum order retrieval time*	*Alpha value*	*Beta value*
1.4.1 & 2.4.1	2 hours	6 hours	72 hours (3 days)	1,5	24,75
1.4.2 & 2.4.2	2 hours	12 hours	72 hours (3 days)	1,5	9,00
1.4.3 & 2.4.3	2 hours	15 hours	72 hours (3 days)	1,5	6,58
1.4.4 & 2.4.4	2 hours	24 hours (1 day)	72 hours (3 days)	1,5	3,27
1.4.5 & 2.4.5	2 hours	36 hours (1,5 days)	72 hours (3 days)	1,5	1,59
1.4.6 & 2.4.6	2 hours	48 hours (2 days)	72 hours (3 days)	1,5	0,78

The PDFs for the beta distributions used in sensitivity analyses can be seen in Figure 35. Figure 36 instead shows the CDFs. As can be seen, the maximum order retrieval time is left unadjusted, while the mean arrival time has been adjusted.

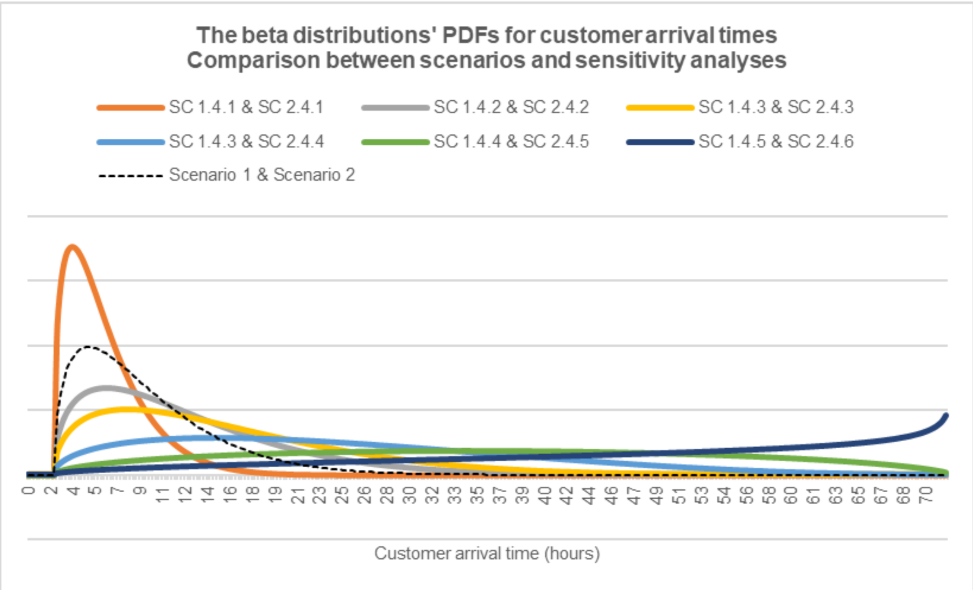

Figure 35 The PDFs for the beta distributions used for the sensitivity analyses compared to the PDF for the base scenarios.

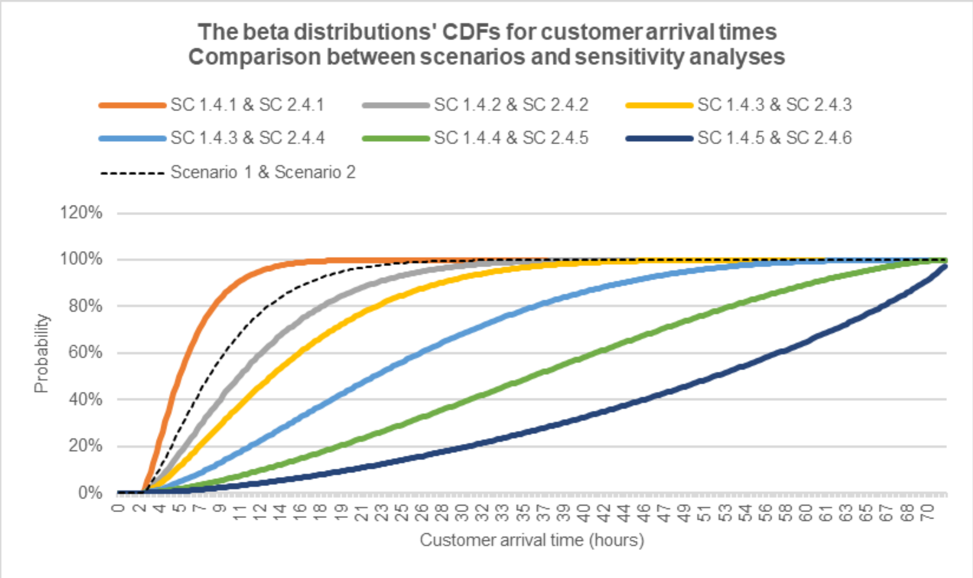

Figure 36 The CDFs for the beta distributions used for the sensitivity analyses compared to the CDF for the base scenarios.

Sensitivity Analyses for Factor Analysis 5: Schedules of the UCDP Service Provider

In *scenario 1* and *scenario 2*, the order preparation employees' working schedule and UCDP operators' access to the UCDP is 24/7. One sensitivity analysis studies how a restriction applied to the these affects the UCDP's physical dimensioning. The UCDP is still located next to the store. The schedule is that the order preparation employees work from Monday to Friday between 08.00 to 18.00. The UCDP operators' access to the UCDP is set accordingly. A summary of the sensitivity analysis is presented in Table 14.

Table 14 Summary of the working hours for scenarios 1.26 and 2.26.

SC index	***Working hours***
1.5.1 & 2.5.1	Monday to Friday, 08.00 to 18.00

Summary of Factor and Sensitivity Analyses

A comprehensive summary of all the factor analyses and sensitivity analyses is presented in Table 15.

Table 15 Summary of the simulation configuration indexes, the factor analyses and sensitivity analyses conducted in the simulation study.

SC index	*Factor analysis*	*Sensitivity Analysis*
1.0.0 & 2.0.0	-	-
1.1.1 & 2.1.1	Number of orders	10% increase
1.1.2 & 2.1.2	Number of orders	20% increase
1.1.3 & 2.1.3	Number of orders	30% increase
1.1.4 & 2.1.4	Number of orders	40% increase
1.1.5 & 2.1.5	Number of orders	50% increase
1.1.6 & 2.1.6	Number of orders	60% increase
1.1.7 & 2.1.7	Number of orders	70% increase
1.1.8 & 2.1.8	Number of orders	80% increase
1.1.9 & 2.1.9	Number of orders	90% increase
1.1.10 & 2.1.10	Number of orders	100% increase
1.1.11 & 2.1.11	Number of orders	50% decrease
1.2.1 & 2.2.1	UCDP's localization	Remote location, delivery at around 08.00
1.2.2 & 2.2.2	UCDP's localization	Remote location, delivery at around 08.00 & 16.00
1.2.3 & 2.2.3	UCDP's localization	Remote location, delivery at around 08.00, 12.00 & 16.00
1.3.1 & 2.3.1	Maximum order retrieval time	96 hours (4 days)
1.3.2 & 2.3.2	Maximum order retrieval time	120 hours (5 days)
1.3.3 & 2.3.3	Maximum order retrieval time	144 hours (6 days)
1.3.4 & 2.3.4	Maximum order retrieval time	168 hours (1 week)
1.3.5 & 2.3.5	Maximum order retrieval time	336 hours (2 weeks)
1.4.1 & 2.4.1	Customer mean arrival time	6 hours
1.4.2 & 2.4.2	Customer mean arrival time	12 hours
1.4.3 & 2.4.3	Customer mean arrival time	15 hours
1.4.4 & 2.4.4	Customer mean arrival time	24 hours
1.4.5 & 2.4.5	Customer mean arrival time	36 hours
1.4.6 & 2.4.6	Customer mean arrival time	48 hours
1.5.1 & 2.5.1	Schedules of UCDP service provider	Restricted, Monday to Friday, 08.00 to 18.00

4.2.7 The Concluding Steps of the Developed Simulation model

In the developed simulation study, ten replications were sufficient to provide answers to the simulation study's objectives. However, the simulation configurations needed to be redesigned and run an additional time, since the initial set did not provide fruitful answers to RQ2. This was due to the configuration of the scenarios. In the first set of scenarios, the number of containers the UCDP had were too few to accommodate all the orders. Furthermore, the order preparation employees and UCDP operators' access time to the UCDP were restricted to Monday to Friday between 08.00 to 18.00. This resulted in large spikes of number of occupied containers in the beginning of the next week. Hence, many packs were removed from the simulation model because of this. Thus, the number of containers of the UCDP, and also the storage classes, were increased and the order preparation employees and UCDP operators' access to the UCDP was set to around the clock instead. These changes are reflected in the above-mentioned scenario analyses.

In addition, a program documentation was set as one of the objectives of the simulation study. A full program documentation was written but will be featured in a separate document.

4.3 Chapter Summary

This chapter presented the company, IISSAB, which the simulation study was conducted together with. The problem formulation for the simulation study, as well as the research questions and objectives of the simulation study, were presented. A conceptual model of the UCDP order and return process along with the factors to be analysed in the simulation model, were presented as well. The collected data showed that the acquired sales data constitutes of several orders with a wide range of different articles, whose packs have different dimensions, volumes and weights. The characteristics of the orders though varied greatly between each other. Having described the data, an introduction to Rockwell Automation's Arena simulation software was introduced together with assumptions regarding the data and the simulation model. The V&V process was also described and two scenario analyses, five factor analyses and a number of sensitivity analyses, resulting in 54 different simulation configurations, were introduced. The chapter concluded with describing how the last steps of the structured process in developing a simulation study were implemented in the developed simulation study.

5 Results from the Simulation Study

This chapter presents the results of each scenario, factor and sensitivity analysis in the simulation study. The chapter starts with presenting the nature of the results. This is followed by presenting the results from the scenarios in more detail. The following sections present the results from the five factor analyses, their respective sensitivity analyses and comparing the results to the scenarios. The chapter concludes with presenting the aggregated results per storage class for all the simulation configurations.

It is reminded for the following chapters that *SC 1.0.0* to *SC 1.5.1* represent the traditional parcel locker while *SC 2.0.0* to *SC 2.5.1* represent the automated pillar design by IISSAB. Furthermore, the term number of occupied containers (NOC) and storage classes may be used interchangeably with the terms utilization and dimensioning of storage containers respectively.

5.1 Nature of the Results Data

The simulation model is able to extract a various amount of data. Each simulation configuration was run using ten simulation replications and hence, the result of each replication will be different due to inherit random variations in the simulation model. The output from the simulation run is both the maximum and the average values recorded at an interval of 60 minutes. To make the results more observable, only the maximum values of the replications will be presented. In some cases, however, the average of maximum values will also be presented.

5.2 The Scenarios

5.2.1 **Occupied Containers over Time**

The NOC for the whole UCDP over time for *scenario 1* and *scenario 2* can be seen in Figure 37 and Figure 38 respectively. As can be seen in both figures, the NOC on a macro level is similar for both scenarios. This is more clearly presented in Figure 39, where a comparison is made. There occur regular peaks of occupied containers with a one-week interval. This is due to the nature of the sales data, where weekly peaks occur during the weekends (see 4.2.3 Data Collection).

In both scenarios, there occurs one peak which is larger than the regular peaks. This peak can be explained by one order which consists of only one article but is sold in a large quantity. A total of 256 number of this article was purchased and each article consists of four packs, which means in 1024 total of packs was sold. This order is the most far-right dot in Figure 27 presented previously in 4.2.3 Data Collection. Although there exist several orders which have a large quantity and varied number of articles, these articles are relatively small and can thus fit into few containers of the largest storage classes of the UCDP. The articles inducing the peak in the figures are, however, large. The height, length and width of this article is 32,5 cm, 1,31 m and 74 cm respectively. Nonetheless, the large number of containers the UCDP has in all the simulation configurations, it is able to store this large order. Note that the NOC in the largest peak in *scenario 1* is around 170 containers less than in *scenario 2*.

Figure 38 shows that over the course of the simulation time, the traditional parcel locker used in *scenario 1* uses a few more containers than the automated pillar design used in *scenario 2*.

The final segment starting from 1st August 2017 of Figure 37, Figure 38 and Figure 39 is explained by either an order which has been abandoned by the customer, or one or several packs returned by the customer to the UCDP.

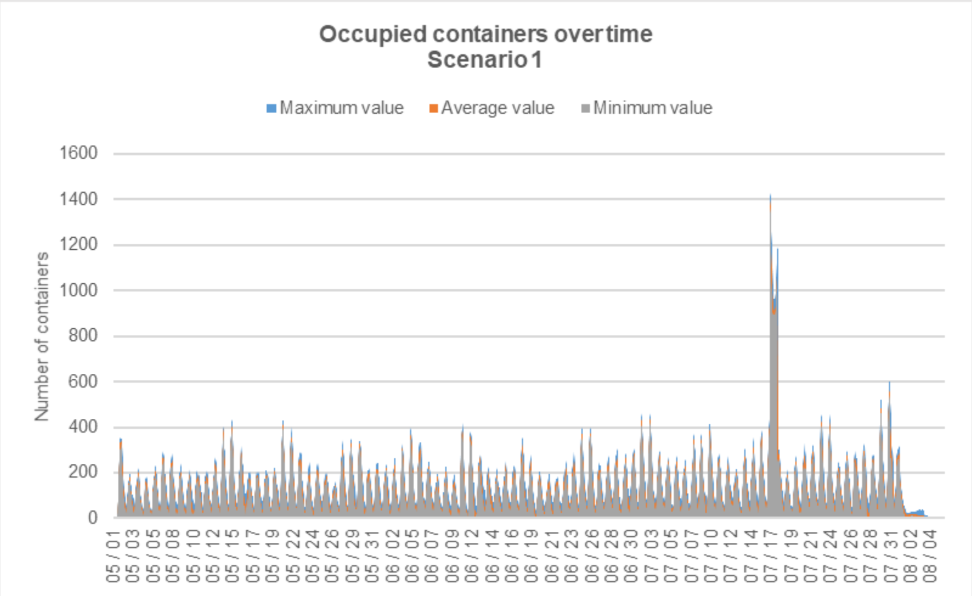

Figure 37 The maximum, average and minimum number of occupied containers for the whole UCDP over the simulation time for *scenario 1*, the traditional parcel locker.

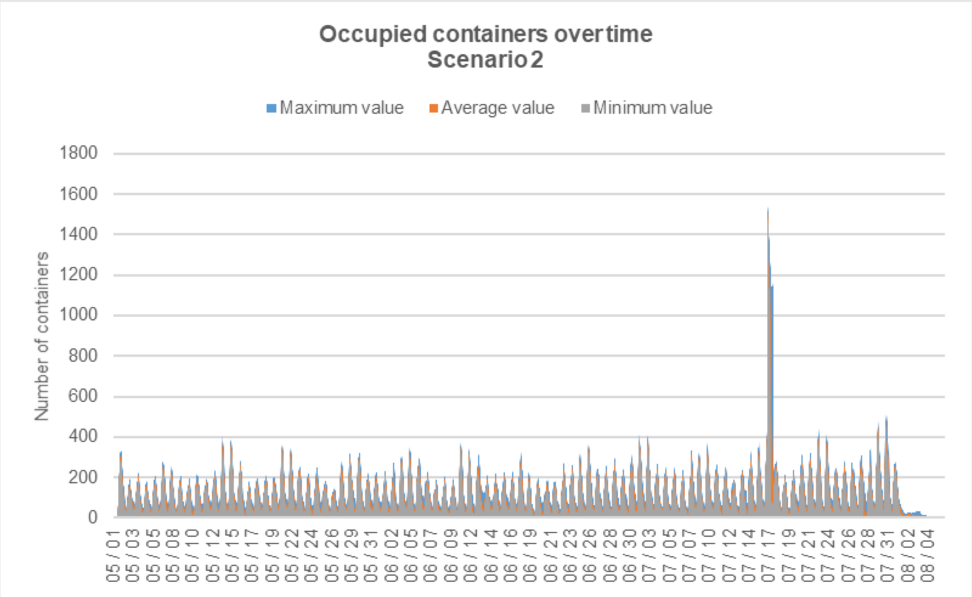

Figure 38 The maximum, average and minimum number of occupied containers for the whole UCDP over the simulation time for *scenario 2*, the automated pillar design.

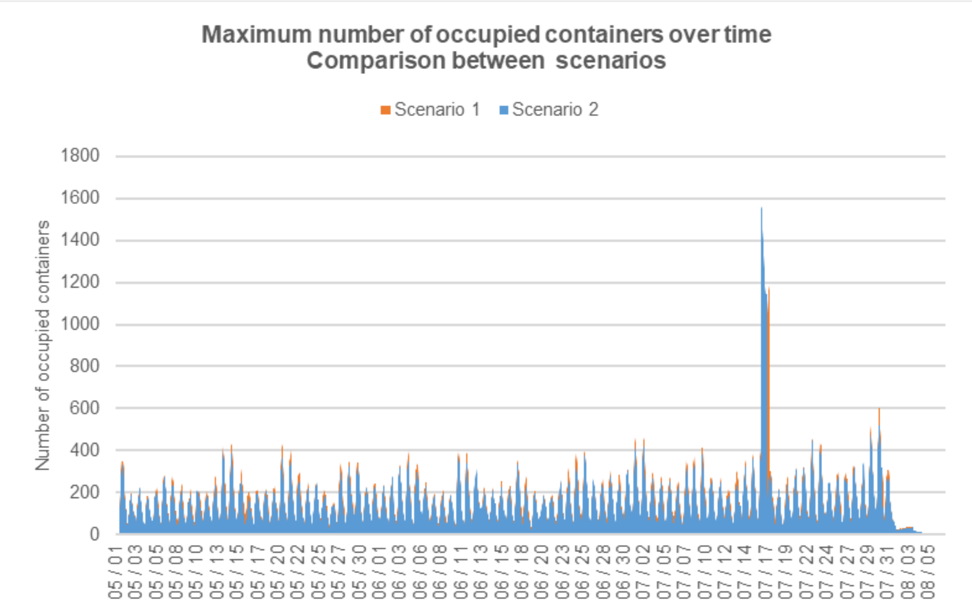

Figure 39 Comparison of the number of occupied containers for the whole UCDP over time between *scenario 1* and *scenario 2*.

5.2.2 **Occupied Containers per Storage Class over Time**

The NOC per storage class is also presented. This number for *scenario 1* and is presented in Figure 40. Since the UCDP used in *scenario 2* is the automated pillar design, it only has one storage class and will hence resemble the figure for the NOC for the whole UCDP (see previously presented Figure 38).

What is noteworthy of the traditional parcel locker in *scenario 1*, is that the first and second storage classes are utilized relatively more than the rest of the storage classes. The algorithm used in the simulation model sees to that the packs are inserted into the storage class with the best fit. Once the largest peak occurs, however, all the storage containers are utilized.

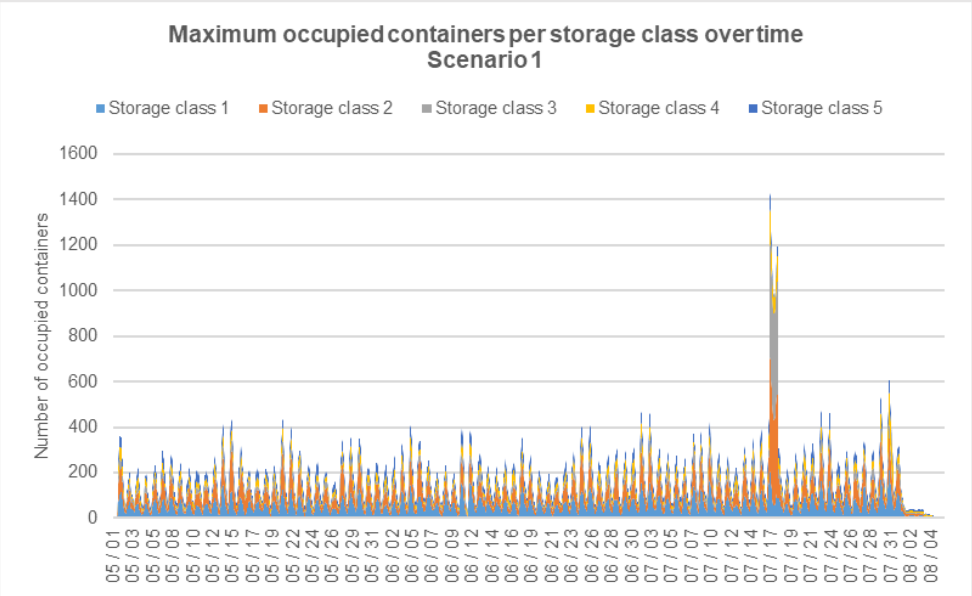

Figure 40 The maximum number of occupied containers per storage class over the simulation time for *scenario 1*, the traditional parcel locker.

The maximum and average NOC per storage class for the whole simulation time are presented in Figure 41 and Figure 42 respectively. For the maximum NOC per storage class for *scenario 1*, it shows that the second and third storage classes are utilized the most. This is however inaccurate, since the large number of the third storage class is mostly influenced by the large peak as previously described. Please note further that the numbers in Figure 41 shows the maximum NOC per storage class for any of the replications in the simulation run.

Figure 42 instead showing the average NOC per storage class for the traditional parcel locker further shows that the two smallest storage classes, the first and second storage class, are on average utilized the most. Additionally, the figure shows that on average, the traditional parcel locker utilizes the containers more than the automated pillar design.

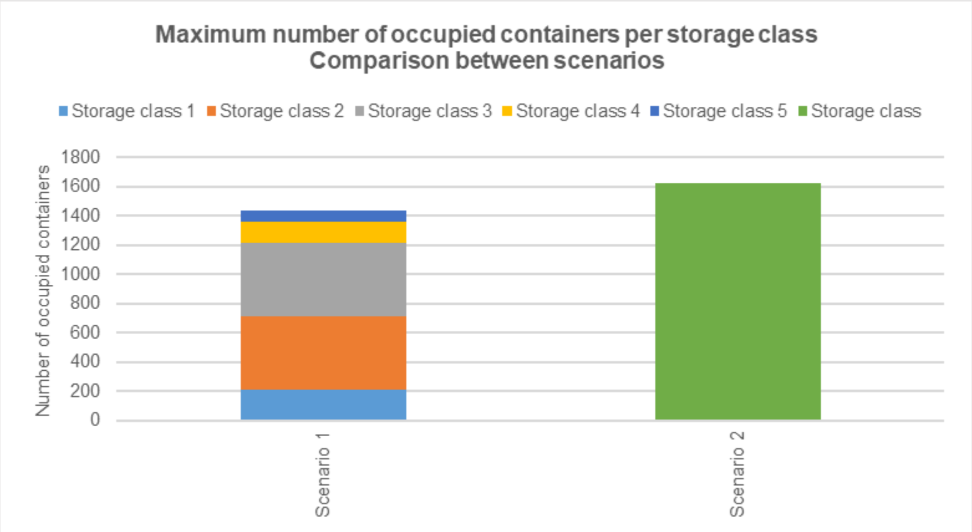

Figure 41 The maximum number of occupied containers per storage class for any replication compared between *scenario 1* and *scenario 2*.

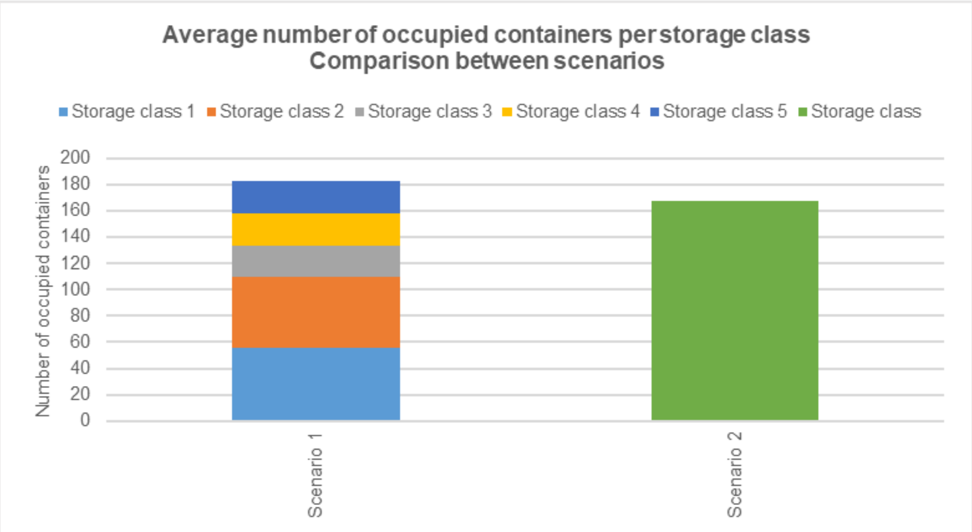

Figure 42 The average number of occupied containers per storage class compared between *scenario 1* and *scenario 2*.

5.2.3 **Packs Inappropriate for Storage**

Packs and articles which are unable to be stored in the UCDP were present in *scenario 2* and all the other simulation configurations using the automated pillar design. The packs and articles were removed due to their dimensions, not fitting into any of the storage classes. For *scenario 1*, no packs were removed because of this. This means that the traditional parcel locker used in *scenario 1* can fit the wide range of different articles present in the sales data. In contrast, the automated pillar design used in *scenario 2* was not able to store 5 800 packs due to their characteristics.

Figure 43 and Figure 44 show the range of dimensions and weight of these packs, as well as the respective dimensions and maximum allowed storage weight of the storage class' containers represented by the dashed lines. As can be seen, neither the maximum dimension or the maximum allowed storage weight of the containers is the issue for the packs being removed. The issue lies mainly however in the mode dimension of the storage class and thus the automated pillar design by IISSAB.

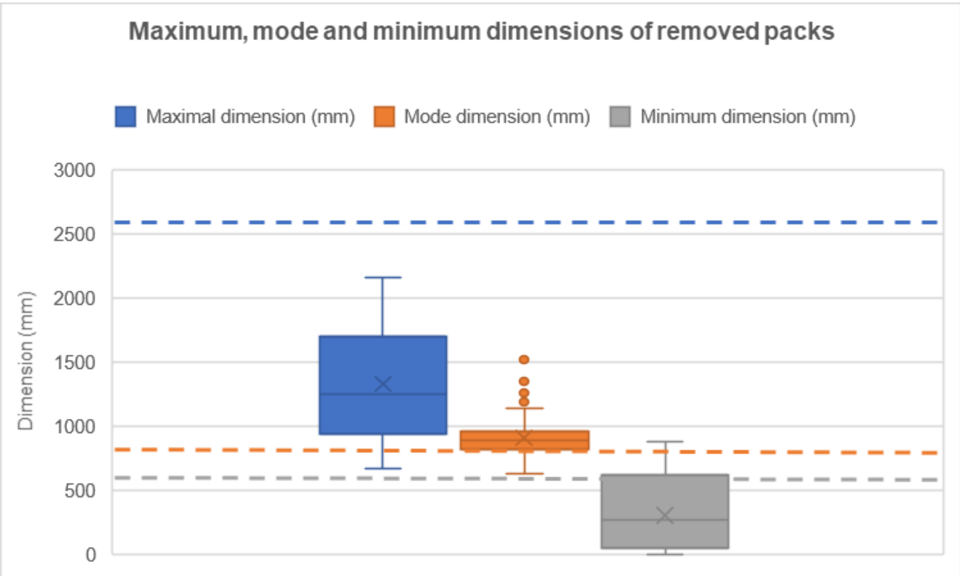

Figure 43 The range of maximum, mode and minimum dimensions of the removed packs. The dashed lines represent the respective dimension of the storage class' containers.

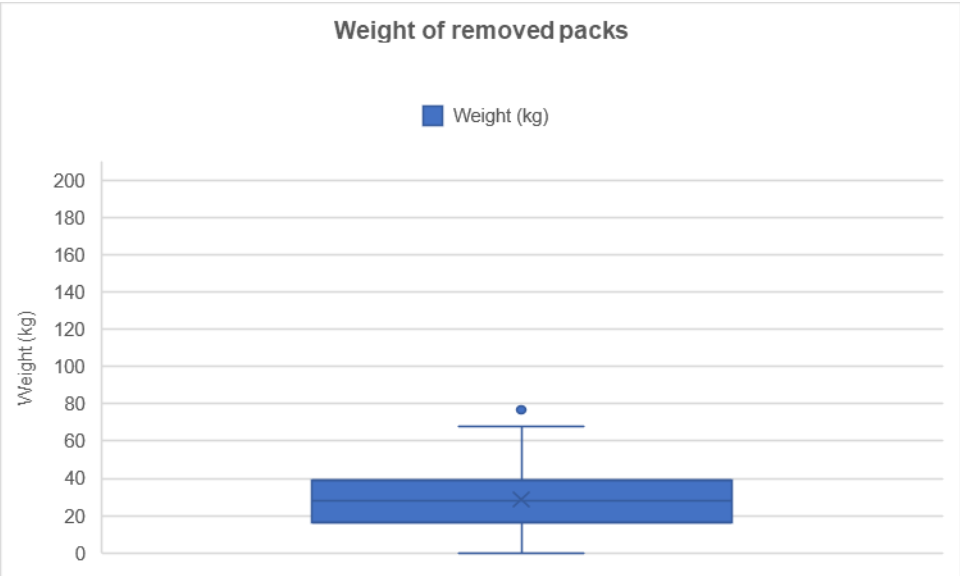

Figure 44 The range of weights of the removed packs. The dashed line represents the respective maximum allowed storage weight of the storage class' containers.

5.3 Factor Analysis: Number of Orders

One factor to analyse the utilization of containers and storage classes was either an increased or decreased amount of orders handled by the UCDP. Eleven sensitivity analyses were proposed for this factor analysis. *SC 1.1.1* to *SC 1.1.10* and *SC 2.1.1* to *SC 2.1.10* had their number of orders incremented by ten percent for each respective sensitivity analysis, while *SC 1.1.11* and *SC 2.1.11* had their number of orders decreased with 50 percent. The decrease in number of orders with 50 percent could be interpreted as the orders being distributed among two UCDPs instead of one.

The following sub-sections first present how the number of orders and packs are adjusted, followed by the results from the simulation runs for these sensitivity analyses, divided into the type of UCDP. The sub-sections furthermore only present the NOC for the whole UCDP over time. The NOC per storage class is summarized in 5.8 Aggregated Occupied Containers per Storage Class.

5.3.1 Adjustment of Number of Orders, Packs and Packs Inappropriate for Storage

As the number of orders increases, the number of packs which should be handled by the UCDP increases as well, and so do the peaks in the sales data. These are aggregated and summarized for all the sensitivity analyses for the factor number of orders in Figure 45. Figure 46 and Figure 47 further shows how the number of orders and packs in the sales data are adjusted over time. In each of the figures, a comparison is made to the scenarios.

As can be seen in Figure 46, the weekly peaks are intact, however Figure 47 shows a similar but not completely the same pattern. This is because in the simulation model, the composition of the manipulated and thus duplicated orders, such as number of distinct articles and packs, remain unchanged. Instead, the order is duplicated and moved to another week but the day and time of day for the order release time are still the same.

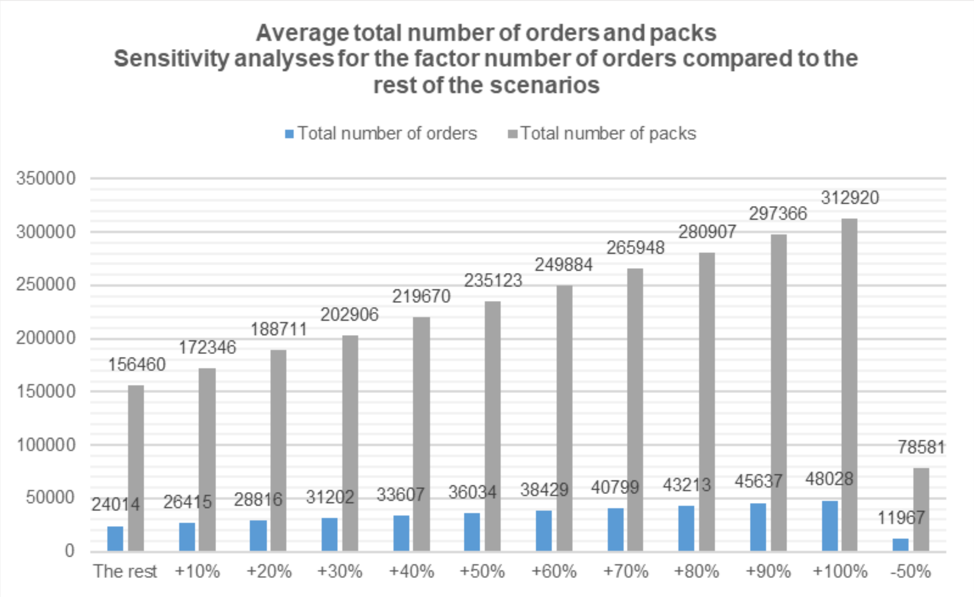

Figure 45 Summary of the average total number of orders and packs due to adjusted number of orders for the sensitivity analyses 1 to 11 for the factor analysis. These are compared to the scenarios and the other configurations.

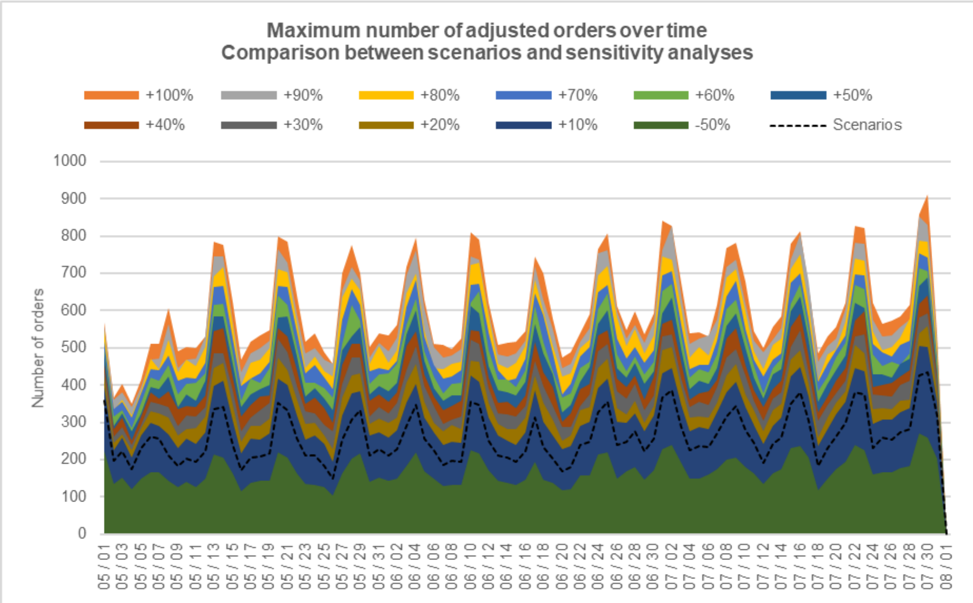

Figure 46 A comparison of the maximum number of orders over time due to order adjustments for the eleven sensitivity analyses for the factor analysis and compared to the scenarios.

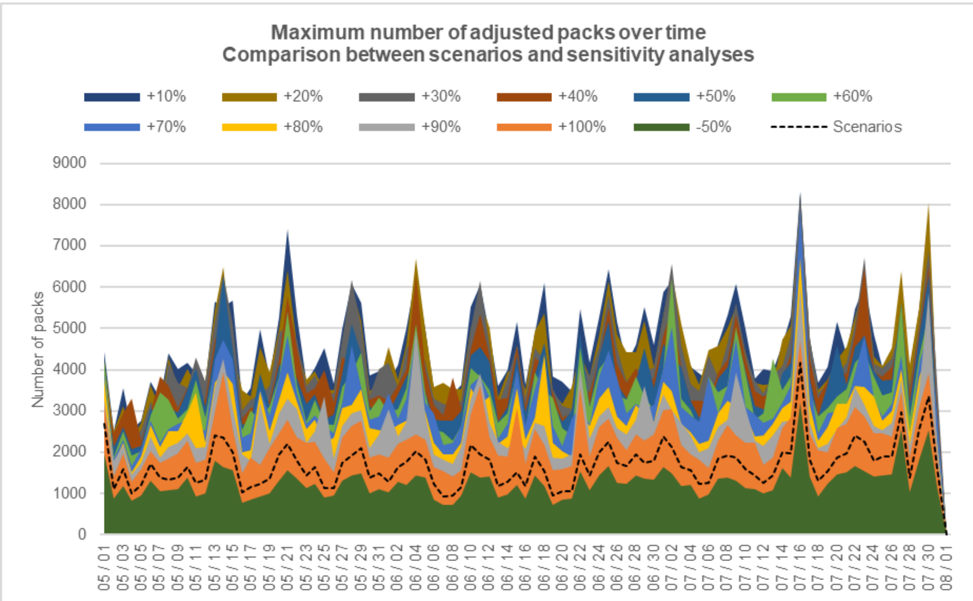

Figure 47 A comparison of the maximum number of packs over time due to order adjustments for the eleven sensitivity analyses for the factor analysis and compared to the scenarios.

The amount of packs inappropriate for storage for the automated pillar design is also adjusted as the number of orders is adjusted. This is presented in Figure 48. Since no change is made to the articles' characteristics however, the articles removed are still the same.

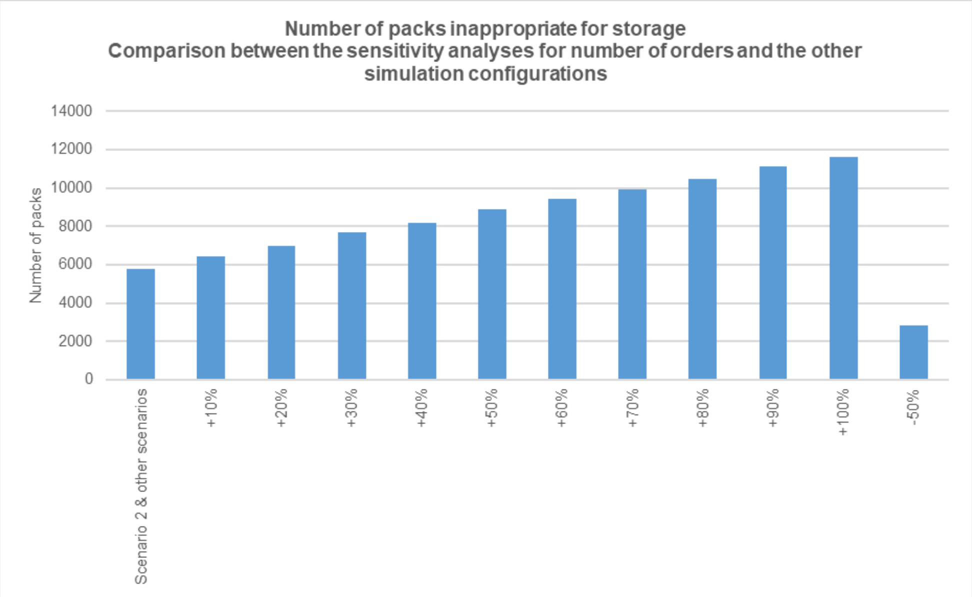

Figure 48 The number of packs inappropriate for storage for scenarios *2.1* to *2.11* compared to the rest of the scenarios.

5.3.2 Increased Number of Orders

The adjusted number of orders and packs affect the total number of containers of the UCDP over time significantly depending on the amount of adjusted orders. This can be seen in Figure 49 and Figure 50 for sensitivity analyses using the traditional parcel locker. Figure 51 and Figure 52 instead show the results over time for the automated pillar design.

As can be seen, as the number of order increases, so does the mean utilization of occupied containers, but also the weekly peaks increase. The peaks are also more frequent, because large orders have been duplicated. Figure 50 shows that if the number of orders is doubled, then the traditional parcel locker at one point will need to have around 2 000 containers to accommodate the largest peak. For the automated pillar design (see Figure 51 and Figure 52) in some of the sensitivity analyses, the UCDP is completely full.

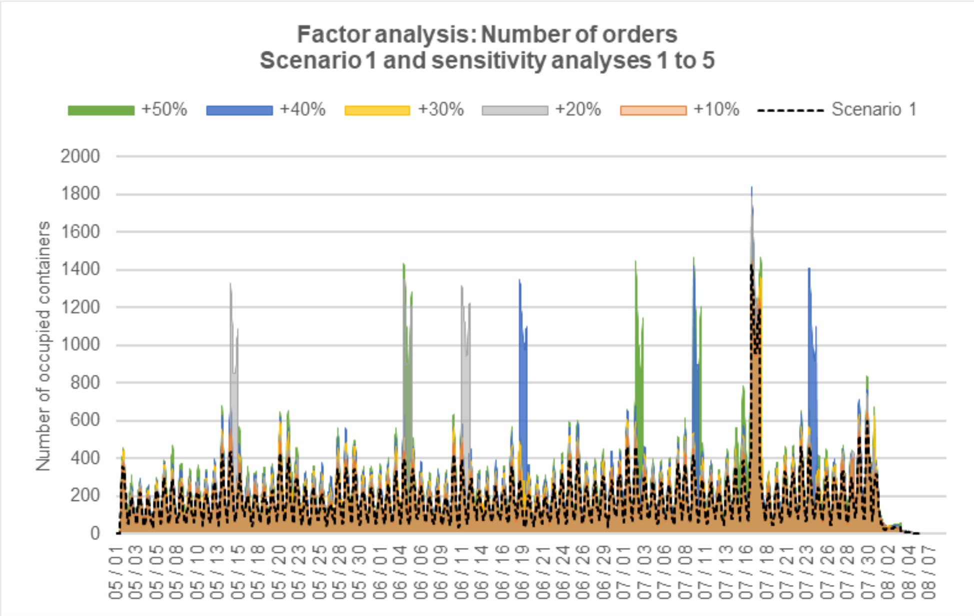

Figure 49 The maximum number of occupied containers for the traditional parcel locker over the simulation time for sensitivity analyses 1 to 5 for the factor number of orders.

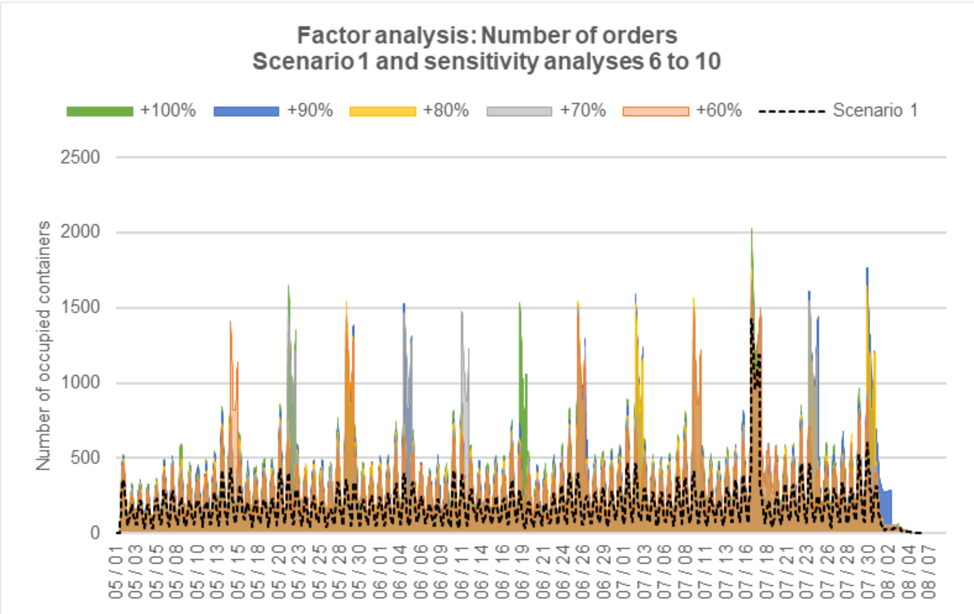

Figure 50 The maximum number of occupied containers for the traditional parcel locker over the simulation time for sensitivity analyses 6 to 10 for the factor number of orders.

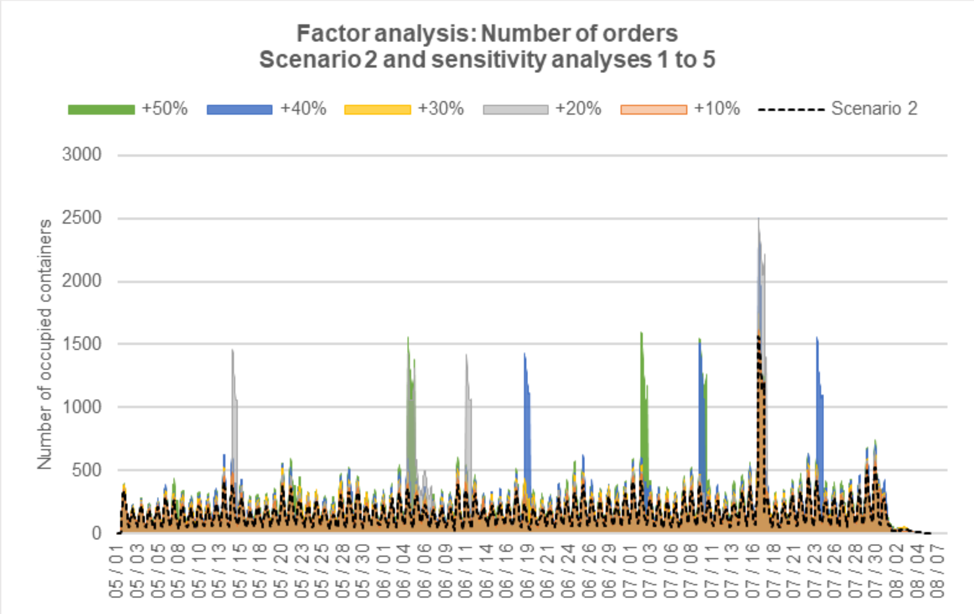

Figure 51 The maximum number of occupied containers for the automated pillar design over the simulation time for sensitivity analyses 1 to 5 for the factor number of orders.

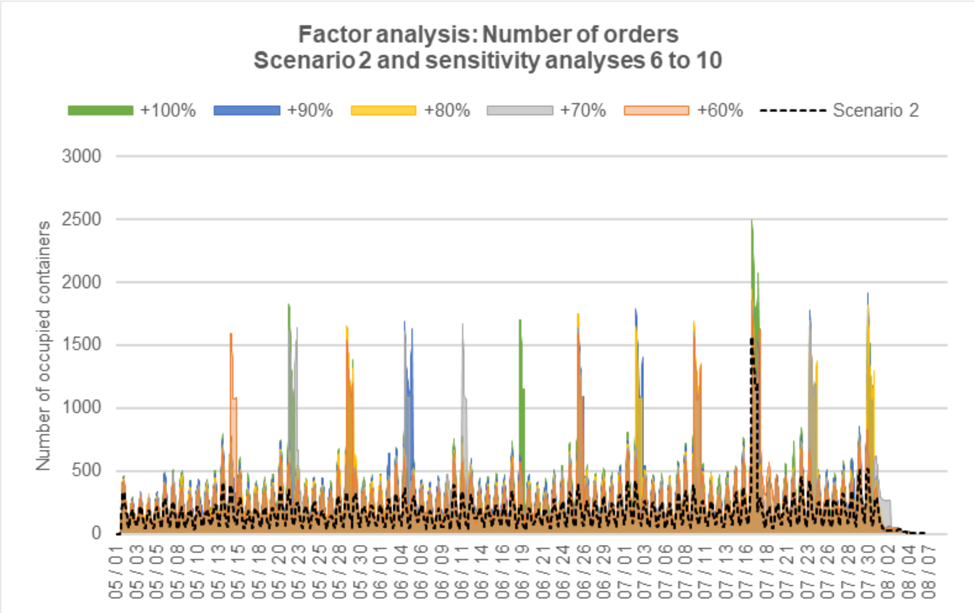

Figure 52 The maximum number of occupied containers for the automated pillar design over the simulation time for sensitivity analyses 6 to 10 for the factor number of orders.

An interesting phenomenon in *SC 2.1.2*, *SC 2.1.4* and *SC 2.1.10* is that at one time, at the already large peak, the UCDP is totally full. This means that all the containers of the UCDP are occupied. This in turn results in that packs are removed, as can be seen in Figure 53.

This peculiar phenomenon needs to be examined in more detail. Figure 47 shows no information regarding the articles' characteristics in the largest keep. However, keep in mind that in *scenario 2*, around 170 more containers were occupied compared to *scenario 1* in the largest peak. Please do also note that the storage class dimensions used in the automated pillar design have relatively less mode and minimum dimensions compared to the third, fourth and fifth storage classes used in traditional parcel locker. Correspondingly, the storage volume is also smaller. These aspects together with the fact that random variation in any of the ten replications occurs in *SC 2.1.2*, *SC 2.1.4* and *SC 2.1.10*, where relatively large orders with large packs are allocated to the same time as the largest peak, could be an explanation to the phenomenon that the automated pillar design is completely full.

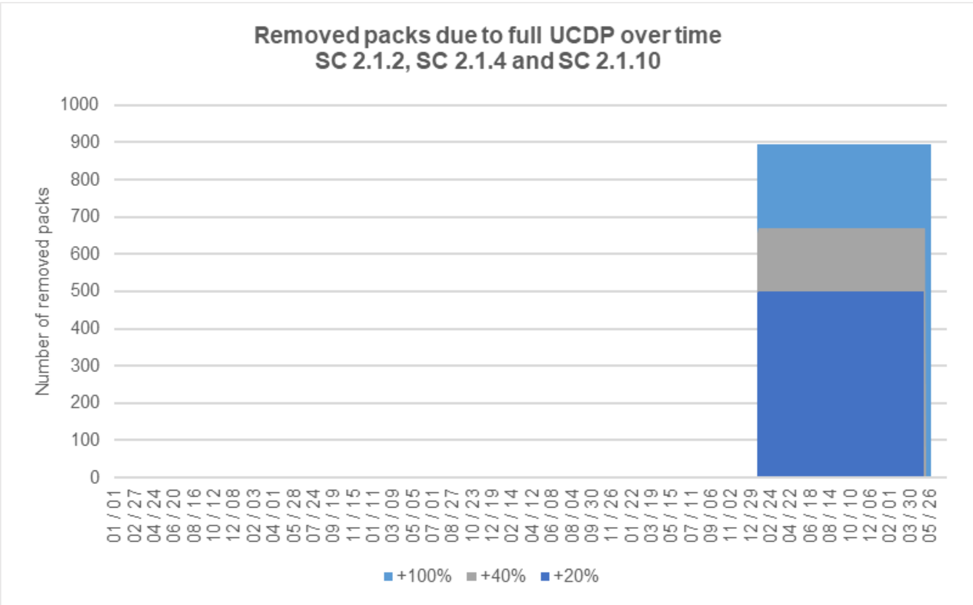

Figure 53 The number of packs removed over time due to the UCDP being full in *SC 2.1.2, SC 2.1.4* and *SC 2.1.10.*

5.3.3 **Decreased Number of Orders**

Figure 54 and Figure 55 for the traditional parcel locker and automated pillar design respectively, instead show that if the number of orders is halved, then the utilization of storage containers will also be less.

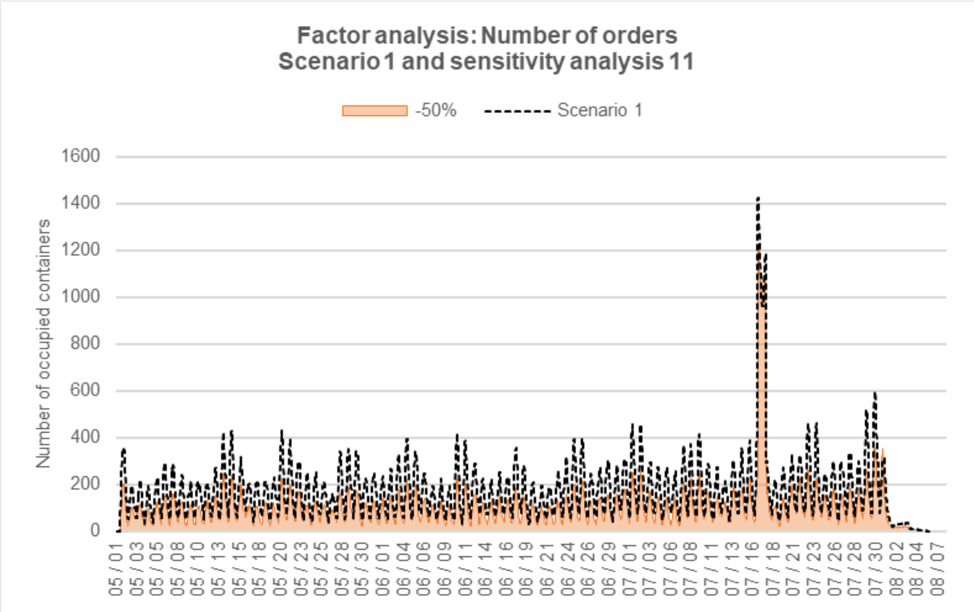

Figure 54 The maximum number of occupied containers for the whole traditional parcel locker over the simulation time for sensitivity analysis 11 for the factor number of orders.

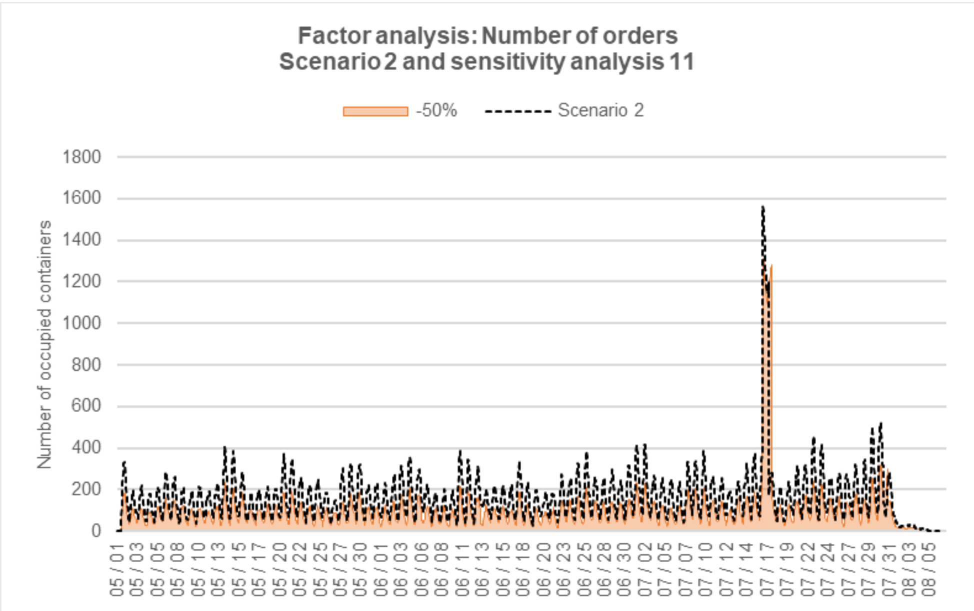

Figure 55 The maximum number of occupied containers for the automated pillar design over the simulation time for sensitivity analysis 11 for the factor number of orders.

5.4 Factor Analysis: The UCDP's Localization

Three sensitivity analyses were proposed for the factor the UCDP's localization. Figure 56 and Figure 57 show how the maximum NOC over time are affected by three different delivery terms if the UCDP is remotely located of the IKEA store. For the first sensitivity analysis for this factor, the delivery vehicles depart at around 08.00 every day, while the delivery vehicles depart at around 08.00 and 16.00 every day in the second sensitivity analysis. Three deliveries occur in the third sensitivity analysis, namely around 08.00, 12.00 and 16.00. As both the figures show, the less the frequency of deliveries to the remote UCDP, the larger the NOC. In order to nearly achieve the same NOC over time as the respective scenarios, three deliveries per day are needed.

The NOC per storage class is summarized in 5.8 Aggregated Occupied Containers per Storage Class.

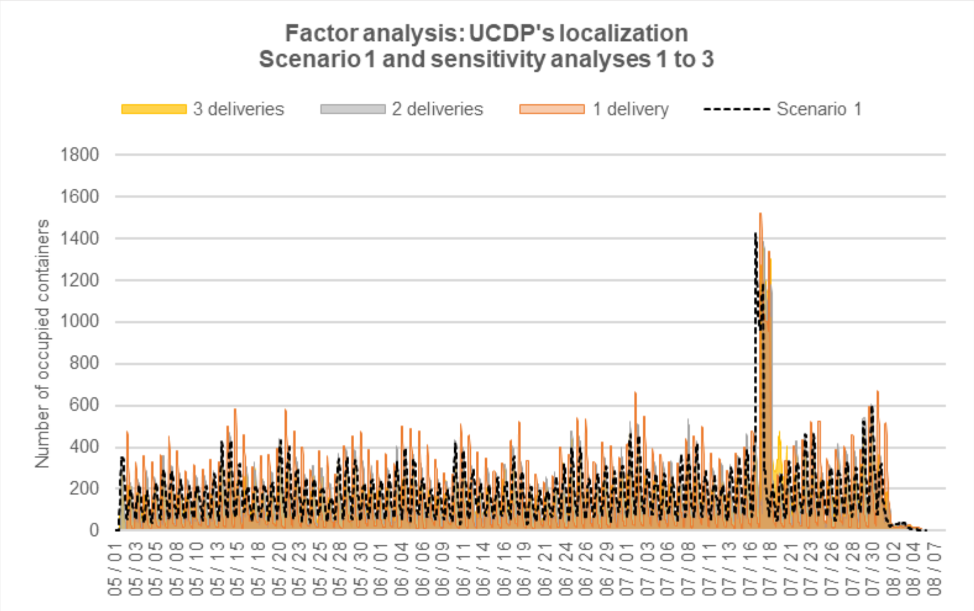

Figure 56 The maximum number of occupied containers for the traditional parcel locker over the simulation time for sensitivity analysis 1 to 3 for the factor the UCDP's localization.

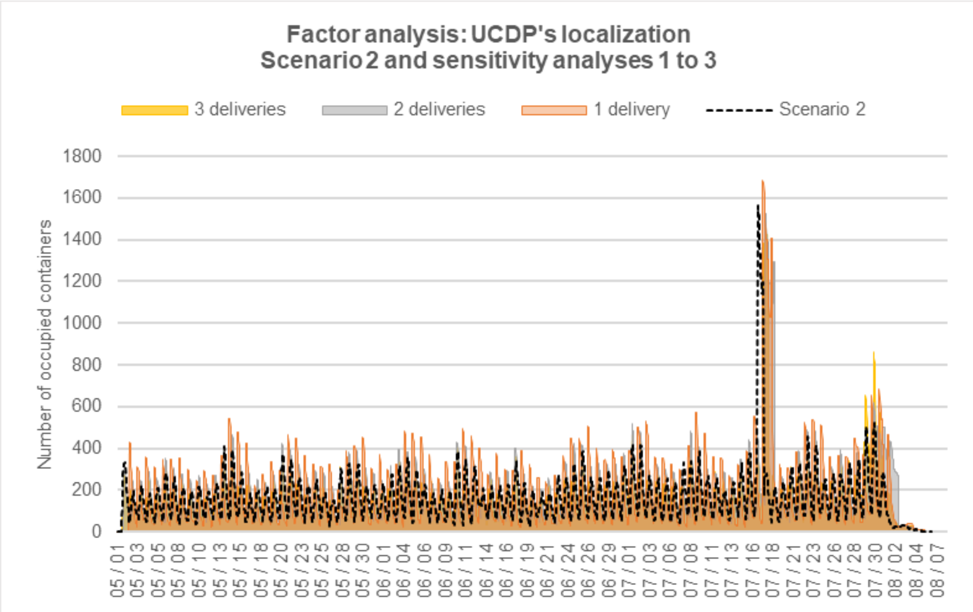

Figure 57 The maximum number of occupied containers for the automated pillar design over the simulation time for sensitivity analysis 1 to 3 for the factor the UCDP's localization.

5.5 Factor Analysis: Maximum Order Retrieval Time

Five sensitivity analyses were proposed for the factor maximum order retrieval time. The impact of increased maximum order retrieval time for the customers is seen in Figure 58 and Figure 59 for the traditional parcel locker and automated pillar design respectively. As can be seen, if the maximum order retrieval time is increased, so is the NOC, although the increase in NOC over time is relatively low. This is because the probability that a customer arrives at the maximum order retrieval time is low according to the presumed beta distributions. The customers' mean arrival times to the UCDP are still nine hours.

However, as can be seen in both Figure 58 and Figure 59, the simulation time is longer than the previous simulations due to the sensitivity analysis where the maximum order retrieval time is two weeks. Regarding the NOC per storage class, these are summarized in 5.8 Aggregated Occupied Containers per Storage Class.

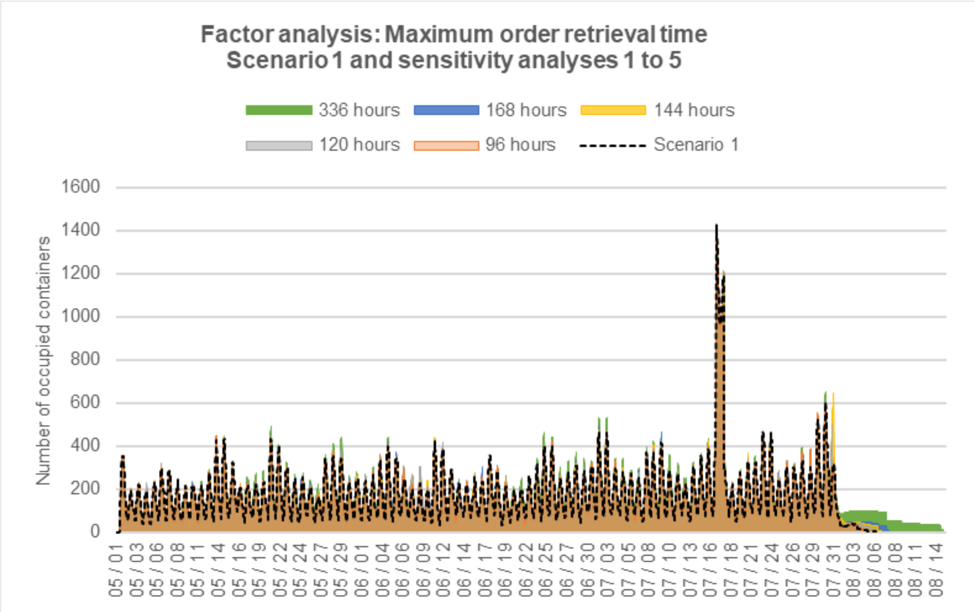

Figure 58 The maximum number of occupied containers for the traditional parcel locker over the simulation time for sensitivity analysis 1 to 5 for the factor maximum order retrieval time.

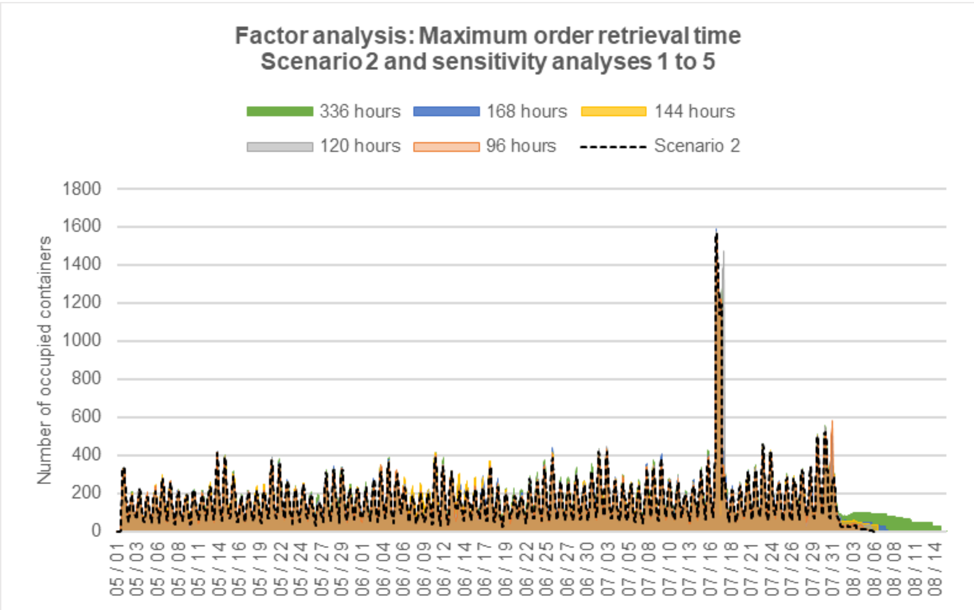

Figure 59 The maximum number of occupied containers for the automated pillar design over the simulation time for sensitivity analysis 1 to 5 for the factor maximum order retrieval time.

5.6 Factor Analysis: Customer Mean Arrival Time

The customer mean arrival time to the UCDP for order retrieval is also another factor of analysis. Six sensitivity analysis were proposed for this factor. The impact of a decreased arrival time (sensitivity analysis 1) compared to an increased arrival time (sensitivity analysis 2 to 6) can be seen in Figure 60 and Figure 61. The impact of an increased mean customer arrival time in contrast to an increased maximum order retrieval time is greater with regards to the NOC over time. It is also worth to point out that the largest peak in *SC 2.4.6* has approximately 250 more occupied containers that the largest peak in s *SC 1.4.6*. The NOC per storage class for these scenarios are further presented in 5.8 Aggregated Occupied Containers per Storage Class.

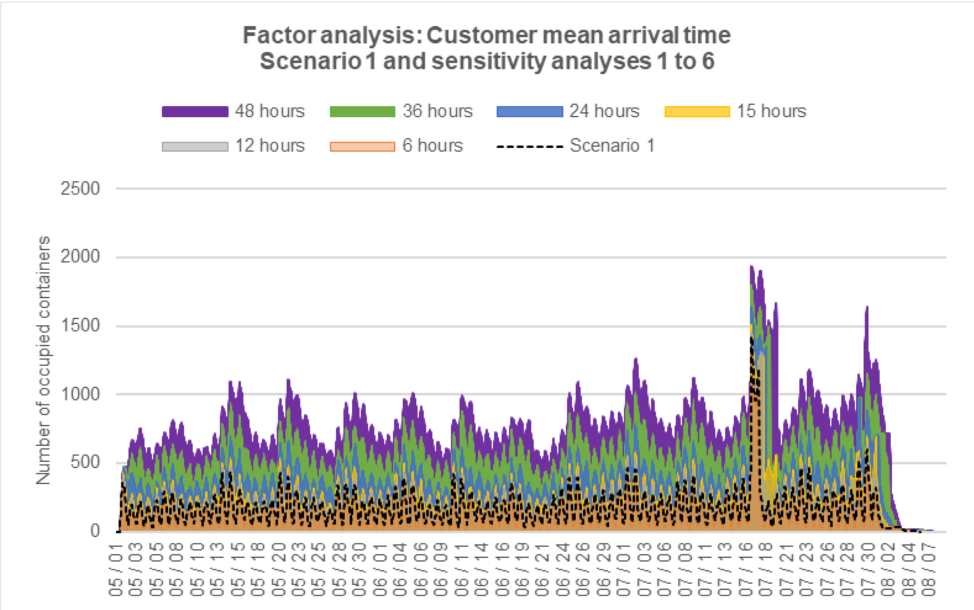

Figure 60 The maximum number of occupied containers for the traditional parcel locker over the simulation time for sensitivity analysis 1 to 6 for the factor customer mean arrival time.

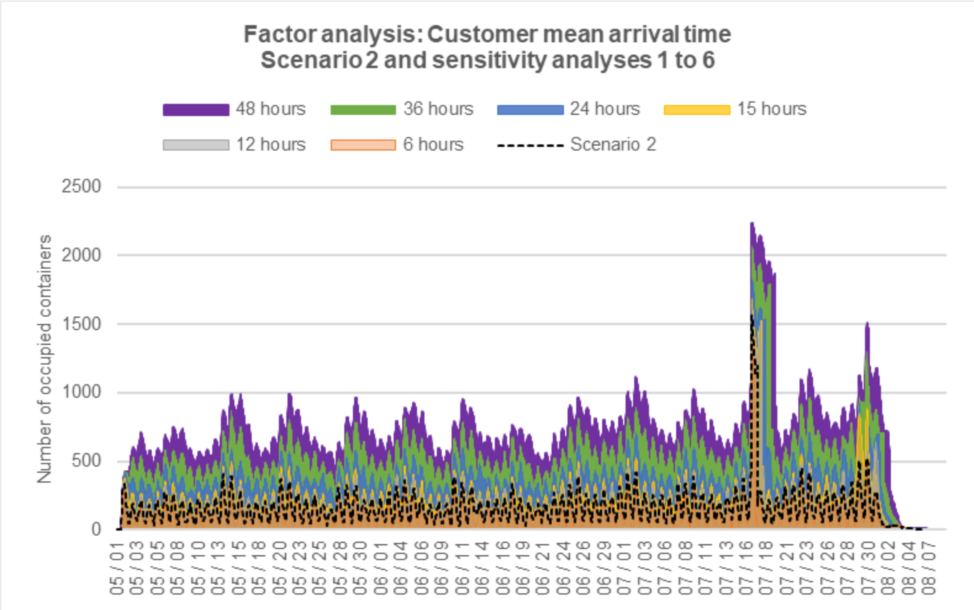

Figure 61 The maximum number of occupied containers for the automated pillar design over the simulation time for sensitivity analysis 1 to 6 for the factor mean customer arrival time.

5.7 Factor Analysis: Schedules of the UCDP Service Provider

The last factor of analysis is the schedules of the UCDP service provider and thus if the orders are not prepared and transported to the UCDP around the clock. Instead, the orders are prepared and delivered to the UCDP Monday to Friday between 08.00 to 18.00. No work occurs during the weekends. In the scenarios, the orders were prepared and delivered to the UCDP around the clock.

The result for the respective UCDP type can be seen in Figure 62 and Figure 63. With restricted working hours limited to Monday to Friday, there occur peaks in the beginning of every week. This is explained by that most of the sales are registered during the weekends, at which time in these sensitivity analyses no orders are either prepared or delivered to the UCDP.

The result per storage class is presented in the next section.

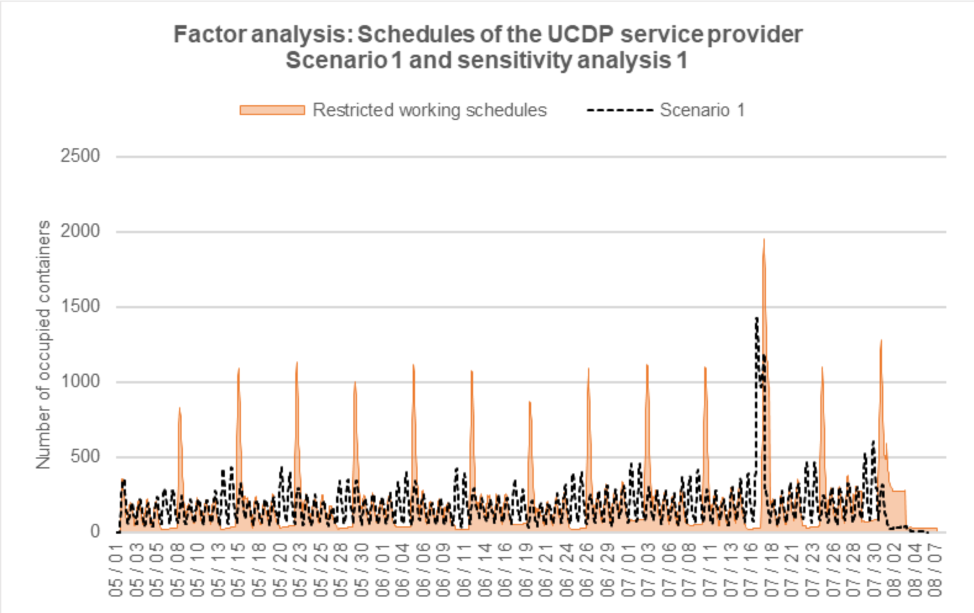

Figure 62 The maximum number of occupied containers for the traditional parcel locker over the simulation time for sensitivity analysis 1 for the factor schedules of the UCDP service provider.

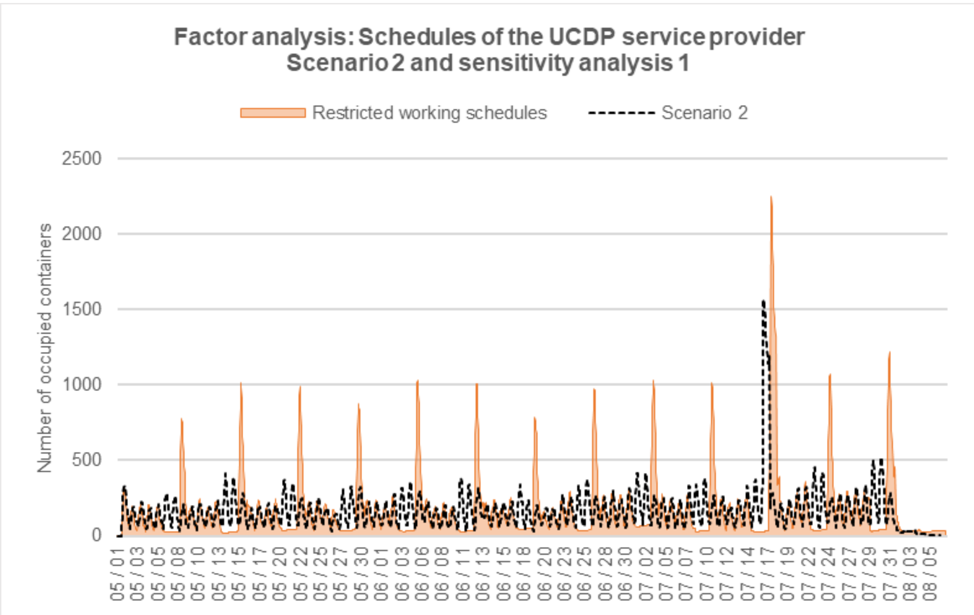

Figure 63 The maximum number of occupied containers for the automated pillar design over the simulation time for sensitivity analysis 1 for the factor schedules of the UCDP service provider.

5.8 Aggregated Occupied Containers per Storage Class

The NOC per storage class over time is difficult to present in a distinguishable way for all the simulation configurations and are thus presented in aggregated numbers in the following sub-sections.

5.8.1 Maximum Number of Occupied Containers per Storage Class

The maximum NOC per storage class for the two types of UCDPs is presented in Figure 64, where a comparison is made.

The maximum utilization of the storage classes for the traditional parcel locker is for the second and third storage classes, although this is presumably a misdirection as the previous sensitivity analyses showed that the third storage class was mostly utilized only when the largest peak occurred.

The peculiar phenomenon for *SC 2.1.2*, *SC 2.1.4* and *SC 2.1.10* which was discussed previously, where the UCDP was full, is more clearly visible in Figure 64. A similar phenomenon seems to have occurred in scenarios *SC 1.1.2* and *SC 1.1.4*, although the UCDP was not full. The maximum NOC is larger than *SC 1.1.3* and *SC 1.1.5*, but as mentioned earlier, this can be due to the fact that this is the maximum value for any of the replications in the simulation runs for the simulation configurations.

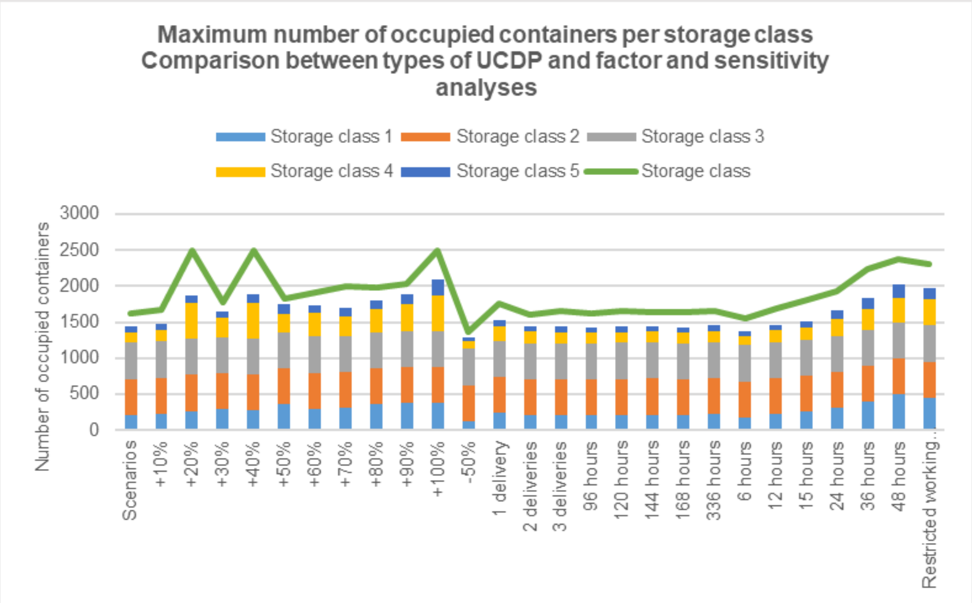

Figure 64 A comparison of the maximum number of occupied containers per storage class between the two types of UCDPs and the different factor and sensitivity analyses.

5.8.2 Average Number of Occupied Containers per Storage Class

The average NOC per storage class for the different simulation configurations is presented in Figure 65, where also a comparison between the two types of UCDPs is made.

A pattern can be recognized for the storage classes of the traditional parcel locker in Figure 65. The second storage class is on average the most utilized one, followed by the first storage class. The third, fourth and fifth storage classes are on average equally utilized, but in some cases the fourth and fifth storage classes are more utilized than the third storage class.

What is further visible in Figure 65 is that on average, the traditional parcel locker requires more containers than the automated pillar design.

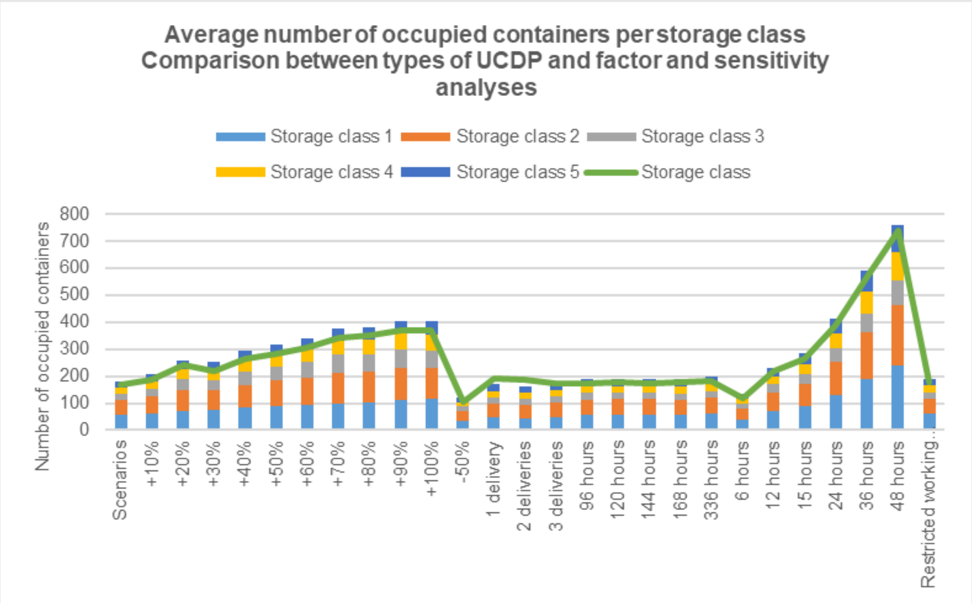

Figure 65 A comparison of the average number of occupied containers per storage class between the two types of UCDPs and the different factor and sensitivity analyses.

6 Analysis and Discussion

This chapter presents the analysis and discussion on the findings and results of the thesis. The first section discusses and compares the identified UCDP solutions. The second section analyses and discusses the results from the simulation study.

6.1 Discussion and Comparison of the Identified UCDP Solutions

Four distinct solutions of the UCDP concept were identified from non-academic sources and these were described in chapter 3 Frame of Reference. These categories of the UCDP concept were: the traditional parcel locker, the automated box design, the automated pillar design and the cart design. The following sub-sections discuss and compare some aspects of these solutions.

6.1.1 **The Storage Configuration**

The storage configuration varies amongst the UCDP solutions. All the identified solutions can store a different range of products in terms of the products' dimensions. The traditional parcel locker has several containers in several storage classes with fixed dimensions. In contrast, the automated box design and the automated pillar design only have one type of storage class. The range of products the automated pillar design and automated box design can store is further limited by the dimension of their gateways. It may be presumed from the description of the cart design that this concept offers storage for a wide range of different products, as the vessel of the products is adjustable. This contrasts with the other solutions; whose storage classes dimensions are difficult to adjust once the UCDP has been installed. Additionally, this means that the cart design has several storage classes.

The advantage of the automated pillar design is that it stores all the parcels on its height. This ability is especially suitable if the UCDP would be in locations with little available floor space. The other UCDP solutions are at disadvantage here: if the area around the UCDP is limited, these occupy a significantly larger amount of horizontal space. Whether the ability to store the parcels on its height or width is an advantage or disadvantage depends however on the circumstance. Since one of the issues with the stationary last mile delivery solutions was the availability of space, especially in dense city areas, then storing products on its height is an advantage.

Another advantage realized by the automated process in the automated box design and automated pillar design is that the interior storage volume is filled more effectively compared to the traditional parcel locker and the cart design. While the storage height of the traditional parcel locker and the cart design are fixed and cannot be configured, the automated designs could stack the packs closer to each other on the height. It may be presumed that as the development of automated UCDP solutions advances, so will the available storage volume be more effectively utilized.

The traditional parcel locker can be configured so that the slots or containers can store products requiring specific storage requirements. For instance, the grocery lockers' containers are temperature regulated and thus products, such as groceries requiring a specific storage temperature, can be stored in this type of UCDP. Another example is the laundry locker, whose containers are equipped with hangers or flat beds especially suited for laundry goods. The cart design is also able to store products requiring temperature regulation. The traditional parcel locker and the cart design featuring these configurations are thus at an advantage compared to the automated pillar design and automated box design, which cannot be configured with these special storage configurations.

6.1.2 The Load-In and Retrieval Process

The UCDP solutions offer different means of inserting and retrieving parcels to and from the UCDP. The traditional parcel locker requires the service provider to load the parcels into the UCDP piece-by-piece. The retrieval process by the customers is also done piece-by-piece. This contrasts with the automated box design and automated pillar design, where the insertion and retrieval process of the UCDP is automated using an ASRS active in the interior of the UCDP. This way, several parcels can be inserted and retrieved at a time from the UCDP. This automated process is an advantage for these two concepts, especially if large orders would be inserted into or retrieved from the UCDP.

Another advantage which was described by the identified product of the automated box design was its ability to configure the work flow of the ASRS based on historic data. This is useful, especially if peaks of order insertion and retrieval would occur.

While automation offers advantages, so does it come with disadvantages. With an automated insertion and retrieval process, there is presumably a greater probability of process disruption compared to the manual insertion and retrieval process offered by the traditional parcel locker and cart design.

The vessels of the cart design can additionally also transport the orders outside of the UCDP's immediate perimeter. This is especially useful for instance if the customers would like to transport their orders to their cars. A disadvantage follows however, since there is no guarantee that the customers return the carts to the UCDP.

6.1.3 The Modularity of the UCDP

Among the identified UCDP solutions, only the automated pillar design does not offer the modularity to either decrease nor increase the number of slots or storage classes. This feature is an advantage for the traditional parcel locker, the automated box design and the cart design. This feature offers the possibility to adjust the number of containers depending on the order flow to the UCDP. The modularity feature of the UCDP concept is important, as the UCDP can be adapted to specific circumstances.

The modularity does not only concern the available storage of the UCDP, but also the number of interaction interfaces. This means for instance that if there is a large flow of customers using the UCDP, resulting in long queues, the number of interaction interfaces can be adjusted accordingly.

6.1.4 Integration to the Surroundings

The different identified UCDP solutions can be integrated into the surroundings using different means. While the identified automated box design solution is the only one which offers full integration to the surroundings by integrating the UCDP into, for instance, a wall, the other concepts offer varied means of integrating the UCDP to the surroundings. For instance, the aesthetics of the traditional parcel locker and automated pillar design can be customized according to the UCDP service provider preferences for instance for advertising or blend into the surroundings. It is however possible that some UCDP products of these two concepts offer full integration. According to the manufacturer of the identified cart design, it can be integrated into the surroundings. It is although difficult to see how this will be done.

6.1.5 Summarizing the Comparison of UCDP Concepts

Figure 66 below summarizes the strengths and weaknesses of each of the identified UCDP solutions resulting from the discussion above. However, assessing whether a UCDP solution is at an advantage or disadvantage is difficult because this depends on the circumstances in which the UCDP is being implemented. Furthermore, it was identified that there several different products of the traditional parcel locker type, but few products of the rest of the solutions. For instance, the automated box design and cart design were based on only one product respectively. While this is problematic, it helped to identify the key features of the different solutions which was presented in Table 3 in 3.2.5

Summarizing the Identified UCDP Solutions.

	THE TRADITIONAL PARCEL LOCKER	THE AUTOMATED BOX DESIGN
+	- Can contain a wide range of products. - Contains several storage classes. - Containers can be configured according to special product storage requirements (for instance temperature regulation). - Manual storage operations decrease the probability of product breakdowns. - Modularity: adjustment of capacities is possible. - Integration to surroundings through the aesthetics. - Can be placed indoors and outdoors.	- The containers' height are flexible, resulting in better storage volume utilization of the containers. - Automated storage operations are more effective for large orders. - The work flow can be optimized to accomodate peak hours. - Modularity: adjustment of capacities is possible. - Full integration to the surroundings is possible.
−	- Its main alignment is horizontal (disadvantage if the horizontal space is limited). - Manual storage operations are ineffective for large orders. - Full integration is not possible.	- Only contains one storage class. - The containers cannot be configured according to special product storage requirements. - The products' dimensions are restricted by the gateway's dimensions. - Automated storage operations increase the probability for product breakdown. - Its main alignment is horizontal (disadvantage if the horizontal space is limited). - Cannot be placed outdoors.

	THE AUTOMATED PILLAR DESIGN	THE CART DESIGN
+	- Its main alignment is vertical (advantage if the horizontal space is limited). - The containers' height are flexible, resulting in better storage volume utilization of the containers. - Automated storage operations are more effective for large orders. - Integration to surroundings through the aesthetics. - Can be placed indoors and outdoors.	- Can contain a wide range of products. - Contains several storage classes. - Containers can be configured according to special product storage requirements (for instance temperature regulation). - Manual storage operations decrease the probability of product breakdowns. - Modularity: adjustment of capacities is possible. - Full integration to the surroundings is possible. - Can be placed indoors and outdoors. - The cart can be used to transport the order to the customers' car.
−	- Only contains one storage class. - The containers cannot be configured according to special product storage requirements. - The products' dimensions are restricted by the gateway's dimensions. - Automated storage operations increase the probability for product breakdown. - Its main alignment is horizontal (disadvantage if the horizontal space is limited). - Full integration to surroundings is not possible. - Does not feature modularity.	- Its main alignment is horizontal (disadvantage if the horizontal space is limited). - There is no guarantee that the customers return the carts to the UCDP, if the carts are moved outside the UCDP's immediate perimeter.

Figure 66 Summary of the strengths (+) and weaknesses (-) of the identified UCDP solutions.

6.1.6 **The Possible Future Exchange of Key Features of the UCDP Solutions**

While the identified UCDP solutions have several distinct features, realizing advantages and disadvantages depending on circumstances, as the development of UCDP products increases, new solutions might emerge. It will be interesting to see in the future if the UCDP products adopt features from one another. Several combinations of the key features of the UCDP solutions could emerge in the future:

- The automated pillar design and automated box design could be equipped with temperature regulated storage or for instance, hangers. Furthermore, these two UCDP solutions could be installed with more than one storage class.

- The automated pillar design can have the modularity feature, so that the UCDP's height, and thus storage capacity, can be adjusted. The number of control consoles and gateways of the automated pillar design might also be configurable.
- The traditional parcel locker and automated box design could be combined, for instance with the locker openings on the front but on the rear of the UCDP, an automated load-in process could be installed.
- The automated pillar design and the traditional parcel locker design could be combined into a pillar design equipped with lockers on the exterior to a user-friendly height. This design could store large orders on the height, but smaller orders in the lockers. The automated load-in process is configured to choose the best possible storage location of the order.

6.2 Analysis and Discussion of the Results from the Simulation Study

This section discusses and analyses the results from the simulation study. It is structured according to the order of the factors presented in RQ2: number of orders, order composition, customers' behaviour, the UCDP's localization and the schedules of the UCDP service provider.

6.2.1 **The Impact of Adjusted Number of Orders**

The results of the factor and sensitivity analyses showed that as the number of orders is adjusted, so will the utilization of storage containers of the UCDP also be adjusted. This order adjustment factor was the second factor which had the most impact on the NOC. The factor did not however show any significant impact on the dimensioning of the storage containers.

A percental increase of orders, however, does not necessarily mean that the utilization of containers of the UCDP will be utilized with the same proportion. This can be seen in Figure 67. This figure shows the relative increase or decrease of the average NOC for both types of UCDP and for *SC 1.1.1* to *SC 1.1.11* and *SC 2.1.1* to *SC 2.1.11* compared to the increase or decrease in number of orders. As can be seen, the increases or decreases of number of orders has not the same proportional increase or decrease in storage utilization. This suggests, for instance, that if the number of orders is doubled, the utilization of containers of the UCDP will be more than doubled.

This result has three explanations. First, the orders which are manipulated into being duplicated still have the same composition, day of week and time of day. Only the week and order number are changed. This leads to increasing peaks in the sales data, as was previously shown. Second, the assumption that a storage container cannot store a mix of orders leads to that large orders need to be split up into several containers. Conversely, even if only one order is being duplicated, this could lead to an increase of utilization of containers which is greater than only one storage container. With this explanation, even if the day of week and time of day separately or in combination would have been change, the suggestion persists. Third, the sequence in which the orders are released matters, as one order might occupy one or more several storage containers which might have been optimal for another order.

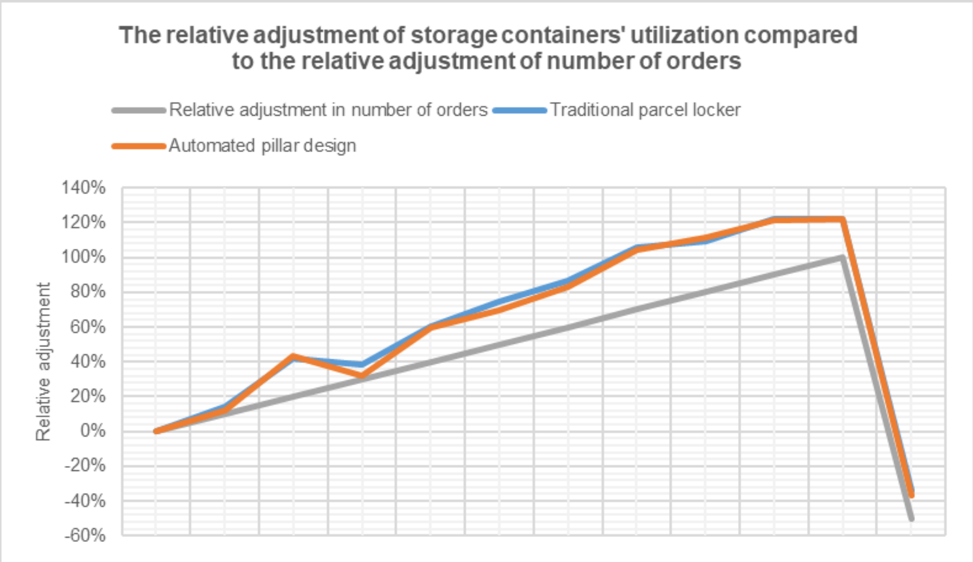

Figure 67 The relative adjustment of average of maximum storage containers' utilization compared to the relative adjustment of number of orders.

Instead of analysing the average of maximum figures for the utilization of storage containers, the NOC over time for the sensitivity analyses for the factor number of orders showed that as the number of orders is increased, so will the peaks and sometimes, unexpected peaks could occur. These unexpected peaks could depend on the significantly large order affecting the large peak in the scenarios was duplicated and moved to another time in any of the replications in the sensitivity analyses. This suggests that the UCDP should either have the modularity feature to adjust its capacity to accommodate these large peaks.

6.2.2 The Impact of the Order Composition

The order composition significantly affected the utilization and dimensioning of the storage containers.

First, the order composition led to the automated pillar design was not able to store several articles and hence packs. This is because the storage dimensions of the one storage class of the UCDP was in some cases insufficient to store larger articles. The traditional parcel locker used was able to store all the products. This suggests that the order composition affects the dimensioning of the storage classes.

Second, in correspondence to the characteristics of the orders, it was seen in the results that the smaller storage classes were utilized more on average than the larger storage classes. The first storage class has, a maximum, mode and minimum dimension of 2,1 m, 50 cm and 45 cm respectively. The second storage class has the dimensions 2,1 m, 90 cm and 33 cm for the maximum, mode and minimum dimension respectively. Their relatively larger utilization compared to the rest of the storage classes are due to the composition of articles in the orders. As was seen in the description of the order data (see 4.2.3 Data Collection and Description), most of the orders constituted of one pack with small dimensions and low weight. This further means that the storage classes (dimensioning of the storage containers) were affected.

Third, comparing the traditional parcel locker and the automated pillar design used in all the simulation configurations, the utilization over time and on average was greater for the traditional parcel locker than for the automated pillar design. The explanation for this could be that since the packs inappropriate for storage in the UCDP were removed from the simulation flow prior to inserting the packs into the UCDP, this also affects the storage containers' utilization over time. In contrast, the maximum NOC showed that this number was observed to be greater for the automated pillar design than for the traditional parcel locker. Additionally, what also could be observed in the simulation results, once the large peak occurred, the traditional parcel locker utilized around 170 less containers than the automated pillar design. The reason for this is that the two largest storage classes in the UCDP used in *scenario 1* have greater dimensions than the storage class used in *scenario 2*. This could be a suggestion that the traditional parcel locker with the chosen storage classes is preferable to store extremely large orders compared to the simulated automated pillar design. This is however only a suggestion. The results do not prove whether the traditional parcel locker or the automated pillar design uses more or fewer containers than the other. However, this is not the focus of RQ2.

What can however be expected but which has not been shown from the simulation results, is that the utilization of the storage space of the traditional parcel locker compared to the automated pillar design is better utilized in the former UCDP type. This is due to the nature of the orders. As mentioned earlier, most of the orders are small regarding the inherited packs' dimensions and number of packs. Due to the automated pillar design only having one storage class, which is relatively large compared to the smaller storage classes of the traditional parcel locker, small orders will only occupy a fraction of the storage space in the automated pillar design's containers.

Summarizing the analysis regarding the impact of the order composition, it can be said that the order composition influences both the utilization and dimensioning of the storage containers. Alternatively expressed, the physical dimensioning of a UCDP affects which products and order sizes can be stored in the UCDP. The smaller storage classes are more utilized than the larger storage classes in the traditional parcel locker. The results also suggest that a restriction should be set to the order sizes and composition the UCDP should be able to handle.

6.2.3 The Impact of the Customers Behaviour

According to the factor and sensitivity analyses, the factor which has the most impact on the utilization of storage containers both on the average values and over time is the mean times of the customers arrival to retrieve their orders. The maximum NOC increased as well but was slightly less than the maximum NOC for both the sensitivity analyses with a 100 percent increase of number of orders respectively. The dimensioning of the storage containers was not affected.

An increased maximum order retrieval time showed no significant impact on the UCDP's utilization of storage containers, both in the maximum and average values and over time. It might be that although the maximum order retrieval time is increased, there is only a slight probability that a customer arrives around the time for the maximum order retrieval time according to the beta distributions. Recall that the mean arrival time was kept constant at nine hours. What could however be observed was that the simulation time was longer.

The mean customer arrival time is a factor which is difficult to control by the UCDP service provider. The arrival time of any customer is dependent on that customer's preferences for retrieving an order. Furthermore, the frame of reference presented no insight regarding the mean arrival times of the customer. However, the mean customer arrival time could be influenced by the maximum order retrieval time. If this time is set to a few days, it might encourage customers to retrieve their orders earlier. Conversely, if the maximum order retrieval time is set to, for instance, two weeks, this could send signals to the customers to retrieve their orders later than normally would have been expected from the customers. The result of this could be a change of the customers' behaviour in retrieving the orders, to instead retrieving an order at a later time than the customer would otherwise do. It may however be presumed that customers want to retrieve their order as soon as the order is available.

6.2.4 The Impact of The UCDP's Location

In the factor analysis for the UCDP's location, and its three sensitivity analyses, the UCDP is located remotely of where the orders are prepared. The scenarios have had the UCDP located next to the warehouse, where the order preparation occurs. This means that once the orders are ready to be issued to the UCDP, they are done so order-by-order. By moving the UCDP to a remote location, for instance to a city centre, the orders must be transported to the UCDP as a batch of orders. This is because it would not be economically viable to transport the orders order-by-order using delivery vehicles. Instead, the UCDP operator wants to fill up as much available space in the cargo area of the delivery vehicles, before transporting the cargo to the UCDP.

The impact of this relocation to, for instance a city centre, was not significant regarding the maximum and average utilization of storage containers. Alternatively expressed, the UCDP's location did not have a significant impact on the average and maximum utilization of storage containers. In addition, it showed no significant impact on the dimensioning of the storage containers.

However, what could be observed during the course of the simulation, is that relocating the UCDP to a remote location could lead to momentary peaks of storage container utilization once the batch of orders arrived at the UCDP. The more deliveries to the UCDP occurring during a weekday, the smaller these peaks would be. This is logical, as fewer deliveries lead to larger batches of orders arriving at the same time to the UCDP. Please do note that in the factor analysis and its three sensitivity analyses, ten delivery vehicles were available but not necessarily used. However, the premise was that all the orders placed during a certain time should be transported to the UCDP as soon as possible.

6.2.5 The Impact of Schedules of the UCDP Service Provider

In the factor and sensitivity analysis for the schedules of the UCDP service provider, the orders were prepared and transported to the UCDP only during certain weekdays (Monday to Friday) and working hours (08.00 to 18.00). Remember that the scenarios had no restrictions regarding when the orders would be prepared nor transported to the UCDP.

The phenomenon which occurs is that there occur large momentary peaks of storage container utilization in the beginning of each weak. This result should not come as a surprise, however. As the sales data pointed out, most of the orders are placed during the weekends. All the orders which were placed during the weekends would thus need to be prepared and transported to the UCDP in the beginning of the following week to fully serve the customers' needs. The maximum utilization of storage containers is affected by this. On the other hand, the average utilization of the UCDP was not significantly affected by the restricted working hours. The dimensioning of the storage containers did not show any significant changes due to this factor.

The results suggest that order preparation should be closely interlinked with the expected peaks of the orders, to avoid creating peaks for the employees and the UCDP's capacity.

6.2.6 **Summarizing the Analysis and Discussion of the Factors Analyses**

To summarize the analysis and discussion regarding the factor analyses, Figure 68 below is presented.

	Number of orders	Order composition	Customers' behaviour	UCDP's localization	Schedules of the UCDP service provider
IMPACT	• Significant impact on utilization of storage containers over time, maximum and average values. • No significant impact on dimensioning of storage containers.	• Significant impact on utilization of storage containers. • Significant impact on dimensioning of storage containers.	• Customers mean arrival time significantly affects the utilization of storage containers over time, as well as maximum and average values. • The maximum order retrieval time does not significantly affect the utilization of storage containers. • Neither factor affect the dimensioning of storage containers.	• No significant impact on utilization of storage containers. • No significant impact on dimensioning of storage containers.	• No significant impact on utilization of storage containers. • No significant impact on dimensioning of storage containers.
FURTHER ANALYSIS	• Not the same proportionate adjustment in storage container utilization. • Unexpected peaks could emerge.	• Not all the products can be stored in the automated pillar design. • Two smallest storage classes of the traditional parcel locker utilized most. • Better storage container volume utilization for the traditional parcel locker.	• The maximum order retrieval time could affect the customers mean arrival time in reality.	• Momentary surges of storage container utilization occurs once batches of orders arrive at the UCDP.	• Momentary surges of storage container utilization occur in the beginning of every week.
SUGGESTIONS	• The UCDP should have modularity feature to be able to adjust its capacity.	• Set restrictions to the order sizes and composition the UCDP should handle. • The traditional parcel locker uses less storage containers.	• Choose a relevant maximum order retrieval time.	• If the UCDP is remotely located, the more deliveries the less storage container utilization.	• Order preparation and transportation should be done close to the sales data's peak periods.

Figure 68 Summary of the analysis and discussion of the results of the factor analyses.

6.2.7 Concluding Analysis from the Simulation Study

The scenario, factor and sensitivity analyses showed that there are several factors which affect the utilization and dimensioning of the storage containers. The previously presented Figure 65 showed that the factor which has the greatest impact on the UCDP's average utilization of containers is the mean customer arrival time followed by the number of orders. The order composition also showed to have an impact on the storage containers' utilization. The rest of the factors did not seem to have a significant impact on the UCDP's average and maximum utilization of containers, although studying the different plots of the utilization of storage containers over time, it showed that the factors did have some impact. The factor that affected the dimensioning of the products was the order composition.

It is arguable whether the factors other than the order composition affecting the utilization of the storage containers also affect the dimensioning of the storage containers. This is because larger storage containers can store more packs. However, the utilization of storage containers should be regarded as the number of occupied containers, while the dimensioning of storage containers should be regarded as the products which are able to fit into the storage container.

Should, then, the UCDP be used for all orders and articles? The answer is no. The UCDP is capable of handling a wide range of products depending on the physical dimensioning, but this does not mean it is able to handle a wide range of order compositions. It is capable of handling most of the orders present in the order data, but the significantly larger orders, those consisting of several large packs, should not be delivered through a UCDP. A clear example of this is present in all the simulation configurations. The peak occurring around the middle of July shows that the UCDP would need over 1 400 containers to accommodate this order (together with the other orders which are already stored in the UCDP). 1 400 containers for a UCDP is not realistic, in contrast to the order which did occur in the real world, although this order is to be regarded as rare. The storage dimensioning used for the automated pillar design also shows that this type of UCDP is not capable to handle all of IKEA's products. This suggests that other solutions to the last mile should be used utilized to deliver significantly large orders, such as the 15 largest orders presented in Figure 27 and Figure 28. Home deliveries could be used as a complement to these. Another way to accommodate large orders in the UCDP is simply to restrict the sales through the UCDP to certain products and order sizes.

7 Conclusion

This final chapter first presents the conclusions of the thesis by answering the proposed research questions. This section is followed by presenting the contributions of the thesis, as well as some general reflections about the simulation study and possibilities for future research.

7.1 Concluding Remarks

The UCDP is an interesting solution to the last mile delivery issue. Like the other last mile delivery solutions, the UCDP has both its advantages and disadvantages. Although countries at the time of writing this thesis have either adopted the UCDP concept or not, as the online retail sales are expected to grow in the coming years, so might the UCDP alternative become a more widespread solution to both customers and organisations. This is also strengthened by the fact that the development and innovation of UCDP progresses as their popularity increases.

Chapter 3 Frame of Reference presented the research which has been conducted in the topic of UCDPs. Although the research presents several different names for the UCDP, the research focused mostly on the same topic. It is however imperative that a common term is decided on by the industry and researchers, as only using the commonly known term parcel locker only presents one of several available solutions. This thesis has used the term UCDP as a collective name.

Most of the already conducted research has heavily examined the UCDP from the customers' perspective but also from the organizational perspective. No research presented the available solutions for the UCDP concept and what their distinct key features and characteristics are. This thesis contributes to the field by thus answering the first RQ.

RQ1: Which solutions exist for the UCDP concept and what are their characteristics?

Four different types of solutions exist for the UCDP concept. These four solutions have been given the following names and have the following key features and characteristics:

- *The traditional parcel locker:* The traditional parcel locker contains several slots with different dimensions and in some instances, special storage configuration such as temperature regulation. The slots are accessed from the exterior and the load-in and retrieval process are done manually by the user. The traditional parcel locker features control consoles for interaction and another feature is that the number of slots and control consoles can be adjusted due to the traditional parcel locker modularity feature. It can be placed either indoors or outdoors.

- *The automated box design:* The automated box design contains several slots in its interior. The parcels stored in the slots are accessed through an opening, or gateway, on the exterior. The process to load-in and retrieve a parcel is done through automation, using a sort of ASRS installed in the interior of the UCDP. The capacity, control consoles and gateways can be adjusted. However, the storage space does not offer for instance temperature regulation. Furthermore, this concept can be placed only indoors.
- *The automated pillar design:* The automated pillar design is similar to the automated box design but stores instead all the parcels on its height. Furthermore, the automated pillar design can be located either indoors or outdoors. The parcels are inserted and extracted through an opening and by using an automated system. The number of gateways and control consoles cannot be adjusted, and temperature regulation is non-existing.
- *The cart design:* The cart design can accommodate carts, flat beds and sometimes full pallets. It offers temperature regulation in some cases and can be placed either indoors or outdoors. The carts can be used to transport the orders outside of the UCDP's immediate perimeter, allowing for easier transport to the customers' cars, for instance.

The existing research did further not present any findings regarding how factors affected the utilization and dimension of the storage containers of the UCDP. To express this in an alternative way, the research did not present any findings regarding the interaction between the UCDP's physical configuration and external usage factors. This was the focal point of the second RQ and the answer is presented below.

RQ2: How do the number of orders, order composition, customer behaviour, UCDP localization and schedules of the UCDP service provider affect the utilization and dimensioning of storage containers of the UCDP?

The results from the simulation study found that the physical dimensioning of the UCDP is affected by several factors in different ways. The overall utilization of storage containers is mainly influenced by the customers' mean arrival time to retrieve an order, the number of orders and the order composition. The maximum utilization of storage containers is also affected by the working hours of the UCDP service provider, but this did not affect the average figure. The location of the UCDP as well as the maximum order retrieval time does not affect the utilization of storage containers of the UCDP significantly. However, both restricted working hours and a remote location of the UCDP create momentary peaks of the UCDP's utilization.

The dimensioning of the storage containers, and hence the dimensioning of the storage classes, is mainly affected by the order composition.

The conclusion from the results of this thesis is that the choice of UCDP solution and its physical dimensioning depends on the circumstance of which the UCDP is implemented in. The UCDP should however not be solely used as a last mile delivery method but should in some situations be complemented by other last mile delivery methods, such as home deliveries.

7.2 Contributions

This Master thesis contributes to the existing research in several ways, which are presented in the following sub-sections.

7.2.1 Using Simulation as a Tool

It has been showed that simulation as a tool is able to provide answers to complex real-world systems. The developed simulation model can be used to predict the utilization and dimensioning of a UCDP's storage containers based on a specific order data and other circumstances. The simulation model is further highly configurable according to the user's preferences and can hence be configured to test different settings of the UCDP and external factors.

7.2.2 Managerial Guidelines

Chapter 3 Frame of Reference presented the themes which have been studied in the research of UCDPs. To extend the themes from the results of this thesis, Figure 69 below is presented.

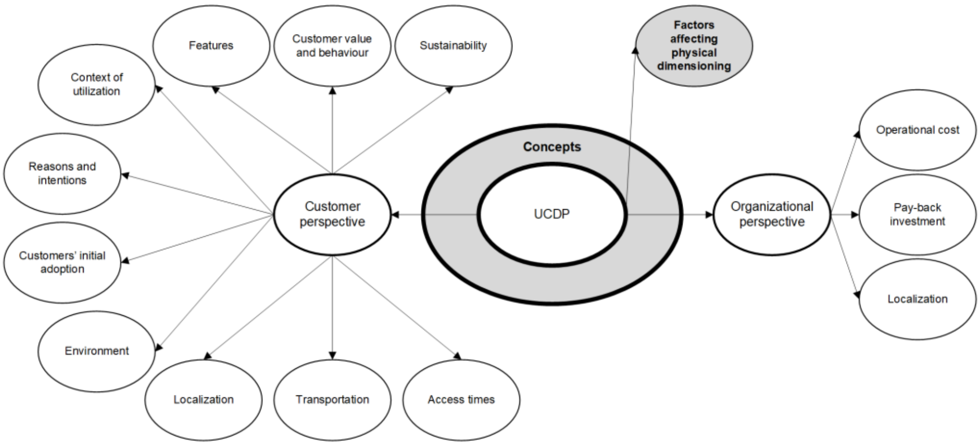

Figure 69 The extended themes for the research of UCDPs.

The extended themes can also be used to as a checklist when providing guidelines and recommendations. The following guidelines and recommendations are presented regarding the implementation of UCDPs for IISSAB:

- Most of the customers access the UCDP in the evening or early night, followed by late afternoon. The customers' preferred access to the UCDP could however depend on the culture and country. In general, the customers prefer to have access to the UCDP 24/7.
- UCDPs should be located in the proximity of areas with a high density of customer flow or on the way of the customers' other errands. Furthermore, since the main transportation method to the UCDP is by car, a parking space should be accessible near the UCDP. Furthermore, the environment of the UCDP should be safe and secure as well for the customers. This can be done by placing the UCDP indoors instead of outdoors.
- In order to increase the adoption intention of the customers to use the UCDP, an overall positive attitude towards the UCDP concept need to be acquired by the customers. This can be done through advertisements and instruction videos showing the benefits of using UCDPs as a delivery method. Furthermore, once the customers have started using a UCDP, it is important to keep in mind that their main intentions to use it is because the UCDP is available 24/7, decreases the transportation costs and has a favourable localization.
- The UCDP should have several features, both in the software and hardware, which simplifies for and supports the customer when using the UCDP. Video surveillance is also recommended as this increases the safety of the customers.
- When the customers use the UCDP, it is important to also acknowledge that the customers are part of the UCDP service process. The values created by the UCDP is thus also created by the customer. If the customer is positively affected when using the UCDP, this increases the value for the customer

and the customer will thus use the UCDP more. On the other hand, should the UCDP not be a preferred delivery method by the customers, this will eventually lead to them not using the UCDP. Consequences of both these reactions are either positive or negative word-of-mouth.

- The UCDP can realize both savings in the form of lower operational cost and lower payback investment compared to other last mile delivery solutions. The proper location of the UCDP can also increase its usefulness for the customers. Furthermore, proper location of the UCDP can also realize savings on the environment.
- The type of UCDP should be chosen depending on the purpose of the UCDP and the current circumstances for implementing the UCDP, as each type of UCDP has its own key features.
- It is recommended to give the UCDP some type of modularity, to be able to increase the storage capacity and/or UCDP interaction interfaces in response to large orders and sales peaks.
- Before deciding on the capacity of the UCDP, it is important to first explore the number of orders, order composition and the customer’s arrival behaviour the UCDP should be able to handle. It is better to give the UCDP some overcapacity so that peak orders can be stored in the UCDP.
- When deciding on the number of storage classes and their respective configuration, it is recommended to first examine which articles and order sizes the UCDP should be able to handle.
- The maximum order retrieval time should be set according to the service level for the customers. This is because the maximum order retrieval time could affect the customers’ arrival behaviour.
- The order preparation and the transportation to the UCDP should be initiated according to the peak periods of the sales, to avoid a congested UCDP.
- If the UCDP is located in a remote location, it is preferred to have frequent deliveries to the UCDP. This should however be economically viable.
- If necessary, set a restriction to which articles and order sizes the UCDP should be able to handle and communicate this to the customers. Offer alternative delivery methods when the customers purchase articles and orders not being handled by the UCDP.

7.2.3 Other Contributions

The results from the simulation study contributed with Figure 67, suggesting that a relative increase or decrease in orders does not generate the same proportionate storage container utilization. In addition to this, this thesis has contributed with a comparison of different UCDP solutions as shown in Figure 66.

7.3 Reflections on the Simulation Study

7.3.1 Reflections on the Data

The results from the simulation study showed that the utilization of storage containers, and the total capacity of the two UCDPs used, is not realistic. This would mean that on average, the UCDP should have around 180 storage containers. The number of storage containers has not been seen in any of the UCDP solutions thus far. The cause is the origin of the sales data. The data used in the simulation model came from in-store purchases from an IKEA store in Glasgow, which was presented in 4.2.3 Data Collection and Description. These sales would probably not have the same composition or characteristics if the sales were purchased through a UCDP. For instance, it would seem illogical that the extremely large orders, with for instance over 1 000 packs or over 80 distinct articles, would be acquired using a UCDP. Instead, it is reasonable to assume that the customers would instead have these products delivered to their homes using for instance home deliveries or third-party logistics providers. It would further not be possible for IKEA to deliver these large orders, or even the number of orders, using UCDPs, because the capacity needed would not significantly larger than the UCDPs that exist nowadays. What is actually analysed with the sales data is if all the purchases done in-store would be moved to purchases done to a UCDP. This is not a viable scenario nowadays but might be in the future as online retail sales and the use UCDP as a last mile delivery solution might increase.

The sales data was also prone to some simplifications, mostly because only some dimensions of the packs in the articles were known. However, with the data assumptions presented, this could be seen as a worst-case scenario. This is because according to the data assumptions, if an article consists of several packs, all the packs in this article have the same size as the largest pack of the article, whose dimensions were known. In reality, these packs would probably be smaller. Take for instance a couch containing the foundation of the couch and the legs of the couch. It is reasonable to presume that the packs with the legs is significantly smaller than the pack with the foundation of the couch. If all the data were available and according to this reason, it might be presumed that the utilization of storage containers in the results of the simulation study would be less. It is although difficult to say how much the utilization would decrease.

Furthermore, the sales data origin from three months of sales during the Summer period. The data thus fail to capture increased purchases due to seasonalities, for instance during the Christmas period. The Summer period might however be one seasonality, because it is reasonable to assume that the customers have vacation during summer and during this time they renovate their residences. Some customers might also move to another residence and thus need to purchase new furniture at IKEA. It would be interesting to run the simulation model with another data set ranging for a longer sales period, for instance a year, to capture the effects of seasonality on the physical dimensioning of the UCDP.

In addition to this, the customers' purchasing behaviour might be different in different countries and cultures. The sales data's characteristics might have been different if the sales came from another country, or even IKEA store within the same country.

To summarize the reflections regarding the sales data used in the simulation study, it can be said that the sales data is not viable if the purpose of the simulation study is to find the best-fit of capacity and storage classes of the UCDP. However, since most of the factors which was analysed with regards to RQ2 are not directly connected to the sales data characteristics, except for the order composition and number of orders, the purpose of the simulation study was regarded as being fruitful to answer RQ2.

7.3.2 Reflections on the Simulation Model Assumptions

A simulation model has the benefit that it can capture the most essential features of any real-system world system and ignores non-essential features. Because of this, the simulation model is prone to simplifications and assumptions. Most of the assumptions introduced in 4.2.4 Model Translation do not need to be reflected upon, as some of them are realistic and viable. However, some assumptions need to be discussed.

The most difficult real world-aspect to capture in the simulation model was how the packs would be stored in the storage container. According to *assumption MA4* (see 4.2.4 Model Translation), the packs are stacked on top of each other on the packs' minimum dimensions when initially testing which storage class the order should be inserted into. This means that there is much free volume in the storage container which may not have been used. Another assumption which could replace this initial test instead is to use a volume restriction instead. But then the question arises, which volume restriction is realistic? It would probably be possible to develop an algorithm to ensure an optimal fit of all the packs in a storage container. If it would be possible to develop in Arena is however another question. If such an algorithm would be able to be developed, the result would lead to less utilization of storage containers, because the fill rate of each container would be increased. But then again, would the employees inserting the packs into the UCDP working according to such an algorithm?

Another assumption which needed to be implemented in the simulation model is *assumption MA1* (see 4.2.4 Model Translation), which says that the packs can be inserted in any way in the storage container. In reality, some packs cannot be stored in a specific way, for instance large kitchen ware such as refrigerators or ovens.

7.3.3 Reflections on the Simulation Model

The developed simulation model has several features and is highly configurable. Section 4.2.4 Model Translation gave a brief presentation of the different features of the simulation model. Appendix A further gives some more information regarding the features of the simulation model and how these work.

If time however would allow it, the following features could have been implemented in the simulation model:

- The initial simulation model only captures one UCDP. In an improved simulation model, the flows of several UCDPs could have been captured. Separate or sequential transportation flows to and from the UCDPs could then also be captured.
- An extended simulation model could capture if the UCDP would be shared between more than one UCDP service provider, each with its own configurations.
- The customers in the initial simulation model arrive to retrieve their orders from one of two different distributions. If data regarding the customers' arrival behaviour could be gathered, the exact arrival time of each customer can be used as input in the simulation model, or the data could be used to estimate a more realistic probability distribution for the customers' arrival behaviour.
- An extended simulation model could also more in detail capture the return-flow of orders to the IKEA store if the UCDP would be located remotely and transportation would be done with delivery vehicles.

7.3.4 Reflections on the Scenario, Factor and Sensitivity Analyses

The proposed scenario, factor and sensitivity analyses constituted of in total 54 different simulation model configurations. These were sufficient to answer RQ2.

However, some sensitivity analyses could be seen as being redundant and could thus have been replaced with additional factor analyses. For instance, the factors with restricted customer access to the UCDP as well as order manipulation where instead the orders weekday and time of day would have been changed are also possible to simulate.

The simulation model permits the user to almost an endless number of simulation configurations. The effects of several factor and sensitivity analyses could also have been studied. This way, a best-fit setting of the UCDP could have been gained.

7.4 Future Research

The existing research in the topic of last mile delivery solutions and more specifically UCDPs is currently scarce. To contribute to a product which use will presumably grow in the future, more research could and should be conducted.

Most of the existing research has been focusing on the customers' perspective, but also on the organizational perspective. However, most of the conducted studies have focused on the same aspects, such as the reasons and intentions to use a UCDP and the UCDP's localization. The other aspects have only been examined in single studies or been studied briefly in some of the studies. It would be interesting to further investigate the aspects in different countries, cultures and settings, as the results can be different.

Something which has not been examined in the research is the customers' purchasing and retrieval behaviour. First, the time until the consumers retrieve their orders, the time during the day and reasoning behind this behaviour could be examined. The simulation study showed that this factor has a significant impact on the utilization of storage containers, and thus capacity needed for the UCDP. Such a study could be conducted either by interviewing customers, or to acquire more accurate results, the actual retrieval times of customers from existing UCDPs if this kind of data is extractable. Second, the customers' purchasing behaviour could be examined. Such a research could study how the order composition of customers would differ if the order would be purchased in-store compared to if the order would be purchased by using a UCDP.

Furthermore, the logistical impact of using UCDPs can be studied by conducting case studies. This aspect has not been studied previously. For instance, how the logistics and supply chain management has changed after implementing a UCDP can be conducted.

In addition to this, more research should be conducted on the available UCDP solutions, to examine which solutions best serve both the companies and customers' expectations and in which settings.

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Appendix A – Explanation of the Arena Simulation Model

This appendix introduces the reader to some common concepts and terms used in Rockwell Automation's Arena simulation model. Moreover, the appendix gives the reader a brief insight into the developed simulation model in Arena.

A.1 Initial Introduction

A simulation model can be developed in several tools. These simulation tools all have different features, creating both opportunities and restrictions. As was presented in 4.2.4 Model Translation, Rockwell Automation's Arena discrete-event simulation software was used in this thesis. This simulation software uses drag-and-drop boxes, also called modules, which can be interconnected to each other to create a flow or sequence of flows. These together construct a system. A module could represent a process, a storage unit, a probabilistic function or logical decision, an assignment to a variable and many other functions which could be depicted using the real-world system as reference. Each module contains several settings depending on which module has been used.

What drives the simulation model forward are called entities, which flow through the model, into modules where certain actions are triggered depending on the settings of the module. To put entities in a more relatable context, a product which will be enhanced in a manufacturing process can act as an entity. The product (entity) flows through several manufacturing processes (modules). Furthermore, to increase widespread functionality of the simulation, other non-module specific characteristics exists, such as attributes and variables. These terms will be explained further in the following sections.

There are several terms and expressions used in the simulation model which will need to be defined to avoid confusion:

1. An *order* constitutes of several *order entries*. Every *order* has a unique *order number*.
2. Each *order entry* represents a distinct *article* in an *order*. The term *product* is also used interchangeably with *article*.

3. An *article* can be divided into one or several *packs*. *Parcel* is also used to describe the term *pack*.
4. A *storage class* of the UCDP represents a category of one or several *containers* with the same configuration. For instance, the *containers* in the same storage class have the same dimensions, allowed storage volume and weight as well as the same special storage requirements.
5. A *container* is a storage unit or storage slot in the UCDP. It could for instance represent a locker in the traditional parcel locker design, a tray in the automated box or pillar design or a cart in the cart design, see 3.2 UCDP Solutions in Practice.
6. A *UCDP interaction interface* represents the console, touchscreen or other means used by the users of the UCDP to interact with it for insertion and retrieval.
7. A *gateway* of the UCDP represents an opening to the UCDP in the case the UCDP is configured according to, for instance, an automated modular box or pillar design (see 3.2 UCDP Solutions in Practice).
8. An *ASRS* of the UCDP represented the means used in the UCDP for automatic load-in, storage and retrieval. As an example, an *ASRS* is featured in an automated box or pillar design (see 3.2 UCDP Solutions in Practice).
9. A *customer* is represented by an *order number.*
10. A *UCDP operator* is the representative of an organization providing service to the UCDP. The *UCDP operator* is responsible for loading in *orders* and *packs* into the UCDP, retrieving returned *packs* and abandoned *orders* from the UCDP. The term *parcel courier* is used interchangeably.
11. A *simulation run* is finished once one or several *simulation replications* have been terminated.

In a short summary, the simulation model first reads information from an Excel spreadsheet containing real-world data but also user settings of the simulation model. Next, the simulation model is run and at the same time, information is written to external TXT-files. Once the simulation model has been run, results from the simulation study are presented in the software and in the external TXT-files.

A.2 Probability Distributions in Arena

Arena has a built-in library of 13 different probability distributions which can be used in the simulation model to generate random numbers. These probability distributions can for instance generate process times and arrival times. However, only three of the 13 probability distributions are used in the developed simulation model. A brief introduction will be given to the triangular distribution (TRIA), uniform distribution (UNIF) and beta distribution.

Arena has a built-in input analyser which quickly can generate data according to a distribution chosen by the user. This tool is useful in order to understand the appearance of some distribution curves, such as the beta distribution.

A.2.1 Triangular Distribution

A triangular or triangle distribution is a continuous probability distribution which requires three parameters: the minimum value, the most-likely or peak value and the maximum value. As the name indicates, the shape of the distribution is that of a triangle (see Figure A.1). The triangular distribution is easy to use because the minimum, maximum and any reasonable statistics of a sample can be used to indicate the minimum value, most-likely value and the maximum value respectively (Stephanie, 2016b). In the developed simulation model, this is the mostly used random distribution.

To calculate the mean (μ) and standard deviation (σ) of a triangular distribution with minimum value (a), peak value (b) and maximum value (c) the following formulas can be used (Stephanie, 2016b):

$$\mu = \frac{1}{3} * (a + b + c)$$

$$\sigma = \frac{1}{\sqrt{6}} * a$$

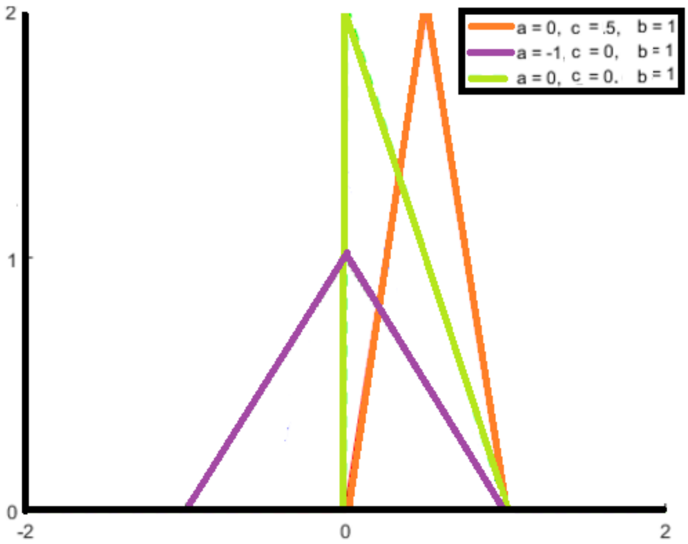

Figure A.1 Examples of triangular distribution using various combinations of minimum values (a), peak values (b) and maximum values (c) (Stephanie, 2016a).

A.2.2 Uniform Distribution

A uniform distribution, which is also called a rectangular distribution, is a probability distribution which has a constant probability. The shape of the distribution curve is according to a rectangle, hence its name (see Figure A.2). It only uses two parameters: a minimum value and a maximum value (Stephanie, 2013). This distribution is only used in two instances of the simulation model.

A uniform distribution with the minimum value a and the maximum value b has the following mean (μ) and standard deviation (σ) (Stephanie, 2013):

$$\mu = \frac{1}{2} * (a + b)$$

$$\sigma = \frac{1}{\sqrt{12}} * (b - a)$$

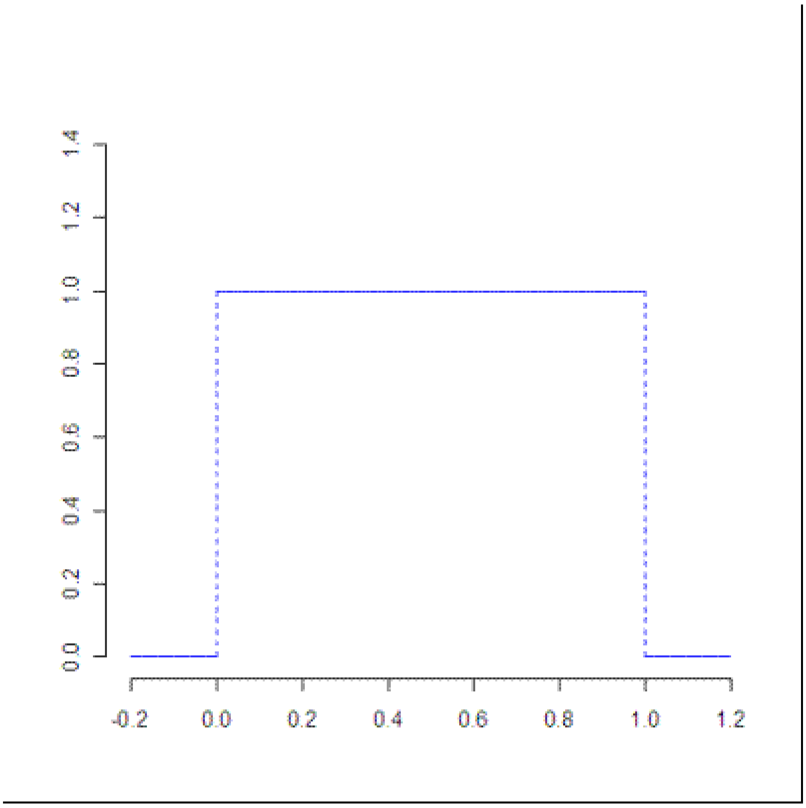

Figure A.2 Example of a uniform distribution ("Uniform Distribution," 2013).

A.2.3 Beta Distribution

A beta distribution (see Figure A.3) uses two parameters, called alpha (α) and beta (β) to shape the beta distribution curve. The two parameters need to be of positive values. It is a versatile way to represent outcomes for percentages or proportions (Stephanie, 2015b). This distribution is only used in one instance of the simulation model, which will be explained later.

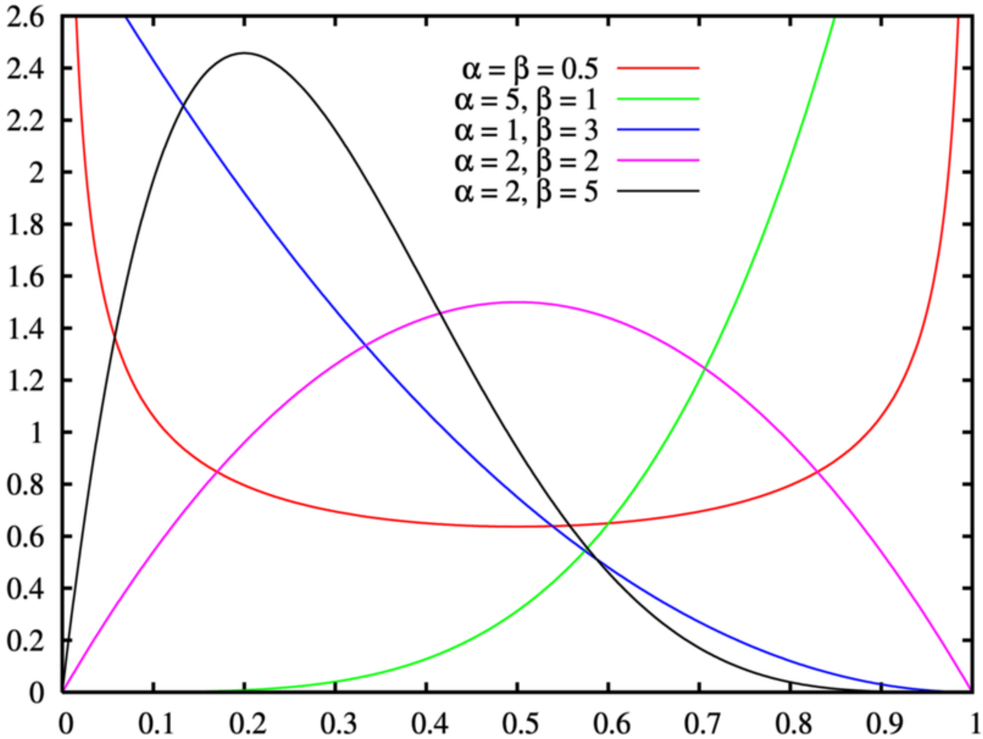

Figure A.3 Examples of the beta distribution using a various combinations of alpha (α) and beta (β) values (Stephanie, 2015a).

A beta distribution with the shape parameters alpha α (shape parameter 1) and beta β (shape parameter 2) has the following mean (μ) and standard deviation (σ) (Bradley, 2007):

$$\mu = \frac{\alpha}{(\alpha+\beta)}$$

$$\sigma = \frac{\sqrt{\alpha\gamma}}{(\alpha+\beta)*\sqrt{(\beta+\alpha+1)}}$$

However, since the range of the beta distribution is from zero to one, a sample X can be scaled to another sample Y with the range from a to b using the equation below:

$$Y = a + (b - a)X$$

This means that if the distribution should have a mean with the value μ, then by knowing either shape parameter (alpha α and beta β) the other shape parameter can be estimated using the following formulas:

$$\alpha = \frac{\beta\mu}{(1-\mu)}$$

$$\beta = \frac{\alpha(1-\mu)}{\mu}$$

A.3 Simulation Input and Output

A.3.1 Input

One perk of Rockwell Automation's Arena simulation software is that it can use collected data acquired from a system in the real world as input in the simulation model. A brief description of the input to the simulation model is that it contains mainly two types of input: order data acquired from IISSAB and user input. The order data can easily be replaced by data from any other company, under the condition that the data fit some set requirements.

A.3.2 Output

There are two ways of acquiring output data from one or several simulation runs in Arena.

The first method is by using the detailed report created at the end of each simulation run in Arena. This report can also be customized according to the user's preferences. An advantage with this detailed simulation report is that is also presents the statistical variations and standard deviations which could occur if several simulation replications would be conducted. However, a disadvantage in this report is that it only gives values accumulated at the end of the simulation runs. This means that if some aspect of the simulation model needs to be studied in more detail over time, this simulation report is not appropriate. Although Arena offers the possibility to draw graphs during the course of a simulation run, these graphs cannot be saved and are also reset in between replications. Furthermore, these graphs are not aesthetically appreciated.

A second method of acquiring output data from one or more simulation runs in Arena is to write data to external files, such as Excel-files, text-files (TXT-files) or databases. This way, one or many aspects of one or several simulation runs can be extracted and studied in more detail. Using this information, further analysis can be conducted since this is extracted raw data. One disadvantage however, is that it the amount of data can become too much to handle. Thus, the number of aspects which will be studied and the time interval of writing the data to the external files need to be carefully adjusted.

In the developed simulation model, both methods of acquiring output data are used. The detailed simulation report is useful to present aggregated data, as well as analysing the statistical variations between the simulation runs for the maintained statistics. The external files are of the text-file type (TXT-files) and are used to study some of the over time.

A.4 Terminologies and Description

This section introduces the reader to some terms and concepts used in the Arena-software.

A.4.1 Entity

As presented earlier, an entity is what drives the simulation model forward. An entity could have a descriptive name, an image displayed during the visualization of the simulation which could change depending on the circumstances and other settings. However, these other settings, which are numerous but not utilized in the developed simulation model, will thus not be further explained.

A.4.2 Set, Resource and Storage

A set in Arena is a group which consists of several members. There are various of types of sets and the type of the members can be different as well, such as queues, resources etc. However, a set may only contain one type of member.

Resources in Arena can be seized and released by an entity and is used to describe something which is needed in a specific process. For instance, a resource can be a delivery vehicle used to transport orders from the warehouse to the UCDP. First, the resource is being seized by an entity and is then released after the transport.

A.4.3 Attribute and variable

Attributes are certain characteristics belonging to a specific entity. In Arena, attributes could have descriptive names and a value. The value could be either a string (text) or real (number). For instance, the dimension of a pack is used as an attribute.

A variable, in contrast to attributes, are non-entity specific and exist globally in the simulation model. A variable can only contain real values (numbers), but could be of both single or multiple values. This means a variable could have a 2D matrix structure, with an assigned number of rows and columns. As an example, there are several variables in the simulation model checking the status of each container of the UCDP.

A.4.4 Statistics

Statistics in Arena is being used to collect certain user-specified information. In the developed simulation model, there are 238 distinct defined statistics which can be categorized into two categories.

A.4.5 Simulation Run Terminating Condition

The terminating condition of a simulation run sets an upper limit to the simulation model when the simulation run needs to stop. Otherwise, the simulation may run indefinitely. The terminating condition used in the developed simulation model is that the model needs to run at least 20 minutes and until the number of disposed packs equals the number of packs specified in the input-file. This way, it is assured that all the packs in the order data have been inserted and then removed from the UCDP, leaving the UCDP completely empty.

A.5 Design of the Simulation Model

The developed simulation model contains several functions, processes and thus modules, resulting in a relatively large and complex simulation model. However, to describe the simulation model to the reader in a pedagogical manner it is necessary to describe the simulation model part-by-part. The simulation model is divided into three support sequences and 12 main sequences which will be described below. For a thorough understanding of the simulation model, it is advised to study the simulation model in Arena. A picture of the whole simulation model as seen in Arena is presented in Figure A.4.

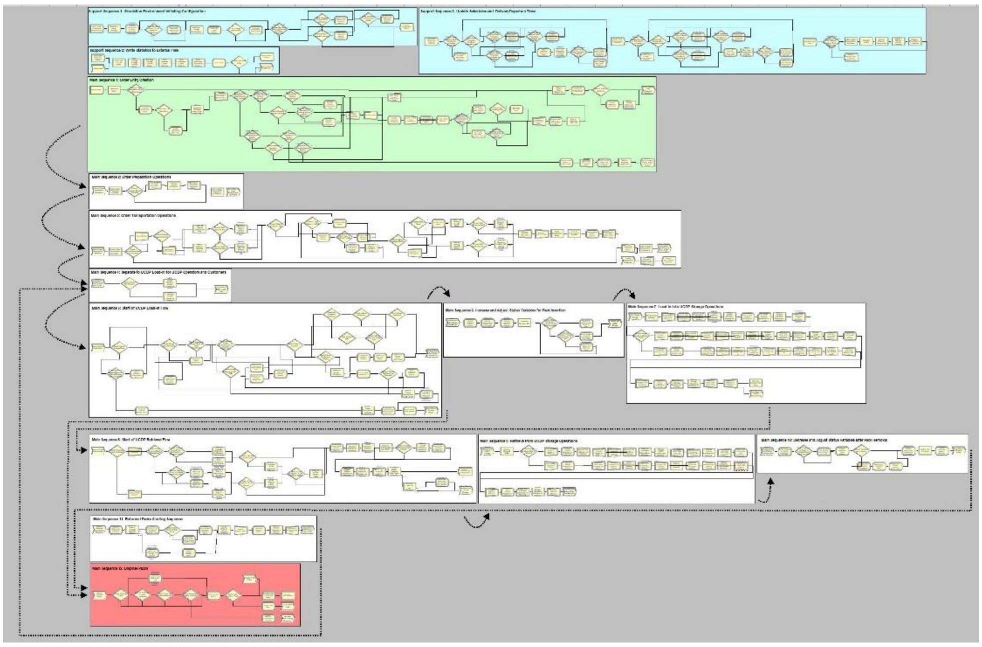

Figure A.4 The developed simulation model as seen in Arena.

A.5.1 The Support Sequences

The three support sequences do not primarily regard anything with the actual flow to and from the UCDP, but rather prepare the simulation model with the correct initial configuration and regular simulation model updates.

Support Sequence 1: Simulation Environment Initiating Configuration

This initiating support sequence is called *Simulation Environment Initiating Configuration* (see Figure A.5). It is initiated in the beginning of the simulation run before any other sequence is initiated. The purpose of this sequence is to configure the simulation model according to the external user input. An entity passes several modules, where the information is read and assigned to the simulation model. Once the entity has passed all the modules, it is disposed, and the sequence will not be initiated again during the simulation replication. However, it will be initiated in the beginning of each simulation replication if several simulation replications have been set for a simulation run.

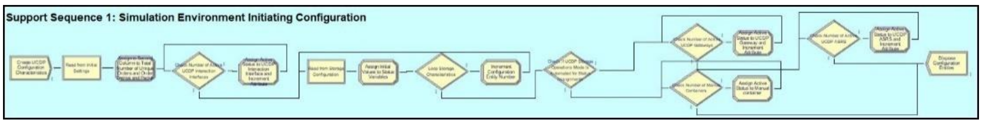

Figure A.5 ***Support Sequence 1: Simulation Environment Initiating Configuration*** **as seen in the Arena simulation model.**

Support Sequence 2: Write Statistics to External Files

The second support sequence is called *Write Statistics to External Files* (see Figure A.6). As the name suggests, the purpose of this sequence is to write statistics to the external files used in the simulation model. The entities flow through several write-modules until it is disposed. The current time interval for the entity creation is set to 60 between each entity creation. This means that data is written to the output files every 60 minutes until the simulation run terminates.

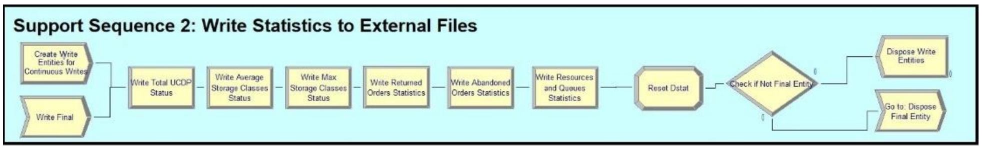

Figure A.6 ***Support Sequence 2: Write Statistics to External Files*** **as seen in the Arena simulation model.**

Support Sequence 3: Update Schedules and Delivery Departure Timer

The third support sequence, *Update Schedules and Delivery Departure Timer* (see Figure A.7), consists of three separate flows. The first two flows regularly update the status for the resources in two of the defined resource sets in the simulation model. The third flow regards if the order transportation mode is activated and the delivery departure criteria is set to a specific time interval, this support flow signals when the deliveries should depart in *Main Sequence 3: Order Transportation Operations* (see next sub-section).

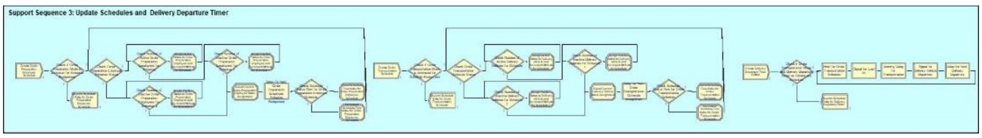

Figure A.7 ***Support Sequence 3: Update Schedules and Delivery Departure Timer*** **as seen in the Arena simulation model.**

A.5.2 The Main Sequences

The main sequences regard the flow of orders, packs, customers and UCDP operators to, at and from the UCDP.

Main Sequence 1: Order Entry Creation

The first main sequence (see Figure A.8) is called *Order Entry Creation* and is where all the entities in the main simulation flow are created. The entities in the simulation model are the order entries from the order data from the input file.

This sequence also contains an order manipulation mode, which can be activated by the user input. The number of orders can either be increased or decreased using the manipulation. There are two types of manipulation modes: random manipulation and weekday interval specific modification.

The following paragraph applies if the number of orders is increased. If the order manipulation mode is set to weekday interval specific modification, then only the orders whose weekday index are within a set weekday interval will be duplicated. In either modification mode, the user input assigns the probability that an order will be duplicated. All the duplicated orders are assigned a new order number and order release time, either by a triangular distribution (in the case of random modification activation) or uniform distribution (in the case of weekday interval specific modification). Furthermore, a new weekday index is assigned in the case of random modification activation, otherwise a new week index is assigned. The original order number, original order release time, original weekday index and original week index are also stored in attributes. The duplicated entities' characteristics are also written to an external file.

If the order manipulation mode is set to decrease, then there is a chance (defined by the user input) that some orders will be removed. In the case of weekday interval specific modification, only orders with a weekday index within the set weekday interval can be removed. The removed entities' characteristics are then written to an external file before being disposed.

Whether the order manipulation mode is set to increase or decrease, the modified total number of orders, order entries and packs, and the difference between these and their original values, are stored in a variable.

All the order entries, both ordinary and duplicated ones, are then put on hold until the time of the simulation run equals the release time of the order, at which point the entity is moved to the next main sequence, *Order Preparation*.

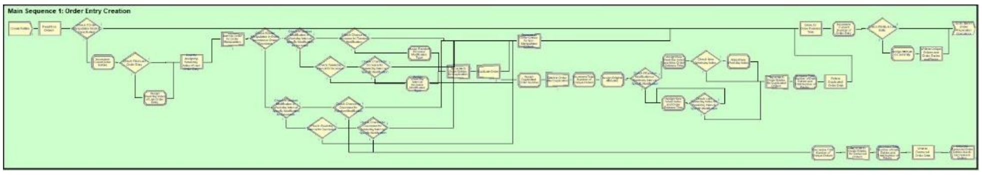

Figure A.8 ***Main Sequence 1: Order Entry Creation*** **as seen in the Arena simulation model.**

Main Sequence 2: Order Preparation Operations

Entities from the *Order Entry Creation* sequence arrives at the second main sequence, *Order Preparation Operations* (see Figure A.9). First, all the entities are put on hold due to the schedule of the order preparation sequence. If the order preparation mode has been activated by the user input, an order will seize an employee resource, be delayed for several minutes according to a triangular-distribution and then release the seized resource. Regardless of the status of the order preparation mode, the order entries are again put on hold according to the order preparation schedule. After this, the entities move to *Order Transportation Operations*.

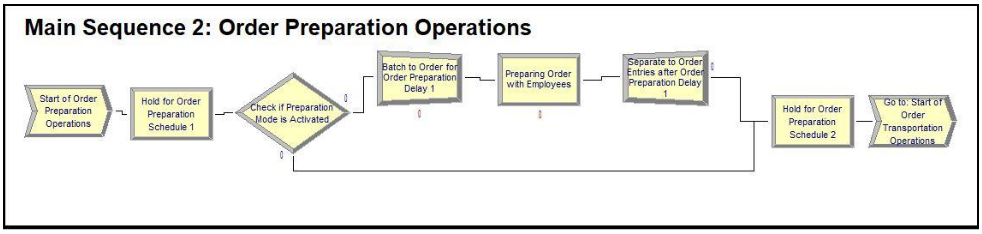

Figure A.9 ***Main Sequence 2: Order Preparation Operations*** **as seen in the Arena simulation model.**

Main Sequence 3: Order Transportation Operations

After having passed the *Order Preparation Operations* sequence, the entities arrive at the *Order Transportation Operations Sequence* (see Figure A.10). The entities are first put on hold according to the order transportation schedule. If the transportation mode is activated by the user input, the entity moves to the transportation operations. First, the order entries are batched into orders and put on hold according to a delivery departure criteria set by the user input. After that, the orders are added to the cargo of a delivery vehicle until the maximum volume of the cargo has been reached. The maximum volume of the cargo is set by the user input.

Once the cargo reaches maximum volume, the cargo is stalled for departure until a criterium is fulfilled. There are three criteria which can be chosen from the user input. The first criterium is that the delivery vehicle departs once the cargo reaches its maximum. The second criterium is that the delivery vehicle departs according to a set time interval, while the third criteria combines the first two criteria, meaning that the delivery vehicle departs either when the cargo is full or at a set time interval.

Once the specified criterium has been fulfilled, the stalled cargo first resets the cargo volume to zero and assigns a new time of departure. Then one out of ten delivery vehicles are seized, and the cargo is transported to its destination. The transportation is represented by a delay where the value is the transportation distance divided by the average velocity of the delivery vehicle. Once the delivery vehicles reach its destination, the delivery vehicle is released. In the same sequence, some statistics regarding the delivery vehicle’s time of departure, the cargo volume and relative cargo volume to the maximum delivery vehicle volume.

Whether the transportation mode has been activated or not, all entities move to the fourth main sequence, *Separate to UCDP Load-In for UCDP Operators and Customers*. However, the order entries are first duplicated into the number of packs it constitutes of according to an attribute. This attribute is assigned from the order data.

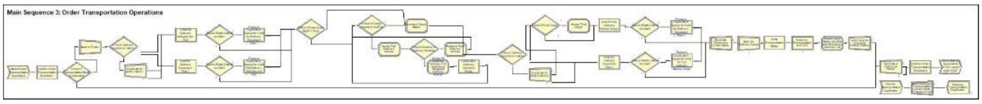

Figure A.10 ***Main Sequence 3: Order Transportation Operations*** **as seen in the Arena simulation model.**

Main Sequence 4: Separate to UCDP Load-In for UCDP Operators and Customers

The separated entities, now being packs, which arrive from the sequence *Order Transportation Operations*, arrive to the sequence *Separate to UCDP Load-In for UCDP Operators and Customers* (see Figure A.11). All the arriving entities are put on hold according to the UCDP operators' UCDP access schedule and customers' UCDP access schedule (for returned packs). This represents when the UCDP operators gain access to the UCDP to insert packs and when the customers gain access to the UCDP to return packs respectively. All the entities move to the next sequence, *Start of UCDP Load-In Flow*.

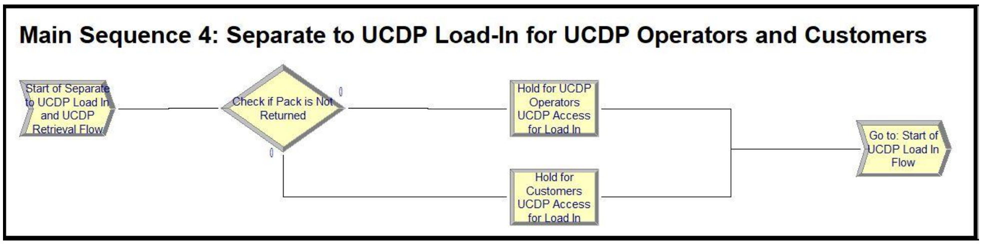

Figure A.11 ***Main Sequence 4: Separate to UCDP Load-In for UCDP Operators and Customers*** **as seen in the Arena simulation model.**

Main Sequence 5: Start of UCDP Load-In Flow

The sequence *Start of UCDP Load-In Flow* (see Figure A.12) is the most complex sequence in the simulation model. The entities arrive from the sequence *Separate to UCDP Load-In for UCDP Operators and Customers* to this sequence. The entities starting from this sequence are mentioned as *pack* entities, but this is not reflected in the simulation model, as the name of an entity in the simulation model cannot be changed during a simulation run.

The first part of the sequence decides if the entity has any storage class in the UCDP which it best fits in due to the characteristics of the storage class such as dimensions, storage volume, storage weight and any special storage requirements. The assigned storage class is stored in an attribute. However, if the entity cannot identify any storage class which it can be stored in, its characteristics will first be written to an external file followed by the entity being moved to the sequence *Dispose Packs*.

The second part of this sequence checks if the whole order can fit into one container in each storage class. This is done by comparing the orders' maximum, mode and sum of its inherited packs' minimum dimensions to the maximum, mode and minimum dimensions of the containers in each storage class respectively. Do note that this comparison does not take the total weight and volume of the order into consideration. Furthermore, as an order can contain packs with distinct special article characteristics, it would also not be possible to assign a specific special article characteristic to the whole order. The comparison is first done to the storage class with the lowest number, but if the requirements are not fulfilled, then the comparison is done to the sequent storage class. If all the available storage classes have been compared to against but without a successful match, the order is assigned to be split in advance. The system determines that in any case, the whole order is unable to fit into any single container of any storage class.

In the next part of the sequence, a comparison is instead done to the individual packs' dimensions, volume, weight and special article characteristics. Note that the weight will not be compared, as this will be done in a later part of this sequence. This comparison is first done against the preliminary storage class assigned from the previous part. If the requirements are not fulfilled, the comparison occurs to the other storage classes.

The third part of the sequence starts with searching through all the containers in the preliminary assigned storage class to see if any container already has an entity stored with the same order number. Following this, one of three situations can occur:

1. *Situation 1:* If a container in the storage class is identified storing packs with the same order number as the entity, then the system checks if inserting the pack into the same container does not exceed the minimum dimension, the allowed storage volume and allowed storage weight of the container. In the case the order is split, the minimum dimension of the storage container may be exceeded, and the limit is set by a maximum allowed volume instead. This whole situation implements *assumption MA4* (see Simulation Model and Data Assumptions). However, if the pack does exceed any of the limits, the system tries to identify any additional containers within the storage class storing the same order number and conducts the previous comparison. If it preliminary fits into the container in the storage class, then the storage container and storage class are set. The *pack* entity then moves to the next sequence, *Increase and Adjust Status Variables for Pack Insertion*. Otherwise, the entity follows the sequent situation.
2. *Situation 2:* If any of the containers in the storage class has not stored any entities with the same order number, then it will be assigned an empty container and the entity is set to the previous situation.
3. *Situation 3:* In the third situation, no containers in the preliminary assigned storage class stores the same order number and all the containers are full. The entity is then assigned a larger or smaller storage class and moves to the first situation. This is done until all the containers in all the storage classes have been checked. When this occurs, the UCDP is completely full and *assumption MA6* (see Simulation Model and Data Assumptions) occurs. In this case, the entities have its characteristics

written to an external file and then moves to be disposed in the sequence *Dispose Packs*.

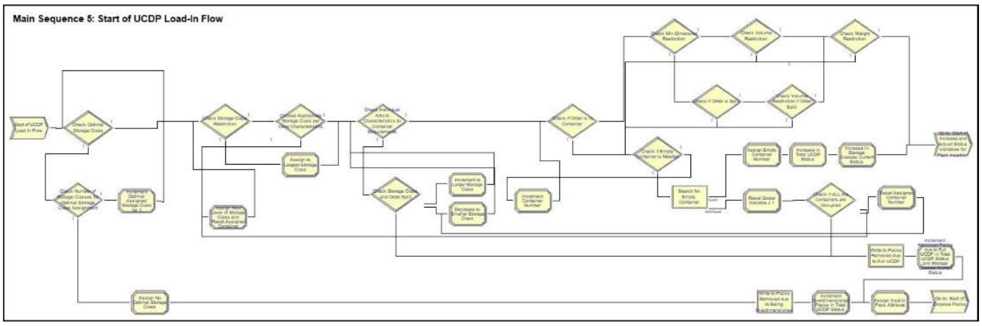

Figure A.12 ***Main Sequence 5: Start of UCDP Load-In Flow*** **as seen in the Arena simulation model.**

Main Sequence 6: Increase and Adjust Status Variables for Pack Insertion

Once a proper storage class and storage container has been chosen in the previous sequence, *Start of UCDP Load-In Flow*, several variables have their values increased due to a pack being added to the UCDP. This is done in the sequence *Increase and Adjust Status Variables for Pack Insertion* (see Figure A.13). All the *pack* entities move to the sequence *Load In into UCDP Storage Operations*.

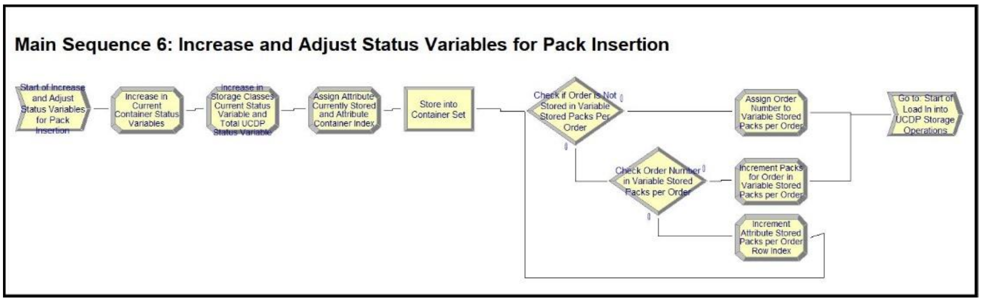

Figure A.13 ***Main Sequence 6: Increase and Adjust Status Variables for Pack Insertion*** **as seen in the Arena simulation model.**

Main Sequence 7: Load-In into UCDP Storage Operations

The *pack* entities arrive at the *Load-In into UCDP Storage Operations* sequence (see Figure A.14) once they have been assigned a storage container in *Start of UCDP Load-In Flow* and status variables have been updated in *Increase and Adjust Status Variables for Pack Insertion*. This sequence represents when the courier or UCDP operator inserts the individual packs by themselves into the UCDP (manual UCDP storage operations) or let an automated UCDP with gateways and ASRS load a whole order into the UCDP (automated UCDP storage operations).

The difference between the automated and manual UCDP storage operations is primarily the delay for the load-in procedure, which is applied to each pack in the manual storage operations, regardless of how many containers the order will occupy. In contrast, if the storage operations are automated, then the delay is applied to several packs instead, and those packs will be loaded into the same container of the UCDP. In both cases, the storage operations delay is represented by a triangular distribution.

For both the parts of the UCDP interaction interface interaction and the UCDP storage operations, the start and end time of each process is recorded and written to an external file as well as recorded in a Record-module.

Once all the packs have been loaded into the UCDP, either through manual or automated storage operations, a notification is sent to the customers and the packs are put on hold in the UCDP. The notification is represented by duplicating the entities. The original entities are kept for storage until they are retrieved by the customers, or UCDP operator in the case of returned packs and abandoned orders. The duplicated entities, which will further be called either *customer* or *UCDP operator* entities, move to the sequence *Start of UCDP Retrieval Flow*.

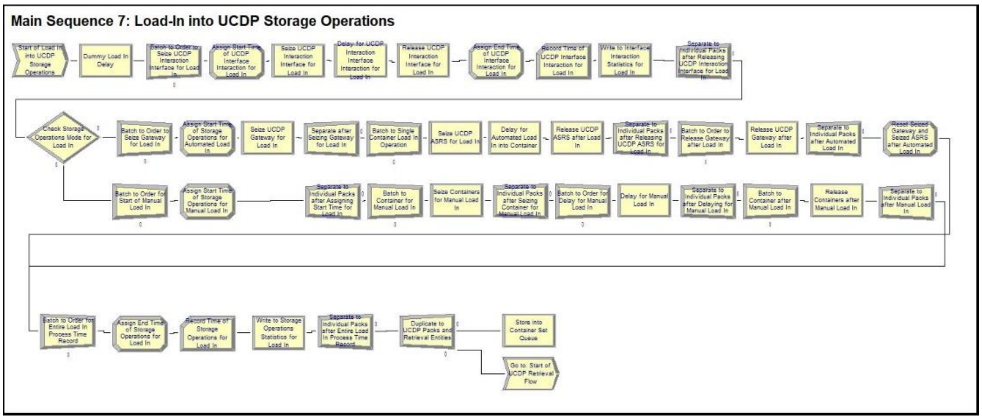

Figure A.14 ***Main Sequence 7: Load-In into UCDP Storage Operations*** **as seen in the Arena simulation model.**

Main Sequence 8: Start of UCDP Retrieval Flow

The *customer* and *UCDP operator* entities from the sequence *Load-In into UCDP Storage Operations* arrive to the sequence *Start of UCDP Retrieval Flow* (see Figure A.15). In this sequence, the following three situations could occur:

1. *Situation 1:* The first situation is probably the most common one, however, this depends on the user input. The *customer* entities arrive at the UCDP after a time decided by a TRIA-distribution or beta distribution. The *customer* entities then wait to gain access to the UCDP according to the schedule for customers’ UCDP access.
2. *Situation 2:* The second situation occurs if the customer decides to abandon the order, meaning the customer decides not to pick up the order from the UCDP (*assumption MA10* in Simulation Model and Data Assumptions). In

this case the *customer* entity will instead represent a *UCDP operator* entity, which will be delayed for a set amount of time. The delay represents the time until the abandoned order will be removed by the parcel courier from the UCDP. Using the schedule for the UCDP operators' access to the UCDP, the *UCDP operator* entity waits to gain access to the UCDP.

3. *Situation 2:* The entity has been returned and in this case the *customer* entity will instead represent a *UCDP operator* entity. The entity is delayed for a certain amount of time in correspondence with the user input stored in the first row and fifth column in *var Customer Return Settings*. This delay represents the time until the returned pack will be removed by the parcel courier from the UCDP. Then the *UCDP operator* entity waits to gain access to the UCDP.

Next, both the *customer* and *UCDP operator* entities check if access to the UCDP has been granted according to their respective access schedules. If access has not been granted, then both the entities are put on hold until access is granted. To ensure that not all the entities put on hold arrive at the same time to the UCDP, there is a chance that some of the entities are applied a delay with by a uniform distribution.

The *customer* and *UCDP operator* entities then proceed with interacting with one of the UCDP interaction interfaces. This would reflect the customer or UCDP operator interacting with the touchscreen or console present at the UCDP, moving through the menus and instructions presented in the interface and also typing in the assigned PIN-code. The number of present UCDP interaction interfaces is set by the user input. The start and end time of interacting with the UCDP interaction interface is also written to an external file and recorded in a module.

Regardless of which situation occurs, the *customer* or *UCDP operator* entities search all the containers in all the storage classes in the UCDP for *pack* entities stored with the same order number as the *customer* or *UCDP operator* entity. The *customer* and *UCDP operator* entities are then disposed, while the removed *pack* entities move to the next sequence, *Retrieve from UCDP Storage Operations*.

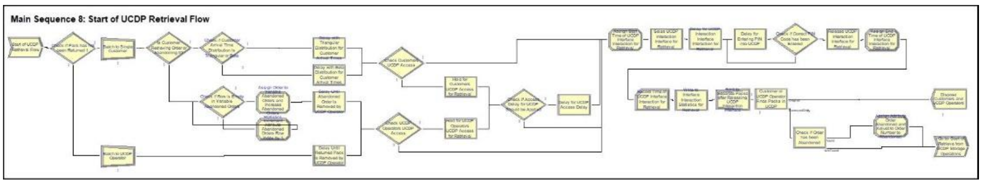

Figure A.15 *Main Sequence 8: Start of UCDP Retrieval Flow* as seen in the Arena simulation model.

Main Sequence 9: Retrieve from UCDP Storage Operations

The entities in the sequence *Retrieve from UCDP Storage Operations* (see Figure A.16) arrive from the sequence *Start of UCDP Retrieval Flow*. The sequence is constructed in the same manner as the sequence *Load In into UCDP Storage Operations*, excluding the UCDP interface interaction part. However, instead of representing that the packs and orders are loaded into the UCDP, this sequence represents instead the retrieval process from the UCDP of the packs and orders. This could also be done manually (pack-by-pack) or by automation (container-by-container) by the customers or UCDP operators (for returned packs and abandoned orders). Also, the start and end time of the storage operations process for retrieval is written to an external file and recorded in a module. The sequence *Retrieve from UCDP Storage Operations* will not be further explained.

All the retrieved *pack* entities move to the next sequence, *Decrease and Adjust Status Variables after Pack Removal*.

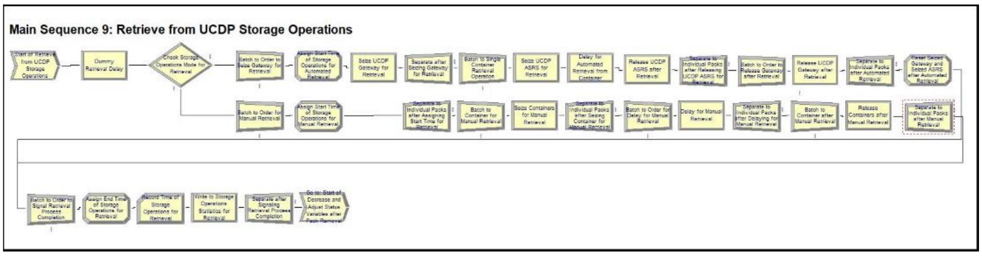

Figure A.16 ***Main Sequence 9: Retrieve from UCDP Storage Operations*** **as seen in the Arena simulation model.**

Main Sequence 10: Decrease and Adjust Status Variables after Pack Removal

Pack entities arriving from *Retrieve from UCDP Storage Operations* enter the sequence *Decrease and Adjust Status Variables after Pack Removal* (see Figure A.17). This sequence is the exact opposite of the sequence *Increase and Adjust Status Variables for Pack Insertion*. This means that instead of increasing the values of several variables, the values are decreased using the previously assigned attributes to the entity. The *pack* entities then move to the sequence *Dispose Packs*.

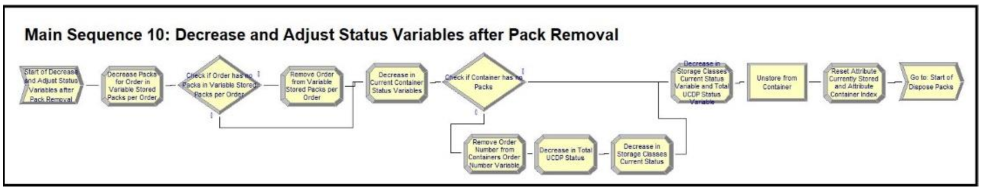

Figure A.17 ***Main Sequence 10: Decrease and Adjust Status Variables after Pack Removal*** **as seen in the Arena simulation model.**

Main Sequence 11: Returned Packs Starting Sequence

Packs which have been returned by the customer must start “from the beginning” in the sequence *Returned Packs Starting Sequence* (see Figure A.18). Returned *packs* arrive from the sequence *Dispose Packs* (see next sequence). They are then assigned the value to an attribute to distinguish it from non-returned and abandoned *packs*.

The returned *packs* are then delayed for a certain number of hours of time according to a triangular distribution. This represents the time the customers take to get back to the UCDP to return the parcel. Once the *packs* are returned to the UCDP, the *pack* entities move to the sequence *Separate to UCDP Load-In for UCDP Operators and Customers*.

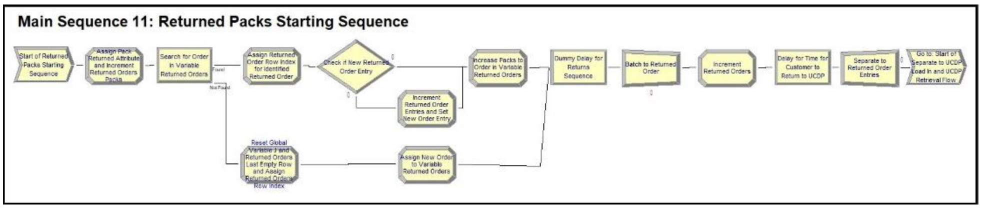

Figure A.18 ***Main Sequence 11: Returned Packs Starting Sequence*** **as seen in the Arena simulation model.**

Main Sequence 12: Dispose Packs

Pack entities arrive from either the sequence *Start of UCDP Load-In Flow* or the *Decrease and Adjust Status Variables after Pack Removal* sequence to the final sequence, *Dispose Packs* (see Figure A.19). The *pack* entities from *Start of UCDP Load-In Flow* have been deemed as invalid packs (packs removed because it does not fit the storage container requirements or the UCDP is completely full), while the *pack* entities from *Decrease and Adjust Status Variables after Pack Removal* have been removed from storage.

Regardless of where the *pack* entities come from, the *Dispose Packs* sequence checks that only *pack* entities which have not already been returned, abandoned or have been deemed as invalid are able to be returned. The probability of a *pack* being returned is decided by the user input. *Pack* entities which will be returned by the customer have first their attributes reset and then move to the previous sequence, *Returned Packs Starting Sequence.* Otherwise, the number of abandoned *packs* are collected, as well as the total number of *packs* before they are being disposed. The recorded total number of *packs* is used to check the terminating condition of the simulation model.

However, before the last entity in the simulation replication is disposed, it moves to the sequence *Support Sequence 2: Write Statistics to External Files* to write the final statuses of the UCDP.

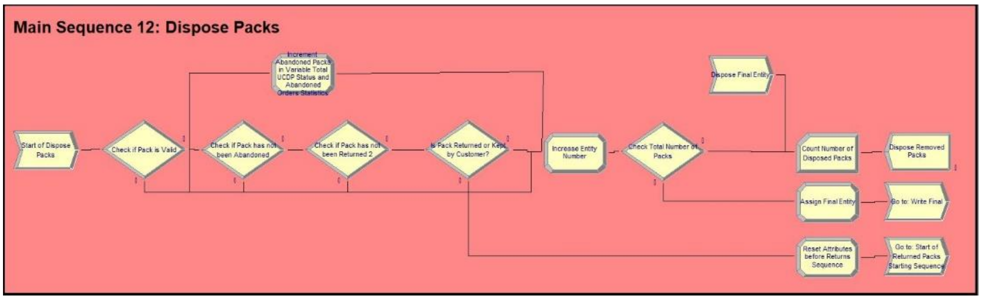

Figure A.19 ***Main Sequence 12: Dispose Packs*** **as seen in the Arena simulation model.**