The Future of Warehouse Automation: Will Drones Ever Take Off?

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Abstract

Title	The Future of Warehouse Automation: Will Drones Ever Take Off?
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Background	In recent years, manually controlled drones have taken off on the commercial market, as well as in the agricultural industry and in humanitarian logistics. This has increased the interest in investing in autonomously controlled drones to increase efficiency and reduce costs. Some projects have been initiated in warehouses but the research in the field is still limited.
Purpose	The purpose of this master thesis is *to examine how autonomous drones are used and why they are not used to a greater extent for automating warehousing activities.*
Research Questions	**RQ1:** *How can autonomous drones be used to improve warehouse operations and activities?* **RQ2:** *Why are autonomous drones not used to a greater extent within warehousing operations today, and what challenges and benefits do they bring?*
Methodology	The thesis is based on a Delphi study made in three rounds, consisting of an iterative process of interviews and surveys. It involved a total of 15 experts which were divided into two panels, representing the drone technology and warehousing experts.
Conclusion & Findings	Autonomous drones are most suitable for automating the inventory management process in a warehouse. The usage of them in warehousing is increasing due to a relative advantage compared to other solutions in terms of costs, efficiency, and flexibility. However, due to the technology not being mature enough yet, and since the use cases still being limited to a few ones, the usage of them in warehousing is still relatively limited.
Keywords	Autonomous drones, UAV, Warehousing, Technology adoption, Delphi study

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The research made is based on the expertise of all the 15 participants in the panels who have enlightened us with their knowledge in this area. We would like to direct a sincere thank you to all interviewees who have answered our many questions and shared their expertise with us. We truly appreciate the time and effort you have put into this.

Lund, May 2023

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Abbreviations

AI	Artificial Intelligence
AGV	Automated Guided Vehicles
AMR	Autonomous Mobile Robot
AMT	Advanced Manufacturing Technology
AS/RS	Automated Storage / Retrieval Systems
CPS	Cyber Physical Systems
CSF	Critical Success Factor
DC	Distribution Center
DOI	Diffusion of Innovation
IoT	Internet of Things
MFC	Micro Fulfillment Center
OFC	Online Fulfillment Center
SC	Supply Chain
SKU	Stock Keeping Unit
TOE	Technology-Organisation-Environment
UAS	Unmanned Aerial System
UAV	Unmanned Aerial Vehicle
WMS	Warehouse Management System

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1. Introduction

Drones, also referred to as Unmanned Aerial Vehicles (UAVs) or Unmanned Aerial Systems (UASs), have had an upsurge in recent years. Historically, due to their flexibility and ability to be controlled remotely, this aircraft operating without a pilot has been used in various areas with a range of different purposes. Their application has stretched from humanitarian rescue operations to surveillance operations (Insider Intelligence, 2021), and from carrying cameras shooting Hollywood movies to reaching a commercial market with more affordable options. Given this rapid development and the broad spectrum of usage areas, substantial attention has been given to its potential and improving its capabilities to extend its usage.

After the first permits for commercial drones were given in 2006 in the US, the market for commercial drones took off (Maghazei et al., 2022), and since then, efforts have been made to apply them within the field of logistics. In 2013, Amazon was the first company to announce that using drones for delivery and transportation would soon become a reality (Kovach, 2013). However, ten years later, drones are still not used for transportation and last-mile deliveries due to the long and complicated process of getting approval to use drones in public (Amazon, 2022). With the existing regulations regarding the usage of drones in many countries, warehousing, which has been the subject of significant transformation in recent years, has been recognized as a safe zone from many of these regulations (Verity, 2022; Maghazei & Netland, 2020).

Due to the challenges of organisations responding to higher customer demand, shorter lead times, flexibility, and a variation of return options, automated and digitized warehouses are becoming more of a rule than an exception. This shift towards more technology-implemented industries and factories is in the literature referred to as the fourth industrial revolution, also known as Industry 4.0. Previously seen as only a necessary expense, warehousing is now recognised as a critical factor in reducing transportation costs and lead times (Faber et al., 2018). Technological developments and increasing e-commerce are driving industries into Industry 4.0 and warehouses into “smart warehouses”, a development led by giants such as Amazon and Alibaba (Zhen & Li, 2022). With new technology such as the Internet of Things (IoT), Artificial Intelligence (AI), and blockchain, warehousing is optimized in terms of storage and operations, leading to increased efficiency and cost savings (Fatima et.al, 2022). In order to enable the implementation of these technologies, significant investments are being made, and these are expected to increase further in the years to come (Kembro & Norrman, 2022).

Being centered around technological development during recent years, Industry 4.0 focuses on the increased digitization in production plants and automated warehouses. However, a new paradigm is on its way. Industry 5.0, the fifth industrial revolution, will reposition industry workers in the center and focus on the cooperation between man and machine. The creativity and innovation of humans will be combined with intelligent systems and technology, and thereby, machines and robots will handle repetitive and monotonous tasks. In contrast, human workers will be responsible for tasks with higher responsibilities in production plants and warehouses (Fatima et al., 2022).

According to De Koster et al. (2017), research within warehousing is now focusing on more than just traditional subjects, such as improving the efficiency of low-level order-picking situations or more classical methods for automation like Automated Storage/Retrieval systems (AS/RS). Attention is increasingly drawn to new technologies that could make warehousing operations more efficient (De Koster et al., 2017), such as drones. For industrial purposes, drones can work as an extension of manual labor, being manually controlled by workers to avoid dangerous tasks that can now be done remotely. With increased research and developments within AI and machine learning, drones are expected to become more automated, calculating their routes and operating without a remote pilot (Maghazei & Netland, 2020) and some of the products on the market are already this advanced (Verity, 2022). Given these abilities, drone technology may be a suitable investment for creating "smart warehouses" and an appropriate way to handle monotonous tasks. However, academic research on the subject is limited in relation to the extensive research on warehouse automation, and finding information about actual implementations of drones in warehouses is even rarer.

1.1 Problem Description

When looking into new technologies and their development, the Gartner Hype Cycle is commonly used to illustrate the different phases of an emerging technology. When a new technology gets introduced, it is common that the anticipations are unreasonable and that it is being exaggerated beyond its capabilities and actual impact. Observing the use of drones for commercial purposes, its global growth has stabilized and is now considered a mature technical innovation here to stay (Amsterdam Drone Week, 2022). Therefore, for this application, the hype is considered over; see Figure 1.1.

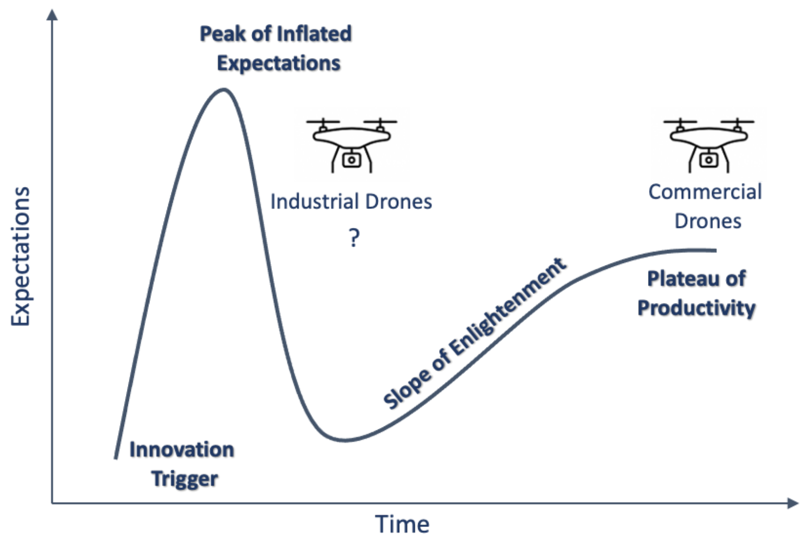

Figure 1.1 The hype curve regarding commercial drones (adapted from Amsterdam Drone Week, 2023).

However, industrial drones within warehouses still need to reach the plateau of productivity. Given the rapid development of drone technology and the broader usage scope of drones presented for commercial and military purposes, the potential of drones for industrial purposes has been lifted and excited in different contexts. Where the technology for commercial adoptions has started to reach stability, the position of drones for industrial purposes has yet to be mentioned as a mature technology. Although relatively much research exists on the last-mile delivery application of drones, research on its usage within warehouses and operations is still in its infancy.

While much research around drones and their technical capabilities exists, there must be more about drones' practical application areas for industrial purposes. For example, although warehouses have a high potential to benefit from this technology in terms of cost, time efficiency, and safety improvements (Maghazei & Netland, 2020), there needs to be more academic research or literature supporting this statement. Some pilot projects of UAV implementation in warehouses have been done, but follow-ups and evaluations are uncommon. Even more infrequent are cases of companies that have gone past the pilot program and implemented drones as a technique in their warehouses.

In recent years, some pilot projects within warehouses have experimented with using drones as enablers for more efficient warehousing. For example, in 2020, IKEA announced a successful pilot test with drone company Verity to automate warehouse inventory management tasks (IKEA, 2020). Similarly, the logistics and transportation company DSV teamed up with the same organisation to introduce drones to inventory management tasks in several of their warehouses

(DSV, 2020). Considering the vast amount of existing warehouses and new ones popping up, as well as large international companies such as IKEA and DSV implementing this technology, it is easy to wonder why more companies are not following their lead.

1.2 Purpose

The purpose of this thesis is - *To examine how autonomous drones are used and why they are not used to a greater extent for automating warehousing activities.*

1.3 Research Questions

Even though there is available information provided for application areas of UAVs within warehouses, there is very limited academic research on this subject. Furthermore, there is less knowledge about actual implementations of how and to what degree drones are included in warehousing activities. By researching the actual usage areas of drones within the warehousing operations, a better knowledge of its relevance will be provided. This might further result in highlighting usage areas that have not received as much attention. This leads to our first research question:

RQ1: How can autonomous drones be used to improve warehouse operations and activities?

From the brief literature review, there are a few examples of warehouses that actually utilise drones. There are mentions of restrictions regarding carrying capabilities and battery capacity that affect its usage. However, our scope was to perform more extensive research on these limitations, as well as understand the challenges and benefits that this new technology offers. This generated our second research question.

RQ2: Why are autonomous drones not used to a greater extent within warehousing operations today, and what challenges and benefits do they bring?

1.4 Focus and Delimitations

As previously mentioned, the application areas of drones within logistics are wide and range from emergency relief efforts to surveillance and transportation. For all these application areas, how they are used, what technology it requires, and the goals of its usage differs. Investigating these questions for all application areas in logistics will therefore be too large of a scope, and this project will thereby be limited to the areas related to warehousing activities conducted within its four walls, as shown in Figure 1.2. Therefore the last-mile delivery usage of drones is not covered in this report. However, the report will not limit the scope to a certain type of warehouse.

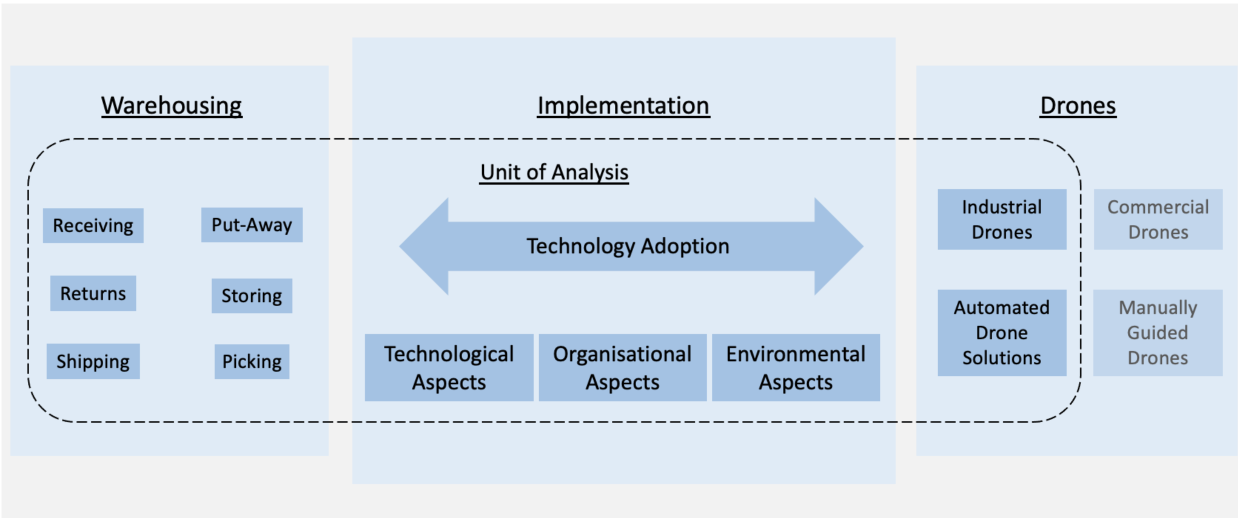

Figure 1.2. The scope of this master thesis.

As mentioned in RQ2, the challenges and drivers for implementing drones will be investigated. This will only be researched on a holistic view of adoption, and not go into detail about how challenges and drivers differ depending on the usage area that drones are used within. Further, this study will only focus on areas of improvement and on what ways the technique can improve warehousing. It will however not quantify any benefits explaining how large improvements that can be obtained from drones. The magnitude of changes in efficiency also depends on the specific type of drones used. The report will therefore not focus on specific drone types or models. Doing this is deemed to be too large of a scope for the time frame available in this thesis.

Lastly, drones can be controlled manually as well as being installed as autonomous solutions for completing tasks. Although occasionally performed warehouse activities can be carried out by remotely controlled drones, this thesis only covers the autonomous drone solutions.

1.5 Disposition

The following presents the structure of the thesis.

In **Chapter 2. Method,** the research design and the process used in this study are presented. It describes how the methodological choices were made in order to answer the research questions and fulfill the purpose of the study. The study follows a Delphi-structure, consisting of three rounds. It further describes how the data was collected and analyzed. Lastly, the research quality of the thesis is evaluated.

In **Chapter 3. Theoretical Framework**, theoretical findings made from the initial literature review are presented, which will lay the foundation for the rest of the study. The theory is divided into the segments of drone technology, warehousing, drones in warehousing, technology adoption, and the hype cycle. These are used to create the conceptual framework used in the thesis.

In **Chapter 4. Round 1: Exploring and Understanding**, the first round of data collection and analysis from the interviews are presented. The findings are presented and are then analyzed using the conceptual framework. Lastly, 23 hypotheses are formed.

In **Chapter 5. Round 2: Assessing Opinions and Rankings**, the hypotheses from the previous round are ranked and commented on by the same participants that partook in the interviews. The findings, as well as the analysis of these rankings and comments, are presented. A summarized view of the rounds is lastly presented.

In **Chapter 6: Round 3: Feedback and Final Comments**, the participants' comments and final opinions on the findings from previous rounds are presented. This chapter puts an end to the data collection and analysis in the study.

In **Chapter 7: Conclusion**, the research objectives are addressed and the research questions are answered by presenting our key findings, thereby concluding the thesis. The thesis's theoretical and practical contribution is also discussed. Lastly, the limitations of the study, as well as suggestions for future research on the area are presented.

2. Method

This chapter presents the methodology of the study, including the research process and design, the collection of data, as well as how the data was analyzed. Lastly, the research quality of the study is presented.

2.1 Research Strategy

Depending on the objectives and purpose of a research project, different research strategies are more or less suitable. What matters the most is that the research strategy is closely connected to the purpose (Yin, 2009). Revisiting the purpose of this report; "*To examine how autonomous drones are used and why they are not used to a greater extent for automating warehousing activities",* it can be argued that the research in this report is of an exploratory characteristic. According to Malhotra & Grover (1998), exploratory research has the objective of exploring a relatively new topic to become more familiar with it, in contrast to explanatory research which aims to explain an already occurring phenomenon. Hence, exploratory research is often conducted in areas where the knowledge has a low level of certainty (Malhotra & Grover, 1998) and when answering why and how something is being done (Ellram, 1996).

The characteristics of the research area determine which research method that is most suitable. One of these characteristics is the maturity of the subject studied. The area researched can either be mature, where the knowledge available is extensive and confirmed by several studies and sources, or it can be in an introductory phase, where little is known about the subject or phenomenon (Malhotra & Grover, 1998). As seen in Figure 2.1, different research methods are more or less suitable depending on the state of knowledge. Early stages of research are most likely done by collecting qualitative data while as time goes on, quantitative research becomes more important. Qualitative results are often presented verbally to present complex relations and interactions, whilst quantitative results are presented in numerical and quantifiable terms. Alternatively, they can be combined (Ellram, 1996).

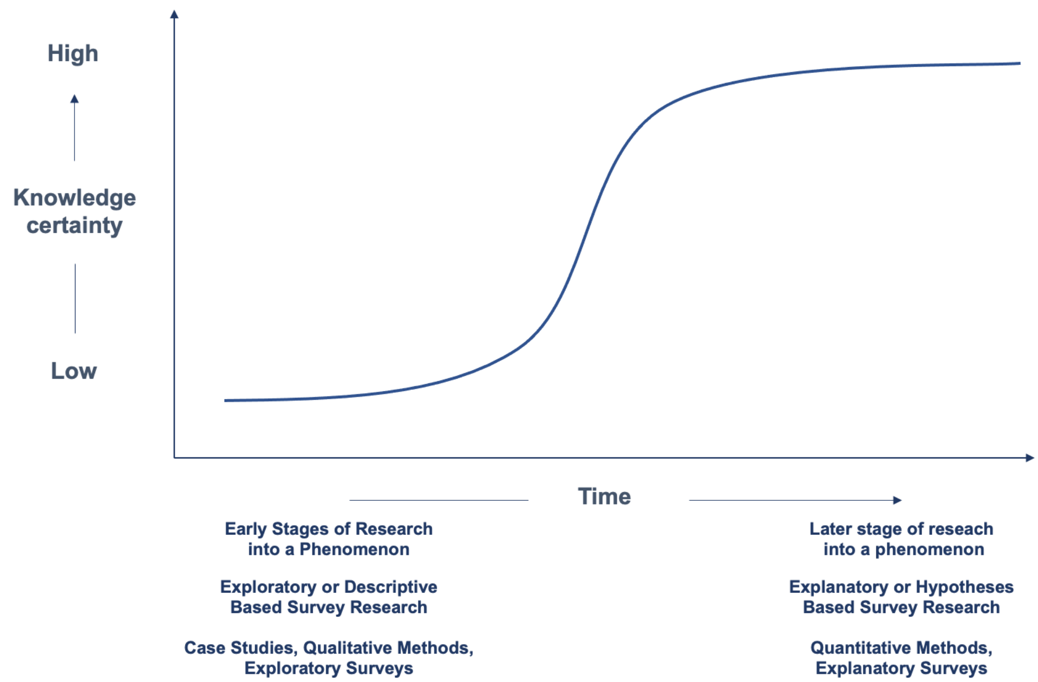

Figure 2.1 Maturity cycle of research (Adapted from Malhotra & Grover, 1998).

Due to the subject covered in the scope of this report being in an introductory phase with limited information available, as well as depending on qualitative data collection, a case study of an actual implementation of the technology researched would have been a suitable choice (Ellram, 1996). However, the case study was discarded since warehouses using drones were located outside our geographical area. Since this report is not funded, traveling there was not possible. According to Steinert (2009), a Delphi study is a research method that can be used for exploratory research since it is often used in situations where the availability of information is limited. Further, it can analyze both qualitative and quantitative information. Thereby, this method is extensively used in various scientific disciplines such as education, health care, medicine, engineering and technology, business, information management, and environmental studies (Beiderbeck et al., 2021). Due to our research questions requiring input from several areas of expertise to get a nuanced answer, as well as the subject being a relatively unexplored research area, a Delphi study was deemed an appropriate method of choice.

The Delphi method was developed in the 1950s during several studies conducted by the RAND (Research and Development) Corporation (Dalkey & Helmer, 1963). It is a scientific method that can be described as an iterative process where experts within the researched area anonymously discuss the subject in a structured manner (Okoli & Pawlowski, 2004). The study is conducted in several rounds where experts are invited to participate and answer a survey or a series of interview questions. Before the next round is started, the results from the previous round are anonymously fed back to the experts, thereby encouraging creative sessions with more room for reflection. Although this is the general characteristic of a Delphi study, there are several variations of the method and how it is conducted. Except for the traditional "classic Delphi" that was introduced in the 1950s, according to Keeney et al. (2001) there is now the "modified-Delphi", "real-time Delphi", and "policy-Delphi", to mention a few. This has led to criticism regarding the rigor of the method since there is a lack of uniformity between researcher approaches (Keeney et al., 2001).

A disadvantage with conducting a Delphi study which was prevalent when writing this thesis was the difficulty of finding experts willing to participate. Although the initial idea was to include 30 experts, only 15 experts took part in the initial round of this study. Therefore, this study has some characteristics of an interview study to increase the information and knowledge collected, with elements taken from the Delphi method. How the study in this report was designed and conducted is described in the following paragraphs.

2.2 Research Design

As an initial step in this research project, a literature review was done to identify areas already researched regarding the use of drones in warehousing operations. This research consists of application areas, drivers, challenges, and implementation issues connected to automating warehouses with drones, as well as the technological capabilities and limitations of drones. These findings served as input for the first round of data collection, and therefore, the initial literature review was crucial for setting the framework for the rest of the study.

The next step was to select the experts and place these in their respective panels, which was done before the actual information gathering was conducted. The data collection was made through three rounds and input from the literature review was, as mentioned, used to form the first round of interviews, whereas, after that, the analysis from each round will serve as input for the next round. The first round consisted of an interview where semi-structured questions that were inspired by the information gathered in the literature review were used. This was to roam the area and encourage creative thinking amongst the experts, avoiding narrowing down the scope too early. Further, in that way, the opinions and biases of the authors will not be inflicted on the experts.

The second round was based on the data gathered from the previous round and the analysis that followed it. Areas deemed important were discussed on a deeper level and information collected from round 1 was validated. Hypotheses were adapted from the findings of the first round to reflect the opinions of the experts. The participants were asked to rank their level of agreement with the hypotheses on a 7-point Likert scale. The third and final round was used to ensure that the experts were understood correctly in the previous rounds, by asking them for their final opinions. A report of the findings made in the report was sent out, to which the experts could make comments. The structure of the round and how they are interlinked is seen in Figure 2.2.

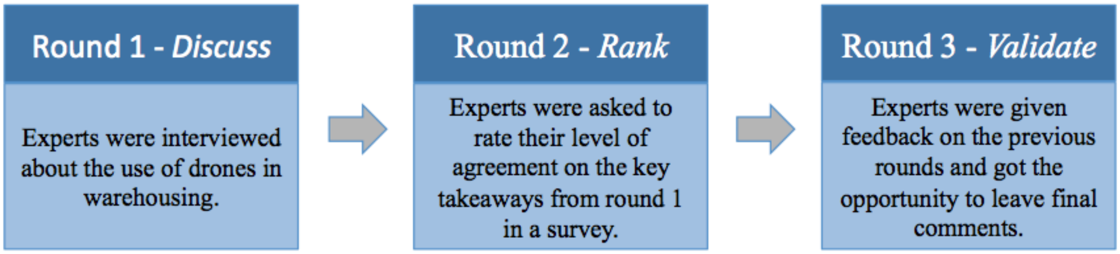

Figure 2.2 The 3 rounds of the Delphi study.

When conducting the final analysis, information from the initial literature review, as well as the analysis from the data collected through the three rounds was compared and used to ultimately present our findings. The research approach in its entirety is illustrated in Figure 2.3, and each process is described more thoroughly in the coming paragraphs.

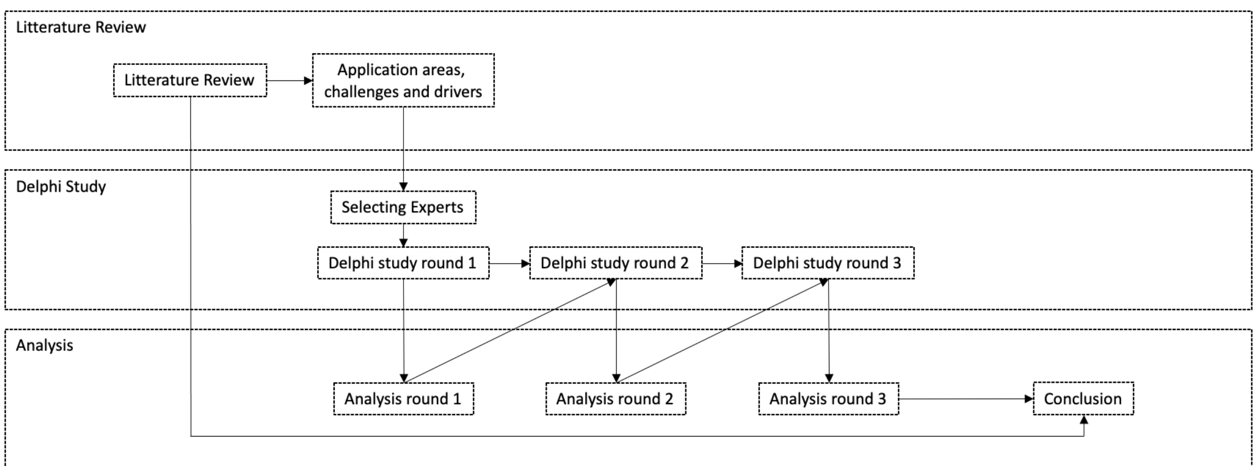

Figure 2.3 An overview of the research approach in the thesis.

2.2.1 Considerations Before Conducting the Study

It is important to recognize that there are both advantages, as well as disadvantages, to the Delphi study as a methodology. These were carefully considered before executing the study to mitigate risks associated with this type of methodology.

The goal of a Delphi Study is often seen as analyzing the level of consensus amongst the experts, which is done by generating insights on either forthcoming or current challenges. This is not necessarily true. According to Goodman (1987), purely looking at the level of consensus in the response can be misleading and introduce the risk of misinterpreting the results. Due to the Delphi method's tendency to converge expert opinions towards agreement, it is important to analyze the full spectrum of answers by analyzing answers that do not change over time. Thereby, Goodman argues that it is the stability of the group response on an item throughout several rounds that focus should be drawn to. In agreement with this, Linstone & Turoff (2011) solidifies her argument by stating that a common misinterpretation is that the aim of the Delphi methodology is consensus. According to them, the method was created as a tool for structuring a communication process in a group, and the number of Delphi rounds should be determined based on when stability is achieved. However, this study is limited by its time constraints and reaching stability would be too time consuming. Therefore, the level of consensus together with a statistical analysis will be used in this thesis.

As with any research that relies on gathering information from interviews or surveys, participant motivation to participate and complete the study is crucial. According to Hsu & Sandford (2007), this is even more important in a Delphi study since the result depends on participants finishing not only one survey but several iterations and rounds. Further, finding experts on a subject could prove difficult which stresses the importance of a high response rate amongst the located participants. Therefore, action for reducing non-response in all rounds of the study needs to be taken. Hsu & Sandford (2007) continue to provide a few guidelines to minimize non-response. Firstly, the purpose of the study, how the experts were found, and why the experts have been chosen should be clearly explained for them. Secondly, experts should be given the opportunity to recommend experts of their own to participate in the study. Thirdly, deadlines for answering the survey should be made clear and no more than a few days extra should be given if the participant fails to respond on time. However, it must be made clear to the experts that their answers are valuable to the researchers.

2.2.2 Literature Review

The literature review will as mentioned serve as a base for understanding before conducting the first round in the Delphi study, and therefore possesses a crucial function. Rowley & Slack (2004) mentions six important areas that a literature review contributes to, namely; (1) identification of research topic, question, or hypothesis, (2) identification of literature to which the research will contribute, (3) understanding the terminology and theoretical concepts, (4) creating a list of sources consulted, (5) suggesting new research methods, and (6) analyzing results and interpreting them. Based on these contributions, a literature review would distill current literature and research, and thereby it is suitable as a first step in the research process of this report. Further, previous research exists where literature studies have been applied in a logistics and technology intersection, see Kalaiarasan et al. (2022), arguing for the use of a literary study as a first step.

There are several methods that can be applied to find relevant literature when conducting a literature review. Examples of literature review strategies are citation pearl growing, briefsearch, building blocks, and successive fractions (Rowley & Slack, 2004), see Table 2.1. Due to limited scientific research available on the intersection between drones and warehousing operations, a briefsearch is arguably a suitable first step to find relevant literature. This will then be built upon using the building block strategy.

Table 2.1 Literature review strategies and their descriptions (Rowley & Slack, 2004).

Method	*Description*	*In this study*
Citation pearl growing	Uses keywords or suitable terms from a small set of initial sources to retrieve further literature	Not used in this study
Briefsearch	Retrieving a few documents quickly and coarsely. Often a good base for further work	Used in this study to quickly find relevant sources to continue from
Building blocks	Uses synonyms and related terms of search statements to extend the span of the search, creating a comprehensive set of documents	Used to extend the literature found from the brief search, finding a larger set of information
Successive fractions	Used to reduce a large number of sources by successively searching within the already retrieved set of documents	Not used due the amount of literature available being scarce

White Literature

Literature searches were made on several databases containing scientific journals and peer-reviewed articles. Mostly, Web of Science (WoS) and EBSCOhost were used to retrieve literature. Two areas were pinpointed as important for reinforcing the research; drones and their usage in warehouses, and technology adoption. Initially, a brief search was done with search terms such as “warehouse” and “drone” to get an overview of the subject, after which the terms “UAV”, and “technology” were added as key search words. To find literature regarding technology adoption the search words “technology adoption” and “technology adoption framework” were used. These keywords were used with boolean operations, such as “and” as well as “or”, that were available on the databases. From the results gathered on WoS and EBSCOhost, an initial reading of the abstracts was done to sort out the articles that were relevant to this report, and discard those that were not. For example, all articles that focused on using drones for transportation and last-mile deliveries were not included in line with the delimitations of the report.

Gray Literature
Due to scarce scientific research on the area of drones within warehousing, gray literature such as whitepapers, reports of test pilots, and announcements on company websites, were considered important to grasp the full picture of the subject and locate as much literature as possible. This was done using Google Scholar and Google's search engine. Search words such as "drone warehouse pilot project" and "drone warehouse whitepaper" were mainly used to locate these sources of information.

2.2.3 Selecting Experts and Populating the Panels

How experts are chosen is essential for conducting a valid Delphi study. The process of choosing experts can be divided into several steps to ensure that the search for suitable experts is thoroughly executed and without any valuable perspectives being missed (Okoli & Pawlowski, 2004). Further in line with their framework, the first step was to categorize what expertise was desired for the project and find suitable organizations, companies and academia that fulfilled these criteria. To receive knowledge from both a technology and warehousing perspective, the experts were categorized into experts in drone technology and experts in warehousing. When strategically choosing a sampling group there is a risk of narrowing the included groups too much and hence missing important and nuanced perspectives (Alvehus, 2019). To keep a holistic and nuanced approach, interesting groups were identified for both panels, who could contribute with valuable input to the study before starting to look for specific individuals, as can be seen in Figure 2.4.

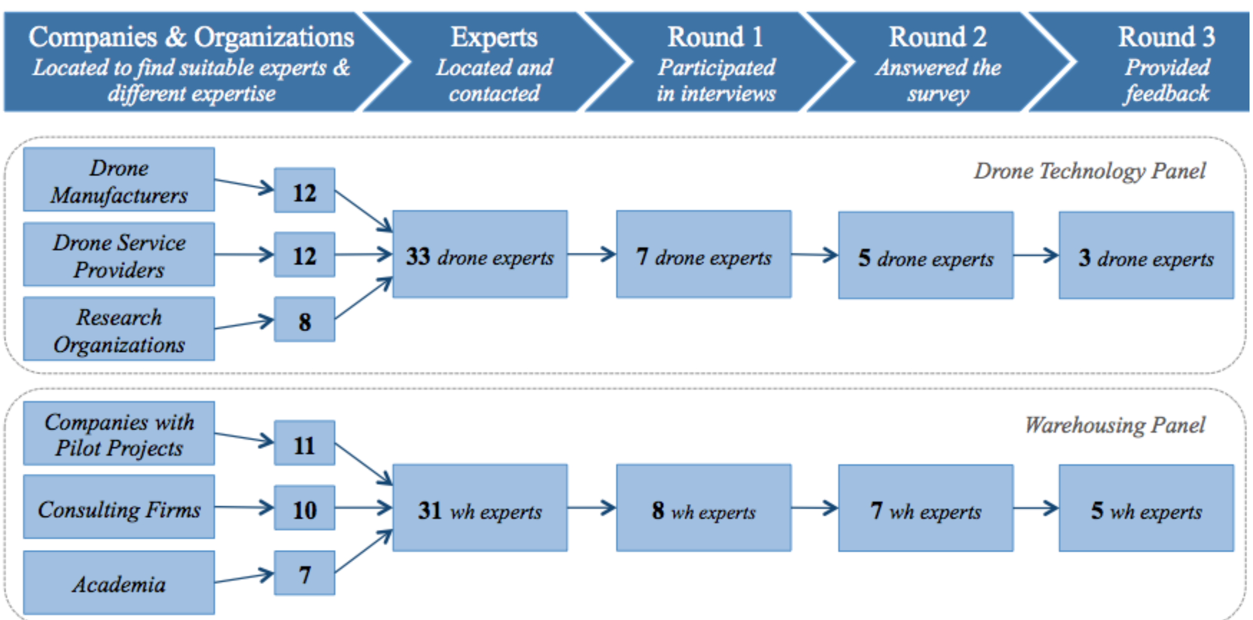

Figure 2.4 Overview of how experts were selected and the panel participation for each round.

To receive knowledge of drones it was decided that drone manufacturers and companies providing additional technology for drones such as software, cameras, scanners or services were included. Including a scientific perspective was also desired, making research organizations on drones an interesting group. Regarding the warehousing panel, consulting firms experienced in warehousing and automation within warehouses were included as well as companies with experience of pilot projects of drone implementations in warehousing. To involve the academic perspective in this panel, universities with research in the subject were included. From the specified groups, a more detailed search for specific organizations and companies matching those criteria was made, in line with the next step presented by Okoli & Pawlowski, (2004). With keywords such as “drones”, “UAV”, “UAS”, “warehousing” and “pilot projects”, combined with the interesting industries, the web was mainly used to find relevant companies and organizations. In Figure 2.4 the amount for each type of company or organization is listed.

To ensure a sufficient level of expertise, certain criteria and qualifications were set as pre-requirements to know who to include in the study. These pre-requirements included years of experience within the field and title. Since there was a gap found between the benefits and feasibility of drone implementation explained in current literature and actual documentation of successful implementations, it was deemed interesting to include experts with experience in real implementations. These persons could bring attention to practical issues that can occur, which otherwise might have been overseen. One criterion for the experts was thereby having practical experience of drone implementations in warehouses, which was also used by Maghazei & Netland (2020) in their conducted Delphi study on drones in industrial environments.

Experts were searched for with the located companies and organizations, but also independently from the mentioned criteria above. To further increase the chances of finding enough experts, already contacted participants were asked to recommend persons that could be contacted, following the recommendation of Alvehus (2019) and Okoli & Pawlowski (2004). A risk with recommendations is that the sample group could become too homogenous (Alvehus, 2019), but this was prevented by contacting a broad variety of people as well as listing and keeping track of participants and their backgrounds.

The located companies and organizations were also contacted to find more suitable candidates for the study, this did however not result in any suitable experts participating. The experts were contacted through Linkedin by recommendation from our supervisor, and by email when the profile could not be found or the expert had not responded. The number of individual people contacted as well as the number of participants for each round are shown in Figure 2.4. Further, all of the participating experts and their experience within the drone and warehousing field are presented in Table 2.2. Since one of the Delphi study traits is the anonymity of experts (von der Gracht, 2012) their names, or a more thorough description of them, are not displayed in the table.

Table 2.2 The experts' experience where the symbols from dark to light represent 10+ years of experience, 5+ years of experience and less than 5 years of experience.

Experts	*Drone Experience*	*Warehouse Experience*	*Experience of Drone Implementations in wh*	*Occupation*
Expert A	✓ (dark)	✓ (light)		CEO of UAV and AGV company
Expert B	✓ (light)	✓ (dark)	✓ (light)	Manager Business Support at company with drone implementation
Expert C		✓ (dark)		Solution Design Manager for Warehouse Automation
Expert D	✓ (light)	✓ (dark)	✓ (light)	Global Business Development Leader at company with drone implementation
Expert E	✓ (light)	✓ (medium)		Chief scientist and researcher in logistics and drone applications in warehousing
Expert F	✓ (light)	✓ (light)		Researcher of drone technology and its applications in warehousing
Expert G	✓ (medium)	✓ (light)	✓ (light)	Researcher on drone applications in manufacturing
Expert H	✓ (light)	✓ (dark)	✓ (light)	Warehouse manager at company with drone implementation
Expert I		✓ (dark)		Head of Logistics Engineering at 3PL company
Expert J	✓ (dark)			Researcher UAV and UAS Technology
Expert K	✓ (medium)			Head of UAS research institute and researcher in UAV/UAS
Expert L	✓ (medium)	✓ (light)		Research and Development Engineer in UAS Technology
Expert M		✓ (dark)		Professor of Logistics and Operations Management
Expert N	✓ (light)	✓ (dark)	✓ (light)	Warehouse Operations Manager at company with drone implementation
Expert O	✓ (light)	✓ (dark)		Professor of Production and Supply Chain Management

A high level of expertise was obtained among the participants, with multiple of them having more than ten years of experience in their field, as can be seen in Table 2.2. The different titles further highlight the varied backgrounds and perspectives included. Besides the experience presented in the table, many experts had additional knowledge, such as experience in other emerging technologies, other warehousing and manufacturing technologies, and other technical expertise in aerospace or aeronautical engineering. Further, four participants worked at companies that had implemented drones in warehouses and had practical experience of the implementation, and one researcher had studied several implementations.

As a rule of thumb, the sample size for a Delphi study is suggested to be 15 to 30 subject-matter experts for a heterogeneous population and five to ten experts for a homogeneous population (Loo, 2002). Therefore, our objective was to acquire a sample size of 15 to 30 experts consisting of two panels. As recommended by Okoli & Pawlowski (2004), experts were divided into different panels since the level of consensus is to be analyzed. Separating the experts based on their expertise allowed us to analyze their views in isolated panels and then compare the results. As further recommended by Okoli & Pawlowski (2004), the panels had a size of seven and eight members.

2.3 Round 1

The purpose of the first round of data collection was to gather qualitative data from the experts which was done by interviewing all participants online through Zoom. According to Steinert (2009), interviews are a suitable method for exploratory studies and for collecting data from a smaller sample size. Due to the sample size of 15 experts in this study, interviews were considered a good tool for collecting qualitative data in the first round. In that way, extensive data could be collected from each expert. The information collected from the interviews was afterward condensed and analyzed with the Gioia methodology (Gioia et al., 2012).

2.3.1 Constructing the Interviews

Interviews are usually categorized based on the level of structure that they have (Qu & Dumay, 2011), where structured, semi-structured or unstructured interviews are the most common classifications (Höst, 2006 (p. 34); Alvehus, 2019 (p. 86)). Since these are all suitable in different contexts, the type of research and purpose should be kept in mind when choosing what kind of interview to use. When it comes to qualitative research, like this study, the semi-structured interview is the most commonly used technique (DiCicco-Bloom & Crabtree, 2006; Alvehus, 2019 (p. 86)). With this approach, interesting areas for the interview and some main questions are prepared beforehand while the protocol is kept flexible with room for follow-up questions, changed order of questions, or other adaptations based on the specific participant. It is thereby a mix between the structured interview where all questions are fixed, and the unstructured interview which is more similar to a conversation where questions are formed during the interview based on the received answers. The semi-structured interview ensures that the scope of the study is covered with the prepared questions and focus areas, while still encouraging detailed answers (Qu & Dumay, 2011). Further, it creates a good interaction between both parties (Galetta & Cross, 2013) where the information obtained is formed based on the knowledge and specific expertise of each participant (Kallio et al., 2016). Given that the experts chosen in this study have different backgrounds and different areas of expertise, this approach was found suitable.

For interviews in qualitative research, adequate preparation and planning is of the essence (Qu & Dumay, 2011). In line with the semi-structured interview approach, an interview guide was thereby prepared (see Appendix A) following the steps described by Kallio et al. (2016). Given that this first round was desired to be more of a brainstorming session, questions were designed by using what, when, where, who, why and how as recommended by Kallio et al. (2016). In line with Höst et al. (2006), introductory questions were also added about the participants to provide a context important for evaluating the expertise in this Delphi study as well as encourage conversation at the beginning of the interviews. The questions were tested on a test panel before the actual study and rephrased or corrected after receiving feedback.

2.3.2 Conducting the Interviews

Interviews were conducted between the 14th and 28th of March 2023. Out of the 18 experts that accepted to participate in the study, 15 were included. Three of the approached experts were not able to participate in interviews online, and could only participate through written answers by email. Since follow-up questions, starting a discussion, and brainstorming the subject were considered essential for this phase, this interview medium was not considered fitting, and thereby these experts were not included in the study. All 15 participants who were included in the study, took part in the interviews of the first round.

To provide the participants with time to prepare for the interview, the interview guide without follow-up questions was sent to them beforehand. This was deemed necessary for receiving as comprehensive answers as possible and the element of surprise was considered to have no effect in this case. The interviews used a semi-structured approach to allow unexpected and interesting discussions. Although semi-structured, all interviews followed the same interview guide, see Appendix A, to establish the same structure and conditions for everyone but with the flexibility of fitting the interview to the expert's knowledge. All interviews were held online through Zoom and were between 60 and 90 minutes long. The length of the interviews depended on how extensive the discussions were but all structured questions were asked throughout all interviews. After half of the interviews had been held clear themes could be observed, and answers started to recur and converge.

When conducting the interviews, both authors were present during each interview with the exception of one occasion. The interview was held by one of the researchers who asked the questions, and the other researcher took notes. However, both were active in asking follow-up questions to enrich the discussion. All interviews were recorded which later allowed for better access to all information when analyzing the data. The location of the participants included in the first round as well as the length of each interview and when they took place, are presented in Table 2.3.

Table 2.3 Interviews held in the first round of the Delphi study.

Interviewee	***Date***	***Duration***	***Country***
Interviewee A	14/3-2023	80 min	South Africa
Interviewee B	14/3-2023	85 min	Netherlands
Interviewee C	15/3-2023	75 min	Sweden
Interviewee D	15/3-2023	90 min	Switzerland
Interviewee E	15/3-2023	70 min	Germany
Interviewee F	15/3-2023	65 min	Germany
Interviewee G	16/3-2023	60 min	Switzerland
Interviewee H	16/3-2023	60 min	Switzerland
Interviewee I	17/3-2023	70 min	Sweden
Interviewee J	17/3-2023	65 min	Finland
Interviewee K	20/3-2023	60 min	Sweden
Interviewee L	20/3-2023	60 min	Belgium
Interviewee M	24/3-2023	60 min	Netherlands
Interviewee N	25/3-2023	65 min	Great Britain
Interviewee O	28/3-2023	60 min	Germany

2.3.3 Data Analysis

It is inevitable that some analysis is being made by the researchers during the data collection phase when it comes to qualitative data, but the following section will describe the process as thoroughly as possible. Beiderbeck et al. (2021), mention different analyzing tools specifically for Delphi studies that include descriptive statistics, qualitative analyses, quantitative analyses and dissent analyses. For the first round however, the main focus has been on brainstorming and thereby more qualitative data has been gathered, which is why the main analyzing tools for the first rounds will be connected to this.

Before starting the analysis the structure of the analysis was to be decided. A differentiation that can be made for the qualitative content analysis is if it should be an inductive or deductive analysis. An inductive analysis is more dynamic where the themes and categories for coding are decided during the analysis of the data, whilst the deductive analysis is based on themes and subcategories that have been decided before the coding starts (Elo & Kyngäs, 2008). The analysis tool used for the first round in this study is the inductive approach of the Gioia methodology. While still retaining creativity and the possibility to generate new ideas, the Gioia approach maintains the qualitative rigor. By first creating 1st-order themes from the data, categorizing the 1st-order themes into 2nd-order categories, and finally further into 3rd-order “aggregate dimensions", a large data set can be condensed to a more comprehensive structure that is easier to follow (Gioia et al., 2012).

The first step of the data analysis was to transcribe the recorded interviews for which an online transcription tool was used. According to (Höst, 2006, p. 34-35) data collected from an interview should be recorded and then transcribed into text for further analysis. Coding of the transcribed material was then done separately by the two researchers as recommended by Beiderbeck et al. (2021) to increase the quality of the analysis and decrease the risk of biases. Descriptions and strings of information in the transcribed material were coded based on its content. This material was then compared between the two researchers to find similarities and differences which were discussed until consensus was reached. Descriptions that were similar, with only minor differences, were grouped and coded as one factor. These factors were categorized using the Gioia methodology, see illustration in Figure 2.5.

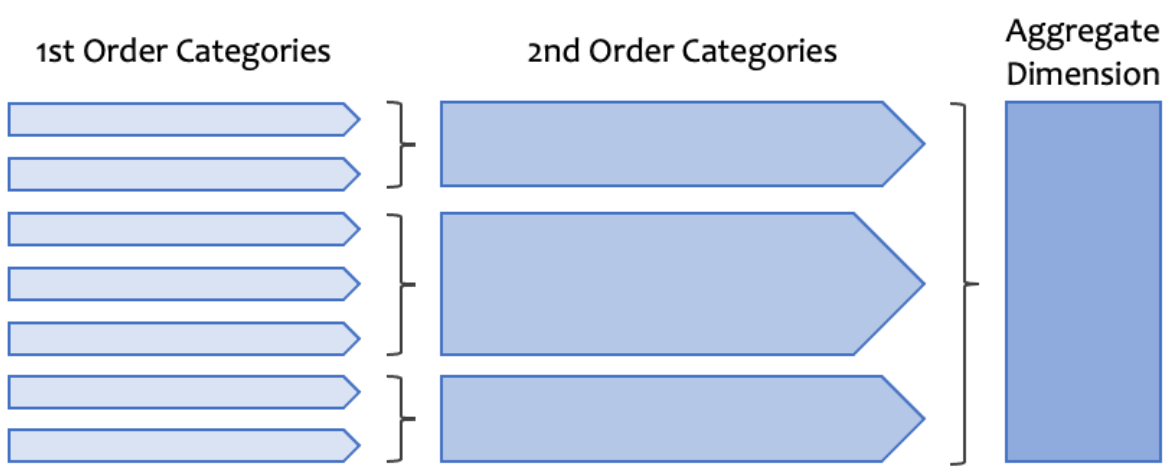

Figure 2.5 Illustration of the Gioia Methodology.

The reduced data, which now represented the 1st-order themes (Gioia et al., 2012), was transferred to an Excel sheet to make the data more comprehensive and ease further analysis. According to Gioia et al. (2012), data from the first 10 interviews could easily be 50 to 100 1st-order categories. These were compared to each other to form 2nd-order categories, to form a more manageable number of categories. Finally, these categories were formed into an aggregate dimension after which the data structure was completed (Gioia et al., 2012). The findings were then analyzed using the conceptual framework which is presented in *3.6 Conceptual Framework.* The conclusions from the first round were used as data input for the second round. In the first round, no distinction was made between the panels and information from both sides was analyzed together.

2.4 Round 2

The second round was created as an extension of the first round by validating the information that was collected and condensed into key findings using a survey. By using multiple methods, such as combining interviews with surveys, a better understanding of the studied phenomenon is given (Höst, 2006, 75). The purpose of the second round was therefore to quantify the qualitative data by having the experts evaluate their level of agreement with the findings from round 1.

2.4.1 Data Collection

Based on the key findings from round 1, the second round took the form of a survey that was distributed to the panelists by email. The survey was distributed on the 13th of April and closed on the 24th of April. Panelists that had not responded yet were given three extra days after which the round was considered closed. Out of the 15 experts that participated in round 1, 12 experts answered the survey, resulting in a dropout rate of 20 percent. This is lower than the dropout rate described as normal by von der Gracht (2008, p. 48), which is 20-25 percent.

The questionnaire was made using Google Survey and contained hypotheses created from the findings that were identified in the previous round, to which the experts were asked to rate their level of agreement. Their level of agreement was based on a 7-point Likert scale, see Figure 2.6. According to Joshi et al. (2015), a 7-point Likert scale is likely to perform better than a 5-point scale in terms of the reliability of responses. Before sending the survey to the experts, the same test panel as for round 1 was used to ensure that the hypotheses were formulated in an understandable way.

Strongly Disagree	Disagree	Somewhat Disagree	Neutral	Somewhat Agree	Agree	Strongly Agree
1	2	3	4	5	6	7

Figure 2.6 Seven-point Likert Scale.

Panelists were also able to leave a comment on their answer to each question in case they wanted to elaborate, or if they did not have an answer to the question. The survey was connected to a Google sheet in which all answers were collected. These were then used to evaluate the level of consensus and make a statistical analysis.

2.4.2 Data Analysis

When performing a Delphi study different statistical methods can be used for analyzing the data. As mentioned, the consensus is usually a parameter being measured where the variance can be an indicator to what degree the experts are agreeing or disagreeing with each other. There are however different ways of measuring consensus among the participants (von der Gracht, 2012). Variance or standard deviation in combination with a mean value is a common statistical way of measuring variances, which has also been used in Delphi studies with different thresholds. However, if extreme answers are desired to be excluded while still looking at the consensus, the Interquartile Range (IQR) can be used (von der Gracht, 2012). It is commonly used in Delphi studies since it is considered an objective measure and it was thereby also used in this study. IQR looks at the variance between the 50% of the participants placed in the middle of a scale and if the variation for these participants does not exceed a pre-decided threshold, consensus can be assumed. The threshold values depend on the size of the scale, which for this study was a 7-point scale. For a 5-point scale, an IQR threshold of 1 is usually used (von der Gracht, 2008, p. 56), while for a 9-point scale, an IQR equal to or smaller than 2 has been used (von der Gracht & Darkow, 2010). Since 1 has been used as an IQR threshold for 7-point Likert scales (De Vet et al., 2005), 1 was determined to be a good threshold.

Even though the IQR is considered a good measure in Delphi studies it is dependent on the number of participants (Birko et al., 2015) and therefore varies depending on the sample size. Because of the smaller sample size, it was deemed useful to include other measurements for consensus as well. Another way of measuring consensus is to look at the level of agreement in percentages agreeing or disagreeing, which is typically useful if Likert Scales have been used (von der Gracht, 2012). One study of consensus measurements in Delphi studies suggests that looking at the percentage of agreement is the most commonly used measurement in the research studied (Diamond et al., 2014). This level of agreement was thereby deemed interesting to include for measuring the number of participants who were neutral, agreed to any extent or disagreed to any extent. The nuances of the 7-point Likert scale were thereby excluded in this measure and the answers 1, 2 and 3 were summarized into everyone who disagreed to some part and the results 5, 6 and 7 were summarized into everyone that agreed to some extent.

There are different levels for the percentages for agreement that have been used in Delphi studies to indicate consensus. The simplest majority used is 51%, but higher percentages up to 95% have also been used (von der Gracht, 2012) to take variations into account and give more trustworthy results. The studies examined by Diamond et al. (2014) had a limit of at least 80% which was hence considered a good threshold for this study to receive reliable results. In some cases, the percentage of agreement combined with securing that the mean value is within the agreement range has further been used, which was also done in this analysis. The analysis was summarized and the results were used as input for round 3.

2.5 Round 3

The third, and last round, was used to validate the conclusions made after the second round. It was initiated the 15th of May and concluded the 24th of May. Answers to the research questions, as well as the statistics and answers from the previous round, were sent by mail to the experts, giving them the opportunity to comment on the results. Utilizing a last round of information collection was deemed appropriate to both share the result with the experts as well as increasing the research quality. Experts could see their own answers, compare them to the rest of the panelists' answers, and information that potentially was missed or distorted during previous rounds could be validated (Yousuf, 2007). Out of the twelve remaining experts from round 2, eight answered, resulting in a drop out rate of 33 percent. This is slightly higher than the 20-25 percent reported by von der Gracht (2008, p.48). The study was concluded after this round due to few experts leaving comments that had any impact on the conclusions. Stability could therefore be argued for (Goodman, 1987), and the Delphi study was ended.

2.6 Research Quality

To ensure a high quality of the research, measures can be taken depending on the characteristics of the research phenomenon. Commonly used terminology in this context is validity and reliability, which is also the foundation for four main criteria that are widely used in research. The criteria are construct validity, internal validity, external validity and reliability (Guba & Lincoln, 1989). However, these criteria are mainly focused on research directed towards quantitative data gathering (Gibbert et al., 2008; Yin, 2009). In line with the shift towards qualitative research within logistics and management, four corresponding criteria that combined can describe trustworthiness have been presented (Halldórsson & Aastrup, 2003). These criteria are credibility, transferability, dependability, and confirmability, which will be used in this study since the study is more exploratory and based on qualitative data gathering. Measures taken to ensure a high research quality is presented in Table 2.4, together with the four criteria.

Table 2.4 The measures for each criteria to ensure a high research trustworthiness.

Criterias	Measures
Credibility	● Method designed with a Delphi inspired approach, having multiple rounds. ● Clear research framework where interview questions were carefully formulated and tested as well as interviews being recorded and correctly transcribed. ● Extensive research in the areas before interviews to improve understanding of participants' perspectives and answers. ● Quotations used were sent out to the experts for confirmation ● No attrition bias since experts dropping out had similar opinions to those continuing with the study
Transferability	● Rigorous descriptions of the participants and their background and expertise. ● Rigorous descriptions of the technology and circumstances. ● Triangulation when selecting participants to increase generalizability.
Dependability	● Structured and thoroughly explained method with the interview guide provided.
Confirmability	● Data analysis process presented and explained. ● Data analyzed over several rounds in an iterative process. ● Using triangulation methods for theoretical perspectives.

Credibility

Credibility seeks to reach trustworthiness by matching the participants' views with those being lifted and presented by the researcher. It is hence based on the concept that no single objectivity exists (Erlandson et al., 1993) and rather focuses on the "objectivity" of each participant's perception (compared to internal validity). Participants thereby have an important part in increasing credibility by correcting the researchers' picturing of their realities (Halldórsson & Aastrup, 2003). This is partially accomplished by the choice of having a Delphi-inspired method, where multiple rounds ensure that the participants are allowed to correct and polish their answers. There is however a risk of experts dropping out during the study, creating attrition bias by those of different opinions being excluded from the results (Flick, 1988). The experts that dropped out of the study had similar opinions of those continuing and no attrition bias was thereby observed. Further, credibility was enhanced by having a clear research framework with detailed measures through the methodology. Extensive research was done before the interviews to ensure that misunderstandings were avoided as well as questions being carefully formulated and tested before the interviews to increase understanding between both parties. Interviews were recorded and transcribed to ensure that the true views of the participants were presented.

Throughout the study, it was seen in articles and mentioned by the experts that drones are suitable for automating inventory management tasks. This can, however, cause confusion since the term inventory management encompasses a large number of activities that stretch beyond the scope of this study. What is actually referred to by the experts in this study is the use of autonomous drones to increase inventory accuracy. Since the broader term was used in interviews, as well as the survey, there is a risk of misunderstandings between the authors of this thesis and the experts, which can negatively affect the credibility. However, the experts used the term as a collective word independently for the tasks connected to using drones for inventory-related tasks, while at the same time referring to existing usage areas such as inventory accuracy, stock taking, and cycle counts.

Transferability

Transferability describes to what extent the research can be transferred and generalized, corresponding to external validity or generalizability. However, transferability takes the circumstances into account, shifting the focus to measuring generalizability in similar contexts. In order to ensure transferability in the research, a crucial aspect is thereby to have rigor in the descriptions of the contexts (Halldórsson & Aastrup, 2003), such as the technology, unit of analysis and participants, clarifying what situations generalization can be made in. Increasing generalizability within the "sample group of the study" is thereby desired (Levitt, 2021), and was done by data triangulation where experts/participants from different fields and backgrounds were selected to provide a more nuanced picture.

Dependability

Dependability is another dimension of trustworthiness and is similar to the term reliability. Whereas reliability measures are more focused to erase variances when replicating the research, dependability focuses more on tracking those variances since they are expected to occur naturally in reality and not only as a result of methodologic errors. In order to maintain dependable research, Halldórsson & Aastrup (2003) emphasizes trackability and the importance of documenting the processes being carried out. Focus was thereby put on transparency and thorough documentation and descriptions of the method. This further included documentation of motivations for the chosen methodology, data collection, basis of analysis and changes that occurred along the way to make sure the process can be followed in detail.

Confirmability

Confirmability is used to ensure integrity in the results, similar to the criteria of objectivity. It refers to how the data can confirm the results and thereby focuses on how well the presented findings can be tracked in the process back to the original data (Halldórsson & Aastrup, 2003). Therefore, a clear explanation of the process for analyzing and interpreting the data will be provided. To further increase the confirmability of the research, triangulations for the theoretical frameworks can be used (Amankwaa, 2016). Different perspectives were thereby lifted when interpreting and analyzing the data.

3. Theoretical Framework

This chapter summarizes the theory and information about subjects relevant to this thesis. The subjects deemed important are drone technology, warehousing, usage of drones in warehousing, technology adoption, and the hype cycle. Lastly, a conceptual framework for analyzing the use of drones in warehousing is presented.

3.1 Drone Technology

UAVs, which are also commonly referred to as drones, are aircraft that do not have a pilot on board. They can as mentioned be both manually controlled or autonomous to different degrees. What allows the drone to operate is its hardware and software. The hardware is the material that the drone is physically made of, such as the rotors, the battery, and the frame, while the software constitutes the non-physical capabilities such as the program that makes the drone functional. Both these parts are needed for the drone to function, however, the capacity of the two affect different aspects of the drone's capabilities. Developing the hardware could increase the carrying capacity, flight time, and battery life of the drone while developing the software could increase the analytical capabilities such as the accuracy of the drone as well as allow it to work autonomously.

Due to the many separate applications for drones, there are a lot of different models and variants, where size, weight and amount of rotors differ. Not all models are suitable for an indoor environment and hence this section will only talk about the technology appropriate for indoor usage. The drones that are researched in this report are multi-rotor drones, which consist of several rotors, allowing high flexibility and vertical takeoff. Other models are the single-rotor, fixed-wing, and tilt-wing drones (DHL, 2014).

To fully understand the potential of drones it is important to grasp their technical capabilities and know what possibilities and limitations they provide. In doing so, it is meaningful to separate analytical capabilities from physical capabilities (Maghazei & Netland, 2020), where the analytical includes processing data by scanning or taking pictures, whereas the physical aspect concerns actual physical labor that can be performed, such as moving objects.

Given the possibility to equip drones with additional technology such as sensors, cameras, and scanners, they could potentially have a lot of analytical capabilities (Maghazei et al., 2022). With these technologies, drones are mainly used to gather data of different kinds which is later transferred and processed, potentially to a warehouse management system (WMS) in a warehousing setting (Stanko et al., 2022). Its analytical capabilities are hence restricted to the type of additional technology that is attached to it.

Autonomous drones can navigate with the help of GPS which is done when orienteering outdoors (Hell & Varga, 2019), however, this navigation is not possible in an industrial setting where the GPS does not work. Hence, creating autonomous drones that can properly navigate inside warehouses has been mentioned as a challenge for this application area (Alajami et al., 2022). Solutions containing Radio-Frequency Identification (RFID) or 3D Light Detection and Ranging (LIDAR) have been explored (Fernández-Caramés et al., 2019).

Discussing the physical capabilities, often comes to a trade-off between battery capacity, payload and flight time (Wawrla et al., 2019). When experimenting with UAVs for delivering or physical applications, constraints such as maximum payload, volume, travel distance, travel time and weight of the UAV need to be considered (Kuru et al., 2019).

3.2 Warehousing

Warehousing includes a range of activities whose purpose is to store goods for further distribution, sales, or manufacturing (Bartholdi & Hackman, 2010) with the aim to reduce lead time and transportation costs (Kembro & Norrman, 2022). Its operations consist of inbound activities; receiving, and put-away, as well as outbound activities; picking & sorting, and packing & shipping, between which the goods are stored at the warehouse (Bartholdi & Hackman, 2010). In regards to retail warehouses, increases in online retail in recent years have added the flow of returns, as well as cross-docking, to the list of warehouse operations, see Figure 3.1. Further, there are several different types of retail warehouses, e.g. Distribution Centers (DC), Online Fulfillment Centers (OFC), and Micro-Fulfillment Centers (MFC) (Kembro et al., 2018).

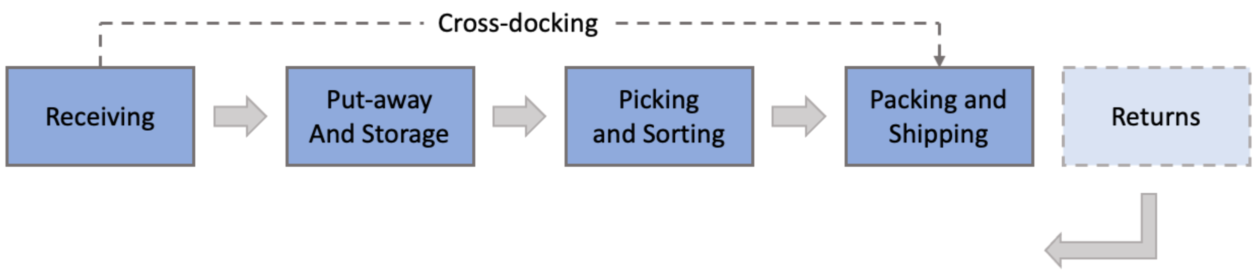

Figure 3.1 Overview of warehousing operations (adapted from Kembro et al., 2018).

Goods received at the warehouse are inspected in terms of quality, count, and damage before being scanned as delivered and staged for the put-away process. When the storage area for the product has been determined, it is put away into its assigned storage location (Bartholdi & Hackman, 2010). Storage areas, which include picking and bulk areas, can be further divided into zones where Stock Keeping Units (SKUs) are stored depending on their physical characteristics and/or order characteristics (Eriksson et al., 2019). Picking typically accounts for the majority of operating costs, 55%, within the warehouse (Bartholdi & Hackman, 2010) and is thereby a widely researched area. Further, there are several different types of picking methods, the most common ones being single-order picking, batch-picking, and zone-picking (Gu et al., 2007).

Inventory management is a term that is used widely within Supply Chain Management and is further used within warehousing. Inventory management is defined as "the continuing process of planning, organizing and controlling inventory that aims at minimizing the investment in inventory while balancing supply and demand" (Singh & Verma, 2017). One aspect of inventory management that is relevant within warehousing is inventory accuracy management, which includes activities such as stock-taking and cycle counting. Inventory accuracy is defined as "a measure of the extent to which inventory records are in agreement with actual stock counts (Mapes, 2015).

The need for inventory related activities and how often they are performed varies for different companies (Tubis et al., 2021). Warehouses that handle perishables are listed as a sector where inventory management is of importance and where great challenges can occur due to the characteristics of the stored products (Bartholdi & Hackman, 2010). Manually performing inventory management tasks related to inventory accuracy can incur high costs in terms of labor. Combined with workers blocking other activities in order to count the inventory, efforts have been made to try to automate the process (Alajami et al., 2022). Tubis et al. (2021) further confirm the need for automation in the process and how that could lead to reduced human errors and higher inventory accuracy.

Needless to say, it is not only inventory management tasks that are being automated. Picking and other labor intensive operations have been automated in recent years with the help of automation technology such as AGV-assisted order picking systems, automated picking workstations and more complete solutions such as autostore (Boysen et al., 2019). Automation of labor intensive processes is more common in countries and areas where the cost of labor is relatively high. According to Bartholdi & Hackman (2010), warehouses in Europe, and especially in France and Germany, are characterized by inflexibilities of the workforce and labor costs that are relatively high. This encourages solution designers to turn to engineering solutions instead of social solutions to solve the challenges at hand. Bartholdi & Hackman (2010) further exemplifies this by saying that there is a greater tendency to integrate automation solutions in warehouses in Europe than in equivalent facilities in North America.

3.3 Usage of Drones Within Warehousing

The intersection between autonomous UAVs and warehousing operations is, as already mentioned, relatively unexplored. There are a few examples of some activities that could be automated by the use of UAVs and their technological benefits. These activities are within inventory management, intra-logistics, and surveillance, where some have been more researched and tried in practice than others.

The most attention when it comes to the usage of drones in warehouses has been given to applications within inventory management (Maghazei & Netland, 2020; Verity, 2022). It is the most researched application area for drones for indoor industrial use (Malang et al., 2023). As mentioned, inventory management is a broad term within supply chain contexts, including several operations, not all of them being a part of warehousing operations. The more specific activities mentioned within inventory management are those related to cycle counting, inventory checks and inventory accuracy (Maghazei & Netland, 2020; Maghazei et al., 2022; Radácsi, et al., 2022). However, some literature uses the more broad term of inventory management or the term in combination with more specific activities (Stanko et al., 2022; Malang et al., 2023), indicating that there might be other potential application areas for autonomous drones related to inventory management within warehousing. Further, one supplier of the technology brands autonomous drones as a solution directed toward improving inventory management in warehousing settings (Verity, 2022).

When doing their literature review of implementation and critical success factors for autonomous drones in warehousing, Malang et al. (2023) mapped different application areas for the technology. In doing so, they categorized inventory management as a warehouse operation, including the activities of inventory audit, stock management, cycle counting item search, buffer stock maintenance, and stocktaking. This definition of inventory management in a warehousing context was used in this thesis when referring to inventory management. Even though there is a much broader definition of the term from a supply chain perspective, this is the definition that is referred to when using the term inventory management.

Since the major benefits from drones are expected to be that they can reduce labor costs and increase efficiency by doing autonomous and repetitive work, inventory checks and item searches are suitable tasks for autonomous drones (Radácsi, et al., 2022), as previously mentioned. To perform these tasks, drones are paired with other technology and hardware to expand their capabilities. One of these technologies is barcode scanning (Maghazei & Netland, 2020; Xu, et al. 2018) which could be used in inventory scanning and possibly other areas as well.

Implementations of UAVs in warehouses for tasks related to inventory management already exist and further research is being done to make the implementations even more optimized (Radácsi, et al., 2022). However, their usage within warehousing is not yet widely found and information or results from companies having tested and made pilot projects are rarely shared in public (Stanko et al., 2022).

In their study of autonomous drones used for warehouse inspections, Stanko et al. (2022) mention that no studies or successful experiments have been done for inspections to their knowledge. There is further research on UAVs for picking (Han et al., 2022), but this is mostly theoretically around algorithms and the software of the application where the feasibility of the solution has not been taken into account. Applications of autonomous drones being used for deliveries outdoors have been made, making it plausible that experiments and applications indoors for intralogistics could come in the future (Wawrla et al., 2019).

The implementation of drones inevitably affects its surroundings and specifically social impacts are listed in the literature regarding the effects of drones. Some of these are physical risks associated with collisions or technical breakdowns, stress caused due to surveillance, and also the fact that it competes with the human workforce (Kwon, et al., 2017). These impacts could all act as barriers to implementing UAVs. Other general barriers to technology implementation, such as implementing drones, are privacy and security concerns, data management, and lack of top management support (Rathore, et al., 2022). However, drones are not only a safety concern for companies but are also seen as a good option for improving security issues within the industry (Maghazei et al., 2022; Maghazei & Netland, 2020).

From what can be found regarding pilot projects and implementations, those related to inventory management, in terms of cycle counting, inventory checks and inventory accuracy, seem to be the only application areas where autonomous drones have been tested and used. How widely adopted the solution is, has however not been established in many studies. Even though inspection and surveillance have been mentioned as a possible application area for autonomous drones, there is to our understanding no studies that have been made for these applications, establishing if they are possible or not. The same accounts for using autonomous drones for any kind of physical labor.

3.4 Technology Adoption

When looking at technology adoption frameworks different ones are mentioned in the literature. The technology Readiness and Acceptance Model (TRA) is one of those and another one extending the TRA is the Technology-Acceptance-Model (TAM). Given that the frameworks have different focuses and perspectives, the circumstances and the specific situation should determine which one to use. The ones listed formally have a higher focus on how the individual perceives an innovation or new technology (Taherdoost, 2018). However, since a more holistic approach was desired, other frameworks such as the diffusion of innovation (DOI) model and the Technological-Organisational-Environmental (TOE) framework were deemed more appropriate, which will both be further explained in this section.

As previously stated, the hype cycle is a way of evaluating what phase an emerging technology is in and the characteristics of each phase. Given the novelty of autonomous drones in the warehousing setting, the hype cycle was also considered important when investigating the technology.

3.4.1 The DOI Framework

The DOI model was created by E.M. Rogers and it describes the pattern and speed of how a new product, innovation, or solution is adopted and is therefore suitable to have when looking at new technologies. The framework is quite broad with different parts such as main elements, variables affecting the adoption and rate, phases of acceptance and the different types of adopters based on their approach towards these innovations.

The four main elements in the framework are innovation, communication channels, time and the social system. The innovation element consists of five characteristics that can further be used to explain the rate of adoption. According to Rogers (2003, pp.221-222) these five attributes are the ones having received the most attention in research since they account for between 50-80% of the variance in the adoption rate of innovations. These characteristics are relative advantage, compatibility, complexity, observability and trialability which can be seen in Figure 3.2. Because of their significance, these attributes are sometimes used separately without the rest of the framework and sometimes in combination with other frameworks, which will also be done in this thesis.

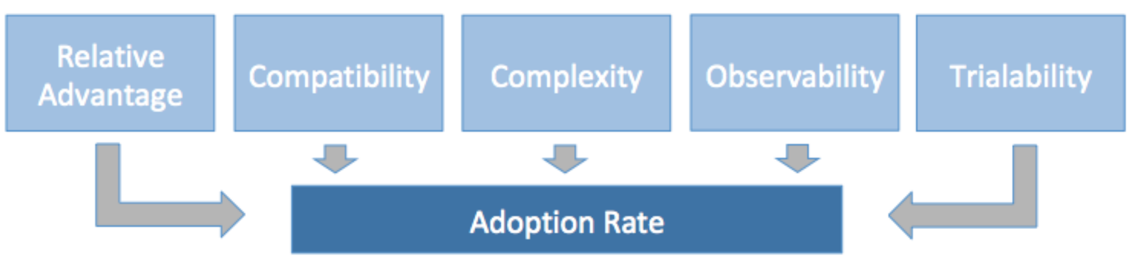

Figure 3.2 The characteristics of an innovation that affects the adoption rate.

Starting with relative advantage, it explains to which degree an innovation is viewed as being more advantageous than the current solution. This characteristic is therefore broad and can contain different types of advantages depending on what innovation is being investigated. Because of this, the relative advantage has received some criticism for its inconsistency and in different studies it can be seen that this variable is further categorized into different advantages. Rogers (2003, pp.230) mentions that of all the different factors that could be included in this aspect, the economic factor is seen as the most crucial and commonly used. The initial investment has a large effect on an innovation's adoption rate but there could also be other advantages depending on the innovation, such as gaining social status (Rogers, 2003, pp.230). Cost efficiency (Tsai et al., 2010) or cost savings in terms of low maintenance costs (Oliviera et al., 2014) could be included as economic advantages. Other advantages such as making operations more efficient, increasing productivity and task speed, improving the quality of operations (Oliviera et al., 2014) or improving inventory replenishment (Tsai et al., 2010) have been used in previous studies for describing relative advantages for new technologies in the industry.

Compatibility explains to which degree an innovation is perceived as in line with existing values and business operation activities of potential adopters. If the innovation is compatible with existing values and norms of the system, it will more likely be adopted and adopted more rapidly (Rogers, 2003, pp.15). According to Rogers (2003, pp.249), past research on new technology diffusion suggests that this variable may have less effect on the rate of adoption compared to relative advantage. Factors that make innovations more compatible could be that it fits with the workstyle of the adopters or that it is compatible with current business operations, culture, values and existing software or hardware (Oliviera et al., 2014).

Complexity is the relative difficulty of applying and understanding an innovation. If the innovation requires new knowledge or skills for the ones using it, it will likely be adopted much slower (Rogers, 2003, pp.16). As further stated by Rogers (2003, pp.257), the complexity aspect could potentially have less importance compared to the former two characteristics. However this is the general case for all innovations and when it comes to more technical innovations, he mentioned that the complexity aspect could be of greater essence. This was further confirmed by Tsai et al. (2010) who stated that: *"Previous studies have suggested that relative advantage and complexity are the best predictors when evaluating the benefits and challenges of technology innovation".* Some factors that could increase the complexity of a product are if it requires a lot of mental effort or if too complex skills are required from the employees (Oliviera et al., 2014).

Observability explains to what degree results from the innovation are visible to others. Rogers (2003, pp. 16) mentions that this aspect affects the individuals using and implementing it, who if they can see the benefits and results are more likely to successfully adapt to it. The last aspect, trialability, explains the degree to which an innovation may be experimented and tested. An innovation that could be tried beforehand offers less uncertainty, making it more likely to be adopted rapidly (Rogers, 2003, pp.16).

When talking about different adopters of a technology there are five categories: innovators, early adopters, early majority, late majority and laggards, which all can be seen and how they are distributed in Figure 3.3. According to Rogers (2003, pp. 257-259), the characteristics of innovations could be of different importance for the adoption rate for the different types of adopters. He specifically mentions trialability as an aspect that becomes more important for innovators and early adopters compared to the later categories since later adopters also can rely on good examples set by the former category. It hence becomes more important to be able to test the technology when no comparisons or insights can be taken from previous examples. Another factor mentioned in the relative advantage that seems to be more important for early adopters is gaining social status (Rogers, 2003, pp. 231).

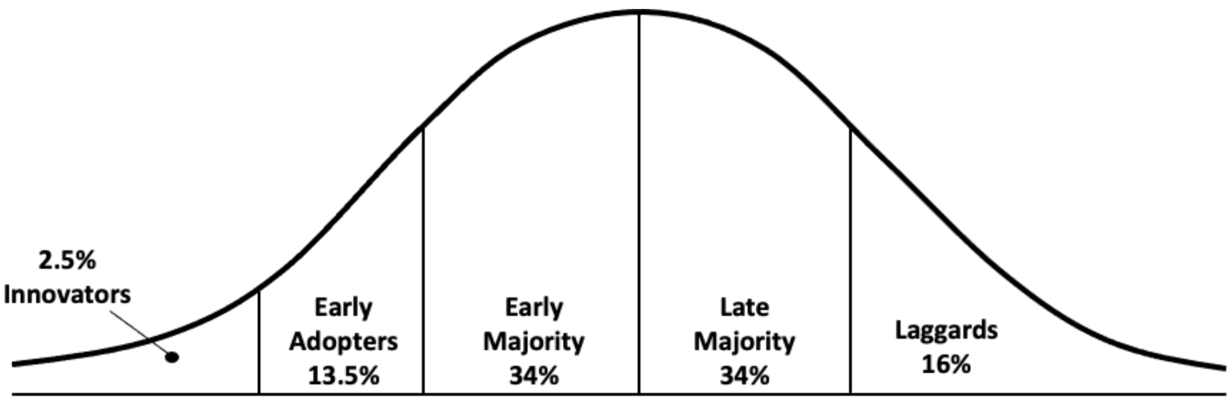

Figure 3.3 Different types of adopters of a new innovation (adapted from Rogers, 2003).

The curve looks similar to that of a normal distribution with the majority placed somewhere in the middle and a few exceptions being either really early or late adopters, which is seen by the distribution percentages. Even if the characteristics may be of different significance depending on the type of adopter, innovations that are perceived to have higher relative advantage, compatibility, trialability, observability and less complexity will hence be adopted more rapidly.

3.4.2 The TOE Framework

The TOE framework extended the DOI model for understanding the process of technology adoption, by adding the environmental perspective and the context in which the technology is adopted in. According to the TOE model, technology adoption can be assessed by the technological factors (external and internal technology available for the organization), organizational factors (characteristics of the organization), and environmental factors (the industry an organization operates in, with its customers, competitors and governmental structures) of the context in which the technology is adopted (Ediriweera et al., 2021), see Figure 3.4. Within the research on logistics and supply chain management, the TOE framework has for example been used to investigate the adoption of blockchain technology (Chittipaka et al., 2021), RFID (Bhattacharya & Wamba, 2015), and Big Data Analytics (Chen et al., 2015) and the barriers and challenges of Industry 4.0 technology adoption (Ghobakhloo et al., 2022).

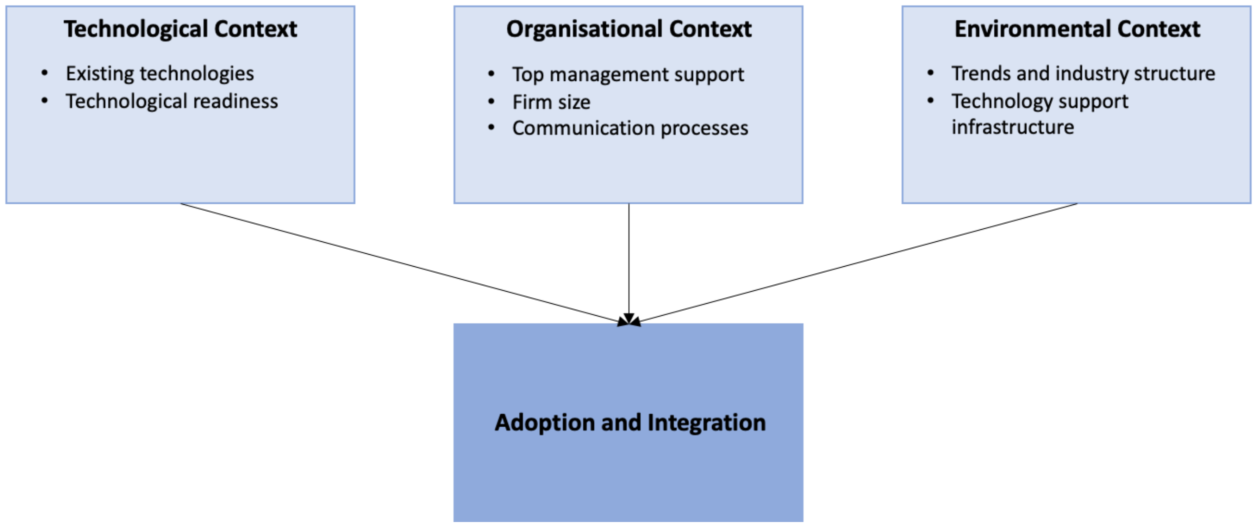

Figure 3.4 The TOE Framework (adapted from Baker, 2012).

The technological context encompasses all technologies that are relevant for the firm or company, both those used, as well as those existing on the market but that are not currently used in the company. Which technologies that already are in place are important because they set a broad limit on the pace and size of technological change that a company can undergo (Baker, 2012, pp.232). In that sense, the technological context will determine if the technological readiness of the organization will facilitate or limit the adoption of new technologies (Oliviera et al., 2014). Thereby the technological context of the TOE framework includes the aspects of the DOI framework that looks at the technology of the solution itself, as well as the structures and technological knowledge in the company. Examples of determinants that increase the likelihood of a successful adoption are a user-friendly human-machine interface and a low-complexity technology that is easy to integrate with workers and systems (Ghobakhloo et al., 2022).

By organizational context, the framework refers to the characteristics and resources in the firm, as well as organizational structures that enable the adoption of new technologies (Baker, 2012, pp. 233-234). Common success factors for different types of technology adoption, or Industry 4.0 adoption, are those related to management, organization, and strategy (Maghazei et al., 2022; Tahriri et al., 2022; Tortorella et al., 2022). Communication processes are one of the determinants that can enable or disable innovation. Cross-functional teams, as well as formal or informal links between employees of different departments, have been proven as valuable traits for technology adoption and innovation (Baker, 2012, pp. 233-234). One of the most highlighted organizational factors for adopting new technologies is top management support. If executives understand and recognize the benefits of the solution, resources can be allocated toward its adoption (Oliviera et al., 2014). There might however be a bias toward new technology when it comes to realizing the benefits, specifically for the economic aspects where the traditional way of looking at this when investing often oversees the possible long-term benefits and learning curves (Maghazei et al., 2022). This is further expressed through the uncertainties of the economic potential for new technologies, which could make companies more hesitant to adopt new technologies (Kapoor & Klueter, 2021).

Ghobakhloo et al. (2022) state that one of the organizational determinants for technology adoption is the organizational culture, including the employee openness or resistance to change, resistance to diffusion of new technologies, and social security concerns of employees. The top management has an important role in creating an organizational context in which innovation and change are welcomed, indicating the importance of innovation to subordinates, and rewarding innovation formally and informally. Thereby, it is more likely that employees accept the change (Baker, 2012, pp. 233-234).

The environmental context includes the surrounding in which the organization operates. The structure of the industry is one of the aspects that affect the adoption of new technology. Firms and organizations in fast-changing and growing industries have been shown to innovate at a higher pace (Baker, 2012, pp. 235). Ghobakhloo et al. (2022) argue that the current digitalization race toward Industry 4.0 creates a competitive environment that pushes for innovation and adoption of new technologies. Other characteristics of the industry such as high labor costs and difficulties to find labor have also been shown to motivate companies to automate (Baker, 2012, pp. 235). The availability of technology, vendor support, and vendor trustworthiness are also determinants of innovation. Having greater access to vendors and their support is necessary for companies to adopt the new technologies (Ghobakhloo et al., 2022).

To summarize the framework, the three parts of technology, organization, and environment present both the opportunities and limitations for innovation and technology adoption, influencing the technological innovation level in the organization (Baker, 2012, pp. 235).

3.5 The Hype Cycle of New Technologies

The introduction of new technology is often accompanied by high expectations of new technological possibilities. Hope and excitement of a technology's infancy have an important role in guiding research towards it to create legitimacy which can attract further resources from companies and early investors. Thereby, the expectations can benefit the development of the technology. This symbiotic relationship favors the technology, but from a holistic view, it is not entirely innocent. An overtrust in the change of a specific technology can damage the technology in the long run if its actual capabilities are revealed to be less than was initially expected. These waves of expectations can be considered “hypes”, and the ebb and flow of rising and descending can be regarded as the hype cycle (van Lente et al., 2013).

A method for evaluating the position of a specific technology in regards to its hype is The Gartner Hype Cycle, which was presented by Gartner Inc. in 1995 and describes the general path a new technology or innovation walks from being introduced, to reaching a point of stabilization. Presented to the right of Figure 3.5, the Hype Cycle measures the expected or visible value it brings on the y-axis and time on the x-axis. Its shape is formed by merging two different graphs into one, the human-centric curve presented in the middle, and the technology-centric curve placed to the left (Dedehayir & Steinert, 2016).

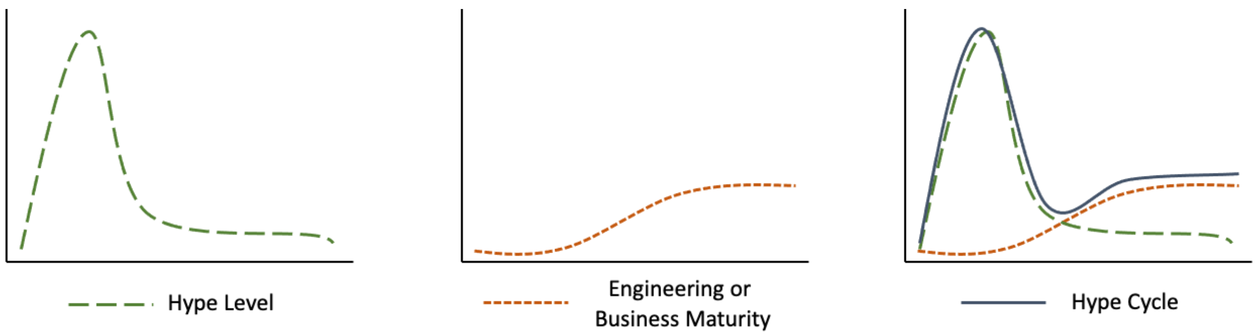

Figure 3.5 The human centric and technology centric graphs add up to the hype cycle (adapted from Dedehayie & Steinert, 2016).

The first increase in expectation in the hype curve is based on the exaggerated and irrational positive response that humans tend to have toward the introduction of new technology (Dedehayir & Steinert, 2016). Fenn & Raskino (2008) argue that three aspects of human nature create the shape of the human-centric hype curve; a willingness to discover and learn by yourself, an attraction to novelty, and social contagion. The second, and slower, increase in expectation as time passes, is derived from the maturity of technology. This can be visualized and described by the S-curve of technology maturity. A mature technology " is one in which the inherent flaws have been removed or reduced" (Forbes, 2022). According to the S-curve model, the maturity of a technology moves from its embryonic phase to the growth face, the mature face, and lastly, the aging phase in which the technology performance stagnates (Nieto et al., 1998).

As seen in Figure 3.6 depicting the hype cycle, innovations and new technology move through the stages of Innovation Trigger, Peak of Inflated Expectations, Trough of Disillusionment, Slope of Enlightenment, and Plateau of Productivity according to the Hype Cycle model. Each stage has its indicators for assessing the development stage of a given technology (Dedehayir & Steinert, 2016).

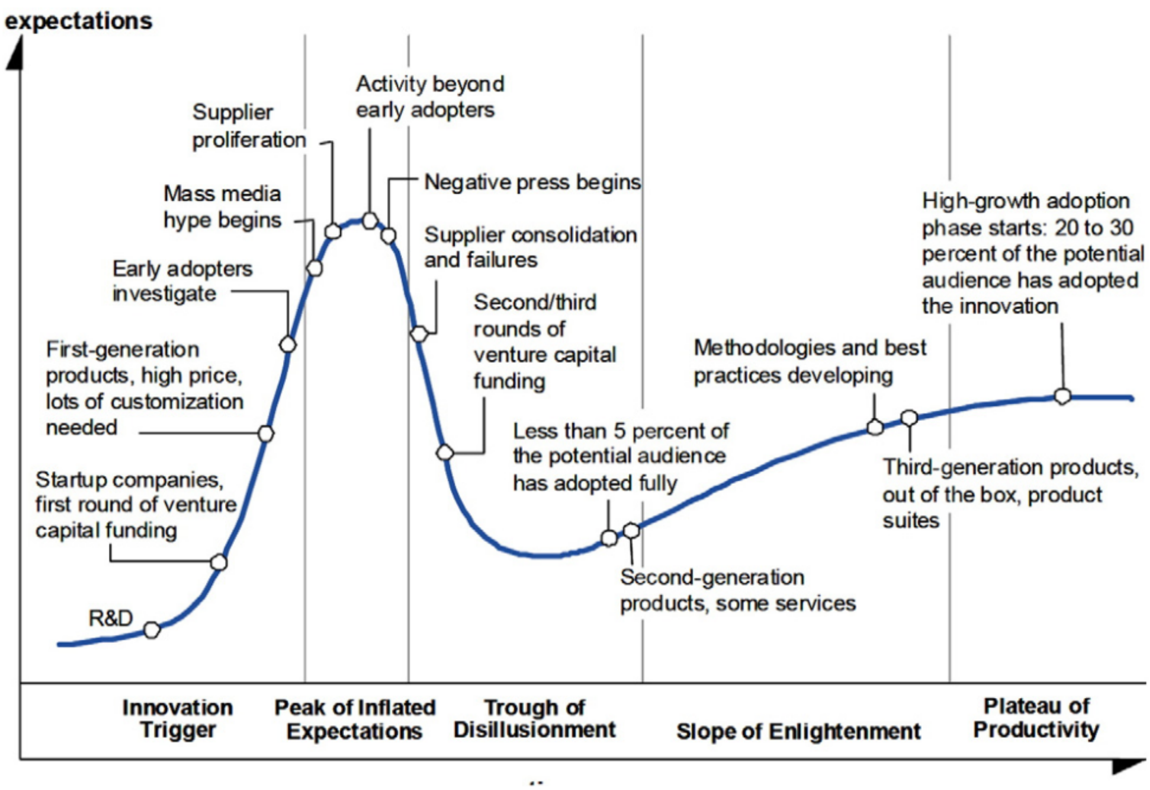

Figure 3.6. The different stages of the hype cycle (Dedehayir & Steinert, 2016).

Innovation Trigger

An innovation trigger occurs when new solutions or products are developed from new technologies. Interest is shown by the media which increases the expectations of the product. There is, however, often no market value or potential commercialization (Kondo et al., 2022). Startup companies create the first generations of products which often are characterized by their high price and high level of customization (Dedehayir & Steinert, 2016).

Peak of Inflated Expectations

At this stage, some success stories are shared but the number of companies involved is few. Expectations are rising increasingly due to the successful cases reported, leading to unrealistic and over-enthusiastic reports from the media (Kondo et al., 2022). This can create a bandwagon effect where companies invent without a clear strategy or solid business case (Dedehayir & Steinert, 2016).

Trough of Disillusionment

Expectations start to decline drastically due to unexpected experimental results and failed commercialization efforts. Suppliers must deliver products that meet the early adopters' needs to ensure sustainable investments. Media interest declines as expectations are adjusted to more realistic levels and skepticism about the market value is increasing (Kondo et al., 2022).

Slope of Enlightenment
Early adopters that continued to develop and work with the technology began to reap the benefits from the solution (Dedehayir & Steinert, 2016). A 2nd and 3rd-generation of features enter the market for improved next-generation products. Thereby, a more thorough understanding of how the technology best can bring profit is formed. More conservative organizations and companies are still hesitant to invest and observe the successful parties (Kondo et al., 2022).

Plateau of Productivity
A realistic valuation of the technology is reached and its adoption accelerates into a larger audience than the early adopters (Dedehayir & Steinert, 2016) making the technology widely recognized (Kondo et al., 2022).

3.6 Conceptual Framework

To analyze the adoption of drones from as many relevant perspectives as possible, a conceptual framework consisting of the presented technology adoption models and the hype cycle was developed. Using the DOI framework, the technological aspects of drones and their relation to the organization where they are adopted were included. The TOE framework extends that of DOI, including the context the technology is placed in. This incorporates the technological, organizational, and environmental determinants that affect the success of adopting a new technology. Finally, the hype cycle adds the dimension of human willingness to adopt new technology, as well as the maturity of the technological solution. The framework in its entirety is presented in Figure 3.7.

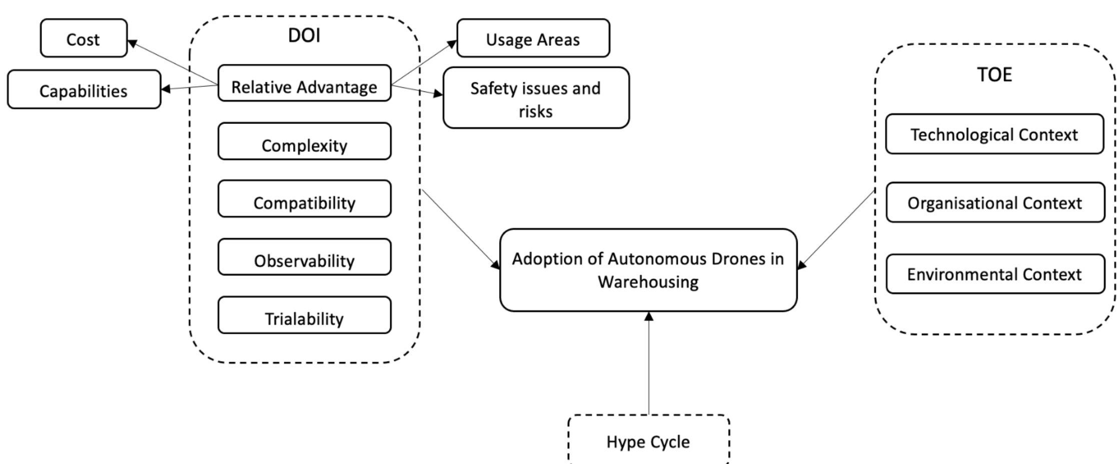

Figure 3.7 Conceptual framework for analyzing drone adoption in warehouses.

4. Round 1: Exploring and Understanding

In this chapter, the empirical findings, analysis, and discussion from the first round are presented. First, the findings and categorizations from the data using the Gioia methodology are presented. Thereafter the findings are combined with the conceptual framework to analyze the empirical findings with guidelines from the theoretical perspective. Lastly, a discussion on the first round is presented.

4.1 Findings From the Interviews

When looking through the results from the 15 interviews, the Gioia method was used to compile the results. The interviews resulted in 5 aggregate dimensions, 19 second-order themes and 84 first-order themes. Given the many first-order and second-order themes localized, the text will be presented using the aggregate dimensions as headings in the following sections. The aggregate dimensions describe the overarching themes of the findings and consist of; How are they used, What are the benefits, What are the challenges, The warehousing context, and The future. The full categorization of first, second, and third-order themes can be seen in Figure 4.1. These are presented and explained more thoroughly under their overarching category.

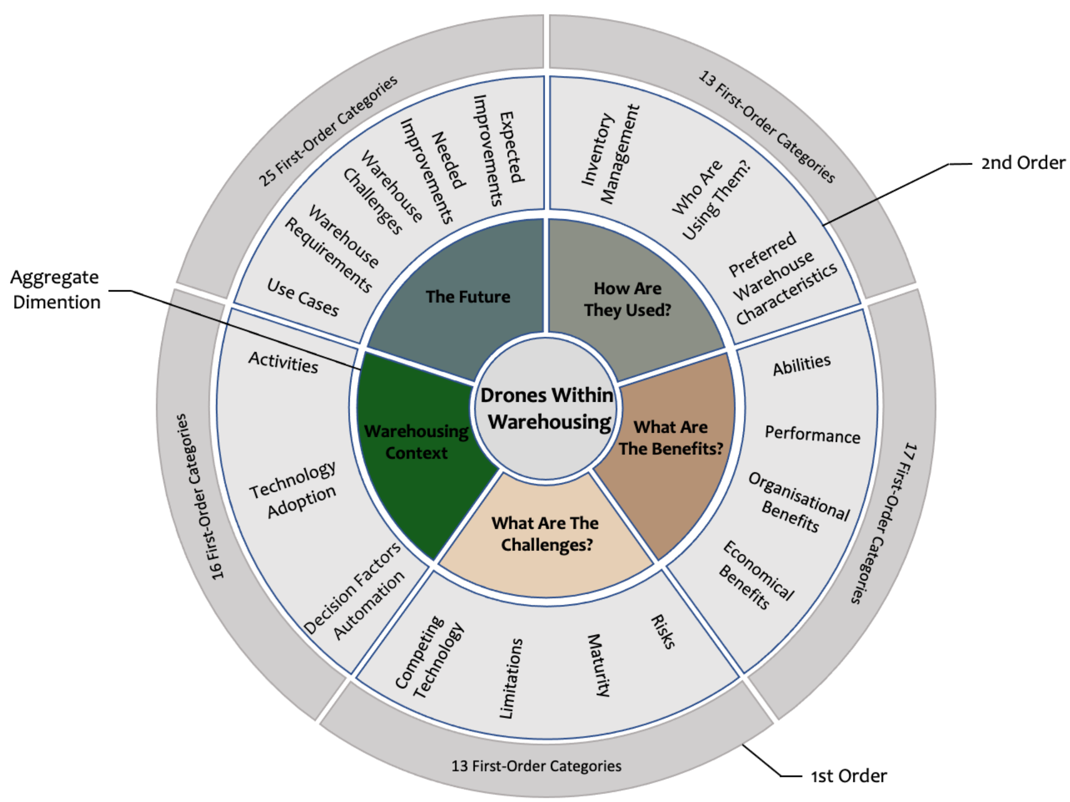

Figure 4.1 Findings presented using the Gioia framework.

4.1.1 How Are They Used

Interviewing the experts included, amongst others, interviews with those responsible for drone implementation projects and people who were involved in the process of using autonomous drones in their daily operations. The other experts, such as those from the research perspective of drones, as well as warehousing experts from both practice and research, also shared their knowledge of autonomous drones although not from a practical perspective. This resulted in information about how autonomous drones currently are being used, who is using them, and warehouse characteristics of where they are used, see Figure 4.2.

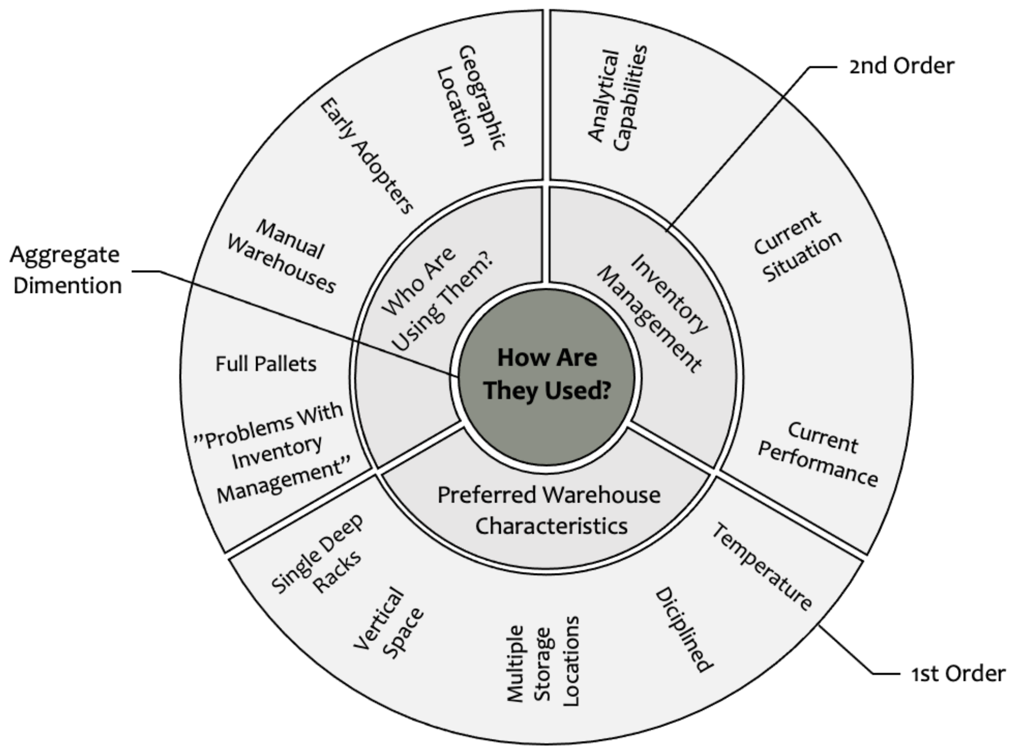

Figure 4.2 The aggregate dimension "How Are They Used?", categorized in second and first-order themes.

Inventory Management

Throughout all of the interviews, the analytical usage areas of drones were deemed superior to using them for physical operations. One participant from the drone research perspective said that: "*we tend to look at them or think of them as data collectors*", and another expert from a drone company emphasized that drones are: *"a lightweight data collection system"*. Physical operations performed by autonomous drones in a warehouse environment was seen as unrealistic by the experts. When asked about whether drones can perform physical operations autonomously, one expert answered: "*Physical operations? No, I can't think of any use for physical operations",* another responded: "*To transport things in the warehouse. It's not* *realistic",* and a third expert said: *"Drones will most likely not solve any picking topics. But it can impact and support the availability of the goods"*.

Out of 15 participants, 14 mentioned that drones can be used for automating inventory management tasks. Four experts, who all had been part of implementation projects, mentioned that their drones are currently used for stock taking and cycle counting of bulk storage. The whole process from take-off to landing is completely autonomous. The drone is programmed to be activated outside operating hours and is charged in its dock during the day. When activated, the drone leaves its charging dock and flies through the aisles where it scans the labels on the full pallets and the barcode on the rack which indicates the position. This is done with a scanner or a camera that takes a photo which is analyzed by the software. It was emphasized that this only can be done for full pallets, with one participant saying: *"We're currently only looking at the inventory part, so actually counting. And for now, at this moment, we can only scan full pallets"*. The information collected through scanning or footage is compared with the information in the WMS to assure that the information on the pallet positions in the system is correct. If the information differs, the pallet is flagged so that an operator can correct the error and move the pallet the next day. One of the experts mentioned that they thereby can find human errors that have not been taken into account in the WMS.

Who Is Using Them?

The four experts that had or were involved in autonomous drone implementations for inventory control come from three different companies within three separate sectors. The participants from two of the companies all said that they have rolled out the solution in several of their warehouses, located in different countries across the world. The participant from the third company had implemented it in one of their DCs. All said that they were satisfied with the drone's performance, and three of the experts stated that they are planning on expanding the solution into several warehouses. They further said that they first implemented the solution in high labor cost countries. According to them, this is where the biggest cost savings could be made since inventory management tasks such as stock-taking are labor intensive: *"We have started in the high labor cost countries for obvious reasons"*.

Some of these experts mentioned that their companies have organizational structures in place to promote innovation and invest in new technologies. For one company, innovation is part of their corporate strategy while the other one stated that they do not usually consider themselves to be an early adopter but was in this case. The expert mentioned that they are quick to adopt technologies that have been proven: *"We call ourselves a fast follower"*. A third expert did not mention anything about their strategy regarding innovation. They were approached by a vendor that presented the business case which the executives found interesting. According to the expert, their issues with lost pallets and keeping an accurate inventory made the solution beneficial for them, and since it was proven to work they decided to invest. An expert that has not been part of any drone implementations mentioned that those currently using autonomous drones most likely have special needs or have a specific environment that makes autonomous drones for inventory management useful.

Preferred Warehouse Characteristics

Depending on the characteristics of the warehouse, such as its layout, and the number of storage locations, drones are more or less suitable for automating tasks related to increasing inventory accuracy. The expert from the grocery company mentioned that the autonomous drones could be used everywhere in their warehouse except for the cold storage. Here a semi-automated drone was placed by a worker instead. Autonomous drones could not be kept in the cold regularly since the cold temperature negatively affects the battery. The preferred environment is room temperature. Another preferable aspect is a disciplined warehouse that is kept clean. One participant mentioned that they needed to keep the warehouse clean and avoid having objects hanging out or down from the racks that could cause the drone to crash. One of the experts mentioned that they found the environment where they used drones suitable. With movements and objects on the floor, the drone's ability to fly over obstacles is beneficial. With more movement, the risk of inaccuracies increases, making drones more useful, according to the expert.

In regards to the layout of the warehouse, drones are limited to single deep racks. The drone can not fly inside the racks and can therefore only scan the pallet from the aisles. Thereby the preferred storage layout is single deep racks. The drone also has an advantage in warehouses with plenty of vertical space. Due to the flying ability of drones, their usefulness increases if pallets are stored high above the ground since other solutions are limited regarding this. Further, a large number of storage locations increases usability. According to several experts, doing frequent inventory checks with drones is more useful in warehouses with multiple storage locations since the capacity of the drone is utilized to a greater extent due to increased savings on labor costs. Further, manual and semi-automated warehouses are preferable for adopting autonomous drones according to the panelists since fully autonomous warehouses make drones obsolete.

4.1.2 What Are the Benefits

When asked about the benefits of autonomous drones, the experts mentioned several advantages of adopting drones in warehousing. These formed into first-order themes which then summed up into second-order themes, namely Abilities, Operational Benefits, Organizational Benefits, and Economical Benefits, see Figure 4.3.

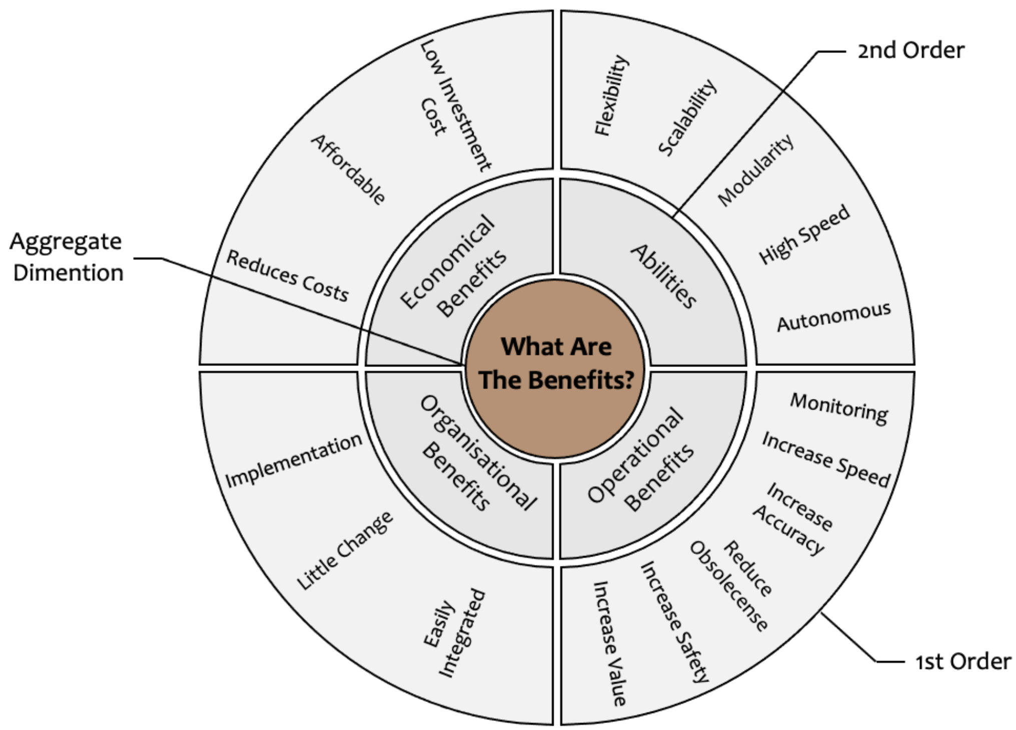

Figure 4.3 The aggregate dimension "What Are The Benefits?", categorized in second and first-order themes.

Abilities

Flexibility, scalability, modularity, speed, and being autonomous are all first-order categories that explain the abilities of drones, and more specifically those abilities that were considered beneficial attributes of the technology. The ability of the drone that was mentioned most times by the experts when asked about drone benefits was its flexibility: "*We did find them to be very flexible. There is one good thing about them that you can move them around. So a very good use case for drones is for audit purposes*". Another statement that was made is that drones are more lightweight and less cumbersome than other automation technology. By not being mounted statically to any other structure, the drone is a portable solution that can be applied where it is needed. Seven of fifteen experts highlighted its ability to move both vertically and horizontally. By doing this, the drone can access areas that are hard to reach, such as pallets placed on the highest shelves of the racks. Their small size further allows them to access narrow areas which also adds to the flexibility of the solution.

Autonomous drones are according to the experts a scalable solution that can be adapted to the operation it supports. Drones can operate in swarms and the number of drones used can be increased or decreased depending on the need. Experts in the study which had implemented drones said that they used several drones, stating: *"You never have one drone. The bigger area and more complicated area, the more drones you need in order to cover, because the drone will not be able to fly for as long as it has a limited battery length"*. According to the experts, the scalability hence allows for gradual implementation. The drone is also a modular solution, where the additional technology used can be adapted and suited to its purpose. For analytical purposes, the drones can be equipped with different types of sensors, cameras, and navigation systems.

Autonomous drones can also fly and work relatively fast. From the interviews, it became evident that drones can perform tasks such as inventory control and checks much faster than human workers currently can. Lastly, the fact that drones can work autonomously is a large advantage of the solution. Experts mentioned that this is possible for inventory management tasks where the drone charges itself and performs its tasks autonomously. The drone is charged during the day and can operate by itself on off-hours when no one is at the site. As mentioned by the experts, this further makes the solution easier to use and understand and does therefore not require any advanced technical skills from workers.

Operational Benefits

Another second-order theme discovered was the operational benefits that autonomous drones bring to the warehouse. The first-order themes forming this broader category were ease of monitoring, increased accuracy, increased value, increased speed, increased safety, and reduced obsolescence. The majority emphasized that autonomous drones could lead to increased accuracy of the stock by being used for inventory management purposes. An expert who had participated in one implementation of autonomous drones for a food and grocery company mentioned that the increased accuracy in inventory due to more frequent inventory controls led to reduced costs of obsolete products. The increased accuracy could be traced to the drone implementation since the performance of the drone easily could be monitored and measured, both visually by seeing them work and also by analyzing the data points captured by the drone. This was mentioned by the four experts that have been part of implementation projects.

Seven out of fifteen experts mentioned that drones could automate boring and repetitive tasks and also specifically those operations that are prone to human error, such as inventory management tasks. One expert said that: *"Drones are mostly used for automating tedious or time consuming processes. So that's an advantage for inventory management or stock-taking, which is quite tedious"*. These time consuming tasks can be performed faster by the drones, enabling more frequent inventory checks. Employees that otherwise would perform these activities could perform less monotonous tasks and focus on other value-adding tasks. One participant, who had implemented drones in their warehouse, said that activities such as looking for lost pallets bring very little value in contrast to other activities. Further, experts mentioned that drones can automate otherwise dangerous tasks and thereby increase the safety of the employees: *"Instead of a worker having to climb up and count on heights, risking to hurt himself, a drone could be used"*. Hence, the safety aspect mostly circulated around working on heights, which can be reduced or eliminated with the help of drones.

Organizational Benefits

Autonomous drones also have organizational benefits regarding implementation, integration, and the relatively few changes it brings for the organization embracing them. Five out of fifteen experts, including the experts that had been part of implementation projects, stated that before implementing the solution in full, it was easy to test the solution and have pilot projects and demos beforehand due the drone's portability. Manual drones could also be used first for testing the solution before implementing autonomous drones. This made the transition to full-scale implementation smoother, which according to them also was relatively short. For one company, the first flights were done around two months into the implementation phase, and for two of the companies, the system was fully integrated in nine months to one year.

The integration of drone technology is based both on systems integration and integration with the workers. According to the experts that have implemented it, both aspects of integration proved to integrate well when adopting drone technology. Regarding system integration, the drone is easily integrated with one expert saying *"The integration is minimal because you only need to send back and forward inventory data and results. So the integration part is pretty lean"*. According to the same expert, the drone system is integrated with the WMS and can in that way pinpoint discrepancies. Human integration also proved to be successful, and those with implementation experience mentioned that workers have a positive attitude toward drone integration. It was mentioned that there generally can be problems with workers worrying about losing their jobs when new technologies are introduced, but this was not the case for autonomous drones in the experts' opinions. The implementation of the technology came with relatively small changes, making it easier for the workers to understand and use, as well as accept it. In terms of changed processes, minor adjustments had to be made, including making sure that the labels on pallets were facing toward the aisles, and ensuring that no plastic wrap was hanging out, which otherwise could limit and damage the drones.

Economical Advantages

Several experts argued that adopting autonomous drones have economical advantages, such as being a relatively affordable solution. Six out of fifteen experts listed affordability as one of the benefits of autonomous drones compared to other autonomous alternatives for inventory management. One of the experts that had been part of an implementation project mentioned that: "*If you are investing in whatever kind of technology, it's super heavy, it's a lot of stuff and it's quite expensive. If you compare it to that, investing in a couple of drones is from an investment* *perspective, connected to a fast return on investment which makes it a no-brainer to go for it*". Further, experts mentioned that there is no big technological readiness needed in organizations implementing drones.

According to one of the experts, who had drones implemented in their warehouses, the return on investment in one of their 100,000 square meter warehouses is around two years. The expert did however mention that the return on investment is dependent on your operations, stating that: *"the more you count, the shorter your return on investment is because you can replace it all with drones"*. Compared to manual ways of conducting inventory management where workers did the inventory tasks, autonomous drones can reduce the costs incurred. Reduced labor costs were mentioned as one of the economic benefits, as well as reduced operating costs due to the improved accuracy.

4.1.3 What Are the Challenges

Based on the answers from the interviews, four categories were located as the greatest challenges for autonomous drones in warehousing. These were limitations of the technology, other competing solutions, risks, and the lack of maturity of autonomous drones in warehousing contexts, which are all presented in Figure 4.4. For each of these, their 1st order themes are listed in the figure as well.

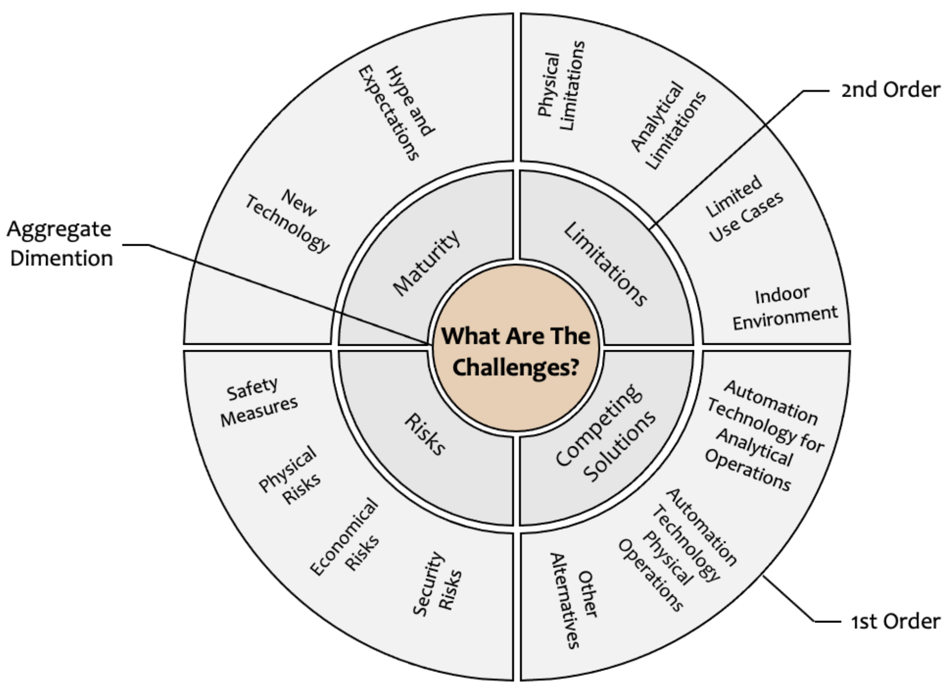

Figure 4.4 The aggregate dimension "What Are The Challenges?", categorized in second and first-order themes.

Limitations
Starting with the limitations of the technology, this category was based on physical limitations, analytical limitations, limited use cases, and the limitations of an indoor environment.

The limitation that was lifted by most participants was that of the technology. Technical limitations were emphasized by the participants researching drones who talked more about the tradeoff between weight, flying time and payload compared to the warehousing experts: *"So it's a tradeoff between the weight and the flying time, charging time and so on"*. According to one of the experts, a drone can only lift up to 30 percent of its own weight. Equipping the drone with additional attachments would therefore reduce its carrying capacity.

When it comes to the analytical limitations, the fact that autonomous drones could only count full pallets was lifted the most. This was especially emphasized among the experts having implemented drones where one said: *"I think there are still limitations to the solution itself. Like I said, we can only do full pallet counting currently"*. The accuracy of the technology was also lifted as a potential limitation where some meant that the solution was not accurate enough. One of the implementers specifically talked about the problems with data accuracy and poor drone performance, which they experienced in the beginning. Another limitation of autonomous drones in warehousing that was identified was the limiting use cases. As mentioned by one expert: *"The other thing is that with drones, you would invest a lot of money in using drones for very limited use cases."*. With this, experts meant that the technology is currently only useful in certain use cases which could be a limiting factor for it.

Flying drones indoors puts restrictions on their size and thereby affects the possible payloads and the flight time they can have. The closed environment further puts higher requirements on safety and precision in their navigation, ensuring that crashes are avoided. The navigation for drones also gets more difficult indoors since GPS does not work in a warehouse environment, calling for other solutions. While the ones implementing the solution said that their suppliers had managed to accurately fix the navigation of the autonomous drones indoors, many other experts lifted the navigation as a challenge for developers and something that needs to improve.

Competing Solutions
One of the located categories for the technology was competing solutions. Since the capabilities of drones are distinguished in analytical and physical capabilities, the competing technology was divided based on the analytical and physical aspects. Besides those two categories, other solutions which were not considered direct technology competitors were located as a third 1st order theme.

Starting with the competing automation technology for inventory management some competitors to autonomous drones were mentioned. Among those were fixed cameras, tethered drones, and

AGVs equipped with a pneumatic mast. One participant mentioned that there is no real competing technology that also is autonomous for inventory management. However, one expert who worked with both AGVs and drones, said that: *"AGVs, I would say are a major competitor to drones and superior in performance. However, they're not as cheap"*. The experts had generally very different opinions as to what degree other technologies were competing with autonomous drones and if there were any realistic autonomous alternatives. For other, potential analytical tasks, such as temperature checks, surveillance and inspections, fixed cameras and sensors, as well as those attached to manual drones, were the most commonly mentioned competitive technology to autonomous drones.

A lot of competing technologies were mentioned for physical operations. Some of those were AGVs, AMRs and conveyor belts, but also other solutions such as forklifts. These were all considered superior to drones in this aspect due to higher payload and longer run times. Some mentioned the trade-off between physical capabilities and costs, stating that even if there would be a feasible solution for autonomous drones in physical operations within warehousing, it would not be cost-competitive to the already existing alternatives. All 15 participants emphasized that for physical operations, there are already other established alternatives that are more competitive than autonomous drones.

Besides competing automation technology for inventory management, other solutions were also listed. These solutions both included manual labor and semi-automated ways of doing inventory management as well as fully autonomous solutions affecting the inventory management process. When it comes to more manual solutions, inventory management done by manually controlled drones were mentioned as well as workers with handheld scanners: *"The competing way is that the co-workers do it manually through their handheld device"*. Both of these could be used instead of autonomous drones. Having fully autonomous warehouses was also listed as a competing solution to autonomous drones: *"And another very big competitor is fully automated warehouses"*. Other experts framed that Autostores or other fully autonomous solutions do not specifically compete for automating the same activities, but that such a solution would make drones obsolete: *"As soon as you automate the process from replenishment to goods are handed out, a fully automated process, then you don't need drones. Then they are obsolete"*.

Some experts meant that the inventory can be properly tracked with sufficient accuracy through WMS which thereby makes drones unnecessary: *"The main thing is still that everything is tracked in the sense that with a modern warehouse management system, you don't need it"*. The four interviewed experts that had implemented the solution, instead stated that the human errors were not taken into account by the WMS and that the accuracy from the autonomous drones was much higher. Thereby, the WMS was not seen as a competing alternative for them.

Risks

When asked about the risks associated with autonomous drones, four main categories were identified from the answers, Physical risks, Safety measures, Economic risks and Security risks. Physical risks were the most commonly lifted category and all 15 of the interviewed experts mentioned this and the different damage it might result in. The most frequent concern was that of drones crashing and physically hurting people, damaging goods, infrastructure (racks etc.), packaging, or the hardware itself. However, there were different opinions as to how severe this risk of crashing is. While some argued that it could be a cause for its restricted usage and hesitation for implementing it in warehousing contexts, others stated that this risk was not considered too severe. With the right and relatively easy safety measures, they could be sufficiently mitigated or eliminated.

The safety measures lifted were mostly regarding the physical risks. One of the implementers mentioned that: *"Yeah, if one of the drones glitched and crashed, for example, which didn't happen very often. I think we lost about maybe over the course of a year and a half, three drones maybe",* indicating that crashes did not occur often. A drone researcher added that: *"Now the risk with a drone is similar. The drone can hit someone. But if you do it outside office hours or outside working hours, then there is no one on the floor. So there's only a risk of damage. The drone flies and hits something, but not someone".* As further confirmed by all the users of autonomous drones, they were only used at night or in closed aisles or areas.

Another aspect lifted was the economic risk of investing in autonomous drones. This risk mostly circulated around the fact that autonomous drones are a relatively new technology with uncertainties, creating insecurities as to whether the investment will pay off or not. Hence, this was more directed towards early adopters and generally being the first to implement new technology. With being an early adopter, some mentioned the risk of becoming too dependent on your supplier which adds to the financial risk. As mentioned by other experts, the risk of new and better solutions emerging after investing in new technology is also something contributing to the economic risks an investment in autonomous drones might bring. Another aspect of the economic risk was its usefulness and if investing in them would pay off, as mentioned by one expert: *"There's uncertainties of how much value you create with this, for some".* The four persons having implemented the solutions stated that for them it did pay off to have autonomous drones within inventory management. However, for other purposes, an expert stated that: *"So we always look at what is the cost and what is the benefit. And the risk is that the cost is higher than the benefits we get from it. So that I think is the biggest threat to drones".*

Other risks mentioned were those of concern for security, such as the risk of drones being hacked or risks related to GDPR. When working with autonomous solutions, the dilemma of who is responsible for it and if something were to happen was also listed as a security risk. As stated by one of the experts, *"You have that data protection issue. So who knows where that video* *recording goes? It could be hacked. Actually today, everything's hacked. "*. However, it was mentioned that this is not specifically for drones but could be a potential risk for several technologies.

Maturity

The maturity of the technology could be divided into two categories, the fact that autonomous drones are a new technology within warehousing and the expectations from the hype of drones.

When asked why the technology was not used to a greater extent the majority lifted the novelty of the technology as one of the reasons: *"No, but it is still quite a new technology"*. Another expert answered: *"So I don't know why. I guess it's just such new technology",* while a third stated that: *"Well, I think there can be multiple reasons. Most of the technology is not, let's see, it's not reaching that high level of TRL [Technology Readiness Level] level yet".* The problems around the newness of the technology were also noted by many when discussing what the greatest challenges for the technology are. The fact that autonomous drones have not been on the market for a long time creates other challenges that according to multiple experts affect the usage of drones. According to the expert from the warehouse containing perishables that invested in drones, there were a lot of false exceptions in the beginning, increasing the work rather than relieving it.

With new technology, there is usually a lack of proven successful cases: *"I think given that it's a new technology, it's not widely adopted, right? So there are not a lot of proven use cases by others that can also hold you back".* When a technology is new and still developing, the insecurities and changes there could also lead to companies being more restricted when it comes to implementing the technology or not: *"I think one of the issues with drones is that they are developing very fast. And sometimes some companies actually take a step back and then they say, well, as long as we don't know, we'd rather not move on"*. Several experts further mentioned that due to the novelty of the technology, the supply chain for autonomous drones in warehousing is not stable or mature yet. There are only a few suppliers today that can deliver the technology as a reliable solution according to them.

The hype of the drones was also mentioned as a challenge that has led to inflated expectations of the technology and thereby could be a reason for its restricted usage. When talking about the hype cycle and where autonomous drones within warehousing are located on this curve, one expert stated that: *"Well, it has not yet reached its plateau, I think, but it might reach its plateau. And then, of course, the trough of deception, I don't know. It will stabilize and it will find a way because it is definitely a place for drones. So it will be more accepted. But right now it's inflated expectations".* The hype was further lifted by another expert who stated that: "*the hype [of drones] is both the enemy and the thing that can drive it or accelerate the implementation*". The hype was hence not only seen as something hindering the technology but also something that could result in its further usage and spread.

4.1.4 The Warehousing Context

This Aggregate dimension summarizes the findings of the warehousing context in which autonomous drones are introduced. Using the information from the interviews, three second-order categories could be formed; decision factors that are considered when choosing automation technology, technology adoption, and warehousing activities. These can be seen in Figure 4.5, together with their first-order themes.

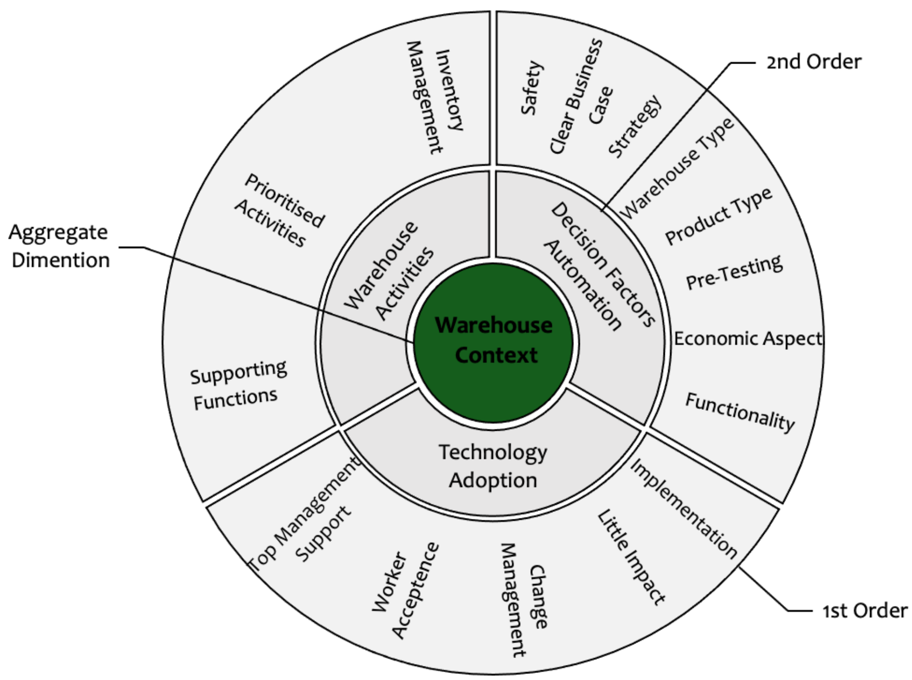

Figure 4.5 The aggregate dimension "Warehousing Context", categorized in second and first-order themes.

Warehouse Activities

Some warehousing activities are more prioritized in terms of automation than others and this depends on the costs that the said activity incurs, as well as how well the process can be automated. Picking was brought up by the experts as one of the most important activities to reduce cost and where a lot of progress has been made in recent years: *"I think picking is the one that is increasing the most and will become more and more important. I mean, all areas will probably be more automated, but the picking part is the one that has accelerated the most lately"*. Another expert mentioned that picking and storage are likely to be automated, saying that Automated Storage and Retrieval Systems (ASRS) is a big thing right now in the warehousing industry: *"If you are an E-commerce company in Sweden, you can always pick an*

AutoStore and no one will say you did a wrong pick. It's probably not the best pick, but it's always a decent pick. So it's like a safe choice right now".

In relation to other activities in the warehouse, inventory management is not the most prioritized one according to one of the experts: "*...it's not a big problem with inventory anyway".* Another expert added that inventory controls are not done that often in comparison to activities such as put-away or picking, which are done daily. These opinions were mainly mentioned by those not being part of implementation projects. Some participants instead say that warehouses usually have a problem with accuracy, and that improving it greatly improves your operations. The expert who implemented drones for their DC of food and groceries said that inventory management is very important for them since improved accuracy of stock reduced their costs of obsolete products. One expert from a company that had implemented drones also said that inventory management is important for them: "*... it's not our inventory, but it's the customer's inventory. So we want to have the most reliable inventory levels and accuracy, but also for operational benefits. If your inventory is correct, you will never have a picker not finding his inventory or someone who's doing put away not finding an empty spot".*

Supporting activities in the warehouse, such as security checks, inspections of the roof and racks, and climate checks, also has a purpose. These are not done that often but still need to be done to ensure the safety of the people in the warehouse as well as the goods it stores. Several experts mention that these activities are done visually and that a drone could automate them. For some warehouses, certain supporting activities are more important due to specific safety regulations: "*We always have to make sure that there is no damage, there's nothing that has happened to the racking. So this is also something we need to control all the time. And it takes a lot of time and it's very manual".*

Decision Factors New Automation

When asked about what aspects that influence the choice of automation, the economic factor was considered the most important, where eleven participants, and everyone in the warehousing panel, mentioned this. For executives to green-light the decision to invest, there first of all needs to be a clear business case with an ROI that is acceptable: *Of course, we need to get a business case and show that we have a return on investment within a certain amount of time".* Another expert mentioned that the functionality of the solution is most important. The technology needs to work and perform what it is supposed to do without major hurdles. How the solution completes the task is less important: *"If this thing helps me, I'll use it. If it doesn't help me, it'll just sit there. I don't care how new it is. It must help me. It must work. It mustn't get in my way. It mustn't irritate me. I'll use it. If it irritates me, I'll just use a pen and paper".* To ensure that new automation technology will improve your operations, it is beneficial if the solution is triable. Pilot testing and demonstrations can increase the confidence in the solution.

Characteristics of the company and the warehouse, as well as the type of product it inhabits, are also factors that influence the choice of automation. When asked about what type of companies that invest in new automation technology, one expert argued that a company with a strategy focusing on innovation is more likely to invest in new automation technology: *"I think it's related to the strategy of the company and how much focus they have on innovation".* The type of warehouse and the challenges it faces also affect the choice of automation technology. The scale of warehouse operations is one of these factors, according to the experts. Furthermore, the type of products also has an effect on which automation technology is suitable. Experts mentioned that the solution differs depending on the uniformity of products and whether it is the handling of full pallets or separate pieces that is to be automated.

Another reason for automating warehouses that was mentioned is to increase safety: *"Safety is important for some customers, they always talk about safety. It's very important".* As further confirmed by one expert, automation could be a way of increasing safety by reducing the risks: *"...you can maybe reduce some of the risks and make automation solutions do that instead".* Some experts were, however, critical to how important this aspect is for companies when looking into new solutions, but the majority found this to be a factor that affects the decision.

Technology Adoption

When it comes to the adoption of new technologies or any technology at all in the warehouse, several pieces need to be in place at once: *"...it's all four dimensions. It's the technology, it's the people, it's the data and the process. All of that needs to be developed together"*. Support from top management was mentioned as a crucial aspect for adopting a new technology and getting resources in place. For the technology to be accepted on an operational day-to-day basis, the workers in the warehouse must see the benefits of the new solution. If people see the improvements from a solution right away and understand why their tasks will be replaced, the acceptance of the technology will be much faster.

The implementation phase is, according to the experts, very important for a successful adaptation of new technologies and solutions. Adopting new technologies leads to operational changes in the warehouse, and for new processes to form. For implementing drones, one of the four implementers mentioned that: *"the major one is change management, getting people to accept but also to change their behavior in relation to cleanliness and discipline".* Change management is important for all changes and is necessary for ensuring productivity and employee satisfaction. Changes with lower levels of impact will make it easier for employees to adapt to new ways of working and shorten the implementation phase.

4.1.5 The Future

The future category consists of both the aspect for autonomous drones and the aspect for warehousing in general, which can be seen in Figure 4.6. When it comes to the future of autonomous drones, use cases, expected improvements and needed improvements of the technology are included. For warehousing on the other hand, future challenges and warehouse requirements were lifted and included in the future category.

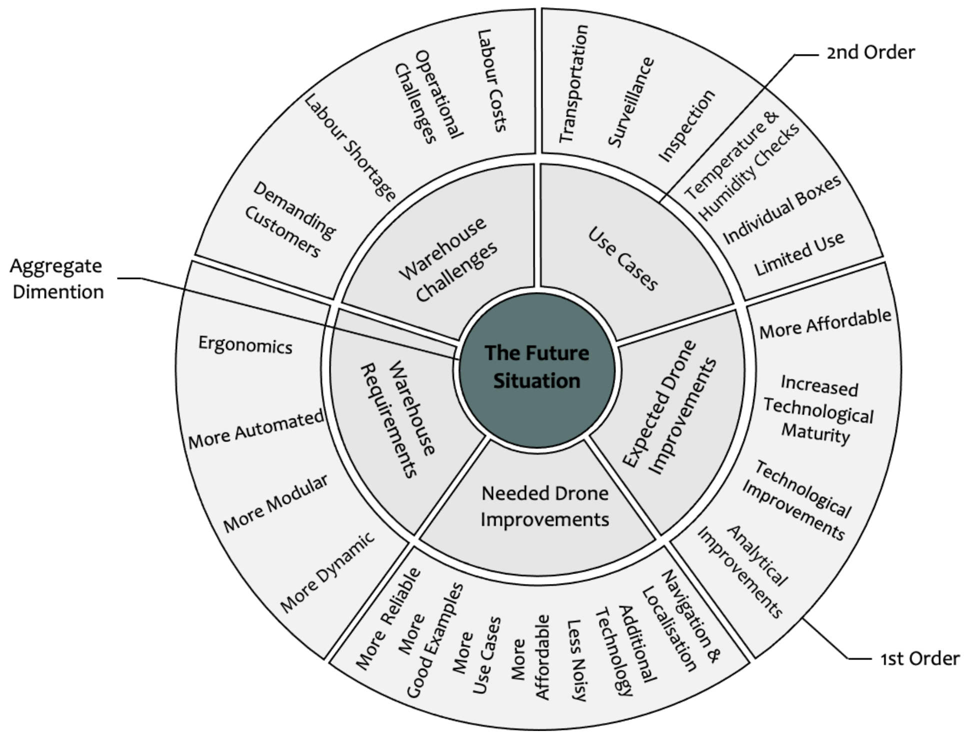

Figure 4.6 The aggregate dimension "The Future Situation", categorized in second and first-order themes.

Future Use Cases

During the interviews, potential future use cases were discussed and the ones that were lifted were transportation, surveillance, inspection, monitoring, temperature and humidity checks and counting loose boxes. Another theme among the interviewed experts was that there did not seem to be so many more potential use cases for autonomous drones than there already are, which is within inventory management.

A few participants mentioned that drones could potentially be used for special transportations of smaller objects in the future. However, this would only be for special occasions and not for automating the whole transporting, picking or put-away operations. Having autonomous drones perform physical activities in terms of lifting or transporting objects in these operations is not realistic with the current limitations of the technology, and is neither seen as a feasible alternative for the feature: *"We also asked them [the supplier] how long it will take for them to come up with a drone for picking. But that's never going to happen"*. Another expert stated that: *"Drones will most likely not solve any picking topics. But it can impact and support the availability of the goods"*. These transports should according to one participant only be for special occasions and when time is of essence: *"If there is something that is time critical and needs to be brought somewhere. This is where I would see potential for using drones because they are really fast"*. However, the usefulness of this kind of transportation within warehouses was questioned: *"We will talk about moving small packages. So for me, it's hard to see, unless you have some very strange special occasion where you need to move things from one side of the building to the other and it's not high volume, but you don't want to drive it on the floor. I cannot think of one"*.

In some of the interviews, surveillance within the warehouse was also mentioned as suitable work for autonomous drones: *"And another thing where I think drones have a potential, in a warehousing context, is surveillance and data capturing. And again, I think one benefit could be lower costs"*. Another way of collecting data could be through sensors measuring temperatures and humidity which was emphasized by one expert:*"We have pharmaceutical warehouses where we have to actively monitor the temperature or the humidity. The drones are flying up high anyway, why not have them checking that as well? Racking inspection, security inspection, security walks and fire sprinklers could be done while the drones are there anyway. So we're looking into these kinds of developments"*. As mentioned, other use cases could also be inspections of racks, sprinklers or the facility. Two participants working with the solution mentioned that this feature is being looked into.

For these additional data collecting features such as surveillance, temperature and humidity checks and inspections, the necessity of using autonomous drones was discussed. When asked if there is any point for inspections of the facility, racks, and sprinklers to be autonomous one participant answered: *"That would be manually controlled. So there is no point in having it automated then"*. While some experts meant that these kinds of inspections are done too seldom for it to be necessary to have autonomous drones, others stated differently: *"We always have to make sure that there is no damage, there's nothing that has happened to the racking. So this is also something we need to control all the time. And it takes a lot of time and it's very manual. So we are looking into how to use drones to do that type of checks as well"*.

One of the previously mentioned limitations of autonomous drones was that they currently only can count full pallets. However, some of the participants working with autonomous drones said that a solution for counting loose boxes as well would probably be rolled out later this year. With this, autonomous drones could also do inventory checks for picking locations: *"So that is huge. We can count so many locations, but if we can add the picking locations, that will be huge. But that's still under development. But we expect that to come this year. So it's mostly inventory now, but also and that's, again, already going to the future features"*. Other experts also mentioned that a feature for counting loose boxes would be very useful and the possibility of using the technology for picking locations will increase its usefulness.

Apart from the mentioned future usage areas that could come for autonomous drones, experts also seemed to agree that the main operation for drones is within inventory management: *"Drones are being mostly used for automating tedious or time consuming processes. So that's an advantage in inventory management or stock taking, which is quite tedious. But apart from that, for other tasks, they're just too expensive. The battery runtime is too low and they are dangerous. So there's no point in using them as of now"*. More experts agreed that even though some improvements and additional use cases could be added for autonomous drones, their main use case has already been discovered within inventory management for warehousing.

Expected Drone Improvements

When looking at the expected future improvements the technology will undergo, the common themes mentioned in the interviews were becoming more affordable, more mature, and that it will improve in a technical, physical, and analytical aspect.

With the increased production of the technology combined with less research and development costs involved, autonomous drones are expected to become cheaper in the future than they are now: "*Once it's [autonomous drones] getting more and more popular, more companies are using it. When the new technologies are ready, we can reduce the weight and also reduce the hardware requirement of the drone itself, then I think those costs can be reduced a lot"*. However, one expert mentioned that the raw materials for autonomous drones may become more expensive due to shortage of certain components since everything is being electrified. The most common understanding among the experts was that the technology would become more standardized in a warehousing context and thereby more affordable: *"But I would expect them to be more and more affordable and I would expect the benefits to grow as we have more use cases along the way"*.

Several participants mentioned that the hype will fade and unrealistic expectations will be replaced by insights and better knowledge of the technology in the warehousing setting: "*It will become more natural. I think the hype will fade out, so to say. It will not be considered as something extraordinary"*. Another expert also highlighted that the technology is expected to become more mature: "*So it's getting more known and in that sense it will be bigger"*.

When it comes to the technical and physical improvements, the most commonly mentioned improvement was that of the battery and battery time. With an expected increased battery time, experts further predicted that this would increase their usefulness and efficiency: *"There is research going on now that looks into two completely different batteries where you have maybe four times the capacity. But then the battery size will become much less, the battery weight will* *also be much less. So as time goes on, we will probably see more and more efficient systems".* Experts further expect that drones will become safer in the future, partly because of the drone becoming more lightweight. Improvements of the additional technology was also lifted: *"I think there will definitely be an improvement in the cameras and there can be an improvement in the cameras and scanners which will help to scan faster. So, your drone can do more in the available time".* Another researcher further pushed the rapid development of cameras and sensors. One expert talked about research on the propellers being done with the hopes of getting more silent drones and thereby making them less disturbing for people. While these technical improvements were lifted, experts were skeptical that drones within warehouses would be able to lift significantly heavier weights in the future: "*we can start thinking about picking actual boxes. But then you will need the drone the size of a reach truck. So don't bother".* As mentioned by this expert and many more, a drone that potentially could lift heavy objects would not be feasible in a warehousing context.

Some analytical improvements were mentioned regarding the software, positioning, and localization technologies. Specifically, the ones researching drones stated that due to the rapid development in the drone industry and a lot of research being made, the software, as well as the hardware, are expected to improve a lot in coming years.

Needed Drone Improvements

When asked what it would take for drones to be used more extensively in warehousing, common themes identified from the participants were the need for improved navigation systems, improved additional technology, that they would become less disturbing, more affordable, more use cases for them, more good examples and higher reliability.

During the interviews it was mentioned that the navigation for autonomous drones indoors needs to improve and become more accurate: *"The navigation needs to improve. I think that's the critical part, the battery and the navigation. Yeah, if that can become a lot easier and a lot longer, then if drones can become more affordable, you can start using swarms, which means you can have multiple drones".* It was further stated that there are not many suppliers which have an accurate positioning of their indoor drones. One of the implementers of the technology specifically mentioned that the software needs to be improved to become more accurate. Higher reliability of the technology, both in terms of its physical and analytical performance was also mentioned as a required improvement.

The need for improvements in the additional technology was brought up as well: *"You need both better IT and better cameras, better use of the cameras, better software and better hardware and reduce the noise. So there are many points of improvement potentially still".* Experts also pointed out that drones are noisy and need to become less disturbing to work around moving forward.

When asked if and when a breakthrough for drones will come, one expert said: *"As soon as we will have the forerunners now being capable of showing more of the advantage of drones more companies will start to invest in drones"*. Another similarly stated that: "*If other companies see the benefits and see how useful this kind of solution is, it will be adapted more and more"*. In total, twelve of the experts expressed the need for more good examples for organizations and companies to follow in order for the technology to become more widely used. Experts also said that in order for the technology to be used further, it needs to become more affordable while others said that more use cases for the technology will be needed: *"And then as well from a price level, it needs to become more affordable, then I think it's going to be normal to have drones for this kind of processes in warehouses. I don't see any reason why not"*. This was mentioned by four out of fifteen experts where some mentioned the research costs that usually make a new technology more expensive in the beginning but which will decrease over time.

Future Warehouse Requirements & Challenges

Regarding future challenges in warehousing, the requirements for more dynamic, more modular, and more automated warehouses were lifted. It was mainly the experts in the warehousing panel that lifted the need for warehouses to become more modular and dynamic to meet the future needs from customers: "*There will be a pressure of more dynamic warehouses for the future, being able to handle different needs and a fast shifting market"*.

When talking about future challenges it was said that the challenges will mostly be seen in the manpower-heavy operations of warehousing, such as picking, put-away, receiving and shipping. It was further stated that there is currently, and will become an even bigger labor shortage in warehouses in the future: *"Standard challenges are finding labor, affordable and skilled labor, I think this is one of the greatest challenges for nearly every warehouse or nearly every operation"*. This was mainly concerning workers for doing physical labor. Similar to this, increased labor cost was further something that specifically the experts in the warehousing panel highlighted: *"Also there you have various challenges, right? If you are thinking about how few people are available on the labor market. So that's a big one. And from a capacity perspective, the demand towards warehouses is constantly increasing. It is simply a fact that our buying behavior is changing. And with that, the requirements for warehouses are increasing"*.

During the interviews it was also said that warehouses will become more automated in the future and that the trend goes towards more automation. This trend is driven by labor costs and labor shortages, forcing warehouses to find new ways of operating. Another reason for increased automation is the requirements of warehouses being more dynamic and responding faster to the market, which can be seen in the quotations presented. Worth noting is that these expected requirements, challenges, and the trend towards more automated warehouses depend on the geographical location of the warehouse, and as stated by the interviewed experts, is expected to look different around the world.

4.2 Analyzing the Interviews With the Conceptual Framework

The analysis of round 1 was made by combining the empirical findings from the interviews with the conceptual technology adoption framework presented in chapter 3. This resulted in 23 key findings that are presented as hypotheses, see Figure 4.7.

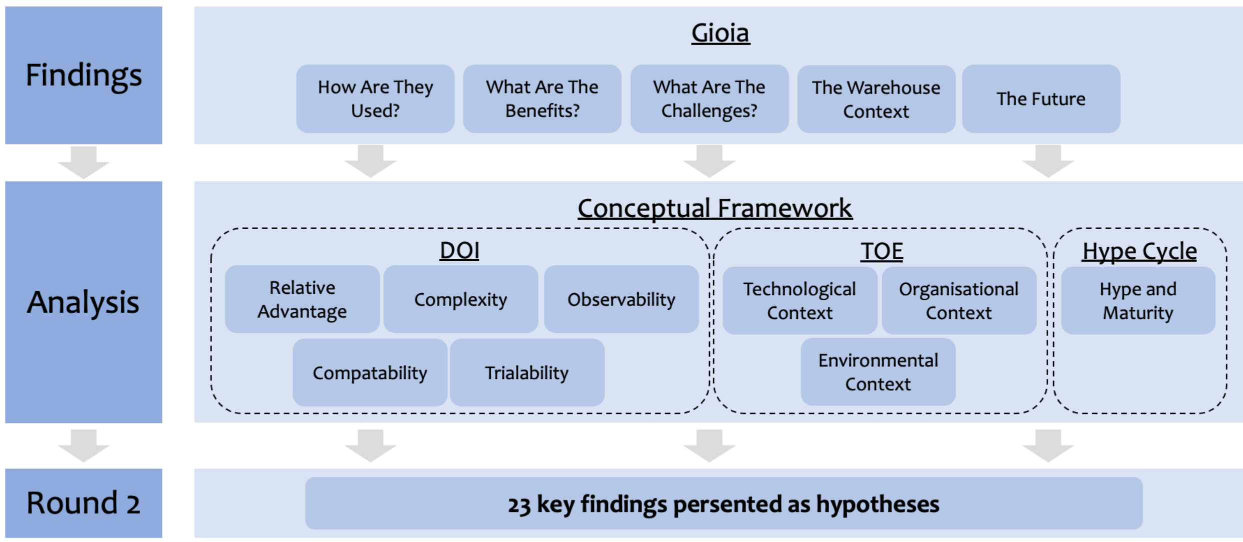

Figure 4.7 The analytical process of round 1.

4.2.1 DOI

Relative Advantage

When talking about the relative advantage, the most common aspect that is usually determining the relative advantage is the economical (Rogers, 2003). Given that eleven of the participants and 100% of the warehousing panel also lifted that the main focus from warehouses when choosing automation technology is how much it costs, how big of an investment it is and what the return of the investment will be, it confirmed that the economic aspect should be one of the main considerations when looking at the relative advantage for autonomous drones. In doing so, six of 15 listed the affordability as one of the main benefits with autonomous drones compared to other automation technology. However, four of 15 lifted that in order for the technology to be used more widely it needs to become more affordable. These answers were all for the currently existing use case of drones, in inventory management.

It is not only the cost of the technology and investment that is included as an economic aspect in the relative advantage but also the cost savings and reduced costs that it brings. Previous studies have listed increased cost efficiency (Tsai et al., 2010) as a relative advantage where factors such as reduced stock loss and freed human assets have been lifted. Similar features mentioned for autonomous drones during the interviews were that the technology can reduce both labor and operating costs in inventory management, they can enable workers to put their time to more value-creating activities instead of doing inventory checks, and human errors and lost pallets resulting in obsolescence can be prevented.

Convenience and Satisfaction are also indicators of the relative advantage for an innovation (Rogers, 2003), which could be seen in the effects a technology has on the operations. Improved inventory replenishment or increased product security (Tsai et al., 2010) could be one of those. Improved quality of operations or tasks made quicker are also factors that have been mentioned as relatively advantageous for an innovation (Oliviera et al., 2014). This was also confirmed by the experts who stated that the actual functionality of a solution affects the choice of implementing it or keeping it. The mentioned speed for drones and the increased task speed obtained by them thereby speaks for their relative advantage. In this aspect, the drones mentioned flexibility in all three dimensions combined with it being lightweight, enables its performance and further offers an advantage to the technology compared to other alternatives. It was also mentioned that the technology can improve accuracy which results in operational benefits. Even though some experts stated that a WMS or other tracking systems would give a good enough accuracy to the stock, the most common opinion was that autonomous drones result in better stock accuracy since a WMS does not take human errors into account.

Another advantage mentioned in the interviews that autonomous drones bring is increased safety. By automating tasks done on heights, such as inventory management, workers can be prevented from hurting themselves while doing dangerous tasks. This further goes in line with what has been mentioned in previous literature about the benefits of drones in industrial purposes (Maghazei et al., 2022; Maghazei & Netland, 2020). Increased safety was also lifted as a reason for automating warehouses in the interviews, implying that increased safety could be regarded as a relative advantage for warehouses. However, there are two sides to the safety aspect since safety issues with having autonomous drones operating in warehouses also were lifted. Considering that the technology operates when no one is at the site, and all four of those who had been a part of an actual implementation of autonomous drones in warehouses confirmed this as well, it indicates that safety is not an issue with the right risk mitigations taken.

The numerous different advantages listed for autonomous drones within inventory management in terms of economic benefits, operational improvements, functionality and improved safety indicated that they do have a relative advantage. Hence, this resulted in a first hypothesis being formed.

***H1.** Autonomous drones have a relative advantage compared to current ways of conducting inventory management which speaks for its further usage and growth.*

Other activities listed as possible use cases for autonomous drones were monitoring, surveillance and inspection. Some of the participants working with the technology in their warehouses mentioned that this feature was being looked at for autonomous drones. This would then be an additional feature where the drones could do inspections or checks of temperature and humidity while doing inventory checks. It was lifted from some experts that warehouses generally are not interested in these kinds of activities on a regular basis. One expert having implemented drones in warehouses stated that there was a risk when looking at additional use cases that the costs would be greater than the benefits. Experts also stated that there are other alternatives that would be more competitive than autonomous drones for inspection and surveillance purposes such as static cameras. However, the participants talking about this upcoming feature reasoned that it would be a good addition to their autonomous drones. There was not any clear relative advantage lifted for autonomous drones in this application area and combined with previous discussions a second hypothesis was formed.

***H2.** Activities such as inspection of racks, sprinklers, etc., temperature checks and surveillance are done too seldom for it to be beneficial to have autonomous drones solely for this purpose.*

Compatibility

One factor that could speak of the compatibility of an innovation is that of the compatibility with current technology and technical systems in the warehouse, software and hardware (Tsai et al., 2010). In the interviews it was mentioned that autonomous drones are relatively easily integrated with warehousing systems and that there should not be any problem with its compatibility in this aspect. No arguments speaking against this were lifted, hence a third hypothesis was formed.

H3. The ease of integrating autonomous drones for inventory management with other warehousing technology and systems makes them compatible which speaks for its further usage and growth.

Another aspect to compatibility, is how well it fits with values and current ways of doing business. Even though workers can react negatively towards new technologies, the majority of experts stated that workers and people in the warehousing environment generally reacted positively towards it and that human integration was successful. As further mentioned by the experts, this is an important aspect in order for a technology to be successfully integrated. This indicates that the technology is compatible in this aspect. However, another aspect lifted by all 15 participants was that drones can crash and hurt workers. Due to this risk and also the technical limitations for autonomous drones in recognizing workers that move around, the technology is currently being used when no one is around. Aspects such as closing specific ailes or other parts of the warehouse while they were operating there was lifted. Further, it was stated by experts that the autonomous drones were operating at night while no one was in the warehouses. Because of this, drones were not considered to disturb daily operations but instead be in line with current business operation activities for these companies.

A technology being fully adaptable with existing business operations is a factor speaking for its compatibility (Oliviera et al., 2014). However, since not all warehouses are closed down during the night the technology might not be as compatible with these types of warehouses. This divided compatibility with the workers depending on the opening hours for the warehouse resulted in a fourth hypothesis.

H4. Due to risks associated with having drones operating next to workers and the disturbances it might cause for operations, autonomous drones are not suitable for warehouses that are operating around the clock.

Complexity

The complexity aspect includes the perceived complexity from a user perspective and takes the workers perceived complexity of the innovation into account. That the technology or the implementation of it requires skills or knowledge which is too complex for the workers or that the technology requires a lot of effort mentally, are aspects that can be seen as increasing the complexity (Oliviera et al., 2014). For autonomous drones eight of 15 experts mentioned that the technology is easy to understand and use in the warehouse from a user perspective, indicating that no complex skills or a lot of mental effort are required for the workers. As further stated by a drone researcher, given that the technology is autonomous there are no complex required skills for the ones working with it even though the solution in itself is rather complex. From this, the fifth hypothesis was formed.

H5. The autonomous drone is easy to understand and use in inventory management, therefore the relative complexity of the technology is not a reason for its limited usage.

Observability

Starting with the technology, it does not only consist of software but also hardware actually moving around in the warehouse, making it possible to visually see the autonomous drones work in terms of their routes, speed and being able to observe if they crash. This contributes to an observability of the technology and how it operates which can give an idea of the performance. Even if the hardware and the performance of that is observable, the observability aspect also includes how visible the results and data are. In the interviews it was mentioned that measuring and monitoring the performance of autonomous drones in warehouses is easy. Four of the interviewed experts, having participated in an actual implementation of autonomous drones in the warehouse, all argued that it was easy to see the improved results when it came to accuracy. Even in the beginning phase when the accuracy of the drones was not yet optimized, the results in terms of how many pallets scanned and so on were easily measured. Furthermore, according to the ones that have implemented autonomous drones, the data that the drone collects is all visible in real-time, making it even more easy to monitor its procedures. With this, a sixth hypothesis was formed.

H6. Even though the performance is easy to measure and observe for autonomous drones in inventory management, the insecurities about what value they bring to a company could be limiting its usage.

Trialability

Trialability can be of different importance depending on how much the technology has already been implemented. As mentioned, relatively early adopters perceive trialability as more important than later adopters (Rogers, 2003). Five of 15 mentioned that pilot projects and beforehand testing are easier with autonomous drones compared to other automation technology. Beforehand testing was also mentioned as a factor that affects the decision of what automation technology to choose, since companies prefer to test a technology before implementing it in full. The ways of testing the technology that was brought up in the interviews were by doing demos, pilot projects and testing with manual drones. The fact that the technology is easily scalable also makes it easier to test the technology and implement it gradually. All of these different ways of trying the technology before implementing it at full speaks for its high trialability. From this a seventh hypothesis was thereby conducted.

H7. The ease of trying the technology beforehand with manual drones, demos, and pilot projects for inventory management, advocates for its further usage.

4.2.2 TOE

Technological Context of Adopting Autonomous Drones

As mentioned in the interviews, drones are not suitable for fully automated warehouses and would be better suited in more manual warehouses. From the interviews it further became clear that there were not a lot of additional investments needed when adopting autonomous drones, in terms of no major infrastructure or additional technology required, leading to a relatively low investment cost. The fact that there are few technical requirements needed before implementing autonomous drones, indicates that this does not provide a limit for its adoption or who is suitable for the technology (Baker, 2012, pp.232).

Given that the characteristics of the technology affect the technical readiness required of the company, the analysis from the DOI framework affects this aspect as well. The technology was considered to have a relatively low complexity combined with a relatively high compatibility, which in line with the determinants mentioned by Ghobakhloo et al. (2022) points to a low technical readiness. These arguments resulted in the following hypothesis.

__H8.__ The low level of technological readiness required for companies to adopt autonomous drones makes the solution accessible for more warehouses, advocating for its growth.

Organizational and Warehousing Context of Adopting Autonomous Drones

The organizational context of strategy, structure, and resources, amongst other factors, that are in place in an organization will determine the support of adopting a new technology. One of the aspects that highly influence the adoption of new technology is the support of top management. If executives understand and recognize the benefits of the solution, resources can be allocated towards its adoption (Oliviera et al., 2014). During the interviews, several experts argued that the return on investment (ROI) is one of the most important factors of gaining executive support when investing in new automation technology. Those that implemented the solution argued that since an accurate inventory was of especially high importance, inventory management could be done more frequently by implementing drones. The drones could thereby reduce the cost of labor put into managing inventory and resulted in an attractive ROI, which they argued made the business case strong enough to adopt the solution. Experts in the study that had not been part of those implementations argued that inventory management is in general not performed very often, making it difficult to create a business case. The usefulness of the solution does therefore depend on the level of accuracy needed in the warehouse and the importance of inventory management. As mentioned by Bartholdi & Hackman (2010), some warehouses are in greater need of inventory management tasks than others, such as those containing perishable goods. This was confirmed by the expert from the food and grocery company who stated that autonomous drones created an extra value for them by locating lost pallets that otherwise would go out of date if not found and incur costs of obsolete products. From this the following hypothesis was formed.

__H9.__ Autonomous drones for inventory management are only useful for companies that do inventory checks often or where an accurate stock is of high importance.

One theme discovered from the interviews was the economic risk that could be associated with investing in autonomous drones. As mentioned, this was mostly due to the novelty of the technology and the uncertainties that follow with a new technology, both in terms of the value they bring and the lack of maturity throughout the supply chain. This further goes in line with the theory of new technologies, where the uncertainties of the economic potential for emerging technologies are emphasized and mentioned as a reason to companies being hesitant to adopt it (Kapoor & Klueter, 2021). The different types of adopters lifted in the DOI framework by Rogers (2003, pp.257-259) which can also be seen in Figure 3.3, are stated to have different characteristics and the ones being early with adopting a new technology are willing to take more risks than the later ones. All of these arguments summarized, in combination with the majority of the experts stating that the economic factor is the most important to consider when investing in new technology, led to the following hypothesis.

__H10.__ The financial risks and uncertainties of investing in autonomous drones now are too high for companies to engage.

Ghobakhloo et al. (2022) state that one of the organizational determinants for technology adoption is the organizational culture, including the employee resistance to change, resistance to diffusion of new technologies, and social security concerns of employees. Implementers of the drone solution for inventory management said that employees did not show any concerns of losing their job to the automation technology. Since the drones performed the monotonous tasks, the employees could work with more stimulating and value-creating tasks. Implementers of drone technology also said that the technology didn't come with very large changes for the employees since the drones operate outside operating hours, making it easier to accept. Further, they mentioned that no major changes in terms of change management were needed for its successful implementation, the biggest being removing plastic wraps hanging down from pallets which could risk drones crashing into them, and urging operators to place pallets with the label facing out so that the drones could scan them.

__H11.__ Implementing autonomous drones within warehouses does not require any big organizational changes which speaks for its growth.

The organizational structure and type of business are reportedly factors influencing the adoption of Industry 4.0 technologies (Ghobakhloo et al., 2022). In warehousing, this can be seen as the warehouse structure and the goods it stores. The experts interviewed mentioned that the goods stored in the warehouse and the structure of the warehouse, such as rack configuration and level of automation, need to be factored in when determining whether to adopt the technology. Since the drones are unable to fly inside the racks, they can only scan the labels on the pallets from the aisles, meaning that the racks have to be single deep in order for the drone to count all pallets. The participants also mentioned fully autonomous warehouses would outcompete autonomous drones. Evidently, the participants state that the warehouse configuration is a limiting factor to where autonomous drones for inventory management are suitable. With the mentioned limiting characteristics, the following hypothesis was formed.

__H12.__ Autonomous drones are only suitable for warehouses that are manual or semi automated and for warehouses that use single deep racks and a majority of full pallets, which is a reason for its limited usage.

Environmental Contexts Affecting the Adoption of Autonomous Drones

The importance of inventory management in relation to other activities was something that was lifted by the participants. Experts argued that increasing challenges of higher customer demand and changing purchasing behaviors put a lot of stress on warehouses, forcing them to become more efficient. Several experts also argued that picking will be a challenge in the future and that it is probable to see continuous efforts to automate this activity. Further, picking stands for the majority of operating costs, 55% (Bartholdi & Hackman, 2010). Some of the experts mentioned that inventory management activities are seldom done in comparison to others, such as put-away and picking. Given that participants mentioned that warehouses will choose the investment that makes the best business case, inventory management might not be a prioritized activity to automate according to them. Hence, a 13th hypothesis was made.

H13. *Autonomous drones are not used more widely in warehousing since companies are more focused on automating other operations than inventory management.*

In the warehousing industry there are also challenges of labor shortage and high labor costs driving the trend towards automating warehouses. Several of the experts mentioned that the constraints of limited workforce availability and the high labor costs are pushing warehouses to find new ways of performing warehousing operations. This corresponds with the literature which states that an industry climate characterized by labor shortages and high labor costs drives innovation and adoption of new technologies (Baker, 2012, pp. 235). Autonomous drone solutions for inventory management were according to those that implemented it a way of cutting down on labor costs and allowed workers to focus on more value-creating activities. As stated by Bartholdi & Hackman (2016), warehouses in Europe are generally characterized by inflexibilities of the workforce and relatively high labor costs. The experts that implemented autonomous drones started their projects in high labor cost countries and areas with limited labor availability. This resulted in the following hypothesis.

H14. *The increase of warehousing challenges in terms of increased labor costs and labor shortage speaks for the increased usage of autonomous drones in inventory management.*

In terms of inventory management, competing technology to drones was discussed during the interviews. Different examples were lifted such as AGVs, tethered drones and fixed cameras. In general it was not clearly stated in the interviews how much these technologies were competing with drones within inventory management. One of the interviewed experts working in a drone company who also developed AGV solutions for inventory management stated that AGVs were more popular with the customers in his experience. Given this general unclarity, a hypothesis was made to receive answers from the whole panel of how influential competing technology is for the usage of autonomous drones.

H15. *Competing automation technology for inventory management is a reason that drones are not used to a greater extent in warehouses for inventory management.*

During the interviews it was further stated that autonomous drones are not suitable in fully autonomous warehouses with warehousing solutions such as autostore. Another theme noticed in the interviews was that warehouses are expected to become even more automated in the future.

This further goes in line with the literature of future changes within warehousing (Kembro & Norrman, 2022). With a trend pointing at more and more fully autonomous warehouses in the future, autonomous drones would become obsolete, leading to the following hypothesis.

H16. *It is likely that more warehouses will become fully autonomous in the future, making autonomous drones for inventory management less relevant.*

4.2.3 Hype Cycle and The Maturity of Drone Technology

Being a relatively new solution in the warehouse context, there are high expectations on what benefits autonomous drones will bring. As one participant mentioned *"the hype [of drones] is both the enemy and the thing that can drive it or accelerate the implementation"*. High expectations on technology without sufficient evidence in the form of good examples and successful implementations can make companies hesitant to invest but the hype itself could also be convincing enough for companies to invest early and direct resources towards its development (van Lente et al., 2013). Four experts, representing three different companies in the study, reported successful implementations of autonomous drones, all of which were used for inventory management. However, many of the participants mentioned that there still is a need for more good examples for a larger group of companies to follow. One expert said that those implementing drones now most likely have a special need or environment that makes autonomous drones for inventory management useful. Thereby a factor explaining its limited usage for inventory management purposes could be that there is a lack of sufficient evidence proving its value. This could inhibit companies from investing, thus the following hypothesis was made.

H17. *The hype and inflated expectations of autonomous drones without sufficient evidence of its usefulness and proven successful examples for inventory management is one reason that the technology is not used more widely.*

Several of the interviewed experts acknowledged that the technology for using autonomous drones for inventory management purposes exists and that there are operational examples. When asked why the solution is not more widely adopted, many of the other experts said that the technology is not mature enough for large-scale adoption. The warehouse containing perishables that invested in drones mentioned that there were a lot of false exceptions in the beginning that increased the work rather than relieving the workers due to software and accuracy issues. A technology where there are inherent flaws left can be considered as not having reached maturity yet (Forbes, 2022). The other participants that had implemented drones reported that they had managed to reduce the flaws in their solution. In the slope of enlightenment in the hype cycle, some successful cases where net benefits are observed, emerge amongst the early adopters although the total number of companies that have implemented it are small (Dedehayir & Steinert, 2016)

Another aspect brought up by the experts is that even though the solution is affordable in comparison to other solutions, the technology still needs to become cheaper. According to them, R&D costs are currently making the solution too expensive for more companies to invest. One of the companies that invested in drones for their warehouses said that the solution will probably not be implemented in their DCs due to higher costs and reduced usefulness. The experts also mentioned that the number of vendors available that can deliver a solution that is operational without inherent flaws are highly limited. This can be compared to the literature regarding the maturity of a technology which states that the number of vendors are limited for technologies that yet have to become mature (Dedehayir & Steinert, 2016).

H18. *The technology is still not mature enough for it to be widely adopted in warehouses for inventory management.*

4.2.4 A Holistic View and Future Expectations

Based on the analysis that has been made for respective parts of the DOI model, TOE framework and the Hype Cycle, a total analysis was conducted. This was done to get a better understanding of how the autonomous drones will be used going forward.

According to the experts, the hope that drones will be able to perform several tasks to improve warehouse operations is very high. However, the use cases for drones that actually work today are slim and this was lifted by some participants as a challenge for the technology. Activities that can be automated with drones are today limited to inventory management. Many of the experts also stated that the technology is most suitable in inventory management and that they could not see any other use case for autonomous drones that could not be solved with other technology. Looking at the application for inventory management, the technology was considered to have a relative advantage, a relatively high compatibility (depending on the warehouse), low complexity, and relatively high observability and trialability. Hence, inventory management was considered the most suitable application, resulting in the following hypothesis.

H19. *Autonomous drones are most likely to be used for Inventory Management in warehousing in the future.*

For inventory management tasks, the usage of autonomous drones is also limited today. In this case to scan full pallets and not individual boxes and pieces which is not yet possible. Since several independent participants mentioned that this solution is on its way, it might soon become a reality. It can then be argued that the use cases would increase and that more companies will follow in the implementation of the technology. Since this could lead to more solid business cases that advocate for drone usage, the experts argue that its actual usefulness will increase, pushing the technology up the slope of technology maturity (Dedehayie & Steinert, 2016). This thereby resulted in the 20th hypothesis.

H20: *Being able to count individual boxes, and not only full pallets would increase the usefulness of drones for inventory management purposes.*

Using autonomous drones for physical operations is less likely to happen according to the experts. According to them the technology is even less mature for the physical operations and there are no pilot projects where drones have been tested for transporting or picking according to the knowledge shared in the interviews. Some experts mentioned that the technology could be used for special transportations of smaller objects in the future. Since this would only be for special occasions, and not a way of automating any standard procedures in warehouses, the experts were skeptical about the usefulness of this type of solution.

One of the experts who is a researcher on drones argued that drones can lift around 30 percent of their own weight. However, equipping the drones with additional technology, such as a function for picking would reduce the weight it can transport. The experts also lifted the restrictions that come with an indoor environment, in terms of size and weight of the drones, both for feasibility and for safety reasons. These restrictions would further limit the possible payload, which would only make it suitable for warehouses that store lighter and smaller objects. Because of the technical limitations, creating a solution that would properly perform physical operations such as picking, put-away and transporting, while simultaneously being suitable for a warehouse environment, was thereby not considered realistic. As mentioned by one of the experts: *"We also asked them [the supplier] how long it will take for them to come up with a drone for picking. But that's never going to happen"*. Besides the feasibility, another expert argued that the level of how autonomous such a solution would be is highly questionable and the drones would likely be manual or semi-automated for this application. Hence, the following hypothesis was formed.

H21. *Because of the technological limitations (payload, battery time, size), autonomous drones are unlikely to be used for physical operations within warehousing in the future.*

Besides the technical limitations of drones, experts also mentioned that there already exist good alternatives on the market for automating these kinds of physical operations. Given that drones are airborne, more energy is required for lifting objects compared to ground-based solutions, making drones less energy efficient for this application. Further, given the tradeoff mentioned between weight, flight time, cost and payload, a solution like this would be very expensive according to the experts. In combination with the previously mentioned feasibility issues that autonomous drones would have for this application, the competitiveness of autonomous drones used for physical operations was deemed low. This thereby resulted in the next hypothesis.

__H22.__ Since better, cheaper and more efficient alternatives for handling and transportation of goods exist, autonomous drones are unlikely to be used for physical operations within warehousing in the future.

Looking to the future, experts both mentioned expected improvements for the technology and needed improvements in order for the technology to be more widely used. When talking about needed improvements some of the lifted aspects were that autonomous drones need to become more affordable, the technical and analytical capabilities need to improve as well as the additional technology. As mentioned by one of the experts: *"You need both better IT and better cameras, better use of the cameras, better software and better hardware and reduce the noise. So there are many points of improvement potentially still".* Experts further stated that they expect the technology to become more affordable. Expected improvements for the technical capabilities of the hardware, battery time and efficiency were also mentioned. Further, analytical improvements for the software were mentioned, which would increase accuracy for scanning and positioning. Regarding improvements for the additional technology, experts also said that a lot of developments are happening in that area, improving the accuracy and increasing the task speed.

For the technology to be used more, it was mentioned that more use cases would be required. Even though no major new use cases were expected to be added for autonomous drones, some improvements are being researched, such as the possibility of scanning loose boxes, doing rack inspections, and temperature or humidity checks. With the mentioned expansion for the solution, it also indicates that more good examples will follow, as some experts said it was necessary for the technology to be more widely adopted. In combination with the previous analysis made for the technology, the surrounding factors and the maturity, a final hypothesis was made.

__H23.__ Autonomous drones for inventory management will be used more in the future than they are now

4.3 Discussions and Implications

From the interviews, it quickly became apparent that there are use cases for drones in warehousing that improve operations and that they are used today to a greater extent than first thought. Although the drone is not used for physical operations today, which many experts thought it never will be, its analytical capabilities and flexibility are used to improve stock accuracy. Since no cases of autonomous drones being used for physical operations were mentioned, the focus in the second round was centered on the use cases of inventory management tasks as well as those related to inspection and surveillance purposes.

The term inventory management was used repeatedly by experts to explain the usage areas of drones. Due to this, the term was further used in the findings and analysis of round 1. As previously mentioned in *Chapter 3: Theoretical Framework*, the term inventory management has a broader meaning that extends outside the scope of this thesis and can therefore encompass more than the tasks used to increase inventory accuracy. However, given the long interviews and discussions, it was evident that the experts referred to the aspects of inventory management related to the definition of it in a warehousing setting which includes stock-taking, buffer stock maintenance, cycle counting, and item searches.

When analyzing autonomous drones using the DOI framework many reasons advocating for the technology being implemented for automating inventory management tasks were found. There were, however, two main themes localized that could limit the willingness to adopt autonomous drones for analytical purposes. The first is that the noise the drone makes and the dangers it poses when used next to workers result in a less compatible solution. Interfering with daily operations and causing disturbances for workers implies that the solution is not suitable for warehouses operating 24 hours per day, seven days a week. The second theme is that the value of the solution is not clear although the performance can easily be tracked and monitored.

Looking at the other mentioned use cases related to supporting activities such as inspections, surveillance and temperature checks, it was concluded from the data that those are done too seldom for being automated by autonomous drones. Meaning that it would not be beneficial to invest in this technology solely for this purpose, but that it could be an advantageous feature to add to the main usage within inventory management.

Except for these three themes that negatively affect how appealing the solution is, the relative advantage, low complexity, and trialability speak for its usage. The key takeaways from the DOI framework that was rated by the expert in round 2 can be seen in Table 4.1.

Table 4.1 Takeaways from analyzing drones in warehousing with the DOI Framework.

DOI	Hypotheses for round 2
Relative Advantage	**H1.** Autonomous drones have a relative advantage compared to current ways of conducting inventory management which speaks for its further usage and growth.
	H2. Activities such as inspection of racks, sprinklers, etc., temperature checks and surveillance are done too seldom for it to be beneficial to have autonomous drones solely for this purpose.
Compatibility	**H3.** The ease of integrating autonomous drones for inventory management with other warehousing technology and systems makes them compatible which speaks for its further usage and growth.
	H4. Due to risks associated with having drones operating next to workers and the disturbances it might cause for operations, autonomous drones are not suitable for warehouses that are operating around the clock.
Complexity	**H5.** The autonomous drone is easy to understand and use in inventory management, therefore the relative complexity of the technology is not a reason for its limited usage.
Observability	**H6.** Even though the performance is easy to measure and observe for autonomous drones in inventory management, the insecurities about what value they bring to a company could be limiting its usage.
Trialability	**H7.** The ease of trying the technology beforehand with manual drones, demos, and pilot projects for inventory management, advocates for its further usage.

Using the TOE framework for understanding the adoption probability of autonomous drones gave mixed results. In terms of the technological aspect, drones do not require a high technological readiness from the company adopting them, making them accessible for more warehouses. However, the organizational context does pose some limitations to where the autonomous drone is useful. Financial risks, together with special warehouse characteristics and company strategies make the number of warehouses that will benefit from the solution as of now limited. Some trends and characteristics of the warehousing industry speak against its usage while others promote it. The increasing challenges in warehousing of finding labor and the high costs of labor speak for the implementation of autonomous solutions such as drones. Lastly, the importance of the activities it can automate, its competing technologies, and limitations of where it can be used does however speak against it. Hypotheses formed from these insights that were brought to round 2 can be seen in Table 4.2.

Table 4.2 Takeaways from analyzing drones in warehousing with the TOE Framework.

TOE	Key takeaways from brought to round 2
Technological Context	**H8.** The low level of technological readiness required for companies to adopt autonomous drones makes the solution accessible for more warehouses, advocating for its growth.
Organizational Context	**H9.** Autonomous drones for inventory management are only useful for companies that do inventory checks often or where an accurate stock is of high importance.
	H10. The financial risks and uncertainties of investing in autonomous drones now are too high for companies to engage.
	H11. Implementing autonomous drones within warehouses does not require any big organizational changes which speaks for its growth.
	H12. Autonomous drones are only suitable for warehouses that are manual or semi automated and for warehouses that use single deep racks and a majority of full pallets, which is a reason for its limited usage.
Environmental Context	**H13.** Autonomous drones are not used more widely in warehousing since companies are more focused on automating other operations than inventory management.
	H14. The increase of warehousing challenges in terms of increased labor costs and labor shortage speaks for the increased usage of autonomous drones in inventory management.
	H15. Competing automation technology for inventory management is a reason that drones are not used to a greater extent in warehouses for inventory management.
	H16. It is likely that more warehouses will become fully autonomous in the future, making autonomous drones for inventory management less relevant.

In terms of analyzing autonomous drones with the hype cycle, a conclusion from the first round is that the technology is not mature enough. Not all participants may agree with this, especially those that have implemented it and found a use case for it where it has proven to be successful. However, from a holistic view, some aspects point towards the solution not being completely mature yet. So far the number of warehouses using the technology is limited and those that have taken the step can be seen as the early adopters. The hype regarding what challenges the autonomous drone can solve is larger than its actual use cases, indicating that it is situated at the peak of inflated expectations. The hypotheses used in the second round can be seen in Table 4.3.

Table 4.3 Takeaways from analyzing drones in warehousing with the hype cycle Framework.

Hype Cycle	Key takeaways from brought to round 2
Hype Human	**H17.** The hype and inflated expectations of autonomous drones without sufficient evidence of its usefulness and proven successful examples for inventory management is one reason that the technology is not used more widely
Hype Technology	**H18.** The technology is still not mature enough for it to be widely adopted in warehouses.

In general, some factors speak both for and against the use of autonomous drones in warehousing. For physical operations, the drone is not suitable and other technologies can perform these tasks more efficiently. The real benefits come from using the drone's analytical capabilities and for this, specific use cases have been found within inventory management. Most likely, the use cases currently in progress will push the development further and increased usage within inventory management would extend its use. The hypotheses related to its future usage are presented in Table 4.4.

Table 4.4 Takeaways from analyzing drones in warehousing through a holistic perspective.

Holistic View	Key takeaways from brought to round 2
Future	**H19.** Autonomous drones are most likely to be used for Inventory Management in warehousing in the future.
	H20: Being able to count individual boxes, and not only full pallets would increase the usefulness of drones for inventory management purposes.
	H21. Because of the technological limitations (payload, battery time, size), autonomous drones are unlikely to be used for physical operations within warehousing in the future.
	H22. Since better, cheaper and more efficient alternatives for handling and transportation of goods exist, autonomous drones are unlikely to be used for physical operations within warehousing in the future.
	H23. Autonomous drones for inventory management will be used more in the future than they are now.

5. Round 2: Assessing Opinions and Rankings

This chapter covers the survey that was used for quantifying the qualitative data collected and analyzed in round 1. First, the experts' level of agreement with the hypotheses in the survey are presented, after which they are analyzed together with the comments made by the experts. A discussion about the implications of the experts' answers is then presented.

5.1 Findings From the Survey

Round 2 consisting of a survey was conducted between 12th of April to 27th of April 2023. 12 participants answered the questionnaire, which means that 80 percent of the experts participating in round 1 completed the survey. The experts that dropped out were two from the drone panel and one from the warehousing panel. The opinions of the experts that dropped out were generally in line with the other experts and therefore it should not be considered a case of attration bias.

The main findings from the second round was the Likert ratings on a seven point scale that the experts provided. Participants were asked to rate their agreement with each of the 23 hypotheses that were identified as key takeaways from the interviews in the first round. In general, participants agreed with the hypotheses presented. The drone panel generally rated their level of agreement higher than the warehousing panel. The general results for the whole group will be further presented and explained while the individual answers for each expert is provided in Appendix B. Further, comments left by the experts will be included in the analysis and can be found in Appendix C.

5.1.1 Mean and Standard Deviation

The first measure calculated was that of the mean and standard deviation for the hypotheses. This was done for all participants totally and for each panel separately, which are all presented in Table 5.1. As can be seen in the table, all hypotheses except H4, H10 and H15 had a mean higher than 4. Looking at the panels individually, the drone panel had no hypotheses with a mean below 4, while the warehousing panel had a mean below 4 on H4, H10 H15, and H18.

Variations within the panels were pretty similar when looking at the standard deviation. Some of the hypotheses where the largest difference between the panel's mean values could be found was for H8, H10, H15 and H18, where the drone panel had higher means for all except H8.

Table 5.1 The mean and standard deviation for each statement, presented for the total number of respondents, the drones panel, and the warehousing panel.

Hypotheses	Total	Drones	Warehousing	Difference (DR-WH)
H1	5.75 (1.1)	5.80 (1.3)	5.71 (1.1)	0.09
H2	5.00 (1.5)	6.00 (1.0)	4.29 (1.4)	1.71
H3	5.00 (1.7)	4.40 (2.1)	5.50 (1.4)	-1.10
H4	3.83 (2.1)	4.80 (2.5)	3.14 (1.7)	1.66
H5	4.92 (1.8)	4.20 (2.2)	5.43 (1.5)	-1.23
H6	4.55 (1.8)	4.60 (1.8)	4.50 (1.9)	0.10
H7	5.50 (1.0)	5.80 (1.4)	5.29 (0.8)	0.51
H8	5.25 (1.4)	4.20 (1.3)	6.00 (0.8)	-1.80
H9	4.75 (2.0)	5.40 (1.9)	4.29 (2.1)	1.11
H10	3.75 (1.8)	4.80 (1.8)	3.00 (1.5)	1.80
H11	4.92 (1.3)	4.00 (1.2)	5.57 (1.0)	-1.57
H12	4.55 (1.6)	4.80 (1.9)	4.33 (1.5)	0.47
H13	4.58 (1.8)	4.40 (2.3)	4.71 (1.6)	-0.31
H14	6.00 (1.0)	6.00 (1.2)	6.00 (0.8)	0.00
H15	3.50 (1.7)	4.60 (1.5)	2.71 (1.4)	1.89
H16	4.25 (1.8)	4.40 (2.2)	4.14 (1.6)	0.26
H17	5.09 (1.4)	5.80 (1.1)	4.50 (1.4)	1.30
H18	4.58 (2.2)	5.80 (1.3)	3.71 (2.4)	2.09
H19	5.75 (0.9)	5.80 (0.8)	5.71 (1.0)	0.09
H20	6.25 (1.1)	6.00 (1.4)	6.43 (0.8)	-0.43
H21	4.92 (2.1)	5.80 (1.6)	4.29 (2.3)	1.51
H22	5.58 (1.6)	5.80 (1.6)	5.43 (1.7)	0.37
H23	5.58 (1.7)	4.80 (2.5)	6.14 (0.7)	-1.34

5.1.2 Median and IQR

The median and IQR were also calculated for all participants together as well as each panel individually, which are presented in Table 5.2. When comparing the total mean value and the total median they are overall similar to each other for the different hypotheses. However, for some hypotheses the difference is significant with the largest differences found for H9, followed by H21, H20 and H16. For H9 the mean value is 4.75 compared to the median of 6. H20 has the highest median of 7 while the mean value is 6.25.

For the IQR, a threshold level of 1 was desired to reach a consensus. Looking at Table 5.2, there was only one statement with an IQR equal to 1 for all participants, H7. For each panel separately, there are more IQR values fulfilling this requirement. The experts within the drone panel have an IQR of 1 for H11, H14, H16, H19, H21 and H22, as well as an IQR of 0 for H9 and H17, thereby reaching a consensus in eight hypotheses with the IQR definition. For the warehousing panel, consensus by this standard was reached for seven hypotheses, with hypotheses H7, H8, H11, H14, H17, H20 and H23. As further seen in Table 5.2, the IQR within the panels was equal to, or below 1 for both the warehousing and drone panels for H11, H14 and H17. However, the total IQR was above 1 for all the mentioned hypotheses, indicating a too large variation between the experts for it to be considered as a consensus among them. The differences can be explained by consensus within the panels, but different opinions between the two panels.

Table 5.2 The median and the IQR for each statement, presented for the total number of respondents, the drones panel, and the warehousing panel. Those in bold indicate consensus.

Hypotheses	Total	Drones	Warehousing
H1	6 (2)	6 (2)	6 (1.5)
H2	5 (1.25)	6 (2)	5 (1.5)
H3	5 (2.5)	4 (3)	5.5 (2.5)
H4	4 (3.25)	5 (3)	3 (2)
H5	5.5 (3.25)	3 (3)	6 (2)
H6	5 (2.5)	4 (3)	5 (1.5)
H7	5.5 **(1)**	6 (2)	5 **(1)**
H8	5.5 (1.25)	4 (2)	6 **(1)**
H9	6 (2.5)	6 **(0)**	5 (3)
H10	3.5 (3.25)	6 (2)	3 (2)
H11	5 (2)	4 **(1)**	6 **(1)**
H12	5 (2)	5 (2)	5 (1.5)
H13	5 (3.25)	5 (4)	5 (2)
H14	6 (1.25)	6 **(1)**	6 **(1)**
H15	3 (3)	5 (3)	2 (1.5)
H16	5 (1.5)	5 **(1)**	5 (2)
H17	5 (1.5)	6 **(0)**	5 **(0.75)**
H18	5 (2.75)	6 (2)	5 (3.5)
H19	5.5 (1.25)	6 **(1)**	5 (1.5)
H20	7 (1.25)	7 (2)	7 **(1)**
H21	6 (3.25)	6 **(1)**	5 (3.5)
H22	6 (2)	6 **(1)**	6 (1.5)
H23	6 (2)	5 (3)	6 **(0.5)**

A boxplot of the answers from round 2 can be seen in Figure 5.1. The x marks the mean value, the line in the boxes marks the median, and the length of the boxes are the IQR values for each hypothesis. For H16, H17, and H23 there are data points outside the whiskers. These are outliers that differ substantially from the rest of the answers and are therefore not included in the range of answers in the figure. However, these outliers were included when calculating the level of agreement in order to show a fair picture of how many experts that agreed or disagreed with the hypotheses.

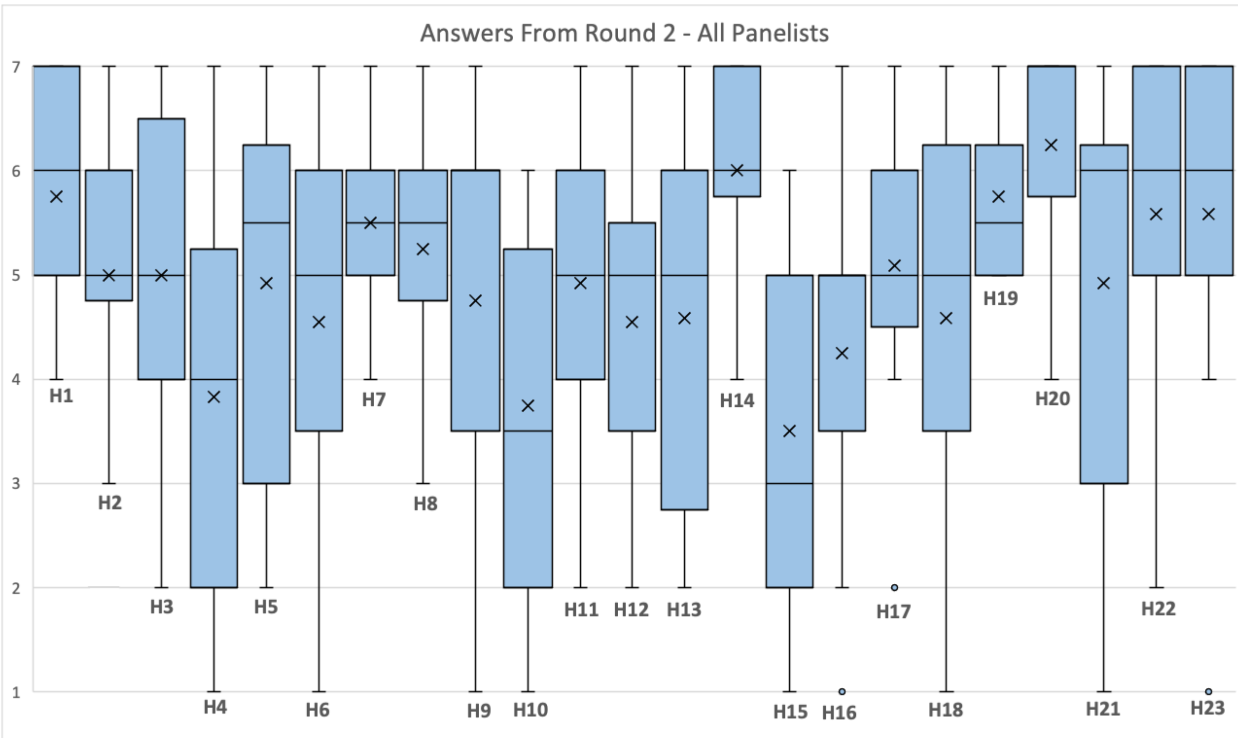

Figure 5.1 A boxplot of the answers from round 2.

5.1.3 Level of Agreement

The level of agreement was calculated based on the percentage of experts agreeing with the statement to some extent (5, 6 and 7 on the Likert scale), the ones disagreeing to some extent (1, 2 or 3 on the Likert scale) and the ones answering neutral with a 4 on the Likert scale. The percentage for agreeing, disagreeing and being neutral are presented for all participants as well as for the individual panels in Table 5.3. As can be seen from the color scheme, a more than 80% agreement for all experts can be found for H1, H7, H14, H19, H20, H22 and H23. The lowest total agreement rate is for H4, H10 and H15 which were also the only ones with a mean value below 4.

Table 5.3 Level of agreement for all participants, the drone panel and the warehousing panel.

	Agree *(5,6,7)*			**Neutral** *(4)*			**Disagree** *(1,2,3)*		
	Total	Drones	Wh	**Total**	Drones	Wh	**Total**	Drones	Wh
H1	**83 %**	80 %	86 %	**17 %**	20 %	14 %	**0 %**	0 %	0 %
H2	**75 %**	100 %	57 %	**8 %**	0 %	14 %	**17 %**	0 %	29 %
H3*	**50 %**	40 %	57%	**25 %**	20 %	29 %	**17 %**	40 %	0 %
H4	**33 %**	60 %	14 %	**25 %**	20 %	29 %	**42 %**	20 %	57 %
H5	**58 %**	40 %	71 %	**8 %**	0 %	14 %	**33 %**	60 %	14 %
H6*	**50 %**	40 %	57 %	**17 %**	20 %	14 %	**25 %**	40 %	14 %
H7	**83 %**	80 %	86 %	**17 %**	20 %	14 %	**0 %**	0 %	0 %
H8	**75 %**	40 %	100 %	**8 %**	20 %	0 %	**17 %**	40 %	0 %
H9	**67 %**	80 %	57 %	**8 %**	0 %	14 %	**25 %**	20 %	29 %
H10	**42 %**	60 %	29 %	**8 %**	20 %	0 %	**50 %**	20 %	71 %
H11	**67 %**	40 %	86 %	**25 %**	40 %	0 %	**8 %**	20 %	14 %
H12*	**58 %**	60 %	57 %	**8 %**	20 %	0 %	**25 %**	20 %	29 %
H13	**67 %**	60 %	71 %	**0 %**	20 %	0 %	**33 %**	20 %	29 %
H14	**92 %**	80 %	100 %	**8 %**	20 %	0 %	**0 %**	0 %	0 %
H15	**33 %**	60 %	14 %	**8 %**	0 %	14 %	**58 %**	40 %	71 %
H16	**58 %**	60 %	57 %	**17 %**	0 %	14 %	**25 %**	20 %	29 %
H17*	**67 %**	80 %	57 %	**17 %**	20 %	14 %	**8 %**	0 %	14 %
H18	**67 %**	80 %	57 %	**8 %**	20 %	0 %	**25 %**	0 %	43 %
H19	**100 %**	100 %	100 %	**0 %**	0%	0%	**0 %**	0 %	0 %
H20	**92 %**	80 %	100 %	**8 %**	20 %	0 %	**0 %**	0 %	0 %
H21	**67 %**	80 %	57 %	**0 %**	0 %	0 %	**33 %**	20 %	43 %
H22	**83 %**	80 %	86 %	**0 %**	0 %	0 %	**17 %**	20 %	14 %
H23	**83 %**	60 %	100 %	**8 %**	20 %	0 %	**8 %**	20 %	0 %

* One participant did not answer these questions. Only 6 of 7 in the warehousing panel answered these questions.

Some differences between the panels can be highlighted here as well. For H4, H10, and H15, the majority of the warehousing panel has disagreed to some extent, while the majority of the drone panel has agreed. Similarly, for H5 where the majority of the drone panel disagreed, while the vast majority of the warehousing panel agreed. There are further hypotheses where more experts from the warehousing panel have agreed to some parts while the drone panel has been more spread out, such as for H8 and H11.

For H19, all participants answered that they agreed to some extent. Besides that, the drone panel had full agreement with the second statement, whereas the warehousing panel was unitedly agreeing to H8, H14, H20 and H23.

5.2 Analyzing Findings From the Survey

The results from the second round were first analyzed for each statement separately based on the clarity of the results. First the clear results are presented, followed by the relatively clear, and lastly the inconclusive results. Since an extensive analysis of the experts' opinions in combination with theory was concluded in the first round, this analysis was more focused on the statistical measurements such as the level of agreement, IQR, mean, and median.

5.2.1 Clear Results

Hypotheses that showed conclusive results were H1, H7, H14, H19, H20, H22 and H23, see Table 5.4. These all had an agreement level above 80 percent and their mean in the agree range. On the 1st, 7th, 14th, 19th and 20th hypothesis, no one disagreed, increasing their credibility. For the 19th hypothesis, all experts agreed to some extent making it the most trustworthy hypothesis, whereas for H22 and H23, two respectively one expert disagreed. For all hypotheses except the 23d one, the level of agreement and mean values between the two panels were fairly similar.

Table 5.4 Hypotheses with at least 80% agreement among experts and a mean in that range.

	Hypotheses	**Lvl.agree + (-)**	**Mean**
Pro Usage	**H1.** Autonomous drones have a relative advantage compared to current ways of conducting inventory management which speaks for its further usage and growth.	83% (0%)	5.75
	H7. The ease of trying the technology beforehand with manual drones, demos, and pilot projects for inventory management, advocates for its further usage.	83% (0%)	5.50
	H14. The increase of warehousing challenges in terms of increased labor costs and labor shortage speaks for the increased usage of autonomous drones in inventory management.	92% (0%)	6.00
	H19. Autonomous drones are most likely to be used for Inventory Management in warehousing in the future.	100% (0%)	5.75
	H20: Being able to count individual boxes, and not only full pallets would increase the usefulness of drones for inventory management purposes.	92% (0%)	6.25
	H23. Autonomous drones for inventory management will be used more in the future than they are now.	83% (8%)	5.58
Against Usage	**H22.** Since better, cheaper and more efficient alternatives for handling and transportation of goods exist, autonomous drones are unlikely to be used for physical operations within warehousing in the future.	83% (17%)	5.58

Based on the comments from the experts responding neutrally to H1, which states that drones have a relative advantage compared to alternative solutions, it seemed like the hypothesis was formulated as being too broad or vague with experts arguing that it depends more on the exact use case. Agreeing experts further commented that the exact use case as well as current preconditions also affects the relative advantage. One expert mentioned that with improvements of the technology, the relative advantage of the technology would be ranked higher, indicating that the relative advantage could potentially be even larger with future improvements. The total level of agreement was 83 percent with a mean of 5.75. However, given the total IQR of 2, no consensus of how much the experts agree can be established with the decided threshold. The comments combined with the results, do indicate that the technology does have a relative advantage within inventory management.

For H7 which states that the high level of trialability of the solution speaks for its further usage, one comment was made suggesting that besides testing the technology, service providers could also give insights on the matter. Since sharing insights is not considered a way of testing a technology before implementing it, and the hypothesis was meant to highlight the trialability of the technology, the comment did not provide any new insights. It does, however, highlight the differences between adopters, where adopters of a later stage are less dependent on the trialability of a technology due to insights and good examples of previous successful implementations being available. Besides the high percentage agreeing with the statement, the IQR for this statement was 1. Hence, consensus by this standard was reached with a median value of 5.5 placed in between somewhat agree and agree.

On H14, stating that the increase of warehousing challenges speaks for the usage of drones, one expert commented saying that saving time and costs are drivers for increased usage of autonomous drones for inventory management tasks. This is rather lifting the relative advantage of autonomous drones and their performance in terms of time and cost savings. This comment did hence not affect the analysis of this statement but rather gave a better understanding of the relative advantage of the technology. For each separate panel, the IQR was 1 with a median value of 6, agree. However, a total consensus was not reached with the standards of IQR, which could be explained by the small sample size. From the level of agreement combined with the total mean value and the comments provided, it seems like the increase of warehousing challenges in terms of increased labor costs and labor shortage do speak for the increased usage of autonomous drones in inventory management.

Two of the comments corresponding to H19, which states that drones most likely are used for inventory management in the future, mentioned that it depends on how far in the future that is being discussed. A third comment mentioned that it will only be for niche applications and contexts within inventory management. Given that all participants agreed and a mean of 5.75, the results indicate that autonomous drones will most likely be used for inventory management in the future.

H20, arguing that box counting would increase the drones usage, received the highest mean value, 6.25, indicating that the level of agreement is not only high, but also strong. Only one comment was made to this hypothesis, mentioning that a solution for this is on its way. It is thereby deemed true that the usefulness of the solution would increase if it was able to count individual pieces and not only full pallets.

No comments were made for H22, which stated that cheaper and more efficient solutions than drones are available for physical operations, and therefore no qualitative data was added to the statistical analysis. Out of all experts, 83 percent agreed and no major difference could be seen between the panels. Thereby it indicated that competing technology for handling and transporting goods are superior in comparison to autonomous drones. This aligns with theory in the way that literature focuses on the theoretical perspective of using autonomous drones for physical operations (Han et al., 2022), in contrast to its usage for inventory management which has been researched through case studies and actual implementations (Maghazei & Netland, 2020. This indicates that more trust is put into its analytical usage areas.

For the 23d hypothesis regarding if they will be used more in the future for inventory management than now, one person within the drone panel strongly disagreed. This expert left a comment stating that: *"We are seeing more demand for our manually operated systems and our AGV based system than for our drone based system"*. This expert worked with selling both drone and ground based inventory management systems. All experts in the warehousing panel agreed with the hypothesis and in total 83 percent agreed, indicating that drones will be used more in the future than now.

5.2.2 Relatively Clear Results

The hypotheses with a total agreement level of at least 67 percent were not considered as secure as the clear results, but still with a sufficient agreement level based on literature found about threshold levels (von der Gracht, 2012). The hypotheses reaching a 67 percent agreement level and with a corresponding mean value within the range were H2, H8, H9, H11, H13, H17, H18 and H21 as can be seen in Table 5.5.

Table 5.5 Hypotheses with at least 67% agreement among experts and a mean in that range.

	Hypotheses	Lvl.agree + (-)	Mean
Pro Usage	**H8.** The low level of technological readiness required for companies to adopt autonomous drones makes the solution accessible for more warehouses, advocating for its growth.	75% (17%)	5.25
	H11. Implementing autonomous drones within warehouses does not require any big organizational changes which speaks for its growth.	67% (8%)	4.92
Against Usage	**H2.** Activities such as inspection of racks, sprinklers, etc., temperature checks and surveillance are done too seldom for it to be beneficial to have autonomous drones solely for this purpose.	75% (17%)	5.00
	H9. Autonomous drones for inventory management are only useful for companies that do inventory checks often or where an accurate stock is of high importance.	67% (25%)	4.75
	H13. Autonomous drones are not used more widely in warehousing since companies are more focused on automating other operations than inventory management.	67% (33%)	4.58
	H17. The hype and inflated expectations of autonomous drones without sufficient evidence of its usefulness and proven successful examples for inventory management is one reason that the technology is not used more widely	67% (8%)	5.09
	H18. The technology is still not mature enough for it to be widely adopted in warehouses.	67% (25%)	4.58
	H21. Because of the technological limitations (payload, battery time, size), autonomous drones are unlikely to be used for physical operations within warehousing in the future.	67% (33%)	4.92

Experts' opinions were generally aligned regarding H8, with 75 percent of participants agreeing that technological readiness is not a barrier for implementation. One comment was made, saying: *"I think it is a mixture of both low technological readiness and cost benefit"* which indicates agreement although the expert responded neutrally. The warehousing panel responded more positively with a mean value of 6.00, while the drones panel had a mean of 4.20. Hence, there was a significant difference between the panels for this hypothesis. The warehousing panel was further unified with an IQR of 1, indicating consensus. As mentioned by Oliviera et al. (2014), the technological readiness needed for implementing a solution can limit its adoption. This seems to not be the case for the adoption of autonomous drones for inventory management, as a total assessment points towards technological readiness not being a limiting factor.

For H11, saying that no big organizational changes are needed for drone implementation, the level of agreement was 67 percent amongst all participants. The panels were not in agreement with the warehousing panel having a median of 6 and a mean value of 5.57, and the drone panel with a median and mean value of 4. Consensus was reached in both panels with an IQR of 1, although the opinions differed between the two groups resulting in not reaching a total consensus. Comments were only made by the warehousing panel. One expert responded neutrally to the hypothesis, saying that it is case-dependent, and another expert who somewhat agreed added that: *"It should lead to new ways of working and to shift focus from repetitive tasks. This might lead to organizational change"*. With the majority of respondents agreeing with the hypothesis, and with the warehousing panel possessing knowledge of actual implementation projects, it is evaluated that there are no big organizational changes needed to implement drones. It should however be noted that this is case-dependent as one of the experts mentioned.

H2 is directed towards analyzing the relative advantage of supporting activities such as surveillance, temperature and humidity checks, and inspections of racks and fire sprinklers, saying that they are not done frequently enough to be automated, unless combined with other activities like inventory management. In total, 75 percent agreed with this statement and only two participants disagreed. One hundred percent of the drone panel agreed, with a mean of 6.00, while the warehousing panel had an agreement rate of 57 percent and a mean value of 4.29. One participant who somewhat agreed to the statement mentioned that they do rack inspections more often in their warehouses, making the solution more attractive. Another expert, who responded neutrally, mentioned that surveillance is done more often and could be a use case for autonomous drones. It was also pointed out by experts that there is a cost aspect included which was taken into account. Lastly, an expert mentioned: "*There are different use models - if drones are not frequently used, they could be rented from a service provider.*". Autonomous drones are very dependent on having accurate navigation which has to be modified for each warehouse for them to properly be used autonomously. In the case of renting drones, this would therefore probably be done by a manual or semi-automated drone. The hypothesis was however based on an autonomous solution and therefore the results point towards validation of the hypothesis.

On the 9th hypothesis, 67 percent agreement and 25 percent disagreement was noted. Panelists from the warehousing panel agreed less than the drones panel and this was also reflected in the difference in mean values with the warehousing panel having a lower mean. Two panelists, one disagreeing and one responding neutrally, seemed to not necessarily disagree with the statement that drones are useful where inventory management is of essence, but emphasized by their comments that inventory management is potentially necessary in all warehouses. Further, one expert *agreed,* mentioning that "only" is a strong word, and thereby indicating that the solution potentially has a value for all warehouses.

In total, 67 percent of the panelists agreed to H13, stating that warehouses are prioritizing other activities than inventory management which limits the usage of autonomous drones. The level of agreement in the separate panels was quite similar, as well as the mean values which were 4.40

for the drones panel and 4.71 for the warehousing panel. No difference between the panels could therefore be identified. One expert, disagreeing, commented that the reason for limited drone usage is not the level of prioritization of activities, but rather the limited knowledge and know-how of drones. Another expert agreed with the statement and emphasized that automating picking has a high focus for many warehouses. A total assessment points toward validation of the hypothesis.

Regarding H17, stating that the hype of drones without sufficient evidence of its usefulness and successful examples being a reason for its limited usage received 67 percent agreement in total. One expert that has been part of an implementation project of drones somewhat agreed with the hypotheses and commented: *"Agree. But we have, with our preconditions, proved its value for us*". Another expert did not rate the hypothesis, stating that no obvious hype could be identified. In general, the panels were in agreement with the drone panel having a median of 6 and an IQR of 0, and the warehousing panel having a median of 5 and an IQR of 0.75. This indicates that both panels agreed with the hypotheses but to a different extent. Hence, the 17ht hypothesis seems to be one of the reasons for the limited usage of autonomous drones.

Regarding H18, stating that drone usage is limited due to it not being mature enough, 67 percent agreed and 25 percent disagreed. All of the disagreeing panelists were part of the warehousing panel and furthermore, all of them were experts that had been part of implementations that are currently using the technology. The rest of the warehousing panel included both answers of neutrality and agreement resulting in a quite high IQR. Experts in the warehousing panel agreeing to the hypothesis stated that battery run time, scanning issues, and compatibility issues need to be fixed for the solution to be more attractive. The drone panel were in agreement with each other, having four out of five experts agreeing with the statement. The relatively high level of agreement indicated that the maturity of the technology needs to increase for it to be widely adopted in warehouses.

The last hypothesis that proved relatively clear results is the H21, stating that drones are unlikely to be used for physical operations due to technological limitations. One participant agreed but commented *"at least in the near future"*. In total 67 percent of the participants agreed and 33 percent disagreed. Those that disagreed was the warehousing panel while the drone panel was more in agreement with the hypothesis. The drone panel was in consensus regarding this with an IQR of 1. Due to the drone panel's higher level of expertise in technical limitations, the hypothesis was deemed as being relatively true.

5.2.3 Inconclusive Results

The hypotheses that did not reach a total agreement level of at least 67% were not considered as giving conclusive results. These were deemed too insecure to make conclusions based on previous literature of threshold when looking at consensus combined with the smaller number of participants. The hypothesis resulting in inconclusive results were H3, H4, H5, H6, H10, H15 and H16 which are all presented in Table 5.6.

Table 5.6 Hypotheses that proved to be inconclusive.

	Hypotheses	Lvl.agree + (-)	Mean
Pro Usage	**H3.** The ease of integrating autonomous drones for inventory management with other warehousing technology and systems makes them compatible which speaks for its further usage and growth.	50% (17%)	5.00
	H5. The autonomous drone is easy to understand and use in inventory management, therefore the relative complexity of the technology is not a reason for its limited usage.	58% (33%)	4.92
Against Usage	**H4.** Due to risks associated with having drones operating next to workers and the disturbances it might cause for operations, autonomous drones are not suitable for warehouses that are operating around the clock.	33% (42%)	3.83
	H6. Even though the performance is easy to measure and observe for autonomous drones in inventory management, the insecurities about what value they bring to a company could be limiting its usage.	50% (27%)	4.55
	H10. The financial risks and uncertainties of investing in autonomous drones now are too high for companies to engage.	42% (50%)	3.75
	H12. Autonomous drones are only suitable for warehouses that are manual or semi automated and for warehouses that use single deep racks and a majority of full pallets, which is a reason for its limited usage.	58% (25%)	4.55
	H15. Competing automation technology for inventory management is a reason that drones are not used to a greater extent in warehouses for inventory management.	33% (58%)	3.50
	H16. It is likely that more warehouses will become fully autonomous in the future, making autonomous drones for inventory management less relevant.	58% (25%)	4.25

For H3, most participants agreed to some extent that the ease of integrating drones with current technology and systems increases the likelihood of further usage. However, two did oppose the statement, three answered neutral, and one did not answer due to the question not being specific enough. As stated by this expert, the ease of integration would be dependent on the system and supplier. Besides the integration being dependent on the supplier, one expert commented that autonomous drones are not easy to integrate with warehousing systems: *"Automated drones are not easy to integrate because they use a 3D navigation system that is not represented inside the customer's systems and needs to be manually mapped and tested, cm by cm in 3 dimensions"*. Even though 50% agreed to some extent, the different opinions of the experts on this statement combined with the comments indicates that this could be case-dependent, making it hard to draw any reliable conclusions from this statement.

Regarding H5, which proposes that autonomous drones are easy to use and that the complexity of the solution thereby does not limit its usage, the total level of agreement reached 58%. However, as can be seen in Table 5.3 and Table 5.2, there are great differences between the panels, where 71% of the warehousing panel agreed compared to the 40% in the drones panel, and a median of 6, respectively 3 were obtained. As noted in Table 5.1, the mean value for the drone panel of 4.2 is in the agreement range above the score 4, indicating a variation within the panel as well. Looking at the comments, three of them mention the case and supplier dependency for this aspect. Due to the results being rather unclear, the hypothesis could not be confirmed or dismissed.

H4, arguing that drones are not suitable for warehouses operating around the clock, received one of the lowest levels of agreement. Only 33 percent agreed, and 42 disagreed. Comments that were made on the hypothesis pointed out different aspects of why drones could potentially work next to workers. Arguments included an increased acceptance of drones by workers as well as the fact that not all parts of the warehouse are operational at the same time, indicating that drones could be used in a warehouse that is operational 24 hours a day. It was especially the warehousing panel that disagreed, with 57 percent disagreeing and only one expert agreeing. However, the total number of experts disagreeing, or the experts agreeing, did not reach the levels of agreement necessary to dismiss or confirm the hypothesis. Thereby, the results on whether drones are suitable to use next to workers or in a 24/7 warehouse proved to be inconclusive.

Only 50 percent agreed, and 27 percent disagreed with H6, which stated that even though performance is easy to measure, insecurities about the value of the solution could limit its usage. As seen in Table 5.2, the IQR of each panel as well as the total number of participants, was quite high, indicating different opinions both within the panels and outside. One expert who did not answer commented disagreement with the first part of the hypothesis but not necessarily with the second part, indicating that the hypothesis asks for two different things and thereby makes it difficult to answer. Another expert who disagreed mentioned that the value easily can be measured but said: *"don't solve a $100 problem with a $10000 solution"*. The panels were quite similar in their responses, but since the answers were pointing in two directions, no conclusion could be made.

Experts´ opinions on H10, which stated that the financial risks of investing in drones are too high, were not unanimous. With 42 percent agreeing and 50 percent disagreeing in combination with high IQR values for both panels as well as the whole sample size, no consensus could be observed. The one comment that was made stated that the risks depend on your preconditions, which indicated that it could be hard to reach a general answer to the hypothesis. Thereby the result was deemed inconclusive.

H12, stating that drone usage is limited to manual and semi-automated warehouses with a majority of full pallets and single deep racks, received varying responses. Although the level of agreement was relatively high at 58 percent, it did not meet the levels set for consensus. Neither did the IQR indicate a unified warehousing or drone panel. The comments made stated that there are workarounds for double deep racks, indicating that this is not necessarily a problem. Another expert stated, as previously mentioned, that a box-counting feature might come later this year. Due to the inconsistent responses and varying comments, the results were seen as inconclusive.

For H15, 58 percent of the participants disagreed with the hypothesis, indicating that competing automation technology for inventory management is not a reason for the limited usage of autonomous drones. It did, however, not meet the standards set for consensus in terms of the level of agreement or IQR, which was higher than 1. The one comment that was made pointed out that "ASRS systems make drones redundant", indicating that there could be some truth to the hypothesis. The assessment was, therefore, that the results were too divided and that the hypothesis could not be confirmed nor rejected.

Regarding H16, two of the received comments state that even though this trend of warehouses becoming more automated exists and that autonomous drones are not useful in this environment, the number of fully autonomous warehouses will remain low, and it will take a long time until the majority has been fully automated. Another comment lifted the RFID solution as potentially disrupting the usage of autonomous drones. In combination with the mixed results, this hypothesis could not be confirmed.

5.3 Discussions and Implications

The second round proved to be a valuable tool for understanding to which degree experts agreed or disagreed with what had been said during the interviews in round 1. It became clear which statements were just the opinions of a few experts and which ones that could be seen as the general opinion.

Given the small sample size, drawing conclusions from the IQR measure can be misleading. Even though some hypotheses reached a consensus with the standards of IQR for the total group and for each panel individually, it is not deemed statistically significant enough to base conclusions on this. Hence the focus was more shifted to the experts agreeing or not, trying to find consensus by looking at the level of agreement measure rather than comparing to what degree the experts were agreeing or disagreeing using the IQR. It should also be noted that other requirements for IQR and level of agreement proving consensus than those chosen could have resulted in different conclusions than this.

Some of the hypotheses touched upon the different characteristics of warehouses and the fact that autonomous drones are not suitable in all types of warehouses, which could be one reason why it is not used more extensively. Even though no consensus could be confirmed with the standards chosen for the different measures, it opens an interesting aspect for future research of autonomous drones where a mapping of which warehouses they are more suitable for could give an even better insight into autonomous drones and their usage.

One recurring theme in the comments from the statement was that it depends a lot on the specific usage of the drone and the specific environment it is introduced in. Therefore, the hypotheses could prove to be right or wrong depending on the specific implementation case. However, the general conclusions that could be drawn from the ratings and comments in the second round are the following.

Why are Drones not Used More for Inventory Management and Its Challenges:

- The focus on automating other, more important activities than inventory management could limit the usage of drones.
- The hype and inflated expectations of autonomous drones without sufficient evidence of their usefulness and proven successful examples for inventory management is one reason that the technology is not used more widely.
- The technology is still not mature enough for it to be widely adopted in warehouses.
- As of now, autonomous drones are only used for full pallets and single deep racks. Being able to count individual boxes, and not only full pallets, would increase the usefulness of

drones for inventory management purposes. Thereby, its current capability of only counting full pallets could be a reason why it is not used more extensively as of now.

Autonomous Drones for Physical Operations:

- The analysis indicates that autonomous drones will likely not be used for physical operations within warehousing since better, cheaper, and more efficient technology exists. Even though it is physically possible for the drone to perform physical operations, the trade-off between size, carrying capacity, and battery time, in combination with the warehousing environment, makes it not feasible and its usefulness questionable.

Drivers for Implementing Autonomous Drones for Inventory Management Operations:

- The autonomous drone has a relative advantage in terms of cost, flexibility, and efficiency as of now, and with further technological developments, its advantage would be even greater.
- The trialability of the solution by making pilots and demos is a benefit that promotes its integration.
- The low level of technological readiness for companies to adopt autonomous drones makes the solution accessible for more warehouses, advocating for its growth.
- Implementing drones does not require big organizational change, which makes it more accessible. It can, however, lead to process changes in the warehouse.
- Having limited use cases towards inventory management could limit the usage. However, inventory management is potentially important for all warehouses.
- The increase of warehousing challenges in terms of increased labor costs and labor shortage speaks for the increased usage of autonomous drones in inventory management.
- Autonomous drones are most likely to be used for Inventory Management in warehousing in the future.

Autonomous Drones for Supporting Activities:

- Although surveillance is performed more often, and the importance of inspections on racks in a warehouse can differ, the supporting activities of inspections, climate control, and surveillance are done too seldom for assigning autonomous drones to solely perform these tasks.

A theme noticed from the comments when the experts were asked to rate specific drivers, benefits, or challenges was that many stated that it is a combination of multiple factors and not solely one. By including all the reasons, a more holistic view was thereby obtained. However, there could potentially be even more reasons to the technology not being used more extensively, as well as benefits and challenges of the technology that works in combination with these.

6. Round 3: Feedback and Final Comments

This chapter covers the final round of the study which was the last point of data collection. First the comments received by the experts are presented, followed by a discussion summarizing all rounds of the study.

For the final round, experts were asked to leave their comments on our conclusions from previous rounds, adding aspects that we might have missed. The conclusions that were sent to the experts were taken from the discussion in round 2, and the whole message that was sent to the experts can be seen in Appendix D. In addition to sharing the conclusions, the statistics from the previous round, together with the experts' own answers were sent out.

All twelve experts that answered the survey were given the opportunity to leave comments on our final conclusions. Eight out of the experts responded to the conclusions, three from the drone panel and five from the warehousing panel, meaning that two from each panel did not respond. This results in a total dropout rate of 33 percent. Some of those that dropped out did not answer at all, while some announced that they did not have the time to continue.

Comments left by the experts validated the conclusions made at the end of the second round. Experts answered that the conclusions drawn gave a good representation of all expert opinions and that the methodology of reaching those conclusions was sound. One expert did, however, add a comment which extended the information on how autonomous drones are used for inventory management. The comment emphasized that the drones are used to check the collected data towards the data in the WMS, which creates a higher accuracy of stock, but he also added that the drone could find empty pallet locations.

The same expert commented on the conclusion that drones are not mature enough to be widely adopted in warehouses, saying that the technology is mature enough but that the initial implementation is labor intensive, which can slow down adoption. It was further added by the expert that there currently are improvements being made where the implementation is simplified in order to make the technology easier to implement and in a shorter time frame.

Since only one comment with new information was received, and the rest of the comments were of a validating nature, it can be argued that stability was reached, and the study was thereby concluded. Our assessment was that the conclusions drawn after round 2 were representative of the experts' opinions, which in turn gave a collective view from both the warehousing and drone technology perspectives. This, in combination with time constraints, led to the study being concluded.

7. Conclusion

This chapter covers the final conclusions of the research project, including how the research aligns with the initial purpose and answers to the research questions. This is followed by the contributions of the study, its limitations, and suggestions for future research areas.

7.1 Fulfilling the Purpose

Revisiting the purpose for a last time, which was: *To examine how autonomous drones are used and why they are not used to a greater extent for automating warehousing activities*, it can be concluded that the research conducted has fulfilled its initial purpose. Returning to the title of the thesis *"The Future of Warehouse Automation: Will Drones Ever Take Off?"*, the question of whether it will take off or not can be pondered. From the research conducted it became evident that the usage of autonomous drones is more extensive than we first thought. However, this does not imply that they have "taken off". According to the hype cycle, a specific technology needs to travel through the stages of its maturity before eventually reaching its plateau of productivity, where it becomes an established solution or product on the market. In terms of that, autonomous drones still have hurdles to overcome, but with promising technological improvements on the way, drones are more likely to be used in the future.

With the information collected from 15 highly qualified experts of various backgrounds in the area and the conceptual framework consisting of multiple perspectives from combined models for technology adoption, a holistic analysis of autonomous drones and their usage has been made. With the chosen research method of a Delphi study, iterating the information was possible, leading to conclusions that most participants agreed to. This further contributed to the holistic approach which was desired. A high research quality could be obtained throughout the study with the mixture of thorough interviews, measuring the level of agreement by ranking the results and validating the conclusions. In order to fulfill the purpose, two supporting research questions were developed, which both have been answered.

RQ1: *How can autonomous drones be used to improve warehouse operations and activities?*

The drone application areas can be divided into two groups: analytical and physical usage areas, which have also been used in previous literature. As of now, the drone can only perform inventory management tasks autonomously, specifically stock-taking and cycle counting of full pallets. There are, however, improvements on the way, and already this year, we might see a solution where the drone can count separate boxes as well. There was a high level of agreement amongst the experts that this would increase the usefulness of the technology, which could drive its further usage.

The experts were also hopeful for some minor additional usage areas, such as rack inspections and temperature and humidity checks. However, these are not usage areas that work today, but they are being researched and could be future ways to improve warehouse activities. It became evident that the physical usage areas are much less likely to ever be helpful in a warehouse environment due to the various limitations of the drone itself and the questionable usefulness of such operations being performed by drones. Other solutions for this area can perform the same tasks better and more efficiently, making drones not competitive enough for this application.

RQ2: *Why are autonomous drones not used to a greater extent within warehousing operations today, and what challenges and benefits do they bring?*

Four main reasons for the limited usage of autonomous drones were discovered and validated. The first is that inventory management, the main usage area for autonomous drones in warehouses, is usually not the most prioritized activity when automating warehouses. It was further concluded that the hype and inflated expectations without enough successful implementations and proven examples could be a reason for companies hesitating to implement the new technology. Similarly, the technology was not considered mature enough to be widely adopted in a warehousing environment. Even though the ones having successfully implemented the technology did not really agree with this, this indicates that the technology is starting to reach a higher level of maturity. Lastly, its limited use cases within inventory management of only being able to count full pallets in single deep rack sections is a limiting factor that prohibits its expansion as of now.

The benefits recognized were that autonomous drones have a relative advantage in terms of costs, flexibility, and efficiency. It is also a triable solution that does not require a high level of technological readiness for the companies implementing it. Similarly, they do not come with any significant organizational changes that must be considered before adoption. Other expected trends, such as increased labor shortages and labor costs, can also drive the implementation of this new technology forward within inventory management.

7.2 Contribution

The theoretical contribution of this thesis has mostly been connected to autonomous drones within warehouses, where knowledge of how they are used and why they are not used to a greater extent has been provided. Given the previous unclarities in these aspects and the little academic research on the subject, this study has offered a solid foundation for the autonomous drone application areas within warehousing by summarizing information from multiple different experts in the field. The study presents 23 hypotheses where 15 of which could be confirmed after testing them on the expert panels. This extends the previous research that has been made in terms of case studies (Maghazei et al, 2022) by providing a holistic view from several perspectives.

Besides specifically contributing knowledge regarding autonomous drones in a warehousing environment, this study has further touched upon technology adoption for warehouses in general. Even though no direct conclusions can be drawn from this study alone for technology adoption of new technologies, the study gives insights into one new technology and the benefits and challenges of how it is adopted. The presented conceptual framework was constructed with new technology adoption in mind, offering knowledge and a scientific foundation for future studies that wish to explore new technologies. Previous studies have used the DOI and TOE framework in combination, but this is, to our knowledge, the first occasion where the hype cycle is combined with them as well. Thereby, this study offers an alternative way of evaluating new technologies. Similarly, it could potentially offer an alternative way of conducting a Delphi-inspired study. When researching the Delphi method and investigating the possible different measures that can be used, it was evident that there is a lack of unity in how consensus and stability are reached. In this research, different measures for consensus were used, but given the smaller sample size, the focus was on using the level of agreement and analyzing the panel as a whole. Further, a combination of interviews, surveys, and comments for validation was used in the different rounds. This study could hence potentially be of inspiration when designing future studies in similar contexts or offer an alternative that could be used when discussing the different ways of conducting a Delphi-inspired study.

Even though this study has not been case specific, and with the main focus being purely theoretical, some minor practical contributions have been made. Many participants have shown great interest in the study and the outcomes of it, both from a warehousing perspective, with warehouse managers being interested in potentially investing in this technology as well as from a manufacturer and developer perspective, with drone developers wanting to know the potential drivers and challenges of the technology. The study presents the challenges of drone technology, which could be an indication to developers as to where improvements are needed. Further, the combined picture of challenges and drivers of implementing drones can prove useful for those looking to automate their warehouses with autonomous drones.

7.3 Limitations and Future Research

In this study, three main limitations that could be improved were identified: The number of experts that participated, the number of rounds conducted, and the broader term of inventory management. These limitations exist due to the time constraints posed by this being a master thesis.

As explained in the methodology section, the number of experts in the study is sufficient, but it is recommended to have even more than this study had. Although a saturation of new themes and opinions was reached during the interviews, having more participants could have given a different result in the second round, and better statistical data and analysis would have been possible. An extensive search for experts was done in the study, but with more time, more experts could have been located. Further, the number of rounds in the study was also limited by the time available. Initially, we wanted to continue with a second and possibly a third round of surveys. This could have led to more hypotheses reaching a consensus and a clearer picture of the results, especially those deemed inconclusive.

A third limitation is the usage of inventory management as a collective term for the analytical tasks of controlling stock and inventory that the drone carries out in the warehouse. Although the term was used by the experts in the interviews without them communicating with each other and an understanding of what was meant by inventory management in this context, there is a risk of misinterpretation since the term covers more tasks than those of having an accurate stock. Further, a more detailed research of the specific tasks within warehouse inventory management would have been interesting, but the time frame of the thesis also limited this. This is something that would be interesting to conduct future research on.

Some other interesting aspects of the findings that we could not evaluate further due to being outside our research scope are the specific warehouse characteristics that make autonomous drones suitable. Some of the characteristics, such as having single deep racks and a majority of full pallets were located, but more extensive research on the subject would give a clearer picture of what specific warehouses and industries where drones are useful. Similarly, the competing technology for drones in terms of inventory management could not be confirmed as a reason for its limited usage. Therefore, research on other technologies for inventory management would add to the knowledge base on automation technology.

When choosing the method for conducting this study, it was concluded that the lack of resources and our geographical location made it difficult to perform a case study of the implementation and usage of autonomous drones in warehousing. However, this is something that we propose for future research. Some articles built on case studies have been published on the adoption of drones, but the area still needs to be examined more. A further suggestion for future research is to quantify the challenges and benefits that come with autonomous drones. This study has taken a holistic perspective of their usage, and it would be interesting to examine the magnitude of their performance and how much the improvements they bring save the company implementing them. This could lead to more proven cases reaching a wider audience and extend the usage of autonomous drones in warehousing.

References

Alajami, A.A., Moreno, G. & Pous, R. (2022). Design of a UAV for Autonomous RFID-Based Dynamic Inventories Using Stigmergy for Mapless Indoor Environments. *Drones, 6*(8). doi:10.3390/drones6080208.

Alvehus, J. (2019) *Skriva uppsats med kvalitativ metod : en handbok*. Upplaga 2. Liber. [online] Available at: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,uid&db=cat07147a&AN=lub.5412788&site=eds-live&scope=site (Accessed: 20 April 2023).

Amankwaa, L. (2016). Creating Protocols for Trustworthiness in Qualitative Research. *Journal of Cultural Diversity, 23*(3), 121–127.

Amazon (2022) *Amazon air prime prepares for drone deliveries*. Available at: https://www.aboutamazon.com/news/transportation/how-amazon-is-building-its-drone-delivery-system (Accessed: 2023-01-05)

Amsterdam Drone Week (2022) *Commercial Drones: from Hype to Trust*. Available at: https://www.amsterdamdroneweek.com/news/urban-air-operations/commercial-drones-from-hype-to-trust (Accessed: 2023-01-30)

Baker, J. (2012). The Technology–Organization–Environment Framework. In: Dwivedi, Y., Wade, M., Schneberger, S. (eds) Information Systems Theory. *Integrated Series in Information Systems, 28*. Springer, New York, NY. https://doi.org/10.1007/978-1-4419-6108-2_12

Bartholdi III, J.J. & Hackman, S.T. (2010). Warehouse & distribution science. [Elektronisk resurs] : The Supply Chain and Logistics Institute, School of Industrial and Systems Engineering, Georgia Institute of Technology. Available at: https://search-ebscohost-com.ludwig.lub.lu.se/login.aspx?direct=true&AuthType=ip,uid&db=cat07147a&AN=lub.1865394&site=eds-live&scope=site (Accessed: 2023-05-07)

Beiderbeck, D., Frevel, N., von der Gracht, H. A., Schmidt, S. L., & Schweitzer, V. M. (2021). Preparing, conducting, and analyzing Delphi surveys: Cross-disciplinary practices, new directions, and advancements. *MethodsX, 8*(1). https://doi.org/10.1016/j.mex.2021.101401

Bhattacharya, M. (2015). A Conceptual Framework of RFID Adoption in Retail Using TOE Framework. *International Journal of Technology Diffusion, 6*(1), 1-32.

Birko, S., Dove, E. S., & Özdemir, V. (2015). Evaluation of Nine Consensus Indices in Delphi Foresight Research and Their Dependency on Delphi Survey Characteristics: A Simulation Study and Debate on Delphi Design and Interpretation. *PLoS ONE*, *10*, 1-14.

Boysen, N., de Koster, R., & Weidinger, F. (2019). Warehousing in the e-commerce era: A survey. European Journal of Operational Research, 277(2), 396–411. doi:10.1016/j.ejor.2018.08.023.

Chen, D. Q., Preston, D. S., & Swink, M. (2015). How the Use of Big Data Analytics Affects Value Creation in Supply Chain Management. *Journal of Management Information Systems, 32*(4), 4-39.

Chittipaka, V., Kumar, S., Sivarajah, U., Bowden, J. LH., & Baral, M. M. (2022). Blockchain Technology for Supply Chains operating in emerging markets: an empirical examination of technology- organization-environment (TOE) framework. *Annals of Operations Research*, https://doi.org/10.1007/s10479-022-04801-5

Dalkey, N., Helmer, O. (1963). An experimental application of the Delphi method to the use of experts. *Management Science, 9*(3), 458–467.

De Koster, R. B. M., Johnson, A. L., & Roy, D. (2017). Warehouse design and management. *International Journal of Production Research, 55*(21), 6327-6330. DOI: 10.1080/00207543.2017.1371856

De Vet, E., Brug, J., De Nooijer, J., Dijkstra, A., & De Vries, N.K. (2005). Determinants of forward stage transitions: a Delphi study. *Health Education Research*, 20(2), 195–205.

Dedehayir, O,. & Steinert, M. (2016). The hype cycle model: A review and future directions. *Technological Forecasting & Social Change, 108*, 28-41.

Diamond, I.R., Grant, R.C., Feldman, B.M., Pencharz, P.B., Ling, S.C., Moore, A.M., & Wales, P.W. (2014). Defining consensus: A systematic review recommends methodologic criteria for reporting of Delphi studies. *Journal of Clinical Epidemiology*, 67(4), 401–409. doi:10.1016/j.jclinepi.2013.12.002.

DiCicco-Bloom, B., & Crabtree, B. F. (2006). The qualitative research interview. *Medical Education, 40*(4), 314–321. doi:10.1111/j.1365-2929.2006.02418.x

DSV (2020) *DSV improves warehouse operations with drone system*. Available at: https://www.dsv.com/en/about-dsv/press/news/com/2020/11/dsv-improves-warehouse-operations-with-drone-system Accessed: (2023-02-27)

Ediriweera, A., & Wiewiora, A. (2021). Barriers and enablers of technology adoption in the mining industry. *Resources Policy, 73*, 102188. https://doi.org/10.1016/j.resourpol.2021.102188

Ellram, L. M. (1996). The use of the case study method in logistics research. *Journal of Business Logistics, 17*(2), 93-138.

Elo, S., & Kyngäs, H. (2008). The qualitative Content Analysis Process. *Journal of Advanced Nursing, 62,* 107-115. https://doi.org/10.1111/j.1365-2648.2007.04569.x

Eriksson, E., Norrman, A., & Kembro, J. (2019). Contextual adaptation of omni-channel grocery retailers' online fulfilment centres. *International Journal of Retail and Distribution Management, 47*(12), 1232-1250.

Erlandson, D. A., Harris, E. L., Skipper, B. L., & Allen, S. D. (1993). *Doing naturalistic inquiry: A guide to methods*. Sage.

Faber, N., De Koster, R. B., & Smidts, A. (2018). Survival of the fittest: the impact of fit between warehouse management structure and warehouse context on warehouse performance. *International Journal of Production Research, 56*(1-2), 120-139.

Fatima, Z., Tanveer, M. H., Waseemullah., Zardari, S., Naz, L. F., Khadim, H., & Ahmed, N., Tahir, M. (2022). Production Plant and Warehouse Automation with IoT and Industry 5.0. *Applied Sciences, 12*(4), 2053. https://doi.org/10.3390/app12042053

Fenn, J. & Raskino, M. (2008). *Mastering the Hype Cycle: How to Choose the Right Innovation at the Right Time*. Harvard Business Press.

Fernández-Caramés, T.M., Blanco-Novoa, O., Froiz-Míguez, I., Fraga-Lamas, P. (2019). Towards an Autonomous Industry 4.0 Warehouse: A UAV and Blockchain-Based System for Inventory and Traceability Applications in Big Data-Driven Supply Chain Management. *Sensors, 19*(10). doi:10.3390/s19102394.

Flick, S. N. (1988). Managing attraction in clinical research. *Clinical Psychology Review, 8*, 499-515. https://doi.org/10.1016/0272-7358(88)90076-1

Forbes. (2022) *Why Technical Maturity Is Critical In 2023*. Available at: https://www.forbes.com/sites/forbestechcouncil/2022/11/22/why-technical-maturity-is-critical-in-2023/ (Accessed: 2023-04-16)

Galletta, A. & Cross, W.E. (2013). *Mastering the semi-structured interview and beyond : from research design to analysis and publication*. New York University Press (Qualitative studies in psychology). Available at: https://search.ebscohost.com/login.aspx?direct=true&AuthType=ip,uid&db=cat07147a&AN=lub.6949006&site=eds-live&scope=site (Accessed: 2023-03-17)

Ghobakhloo, M., Iranmanesh, M., Vilkas, M., Grybauskas, A., & Amran, A. (2022). Drivers and barriers of Industry 4.0 technology adoption among manufacturing SMEs: a systematic review and transformation roadmap. *Journal of Manufacturing Technology Management, 33*(4). doi:10.1108/JMTM-12-2021-0505

Gibbert, M., Ruigrok, W. & Wicki, B. (2008). Research notes and commentaries: what passes as a rigorous case study?. *Strategic Management Journal, 29*(13), 1465-1474.

Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2012). Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology. *Organizational Research Methods, 16*(1), 15-31. Doi: 10.1177/1094428112452151

Goodman, C. M. (1987). The Delphi technique. A critique. *Journal of Advanced Nursing, 12*(6), 729-734.

Gu, J., Goetschalckx, M., & McGinnis, L. F. (2007). Research on warehouse operation: A comprehensive review. *European Journal of Operational Research, 177*(1).

Guba, E. G., & Lincoln, Y. S. (1989). *Fourth generation evaluation*. Sage Publications.

Halldórsson, Á., & Aastrup, J. (2003). Quality criteria for qualitative inquiries in logistics. *European Journal of Operational Research, 144*(2), 321–332. https://doi.org/10.1016/S0377-2217(02)00397-1

Han, C., Jeon, H., Oh, J., & Lee, H. (2022). Dynamic Order Picking Method for Multi-UAV System in Intelligent Warehouse. *Remote Sensing, 14(*23). doi:10.3390/rs14236106.

Hell, P. M. & Varga, P. J. (2019). Drone Systems for Factory Security and Surveillance. *Interdisciplinary Description of Complex Systems*, *17*(3–A), 458–467. doi:10.7906/indecs.17.3.4.

Heutger, M., Kückelhaus, M. (2014) *Unmanned Aerial Vehicles In Logistics: A DHL perspective On Implications And Use Cases For The Logistics Industry*. DHL. Available at: Unmanned Aerial Vehicles in LogisticsDHLhttps://www.dhl.com › full › dhl-trend-report-uav (Accessed: 2023-02-14)

Hsu, C. C., & Sandford, B. A. (2007). Minimizing Non-Response in The Delphi Process: How to Respond to Non-Respons. *Practical, Assessment, Research, and Evaluation, 12*.

Höst, M., Regnell, B., & Runeson, P. (2006). *Att genomföra examensarbete*. Studentlitteratur

IKEA (2020) *How tech for show business can automate IKEA warehouses*. Available at: https://about.ikea.com/en/behind-scenes/innovation-technology/2020/11/19/how-tech-for-show-business-can-automate-ikea-warehouses (Accessed: 2023-02-27)

Insider Intelligence. (2021). Drone technology uses and applications for commercial, industrial and military drones in 2021 and the future. *Business Insider.* Available at: https://www.businessinsider.com/drone-technology-uses-applications?r=US&IR=T (Accessed: 2023-02-23)

Joshi, A., Kale, S., Chandel, S., Pal, D. K. (2015). Likert Scale: Explored and Explained. *British Journal of Applied Science and Technology, 7*(4), 396-403.

Kalaiarasan, R., Olhager, J., Agrawal, T.K. & Wiktorsson, M. (2022). The ABCDE of supply chain visibility: A systematic literature review and framework. *International Journal of Production Economics*, *248*, 108464.

Kallio, H., Pietilä, A.-M., Johnson, M. & Kangasniemi, M. (2016). Systematic methodological review: developing a framework for a qualitative semi-structured interview guide. *Journal of Advanced Nursing, 72*(12), 2954– 2965. doi: 10.1111/jan.13031

Kapoor, R. & Klueter, T. (2021). Unbundling and Managing Uncertainty Surrounding Emerging Technologies. *Strategy Science 6*(1), 62-74. https://doi.org/10.1287/stsc.2020.0118

Keeney, S., Hasson, F., & McKenna, H. P. (2001). A critical review of the Delphi technique as a research methodology for nursing. *International Journal of Nursing Studies, 38*, 195-200.

Kembro, J., & Norrman, A. (2022). The transformation from manual to smart warehousing: an exploratory study with Swedish retailers. *The International Journal of Logistics Management, 33*(5). 107-135. https://doi.org/10.1108/IJLM-11-2021-0525

Kembro, J. H., Norrman, A., & Eriksson, E. (2018). Adapting warehouse operations and design to omni-channel logistics: A literature review and research agenda. *International Journal of Physical Distribution & Logistics Management, 48*(9), 890-912. Doi: 10.1108/IJPDLM- 01-2017-0052

Kondo, Y., Asatani, K., & Sakata, I. (2022). Evaluating Emerging Technologies on the Gartner Hype Cycle by Network Analysis, *In 2022 Portland International Conference on Management of Engineering and Technology (PICMET),* 1-9. IEEE.

Kovach, S. (2013) Amazon experimenting with drones that will deliver packages in 30 minutes. *Business Insider*. [online]. Available at: https://www.businessinsider.com/jeff-bezos-60-minutes-surprise-2013-12?r=US&IR=T (Accessed: 2023-01-15)

Kuru, K., Ansell, D., Khan, W. & Yetgin, H. (2019). Analysis and Optimization of Unmanned Aerial Vehicle Swarms in Logistics: An Intelligent Delivery Platform. *IEEE Access*, *7*, 15804-15831. doi: 10.1109/ACCESS.2019.2892716.

Kwon, H., Park, Y. & Kim, J. (2017). Applying LSA text mining technique in envisioning social impacts of emerging technologies: The case of drone technology. *Technovation*, 60/61, 15-28. https://doi.org/10.1016/j.technovation.2017.01.001

Levitt, H.M. (2021). Qualitative generalization, not to the population but to the phenomenon: Reconceptualizing variation in qualitative research. *Qualitative Psychology, 8*(1), 95–110. doi:10.1037/qup0000184.

Linstone, H. A., & Turoff, M. (2011). Delphi: A brief look backward and forward. *Technological Forecasting & Social Change, 78*(9), 1712-1719.

Loo, R. (2002). The Delphi method: a powerful tool for strategic management. *Policing: An International Journal, 25*(4), 762-769. https://doi.org/10.1108/13639510210450677

Maghazei, O., Lewis, M. A., & Netland, T. H. (2022). Emerging technologies and the use case: A multi-year study of drone adoption. *Journal of Operations Management*, *68*(6/7), 560–591. https://doi.org/10.1002/joom.1196

Maghazei, O. & Netland, T. (2020). Drones in manufacturing: exploring opportunities for research and practice. *Journal of Manufacturing Technology Management*, *31*(6), 1237-1259. https://doi.org/10.1108/JMTM-03-2019-0099

Malang, C. Charoenkwan, P. & Wudhikarn, R. (2023). Implementation and Critical Factors of Unmanned Aerial Vehicle (UAV) in Warehouse Management: A Systematic Literature Review. *Drones, 7*(2), 80.

Malhotra, M. K. & Grover, V. (1998). An assessment of survey research in POM: From constructs to theory. *Journal of Operations Management, 16*(4), 407-425. doi: 10.1016/S0272-6963(98)00021-7

Mapes, J. (2015). Inventory Accuracy. *Operations Management, 10* https://doi.org/10.1002/9781118785317.weom100102

Nieto, M., Lopéz, F., & Cruz, F. (1998). Performance analysis of technology using the S curve model: the case of digital signal processing (DSP) technologies. *Technovation, 18*(6-7), 439-457.

Okoli, C., & Pawlowski, D. S. (2004). The Delphi method as a research tool: an example, design considerations and applications. *Information & Management*, *42*(19), 15-29. DOI: https://doi.org/10.1016/j.im.2003.11.002

Oliveira, T., Thomas, M. & Espadanal, M. (2014). Assessing the determinants of cloud computing adoption: an analysis of the manufacturing and services sectors. *Information and Management, 51*(5), 497–510. doi:10.1016/j.im.2014.03.006.

Qu, S. Q., & Dumay, J. (2011). The qualitative research interview. *Qualitative Research in Accounting & Management, 8*(3), 238–264. https://doi.org/10.1108/117660911111 62070

Radácsi, L., Gubán, M., Szabó, L., & Udvaros, J. (2022). A Path Planning Model for Stock Inventory Using a Drone. *Mathematics*, 10(16). doi:10.3390/math10162899.

Rathore, B. et al. (2022). Identification and analysis of adoption barriers of disruptive technologies in the logistics industry. *International Journal of Logistics Management*, 33(5), 136–169. doi:10.1108/IJLM-07-2021-0352.

Rogers, E.M. (2003). *Diffusion of innovations*. 5. ed. Free press. Available at: https://search-ebscohost-com.ludwig.lub.lu.se/login.aspx?direct=true&AuthType=ip,uid&db=cat07147a&AN=lub.1892845&site=eds-live&scope=site (Accessed: 2023-04-15)

Rowley, J., & Slack, F. (2004). Conducting a literature review. *Management Research News, 27*(6), 31-39. http://dx.doi.org/10.1108/01409170410784185

Singh, D., Verma, A. (2018). Inventory Management in Supply Chain, *Materialstoday: Proceedings, 5*(2), 3867-3872. https://doi.org/10.1016/j.matpr.2017.11.641

Stanko, J., Stec, F. & Rodina, J. (2022). Process automation of warehouse inspection using an autonomous unmanned aerial vehicle. *MM Science Journal*. DOI: 10.17973/MMSJ.2022_10_2022063

Steinert, M. (2009). A dissensus based online Delphi approach: An explorative research tool. *Technological Forecasting and Social Change*, *76*(3). 291-300. https://doi.org/10.1016/j.techfore.2008.10.006

Taherdoost, H. (2018). A review of technology acceptance and adoption models and theories. *Procedia Manufacturing, 22*, 960-967. https://doi.org/10.1016/j.promfg.2018.03.137

Tahriri, F., Mousavi, M., Galavi, H., & Sorooshian, S. (2022). A Decision-Making Model for Predicting Technology Adoption Success. *Processes*, *10*(11). https://doi.org/10.3390/pr10112261

Tortorella, G., Kurnia, S., Trentin, M., Oliveira, G.A. & Setti, D. (2022). Industry 4.0: what is the relationship between manufacturing strategies, critical success factors and technology adoption?. *Journal of Manufacturing Technology Management*, *33*(8), 1407-1428. https://doi-org.ludwig.lub.lu.se/10.1108/JMTM-02-2022-0088

Tsai, M.-C., Lee, W. & Wu, H.-C. (2010). Determinants of RFID adoption intention: Evidence from Taiwanese retail chains. *Information and Management, 47*(5/6), 255-261. doi:10.1016/j.im.2010.05.001.

Tubis , A. A., Ryczynski, J., Zurek, A. (2021). RiskAssessmentforthe Use of Drones in Warehouse Operations in the First Phase of Introducing the Service to the Market. *Sensors, 21*, 6713. https:// doi.org/10.3390/s21206713

van Lente, H., Spitters, C., & Peine, A. (2013). Comparing technological hype cycles: Towards a theory. *Technological Forecasting & Social Change, 80*, 1615–1628

Verity (2022) *Automated inventory management powered by self-flying warehouse drones.*

Available at:
https://verity.net/automated-inventory-management-warehouse-drones-solution/
(Accessed: 2023-01-08)

von der Gracht, H. A. (2012). Consensus measurement in Delphi studies: Review and implications for future quality assurance. *Technological Forecasting & Social Change, 79*, 1525-1536.

von der Gracht, H. (2008). *The Future of Logistics - Scenarios for 2025*. Wiesbaden, Betriebswirtschaftlicher Verlag Dr. Th. Gabler.

von der Gracht, H.A. & Darkow, I.-L. (2010). Scenarios for the logistics services industry: A Delphi-based analysis for 2025. *International Journal of Production Economics*, *127*(1), 46–59. doi:10.1016/j.ijpe.2010.04.013.

Wawrla, L., Maghazei, O., & Netland, T. (2019). Applications of drones in warehouse operations. Whitepaper. ETH Zurich, D-MTEC, Chair of Production and Operations Management. Available at:
https://ethz.ch/content/dam/ethz/special-interest/mtec/pom-dam/documents/Drones%20in%20warehouse%20opeations_POM%20whitepaper%202019_Final.pdf
(Accessed: 2023-02-14)

Xu, L., Kamat, V.R. & Menassa, C.C. (2018). Automatic extraction of 1D barcodes from video scans for drone-assisted inventory management in warehousing applications. *International Journal of Logistics Research and Applications*, *21*(3), 243-258. doi:10.1080/13675567.2017.1393505.

Yin, R.K. (2009). *Case Study Research: Design and Methods* (4th ed). Sage Publication.

Yousuf, M. I. (2007). Using Experts' Opinions Through Delphi Technique. *Practical Assessment, Research, and Evaluation, 12* , Article 4. https://doi.org/10.7275/rrph-t210

Zhen, L., & Li, H. (2022). A literature review of smart warehouse operations management. *Frontiers of Engineering Management, 9*(1), 31-55. https://doi.org/10.1007/s42524-021-0178-9

Appendix

Appendix A - Round 1: Interview Guide

Interview Guide

Internal

Introduction 5 min

Our names are Idun and Filip and we are students from LTH who are writing our master thesis project about drones and their usage within warehousing. We are trying to answer our research questions by gathering and putting together data from an interview combined with a Delphi study. With this we hope to gather more knowledge as to why drones are not more widely used and implemented in warehouses and what challenges and benefits that the technology provides. We would also like to investigate if there are any new potential usage areas of drones in warehouses in the future.

We are interviewing a lot of different experts with different backgrounds and skills to get different perspectives on the area. The interviews and the answers to the questions will be completely anonymous when presented in our report.
We will start with some more personal questions about you and your previous experience within the field and then move on to more specific questions related to drones and then warehousing and automation technology.

Before we start, is it okay if we record? (This will only be used privately for us to make sure that no important details or information are left out)

Personal Questions ca 5 min

1. Present yourself, name and current position?
2. How long have you had this role?
3. What is your educational background?
4. What is your experience within warehousing?
5. What is your experience with drones?
6. What country are you working/operating in?
7. (Years of experience?)

Drone Technology ca 45 min

Today / Current Situation ca 20-30 min

1. What are the major benefits of using drones within warehousing?
    a. What are the benefits of drones compared to other automation technologies? *(Easy to use? Easy to integrate? Resource efficient technology? Flexibility? Low investment cost?, Costs)*
    b. How is drone technology better?
2. Within what areas / activities / operations are they most suitable?
    a. Receiving materials in warehouses?
    b. In the put-away process, for scanning, lifting etc.?
    c. Storing, inventory management?
    d. Picking, for picking materials or scanning
    e. Packing or shipping?
    f. To handle return flows?
    g. Any other functions?
    (Surveillance, security, social sustainability purposes, regulating/checking temperatures or other conditions)
3. What are the major challenges of using and implementing drones in warehousing?
4. Why do you think that drones are not used to a greater extent in warehousing today?
    a. If you have implemented: has the company continued to use drones and implement in other warehouses? If not, why?
5. How well are drones integrated with other warehousing systems and technology?
    a. How long does it take to integrate it successfully?
    b. How long does it take to see results?
6. How well are drones integrated with behavioral factors and workers in the warehouses?
7. What risks are associated with drones?
    a. How is this affecting the usage of them in warehouses?
    b. What measures are taken to limit those risks and the impacts of them?

8. How easy is drone technology to understand and use?
9. How easy is it to measure and monitor the performance of drones implemented in warehousing?
10. How easy is it to try the technology before implementing it at full?
    a. Making pilot projects etc.?

Future Situation & Development ca 15 min

11. How will drones improve or change with all the future development that is happening in the technology?
    a. Will they be able to be more energy efficient?
    b. More autonomous, self going?
    c. Longer battery time? (Other energy sources?)
    d. Will they be able to lift heavier loads?
    e. Improved additional technology?
12. With the improving technology, what are the promising new potential usage areas in warehousing for drones in the future?
    a. What will it take for drones to be used more in warehousing in the future? *(Technical developments, knowledge about drones, cheaper, less risks etc.)*
    b. In your opinion, how will drones be used in the future in warehousing?
    c. Why do you think that?
13. When will we see a breakthrough of drones used in warehousing?
    a. For already designated usage areas, inventory checks, surveillance, mapping etc.
    b. For other potential usage areas? Intralogistics, etc.?

Warehousing ca 20-30 min

14. What aspects affect the choice of what automation technology to use in warehouses?
    a. Technological requirements on automation technology in warehousing?
    b. Type of warehouse?
    c. Organizational and behavioral aspects?
    d. Complexity?
    e. Economic factors?
    f. How well known / familiar the technology is?
    g. How does this affect new technology?
15. How important is the implementation phase when adopting new technology?
    a. How does it matter how long time it takes for the new technology to give results?
16. What are the competing technologies to drones that possess the same benefits?
    a. When will other technology be able to do the same chores as efficiently / effectively as drones are doing now? (inventory checks, etc.)
17. Who is leading the development of new warehouse automation technology?
    (Industry, academia, researchers etc.)
    a. Who is leading the development and research on drones? *(Industry, academia, researchers etc.)*
    a. Why do you think that is?
18. Who is usually the major opposer of implementations of new technology?
    a. For drone technology?
19. What are the biggest challenges that warehousing is facing in the future?

a. How will the need for technology and warehouse automation change?
b. In what areas, activities, operations in warehousing will we see the major challenges?
c. In what ways could drones solve any of these challenges?

20. How are organizational structures affecting the choice of implementing certain automation technology?
    a. What organizational aspects can affect the usage and implementation of drones?
21. What other factors affect the choice when looking for warehouse automation solutions?
    a. Publicity stunts? (Being perceived as a high-tech warehouse)
    b. Sustainability? (Social factors)
22. How can the fact that a technology is developing and changing fast, affect the decision to implement that certain technology?
    i. Could it make people more resistant/willing to implement that technology?

Appendix B - Round 2: Answers From Experts In Survey

	A	B	D	E	F	G	H	I	L	M	N	O
H1	7	7	6	4	7	5	7	5	6	5	6	4
H2	7	5	5	5	6	7	2	5	5	4	6	3
H3	2	4	5	4	7	3	7	6	6	4	7	-
H4	7	2	4	1	7	4	1	2	5	6	3	4
H5	7	6	7	2	3	3	7	3	6	5	6	4
H6	3	5	6	6	7	4	1	4	3	5	6	-
H7	6	4	6	4	7	5	6	5	7	5	6	5
H8	5	7	6	3	4	3	7	5	6	5	6	6
H9	7	6	6	2	6	6	1	6	6	2	5	4
H10	4	5	3	6	2	6	1	5	6	3	2	2
H11	5	7	5	2	4	4	6	6	5	5	6	4
H12	7	5	5	2	6	4	2	-	5	5	3	6
H13	7	6	6	6	2	5	2	6	2	3	5	5
H14	7	7	6	6	6	4	7	5	7	5	6	6
H15	5	2	2	6	6	3	1	2	3	3	4	5
H16	7	6	5	5	1	5	2	5	4	2	5	4
H17	7	5	5	6	6	4	2	4	6	6	5	-
H18	6	2	1	7	5	4	1	5	7	5	7	5
H19	6	5	5	5	7	5	7	7	6	5	6	5
H20	7	7	7	5	7	4	6	6	7	5	7	7
H21	7	7	2	6	6	3	1	5	7	3	6	6
H22	7	7	6	6	6	3	2	5	7	7	6	5
H23	1	7	6	5	7	4	7	6	7	5	6	6

Appendix C - Round 2: Comments From Experts In Survey

Statement:	Comments:
H1	- Cycle counting can quite efficiently be integrated in the pick process. However, for bulk stock additional activities are required which can be overtaken by drones. (5) - It depends on your current preconditions in the unit. (6) - The question is formulated quite broadly - the pros and cons depend on the exact use case I think. (4) - Like all processes that can be taken over by some kind of automation, we will see further acceptance/growth and even need in the future. (7) - "relative advantage" and "current ways" are vague terms, making the hypothesis hard to evaluate (4)
H2	- surveillance (security) can be done more frequently than the other activities (4) - In general yes, but in our stores we check rack damages much more frequently due to the fact that we have customers there. (5) - There are different use models - if drones are not frequently used, they could be rented from a service provider. (3) - There is the cost aspect as well. (6)
H3	- I found the question difficult to answer, as the integration would certainly be system- and provider-dependent. (no-answer) - Automated drones are not easy to integrate because they use a 3D navigation system that is not represented inside the customers systems and needs to be manually mapped and tested, cm by cm in 3 dimensions. (2) - Simple spreadsheet upload from ERP (7)
H4	- Today yes, but work is ongoing to mitigate this, plus it's likely that people will get more used to drones (4) - Not all parts of the warehouse are busy during operating hours, which opens up opportunities for using drones. (4) - I do see it possible to operate next to workers. Drones won't crash into objects. It is the other way around, which makes it a risk. But I think it is possible to organize in such a way, they can operatie next to each other (2) - Most warehouses have areas that can be cordoned off at certain times off the day without inhibiting operations (3) - What difference does it make if it is around the clock or an 8 hour shift? (1)
H5	- Probably differs from different solutions but it is important it's easy to use (7) - Again, I believe this depends on the specific system and how user-friendly the interface is designed. (4) - It is not easy to understand. Technology can be a hindrance for its limited usage. for instance failure of sensors, communication failure, etc. (3) - The UI I worked with was fairly user friendly but needed more improvements. (6)

H6	- There is normally a resistance to new ways of working. There is always uncertainty until you try it out (6) - I disagree with the first part of the question - is the performance really easy to measure? If the drone miscounts something, how are you going to find this out? Hence, I did not respond to the question. (no-answer) - The value can easily be measured but it's not a big enough problem to warrant the hassle . "dont solve a $100 problem with a $10000 solution" (3)
H7	- A test phase is certainly useful and may reduce implementation barriers; there are also service providers that could be hired to give insights into the technology. (5)
H8	- I think it is a mixture of both low technological readiness and cost benefit (4)
H9	- “high stock accuracy is important for all warehouses. So potentially useful everywhere” (2) - This question is difficult to answer - I believe what is even more important is which type of items is stored in the warehouse and how the drone can count it. (4) - or where they do infrequent checks but have a number of warehouses and can move the drone easily between the warehouses. (7) - Only is a very strong word (6)
H10	- It depends a lot on your preconditions. (3)
H11	- It should lead to new ways of working and to shift focus from repetitive tasks. This might lead to org change (5) - Case-dependent.(4) - I am not aware of organizational changes (4)
H12	- Agree but there are work arounds for double deep racks. (5) - Probably the most interesting use case at the moment. (6) - Currently yes, but we can expect box counting feature this year making it suitable for any warehouse operation handling down to box size objects (5) - Maybe we are limited to there usage today and maybe not future possibility. (no-answer) - If the warehouse was fully automated, it could not operate if your assumptions of units in stock are wrong.(2)
H13	- Picking is a high focus for many (6) - I do not agree due to the fact that from my perspective the reason is not to be more focused on other operations but because the knowhow about the capabilities of drones is so limited. (2)
H14	- saving time and costs could also be a reason (6)
H15	- ASRS systems make drones redundant (5)
H16	- more fully automated warehouses: yes. But the total number will remain low. (2) - Rfid is a potential disruptor (5) - If that happens, yes agree. But don't see it going there fast (6)
H17	- Agree. But we have with our preconditions proved its value for us (5)

	- I did not observe a hype regarding drones in this area, hence I did not respond to the question.
H18	- Battery run time and scanning issues are limitations at the moment in my opinion. (5) - the technology is inherently not suited to constant use in an industrial environment so no matter how much it matures, it will always not be suitable. (6)
H19	- for niche applications and contexts (5) - Not a given. Depends how far in the future we talk. (5) - "warehousing in the future" is again vague. (5)
H20	- Being worked on (7)
H21	- At least in the near future. (6)
H22	No Comments
H23	- we are seeing more demand for our manually operated systems and our AGV based system than for our drone based system.(1)

Appendix D - Round 3: Conclusion Sent To Experts For Comments

The Future of Warehouse Automation:
Will Drones Ever Take Off?

We write to you in order to share the results from the previous round, our conclusions so far, and which quotations we have used in our report from the interview with you. All the statistics from the previous round and your answers are attached in separate files while the conclusions and quotations are presented in the text below.

This is the final part of our study and therefore puts an end to our master thesis. It has been both enlightening and interesting to hear your thoughts and opinions on whether there is a future for drones in warehousing or not, as well as the challenges and benefits with the solutions it presents. Although we initially wanted for you to re-rate the hypotheses revised from the comments made by you, the time constraints of our study limits us from doing so. Instead, **we would be very grateful to receive your final comments on the conclusions we have made**. This can be seen as the last point of information collection and we are eager to hear what you think.

Our key takeaways from the survey in combination with the interviews conducted with you are presented below. There are of course other aspects as well that influence the implementation, usage, and adoption of autonomous drones in warehousing but these are the general themes that were were able to localize from the collected data:

Why are drones not used more:

- The focus on automating other, more important activities than inventory management could limit the usage of drones
- The hype and inflated expectations of autonomous drones without sufficient evidence of its usefulness and proven successful examples for inventory management is one reason that the technology is not used more widely
- The technology is still not mature enough for it to be widely adopted in warehouses.
- Being able to count individual boxes, and not only full pallets would increase the usefulness of drones for inventory management purposes. Thereby, its current capabilities of only counting full pallets could be a reason why it is not used more extensively as of now.

Physical Operations:

- The analysis indicates that autonomous drones will likely not be used for physical operations within warehousing since better, cheaper and more efficient technology exists. Even though it is physically possible for the drone to perform physical operations, the trade-off between size, carrying capacity, and battery time, in combination with the warehousing environment makes it not feasible and its usefulness questionable.

Inventory Management operations:

- The autonomous drone has a relative advantage in terms of cost, flexibility, efficiency as of now and with further technological developments, its advantage would be even greater.
- The trialability of the solution by making pilots and demos is a benefit that promotes its integration.
- The low level of technological readiness for companies to adopt autonomous drones makes the solution accessible for more warehouses, advocating for its growth.
- Implementing drones does not require big organizational change with makes it more accessible, it can however lead to process changes in the warehouse
- Having limited use case towards inventory management could limit the usage, however, inventory management is potentially important for all warehouses
- As of now, autonomous drones are only used for full pallets and single deep racks
- The increase of warehousing challenges in terms of increased labor costs and labor shortage speaks for the increased usage of autonomous drones in inventory management.
- Autonomous drones are most likely to be used for Inventory Management in warehousing in the future.

Supporting Activities:

- Although surveillance is performed more often, and the importance of inspections on racks in a warehouse can differ, the supporting activities of inspections, climate control, and surveillance are done too seldom for assigning autonomous drones to solely perform these tasks.

We look forward to receiving your final comments on our conclusion and if you have anything to add on why autonomous drones are not used more, the challenges, and the drivers for its usage.