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Evaluating implementation areas of Real-Time Location System (RTLS) in the production at Scania CV AB Oskarshamn

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PREFACE

This thesis is conducted during the spring of 2021 and marks the end of the authors' Master's Degree in Mechanical Engineering at The Faculty of Engineering LTH at Lund University. The thesis has been conducted in collaboration with the case company Scania CV AB and the Division of Engineering Logistics at LTH.

There are several persons that have contributed to this thesis by sharing their experience, time and knowledge with us. First and foremost, we would like to extend our most sincere gratitude to the case company and all stakeholders involved as this has enhanced the quality of the study. It has been an honour to be granted this opportunity. A special thanks is dedicated to our excellent company supervisor Karl Hammerin for his continuous support and extraordinary guidance throughout the process as it contributed to our sustained level of motivation.

We would also like to express our sincerest gratitude towards our LTH supervisor Magnus Berg and examiner Jan Olhager for providing us with support and thoughtful insights whenever needed. Their availability, commitment and engagement in assisting us has been invaluable. Many thanks are also given to the entire organization of LTH for its high quality of teaching.

Finally, we would like to thank each other for a well performed thesis project. As a team, we made it happen.

Gustav Nacke & Samuel Hirschfeld

Lund, May 2021

ABSTRACT

Title:	Evaluating implementation areas of Real-Time Location System (RTLS) in the production at Scania CV AB Oskarshamn
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Supervisors:	Karl Hammerin, Logistics developer, Scania CV AB Maryana Sjöquist, Logistic Development Manager, Scania CV AB Magnus Berg, Department of Industrial management and Logistics, Lund University
Examiner:	Jan Olhager, Department of Industrial management and Logistics, Lund University
Background:	Scania's production unit in Oskarshamn manufactures and supplies truck cabs to the European market. In order to remain competitive, it is necessary for the company to re-evaluate its competencies and technologies. Thus, it is of great interest for Scania to investigate what value newly acquired technology can provide to the company and its operations.
Problem description:	As a part of Scania's track and trace strategy, the company is currently acquiring and evaluating the possibility of implementing RTLS in their operations. Scania wants to investigate how the technology can contribute to a strategic advantage. Therefore, Scania is curious on *where* and *how* to implement RTLS in order to improve e.g., efficiency.
Purpose:	The purpose is to evaluate and identify appropriate areas of RTLS implementations with the aid of a conceptual framework, designed after existing literature and discussed according to Scania's track and trace operations.
Research questions:	1. What advantages, challenges, risks and requirements do RTLS entail? 2. How can Scania use the RTLS technology and for which applications?
Methodology:	The abductive approach is used. For RQ1, a structured literature review is conducted. For RQ2, a case study is conducted in order to develop a conceptual framework which is then tested and validated in Scania's settings.
Results:	The conceptual framework suggests, on a general level, when RTLS is suitable to implement and what to consider. A checklist is also developed to support Scania when seeking to apply the technology.
Conclusions:	It is clear to say that the RTLS kit for this thesis does not meet the requirements set by Scania. This since what the RTLS is capable of is not in line with the purposes of using the technology. However, RTLS could still be used when testing in areas where the purposes are more fit to the capabilities, i.e., in smaller areas and/or where the degree of disturbance is lower.

Keywords:	Real-Time Location System, Track and trace, Logistics, RTLS implementation, Scania CV AB, Conceptual framework

SAMMANFATTNING

Titel:	Identifiera lämpliga användningsområden för Real-Time Location System i produktionsmiljö på Scania CV AB
Författare:	Gustav Nacke, Samuel Hirschfeld
Handledare:	Karl Hammerin, Logistics developer, Scania CV AB Maryana Sjöquist, Logistic Development Manager, Scania CV AB Magnus Berg, Department of Industrial management and Logistics, Lund University
Examinator:	Jan Olhager, Department of Industrial management and Logistics, Lund University
Bakgrund:	Scania CV AB i Oskarshamn tillverkar och monterar lastbilshytter med vilka man förser den europeiska marknaden. I syfte att förbli konkurrenskraftiga är det för företaget nödvändigt att utvärdera dess kompetenser och teknologier. Således är det av intresse för Scania att undersöka vilket värde nyförvärv av teknologier kan bistå företaget med.
Problemformulering:	Som en del av Scanias *track and trace* strategi befinner man sig nu i en fas där man förvärvar och utvärderar möjligheten att implementera RTLS i sina processer. Scania vill undersöka hur teknologin kan förse företaget med en strategisk fördel. Således är man nyfiken på *var* och *hur* RTLS kan implementeras för att förbättra blanda annat effektivitet och säkerhet i tillverkande processer.
Syfte:	Syftet med denna studie är att utvärdera och identifiera lämpliga områden att implementera RTLS i med hjälp av ett konceptuellt ramverk, designat utifrån existerande litteratur och diskuterat enligt Scanias track and trace operationer.
Frågeställningar:	1. Vilka fördelar, utmaningar, risker och krav medför RTLS? 2. Hur kan Scania använda RTLS teknologin och för vilka applikationer?
Metod:	Ett så kallad abduktivt tillvägagångssätt används för denna studie. För studiens första frågeställning kommer en strukturerad litteraturstudie att genomföras. För studiens andra frågeställning kommer en case studie att genomföras i syfte att utveckla ett konceptuellt ramverk vilket valideras utefter de förhållanden som råder på Scania.
Resultat:	Det konceptuella ramverket föreslår, på en generell nivå, var RTLS lämpar sig att implementeras och vad som bör tas i beaktande. Utöver detta är en checklista utvecklad i syfte att stödja Scania med att applicera teknologin.
Slutsats:	Det är tydligt att RTLS teknologin inte svarar mot de kraven som finns satta från Scania. Detta då vad RTLS tekniken är kapabel till inte uppfyller de syften att använda tekniken i för denna avhandling. Däremot kan RTLS fortfarande användas och testas i andra områden, där syftet är mer passande teknikens förmågor, till exempel i mindre områden och/eller i områden där andelen störningar är lägre.
Nyckelord:	Real-Time Location System, Track and trace, Logistik, RTLS implementation, Scania CV AB, Konceptuellt ramverk

TABLE OF CONTENTS

1. INTRODUCTION

This chapter aims at providing a brief introduction to the thesis and the study object. By stating the background, the problem formulation, the purpose of the study and the research questions, context is provided. Delimitations, target groups and the relevance of the thesis are also addressed. Lastly, the section is summarized in an outline of the report.

1.1. Background

Today's rapidly changing environment, increase in global presence and fast advancing technology pose threats to businesses and enterprises. Organizations must continually reassess its competencies, evaluate its core processes and performance strategies in order to remain competitive. It is safe to say that the digital revolution and the diffusion of technology have revolutionized concepts by providing enterprises with faster, more efficient and convenient ways of operating their businesses.

In the field of supply chain disciplines, the exponential growth of information technology has generated solutions to every function in the value chain. In addition to providing innovative solutions to complex problems, the technology has also made real time decision making available. Pointed out by Introna (1991), it became more and more apparent already in the early 90's that the interest and use of information technology in logistical contexts is growing as the need is increasing.

Information technology is commonly used in track and trace operations. By monitoring and receiving real-time information regarding goods and their properties, visibility and transparency is achieved (Shamsuzzoha et al., 2013). Auto-ID technologies such as Radio Frequency Identification (RFID) makes it possible to track goods both internally in organisations and externally in the supply chain. This is a successful instrument that can be applied within production logistics to facilitate the management of tools and assets. The next step of RFID is the development of RTLS (Real-Time Location System). This technology is similar to the well-known Global Positioning System (GPS) for outdoor application but the RTLS is an indoor version which provides real time information on objects.

1.2. Problem formulation

Since 25 percent of IT implementation projects outright fail and 50 percent need rework nor provide any return on investment, one cannot stress enough the importance of carefully evaluating *where* and *how* to successfully implement newly acquired IT-systems (Alami, 2016). Just over a decade ago, Zang and Wu (2010) highlighted that companies can reap significant benefits from applying RTLS in their supply chain. However, today's companies are struggling with answering the question if RTLS is needed in their enterprise and how the technology can contribute to the strategic advantages.

For the manufacturing company Scania CV AB (from now on mentioned as Scania), evaluating and identifying appropriate implementation areas for RTLS is of a significant importance in their track and trace strategy. Scania is very curious about RTLS and sees great potential for various applications. From Scania's point of view, the purpose of acquiring RTLS is partly to enable fact-based decision making but also to perform deeper analysis of their operations.

At the time of writing, the technology has exclusively been evaluated and tested in a pilot implementation project at Scania's Smart Factory Lab (see Figure 1.1 for a historical perspective). Even though this has created a solid foundation for RTLS, there is still a need to acquire local competence and expertise on the technology. As a step in the acquisition of RTLS, this master thesis was strategically established with the purpose of initiating the testing of the technology in various operations.

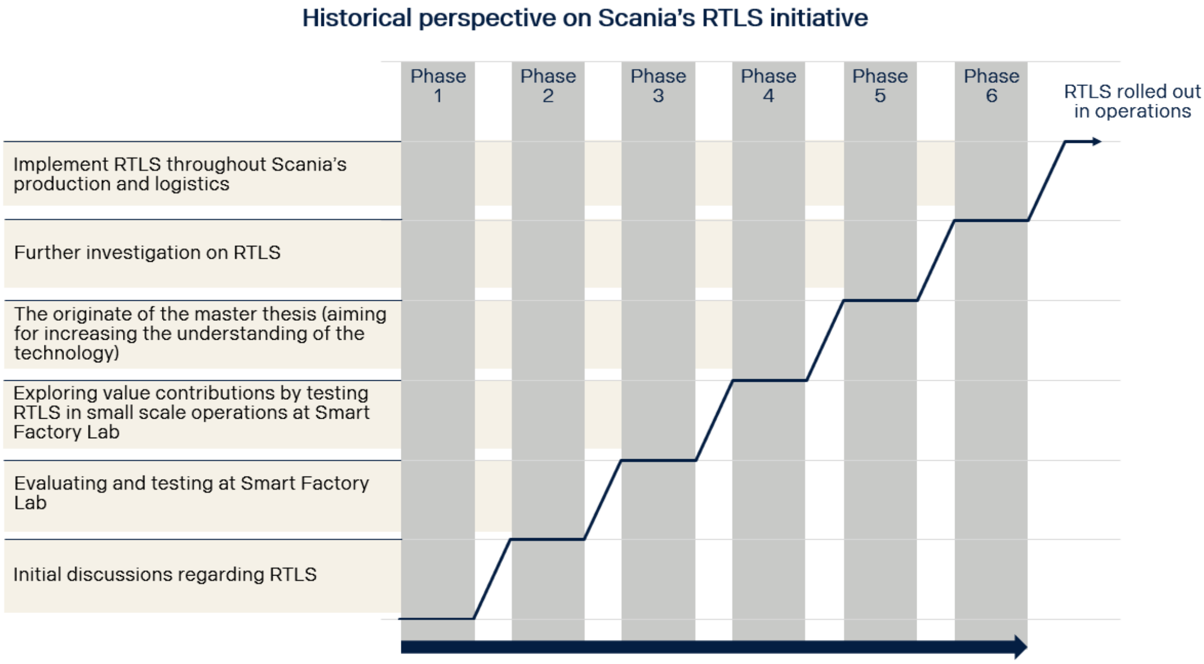

Figure 1.1: Historical perspective on Scania's RTLS initiative.

Based on RTLS's degree of maturity from the academia's point of view as well as Scania's intentions with the technology, this master thesis also aims at exploring and developing a conceptual framework for RTLS suitability. This with the purpose of providing a tool to evaluate and identify appropriate implementation areas for RTLS. With the model in place, Scania will be provided an extended understanding of the technology's potential and applicability while taking aspects such as advantages, challenges, risks and requirements into account. The model will provide support when identifying best-practise areas for the technology.

1.3. Purpose of study

The purpose of this study is to evaluate appropriate areas for RTLS implementation with the aid of a conceptual framework, initially designed after existing case literature and thereafter discussed according to Scania's track and trace operations.

Throughout this master thesis, when an appropriate area for RTLS implementation is mentioned, this is referred to the following definition (see Figure 1.2):

Appropriate area

An appropriate area is defined as an area where operational activity occurs, where there is a need from Scania's point of view to track or trace an object, where it is possible to apply the technology in the physical setting and where the purpose of using RTLS is aligned with the developed conceptual framework.

Figure 1.2: Definition of appropriate area.

1.4. Research questions

In order to develop a research methodology to base this master thesis on, the purpose of this study was translated into two research questions. These take shape as; research question one (RQ1) and research questions two (RQ2).

RQ1: What advantages, challenges, risks and requirements do RTLS entail?

Based on the purpose of this study, appropriate areas for RTLS testing are to be evaluated and identified. Consequently, the first research question will provide a general perspective of the RTLS technology and is an essential step in developing the framework. Based on the limited literature provided from academia, the research was unintentionally narrowed down to the more technical part of the technology. However, in order to capture the bigger picture, more qualitative aspects will also be included. It is intended that answering this question will generate an in-depth understanding of the technology, including what benefits that are achievable. Furthermore, the first research question investigates what challenges organizations implementing RTLS will face. Also, risks that might interrupt or damage the organization as well as what the requirements are in order to leverage the full potential of the technology.

RQ2: How can Scania use the RTLS technology and for which applications?

In order to address this question, it is deemed necessary to establish a conceptual framework on already existing RTLS case-studies. The second research question was developed to match the more practical side of the research. Emphasis here is on connecting the technology and previously gained theoretical knowledge provided from RQ1 with Scania and their current operational situation. Consequently, Scania will be provided with what concrete value the technology entails, giving the company support in future decision-making situations on where to test the technology. Note that RQ2 will be strictly taken into consideration from the perspective of Scania and its operations.

1.5. Focus and delimitations

The focus of this master thesis will be on investigating what areas that are suitable for RTLS at Scania Oskarshamn's internal logistics. This by testing the technology in practice.

A main delimitation in this paper will be to investigate already existing research and studies that have been conducted in the field of RTLS. Since the technology is rather new, the field is rather narrow. Competences, current knowledge and research is not yet as well established as it is among other similar identification technologies. Therefore, it is reasonable to also look at closely related technologies such as RFID.

Another delimitation for this thesis is to focus on testing in logistics and production related activities. This is based on the directive from the company Scania where this thesis was carried out.

A more practical delimitation will be the availability and accessibility of the RTLS equipment provided from Scania Smart Factory Lab in Södertälje. Since four beacons, one tag and a modem are being provided, it is not feasible during this thesis to evaluate and test the technology in larger contexts. Another practical delimitation is related to the spread of the Covid-19 virus. Due to the ongoing pandemic, the researchers encountered various challenges along with the study. Challenges such as limiting the stay at the facility, interventions with carrying out the work etc.

An additional delimitation is that the study is focused on the operational part of RTLS. Despite focusing on the operational aspects, the strategic perspective is not entirely excluded since this is interesting for the first research question.

As a final limitation, evaluating and identifying appropriate areas for RTLS testing's will exclusively be based on the case of Scania. Hence, this research will not investigate already existing RTLS implementations at various companies and include that in the evaluation. This was chosen as a limitation because the authors struggled with contacting other case companies that were willing to share such information.

Provided in Table 1.1 is a summarization of the focus and delimitations related to this research project.

Table 1.1: This master thesis's focus and delimitations.

Focus and delimitations	Investigate what areas that are more or less suitable for RTLS at Scania Oskarshamn's internal logistics
	Investigate already existing research and studies conducted in the field of RTLS
	Investigate closely related technologies
	RTLS testing is focused on logistics and production related activities
	Limited availability and accessibility of the RTLS equipment provided by Scania
	Focus on operational part of RTLS
	Evaluating RTLS suitability will exclusively be based on the case of Scania

1.6. Target group

The target groups of this master thesis are threefold (see Figure 1.3). Firstly, the company Scania who suggested the assignment topic and sponsors the project. The results, findings and lessons learned from this thesis are intended to be of practical use for Scania. Secondly, academia and researchers within the field of Information Technology in logistics and production disciplines. The thesis is intended to explore how existing research on the topic of RTLS can provide a relevant implementation model for evaluating appropriate areas for RTLS. Furthermore, this research will contribute to additional insights promoting the knowledge and understanding of RTLS and the technology's potential. Thirdly, the last target group of this master thesis is students since this thesis aims to increase their interest in identification technologies but also to provide inspiration for further thesis work within the field of RTLS.

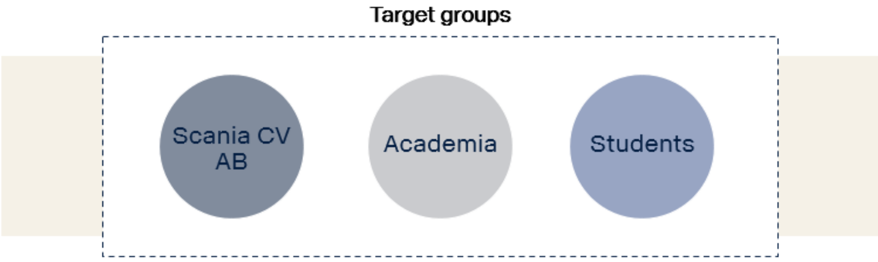

Figure 1.3: Target groups of this master thesis.

1.7. Relevance of this master thesis

1.7.1. Relevance to the research

Gladysz and Buczacki (2018) outlined in their paper on wireless technologies that there exists a need for a reference model concerning both theoretical and practical implications when applying wireless technologies. Such a model could serve as a supporting tool for managers and consider the needs and expectations of different industries as well as different functions in the organization. This master thesis aims at providing the academic community with a conceptual framework on how suitable areas of RTLS implementation could be identified. This research therefore desires to increase the understanding of practical applications of RLTS while taking aspects such as advantages, challenges, risks and requirements into consideration.

1.7.2. Relevance to the practitioners

At the moment of writing, the RTLS technology has been evaluated and tested in Scania Smart Factory Lab located at Scania Södertälje. Consequently, this study will provide Scania and other similar companies a conceptual model for identifying and evaluating appropriate implementation areas for the RTLS technology. This research desires to provide practitioners with a conceptual model that allows for enhanced safety, increased quality and utilization in operations.

1.8. Outline of the report

The report outline for this master thesis is divided into the following seven main parts (see Figure 1.4).

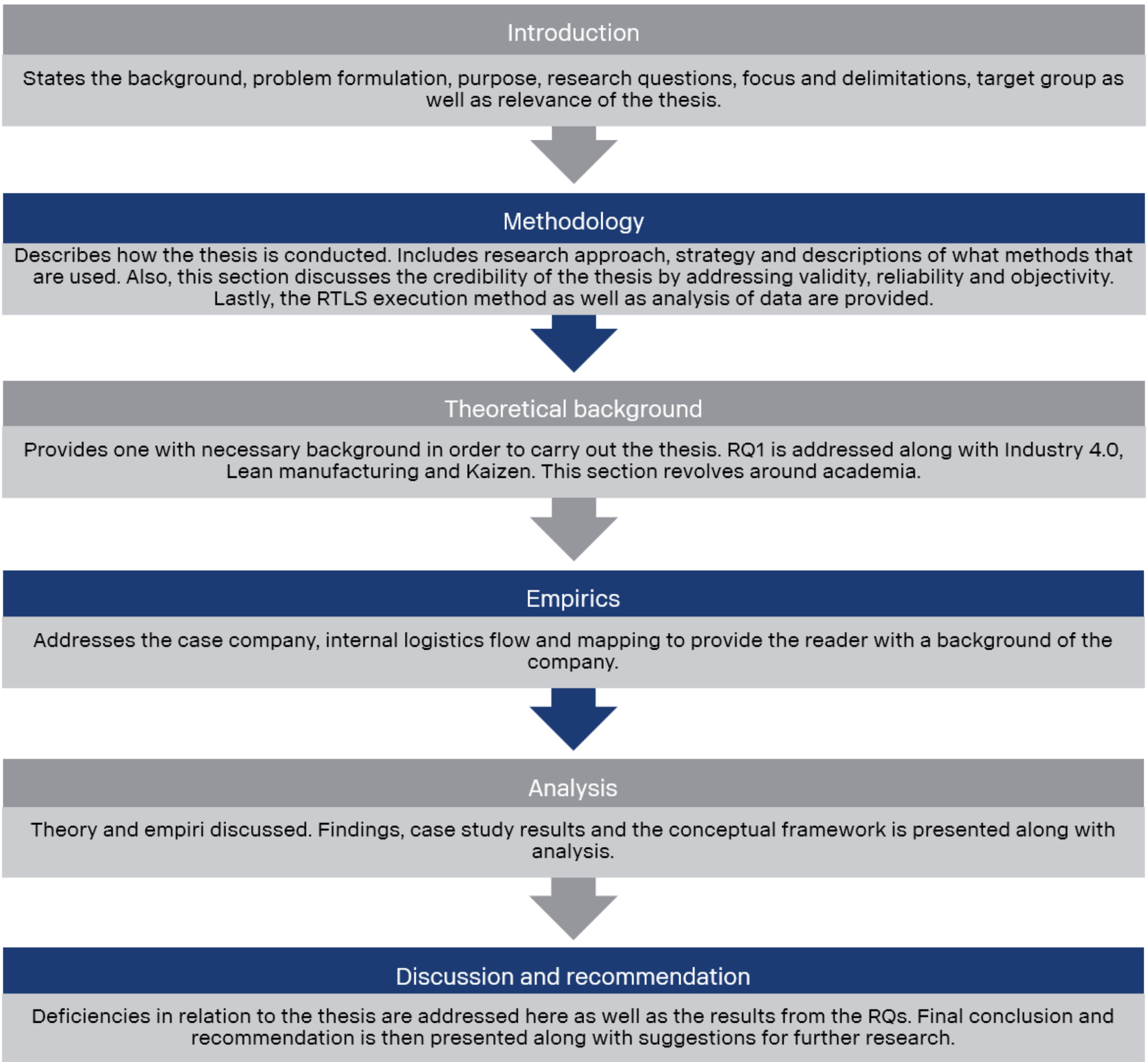

Figure 1.4: Outline of the report.

2. METHODOLOGY

This chapter provides detailed reasonings on different methodology approaches and strategies. The strategies and approaches mentioned are briefly discussed with the purpose of identifying and determining what is the most appropriate methodology to use and apply for this research project. To further clarity, the term "phenomenon" is defined as the concept that is being studied since it is referred to in the sections to come.

2.1. Approach

A first step in developing methodology is to determine what research approach that is suitable. Below follows a description of commonly used research approaches in academia and a conclusion on which approach that suits this study the most. The aim with presenting these approaches is to provide the reader with details on the different courses of action. This since it is believed to enable the reader to better understand the reasoning behind certain decisions and justifications.

According to Spens and Kovács (2005), there are three main research approaches which are commonly used within academia. These are the (1) Deductive approach, (2) Inductive approach and (3) Abductive approach.

2.1.1. The deductive approach

This approach is depicted as one, if not the most, common way of reasoning used within logistical disciplines and is typically quantitative (Näslund 2002; Golicic et al, 2005; Kovács & Spens, 2005). The overall goal is to explore substantive theory that explains, predicts and controls the phenomenon. The starting point is to develop a framework based on literature reviews which is then followed by defining a formal theory which in turn is validated and tested. In short, the process aims to test theoretical knowledge that has already been developed (Kovács and Spens, 2005).

2.1.2. The inductive approach

In contrast to the deductive approach, Golicic et al. (2005) claimed that the inductive approach is typically referred to as being a qualitative approach. This approach focuses primarily on understanding the phenomenon in its own terms or as Kovács and Spens (2005) indicated, the argumentation moves from facts to theory. This process of continuous scientific research subsequently circulates through three main steps. The initial step is to collect data and to rely on empirical observations. The latter two are to describe the phenomenon and to develop substantive theory (Golicic et al., 2005; Andreewsky and Bourcier, 2000; Taylor et al., 2002). To briefly summarize this approach, it aims at developing theory and not testing it.

Despite the historical dominance of quantitative approaches in supply chain management disciplines, it has been recognized that the inductive approach needs more recognition in order to drive logistics research forward (Näslund, 2002; Golicic et al., 2005; Dunn et al., 1994).

2.1.3. The abductive approach

The abductive way of reasoning is considered being a balanced path, which revolves around the idea of complementing the quantitative approach with the qualitative one or vice versa. This since the two observe different aspects of the same phenomenon (Golicic et al., 2005). Furthermore, Kirkeby (1990) explained that the balanced process allows the researcher to apply a new framework or theory to existing phenomenon. Differing from the two previous approaches, the abductive process does not progress in a certain subsequent manner but rather tracks back and forth between steps from the two methods. A framework of the approach methods and their interrelations can be studied in Figure 2.1.

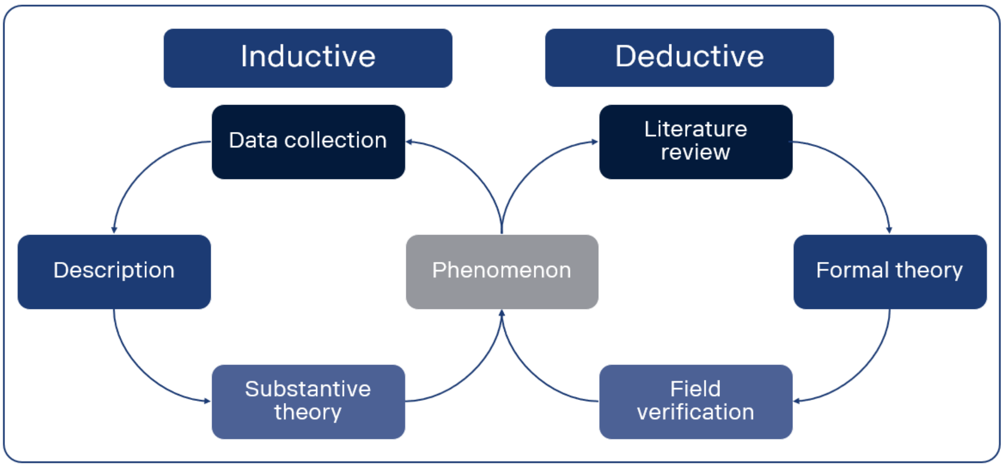

Figure 2.1: The method approach model (Woodruff, 2003).

2.1.4. Choice of research approach

This research project has been boiled down to two concrete research questions as stated earlier. RQ1 is to, via a literature review, understand and identify possible advantages, challenges, risks and requirements with RTLS. Here focus is on gaining a general understanding of the technology. Since the topic of RTLS in general already has been covered by researchers, RQ1 leans towards the qualitative character, hence calling for the deductive approach.

The second research question for this thesis is how Scania can use RTLS and for which applications. To be able to answer RQ2, the technology of RTLS will be tested in production environments at the Scania production facility in Oskarshamn. This will result in gathering and collecting data that later hopefully can provide Scania with substantive theory. Therefore, this calls for a more inductive approach. However, theory gained from RQ1 will also be applied in order to verify and provide aid in what can be observed at Scania. This, on the other hand, indicates RQ2 being more deductive. With the above in mind, it is believed that the most appropriate approach will be a combination of both, hence abductive.

To further clarify, due to the lack of knowledge and experience of RTLS in the Scania Oskarshamn facility, a trial-and-error approach will be used for testing the technology. Therefore, unplanned observations and hypotheses are likely to occur which means that RQ2 will rely on both spot-on observations but also pre-identified ones. Consequently, in order to answer the two research questions thus fulfilling the purpose of this master thesis, a deductive approach is suitable for RQ1 and an abductive approach for RQ2.

2.2. Research strategy

The following subsection will focus on describing suitable strategies within the researching field. This with the purpose of motivating and justifying the choice of research strategy for this master thesis.

2.2.1. Case study

Case studies are known for being well-established qualitative research methods (Starman, 2013). Today, this methodology is often used and accounts for much of the research that is being conducted in our society. Due to the many varying definitions on this type of study, Starman (2013) went on to collect a few and to investigate similarities and differences in them. It is concluded that "*case studies focus a lot on the examination of complexity in a variety of real-life situations*" (Starman, 2013; Simons, 2009). Moreover, a case study is known to explore a phenomenon by characterizing the case, its events and describing the discoveries and features. Despite the research type being recognized for its qualitative nature, it can also be quantitative. The approach can for instance be carried out by acquiring data from observations, interviews, databases and archives (Leonard-Barton, 1990).

Research questions in case studies are often of "how do?" character instead of "how should?" (Punch, 2000). The more that your questions seek to explain circumstances such as "how" or "why" the more likely that case study research will be relevant (Yin, 2015, p.33). Additionally, Yin (2015) composed the case study methodology of six steps which are summarized in the Table 2.1 below.

Table 2.1: Six step methodology for case study (Yin, 2015).

Methodology for case study	
	Plan Decide whether to conduct a case study or not
	Design Develop theory and proposals to generalize the case as well as address what type of case design to use (single or multiple, holistic or embedded cases)
	Prepare Develop protocol and train for case study researchers
	Collect Collecting the evidence and arranging data
	Analyse Watch for promising insights, patterns and concepts
	Share Report the study

2.2.2. Selection of research strategies

For this master thesis's first research question, the main source is gathering information from existing literature and scientific articles. This will provide an understanding and identification of advantages, challenges, risks and requirements regarding RTLS. Consequently, this implies that a literature study is suitable for this part of the research.

Regarding the second research question, the topic is rather open for both discussion and interpretation. Thus, emphasis is put on interviews with key personnel at Scania. Further, data from the actual testing of the RTLS technology in the selected areas will be used as a source of information. In accordance with Yin (2015), as mentioned previously, a case study is often appropriate when research seeks to explain questions such as "how" hence strengthening the suggestion of using a case-based approach for the second research question. Furthermore, since RQ2 is of an exploratory nature it is in line with what case studies typically address which is why this method strategy will be realized.

2.2.3. Unit of analysis

For this research project, the phenomena and unit of analysis is to be specified in order to fulfil the purpose of the master thesis. As have been formulated in section 1.4., RQ1 seeks to answer what advantages, challenges, risks and requirements RTLS entail. RQ2 further aims to elaborate on how Scania can use the technology of RTLS and for which applications. Therefore, the unit of analysis will be dealing with the attributes and applications of RTLS. This covers both RQ1 and RQ2 (see Figure 2.2).

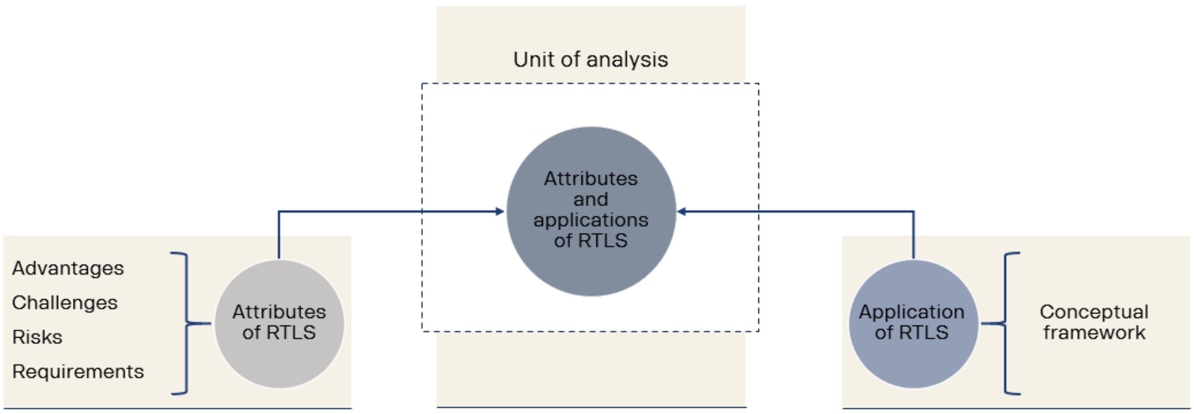

Figure 2.2: Unit of analysis.

2.3. Data collection

This section aims to present the various strategies that have been applied throughout this master thesis's data gathering phase. In general, data has been collected from literature reviews, interviews, observations, internal and external systems. Since both quantitative and qualitative data is collected, strategies on how to gather both are presented.

2.3.1. Literature review

With the purpose of achieving a structured and systematic course of action to the collection of theory and literature, an approach provided by Rowley and Slack (2004) was used as support. The four steps in the execution of the literature review, supported by Rowley and Slack (2004), were: *evaluating information resources*, *literature searching and locating information sources*, *developing conceptual frameworks and mind mapping* and finally *drawing together the literature review*.

Evaluating information resources

When evaluating books and web-based resources that were of use for this research's literature review, two checklists were used as support when evaluating the sources (see Table 2.2). For the latter checklist, evaluating a web-based resource, the questions were reflected upon and discussed in order to ensure credible source gathering.

Table 2.2: Evaluating information resources checklists (Rowley and Slack, 2004).

Checklist – Evaluating books	Relevant to the research topic
	Written by an authoritative authors, the biography details given in the book will summarize the author's experience in the filed
	Up-to-date, signalled by the publication date
	Published by a reputable publisher in the discipline
	One that includes extensive reference to other associated literature
	Cleary structured and well presented, and easy to read
Checklist – Evaluating a web based resource	Who is the intended audience?
	What is the frequency of updates?
	Which organization is the publisher or web site originator?
	What is the web resource developer's claim to expertise and authority?
	Are there links or references to other relevant web, electronic or print sources?
	What do reviews or evaluations of the site say?

Literature searching and locating information sources

In the identification and location of information sources, different tools were used to assist the process. Supported by Rowley and Slack (2004), library catalogues were used for locating books held by a library while search engines enabled the localization of web pages based on keyword searches. Furthermore, online databases provided access to journal articles, papers in conference proceedings, reports and other documents. The four-bullet list presented by Rowley and Slack (2004) were used in order to develop a literature review strategy.

1. *Citation pearl growing*: Useful for newcomers to a topic. Suitable terms from one or a few documents are used to retrieve other documents.

2. *Briefsearch*: This is a good start for further work where a few documents are retrieved crudely and quickly.

3. *Building blocks*: Here the concepts in search statements are extended by using synonyms and related terms.

4. *Successive fractions*: An approach used to reduce a large or too large set of documents. In order to eliminate less relevant or useful documents, searches are made within an already retrieved set of documents.

Developing conceptual frameworks and mind mapping

With the purpose of identifying key concepts in the collected literature on RTLS, the concept of mapping was a useful tool. This since the map was used to understand theory, concepts and the relationships between them (Rowley & Slack, 2004). This came in handy for the development of the conceptual framework.

Drawing together with literature review

Further, the five steps process suggested by Rowley and Slack (2004) was used as a supporting tool when creating the literature review. The steps are provided and clarified below (see Table 2.3).

Table 2.3: Five step process on literature review creation (Rowley and Slack, 2004).

Five steps in the creation of a literature review	
	Step 1: Scanning Documents Scanning documents might give some insight into key themes that need to be included in the literature review
	Step 2: Making notes Making notes will provide a distillation of key messages and themes
	Step 3: Structuring the literature review This step is concerned with identifying key themes in the review. Also to start organizing concepts and documents in accordance with key themes
	Step 4: Writing the literature review Once a broad structure has been resolved, the literature review can be commenced. In a coherent account, the literature review should integrate three different types of materials: 1. A distillation and understanding of key concepts 2. Quotations, in the words of the original writer 3. A distillation of positions, research findings or theories from other authors
	Step 5: Building a bibliography This is an ongoing process from the beginning of the literature search until its completion. The bibliography is a list of all the sources that have been referred to in the literature review

Literature review execution

Since the following steps were used, it is decided to provide the reader with concrete examples on how these were followed through. Regarding the first step in evaluating information sources, websites with more established organisations were primarily investigated.

Regarding the second step, in order to capture as much as possible from existing literature, a structured way of reviewing literature was approached (see Figure 2.3).

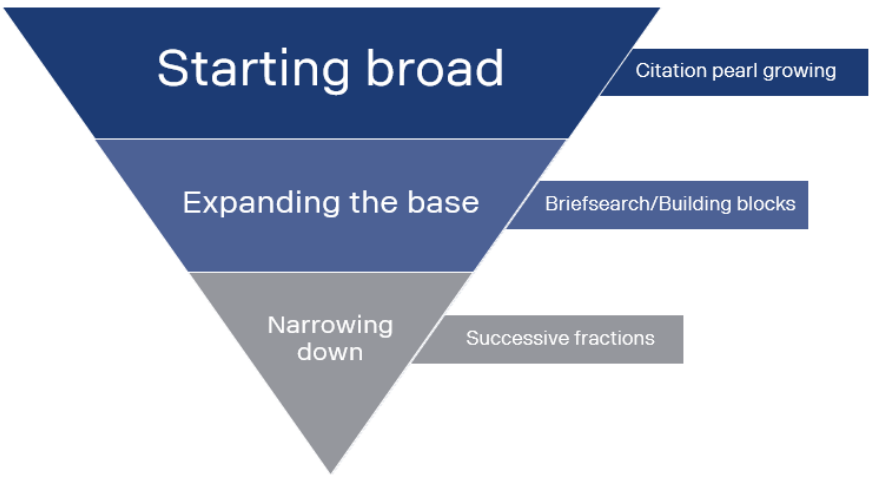

Figure 2.3: The literature review strategy.

Starting broad
By initiating the literature review, keywords were identified from brainstorming sessions. These can be seen in Figure 2.4 below. Given the limitations of time and contributions in academia, a selection of articles and papers on the topic of RTLS was investigated. Further, Figure 2.5 also portrays the keywords used when developing the conceptual framework.

Figure 2.4: Keywords used when looking into RQ1.

Figure 2.5: Keywords used when looking into the case-study review following RQ1.

The initial keywords were used to find established articles and sources in the Google scholar database. By combining the keywords with RTLS or RFID, the screening was initiated. The RTLS implementation cases were also collected from established academia sites such as Google scholars, Sciencedirect, Lubsearch and Researchgate. The selection of cases was not based on a specific industry.

Expanding the base
Having identified several articles, the next step was to study the reference list. Commonly cited articles were investigated further into, assuming that they covered similar topics. From this, it was possible to expand the bibliography.

Narrowing down the selection
Initially in the literature review, the screening process had mainly concentrated on skimming through abstracts, keywords and titles. Thus, the next phase included reading through the contents of the articles to confirm if they were of relevance to the thesis. Lastly, the articles were read through thoroughly in order to generate an understanding of the topic. It was at this point that the literature review first could take place.

The third step was concretely used when the authors categorized the literature into the attributes. This was then followed by the last step, where the literature review was compiled. For the curious reader, in total 51 articles were used for the literature review.

2.3.2. Interviews

Supported by Williamson (2004), interviews have been used in this research as a technique for collecting qualitative data. She also mentioned that interviewing people aims to understand their point of view and is a non-controlling and an open approach to collect data which the researchers have considered.

Furthermore, Williamson (2004) presented a classification of different types of interview to be *(1) Structured (standardized or scheduled)*, *(2) Unstructured (non-standardized, non-scheduled or in-depth)* and *(3) Semi-structured* (see Table 2.4). The classification presented by Williamson (2004) has been used as a supporting tool in the development of the interview guide during this master thesis's interviews.

Table 2.4: Classification of interviews (Williamson, 2004).

Structured interviews	All respondents are asked exactly the same questions in the same sequence. Structured interviews are typically used when it is important to be able to compare results across respondents.
Unstructured interviews	Unstructured interviews are typically useful for exploring a subject or for gaining insight into people. In case studies, unstructured interviews are used to collect extensive data from key people. Also, unstructured interviews are often used before compiling a structured interview schedule
Semi-structured interviews	Semi-structured interviews usually have a standard list of questions. However, it allows the interviewer to follow up on leads provided by participants. To note, the semi-structured approach is closer to the unstructured rather than to the structured.

Throughout this master thesis, unstructured exploratory interviews have had an important role in the data collection. Firstly, in order to gain a general and broad perspective and understanding of Scania's logistics management processes. Secondly, the interviews have had the purpose of obtaining an understanding of where this research's RTLS investigations are suitable.

Interview conduction

Throughout the interviews, inspiration was taken from Patel and Davidson (2014) who established a matrix framework (see Figure 2.6).

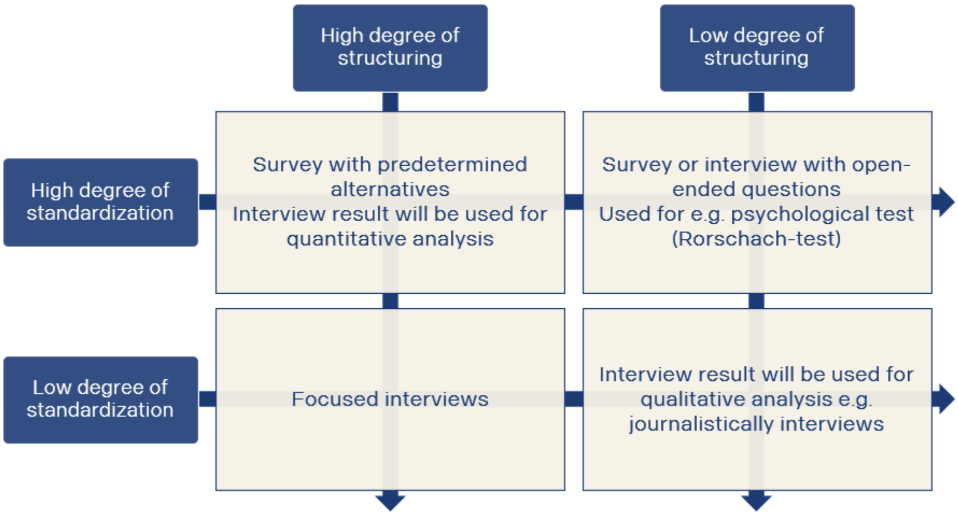

Figure 2.6: Matrix framework for interviews (Patel and Davidson, 2014).

A low degree of structuring and varying degree of standardization was used. This since a broad perspective was applied. The interview questions were not very specific to keep the discussion open and letting the interviewed person lead the discussion. The reason this approach was selected was because the researchers did not have much insight into the company and wanted to understand the employees' views. Thereafter, as the exploratory interviews progressed, the questions to the key employees got even more detailed and directed towards certain areas in Scania's logistics. This with the purpose of identifying logistics processes and operations suitable for investigating the application of RTLS. Therefore, the interviews held with Scania employees were of unstructured and semi-structured nature. Thus, slightly preprepared questions were used as a guide which can be seen in the Appendix A.

Regarding whom was interviewed, the authors were initially introduced to a list of important key staff and personnel in the logistics department. These were selected with the idea of providing relevant and interesting insights into the thesis. Due to the exploratory nature, further members were identified and interviewed when progressing along with the list. In Appendix B one can find what persons were interviewed.

Lastly, workshops were also conducted to gather data and information on what criteria that the company thinks are more important when testing RTLS for each area where the technology was tested in. These criteria were developed during workshops and rated amongst the employees. Qualitative data on change management was also gathered from a similar approach.

Advantages of interviews
According to Williamson (2004), one advantage of interviews is that the interviewer can control the discussion and ensure that the respondent focuses on the areas of interest. During this research, this advantage became apparent when conducting the interviews since the authors could follow up on interesting leads.

Disadvantages of interviews
The number of respondents included in this research's interviews was limited due to the restricted time frame. This is a disadvantage as other more interesting areas could have been identified if more time were given. Williamson (2004) also stated that unstructured interviews are difficult to record and analyse which became apparent when the researchers discussed the outcomes of the interviews.

2.3.3. Observations

Observations have taken place in this study in order to systematically record and observe behaviours. It is also considered a useful technique for understanding certain behaviours and/or what is occurring in certain settings (Duignan, 2016; Williamson, 2004). Williamson (2004) also provided a list of issues that one should be aware of when conducting observations (see Figure 2.7) which has been considered.

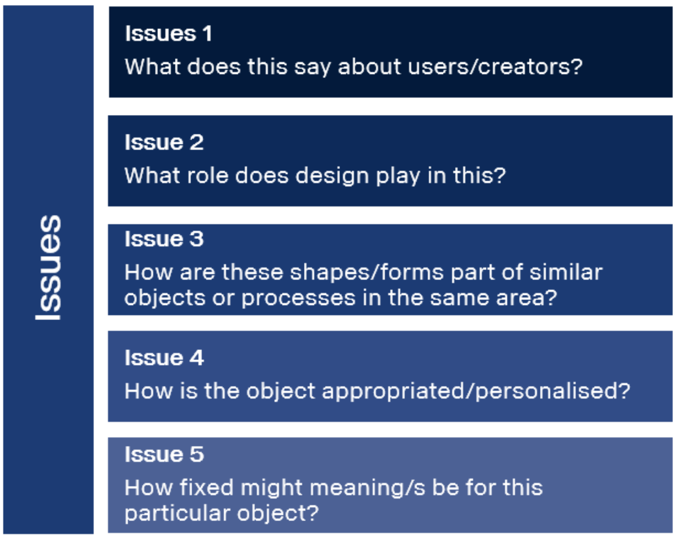

Figure 2.7: Issues when conducting observations (Williamson, 2004).

When selecting areas to apply RTLS to, issue four was very present during the interviews. It was observed that each interviewed person promoted their own identified areas as this would aid them in their work.

Furthermore, Williamson (2004) outlined that there are four main styles in which observations can be performed.

- *Ad Libitum:* Ad Libitum is an appropriate approach when researchers are new to the situation or topic they are studying. It is characterized as a non-systematic approach where a lot of impressions are captured by the observer.

- *Focal:* Performing a focal observation implicates selecting an individual or group and observing all their behaviours or physical characteristics over a period.

- *Scan:* At regular intervals, the whole group or each individual are quickly scanned and information is recorded.

- *Behaviour:* A specific behaviour of interest is selected. Then, everyone who behaves according to this behaviour is recorded and also under what circumstances this behavior occurs.

Observation execution

The observations were carried out in line with Williamson's (2004) continuous recording technique. This means that no specific time slots were dedicated to solely observations, but rather that once something was observed, it was noted. This was suitable as limited time was given at the facility with the staff.

Since the field of research, the physical setting and the company context was new for the researchers, the observation approach was initially conducted in line with *Ad Libitum*. Thereafter, the approach evolved into a *focal* observation since most observations were collected during a period where certain behaviour was noted when tracking.

It was also of interest to investigate how shop floor employees conducted their work in order to deem an area suitable for RTLS. This since in certain settings, it was of interest to track the staff when performing their daily activities.

2.3.4. Internal systems

Throughout this master thesis, there has been no real collection of data from the internal systems at Scania. On the contrary, data such as maps or 2D/3D settings were collected in order to create an understanding of the different operations but also to visualize the results from the RTLS tracking. Some minor log files were also investigated briefly to, outside of this thesis, connect the tracking data with order waiting time and other key performance indicators (KPI). However, such files and maps were provided from employees upon request and not from a specific internal system.

2.3.5. External systems

Regarding the application of the RTLS in the production environment, the provider of the technology was the company Marvelmind Robotics. With its headquarters in Estonia, Marvelmind supplies Scania with their own software in order to be able to study the tracking in real-time. This software is known as Marvelmind Dashboard and this was used frequently throughout this master thesis. The software enabled visualization of the RTLS tracking both in real time as well as it allows for replay sessions of the tracking (e.g., investigating time - and location stamps). Furthermore, an additional system known as Gazpacho was used as a visualization and analysis tool. Gazpacho is a software developed and provided to Scania from the external supplier Virtual Manufacturing. In Gazpacho it was possible to insert and implement 2D maps and transform the tracking data into KPIs such as total distance travelled.

2.4. Identifying interesting areas at Scania

In order to establish findings related to the second research question, the first step was to identify suitable testing areas. This was done by firstly looking into literature to find inspiration and understand the technology's potential. This led to the initiation of the conceptual framework. Thereafter, informal interviews were conducted with employees at Scania. This with the purpose of investigating and identifying possible issues that potentially could be addressed with the use of RTLS. These interviews were carried out with both employees working in the production and project leaders for logistics development. Lastly, observations made it possible to identify which areas that were more practically feasible to test the technology in. The course of action to identify areas of interest is provided in Figure 2.8 below.

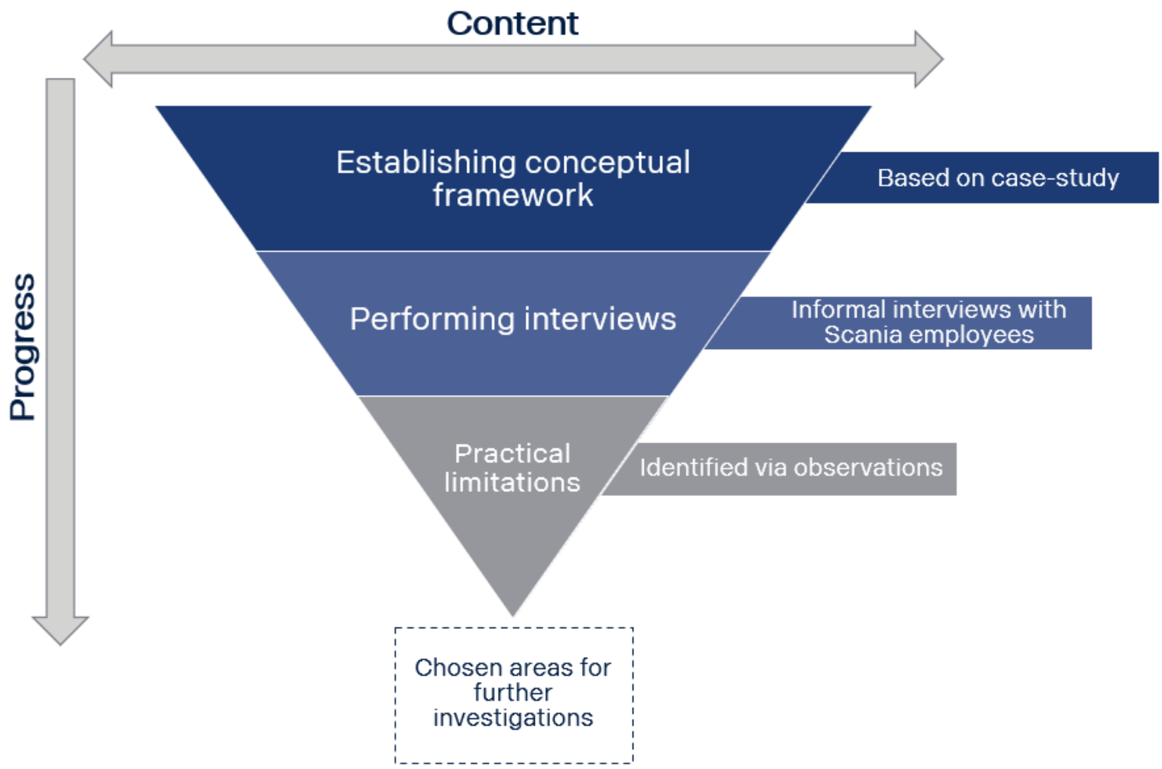

Figure 2.8: Course of action to identify areas of RTLS interest.

2.5. Credibility of the study

According to Denscombe (2010, p.297), the credibility of research is something that needs to be demonstrated. This, as a part of the research process itself. He also outlined that a researcher's credibility should not be taken for granted. Instead, for authors to achieve credibility for their research they need to demonstrate that the findings are based on practices that are acknowledged to be the bases of good research. Denscombe (2010) also presented three dimensions of research quality for judging its credibility. These are validity, reliability and objectivity.

2.5.1. Validity

By validity, Denscombe (2010) referred to the accuracy and precision of the data used in the research. It also deals with how appropriate the data is in terms of the research question being investigated. In order to address the matter of appropriateness and accuracy, qualitative researchers can use *Respondent validation*. Described by Denscombe (2010), *Respondent validation* implies returning to the participants to check the validity of the findings.

According to Björklund and Paulsson (2012, p62), by using multiple perspectives to explain a single phenomenon the research's validity could be increased. As an example, they referred to the triangulation principle where two or more methods are used for the same purpose, studying from different perspectives.

2.5.2. Reliability

Stated by Denscombe (2010, p299), reliability has to do with that the researcher almost becomes an integral part of the data collecting technique. Denscombe (2010) described that reliability can be equalized with asking the question "*If someone else did the research, would he or she have got the same results and arrived at the same conclusion?*". To check the reliability and enable research audit, it is desirable to clearly state what method, analysis and decision-making that have been conducted throughout the research.

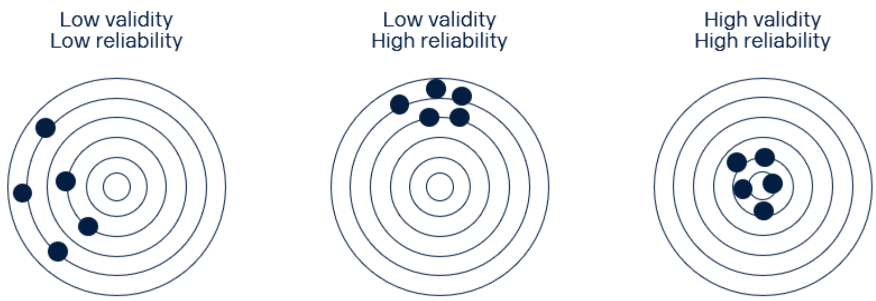

Figure 2.9: Validity/reliability illustration (Björklund and Paulsson, 2012).

Stated by Björklund and Paulsson (2012. p62), a research paper's reliability could be increased by using control questions when conducting surveys or interviews. Thus, the control questions ensure the aspects to be investigated once again with the purpose of studying validity and reliability together rather than in isolation. The outcome can be seen in Figure 2.9.

2.5.3. Objectivity

Conducting biased free research is of great importance in order to increase the credibility of the research. Thus, objectivity concerns to what extent produced findings in qualitative research are free from the influence of the researcher (Denscombe, 2010). However, Denscombe (2010) stated that there will always exist influences in research from those who conducted it. Especially when it comes to qualitative data which is always a product of interpretations.

Presented by Olhager (2021) are some thoughts on the topic of objectivity. Among others, he mentioned that it should be clear what the opinion of the researcher is. Additionally, the content of sources should be reproduced in a correct manner. This by avoiding presenting distorted facts and by not giving appropriate credit to the original source.

In order to cope with the challenges of objectivity, Denscombe (2010, p304) presented a good practice on how to handle the researcher's "self". He suggested researchers provide their interest in the research and to which extent they have approached the research with an open mind. Furthermore, Björklund and Paulsson (2012, p63) stated that higher levels of objectivity are reached when choices and assumptions made during the research are clearly explained and motivated.

2.5.4. Achieving a good quality master thesis

To ensure a well conducted research from Scania's point of view, the course of action, thoughts and results have been continuously discussed and elaborated on with relevant stakeholders at the company as well as from the university. Moreover, data gathered for different logistics and production processes via the execution of the RTLS technology were openly shared with the company. Also, on a regular basis, reconciliations were held with Scania to present conducted work and plan for the next steps. Moreover, as mentioned above, assumptions are clearly stated and highlighted when made.

Through the triangulation principle, the research's validity, reliability and objectivity was ensured. This since the principle was applied in several instances. When developing and confirming the conceptual framework since both theory and empiri from the company is addressed. When making observations since both data and observations were interpreted differently amongst the authors and thereafter discussed. In order to strengthen the credibility, a visit at Scania's Smart Factory Lab took place. Here it was possible to simulate production environments and test other RTLS equipment based on different technologies than the one provided by Marvelmind. This with the idea of adding additional dimensions to the discussion of this thesis.

2.6. Execution method of Marvelmind's RTLS

This section aims to describe the execution method that has been applied when setting up the RTLS technology provided by Marvelmind. Also, emphasis will be on describing how the applications, tools and software's were used to ensure a successful execution of the technology.

2.6.1. Equipment handling

Provided from Scania's Smart Factory Lab, four stationary beacons, one mobile beacon and one modem was included in the RTLS setup kit. These were mounted with the aid of tape and attached to racks, forklifts, caps, stands or shelves. The stationary beacons were mounted so that their signal receivers would face the mobile beacon's transmitter in order to minimize signal interference. Furthermore, the stationary beacons were mounted as high up as possible and more importantly, not too far away from each other. In accordance with Marvelmind's guidelines, a distance longer than 20m is prone to errors.

The modem communicating with the stationary beacons was connected to the computer via a USB-C cable. It was of great importance to have the stationary beacons no longer than 100m from the modem, otherwise the connection loses. When attaching the mobile beacon to the object to be tracked, emphasis was on avoiding covering the transmission sensors.

Lastly, for all areas that RTLS was tested in, two different mounting setups were tested due to the exploratory purpose of the study. For each setup, ten separate tests were performed.

2.6.2. Software handling

When executing the Marvelmind equipment, a software tool was used to setup beacons but also to enable the gathering of data. The first step in the software was to turn on all beacons. Once that was completed, they appeared on random positions in the dashboard at first glance hence not reflecting their real positioning. After a few seconds, the beacons were automatically calibrated. In order to determine whether the calibration was completed, a supporting matrix was provided in the software (see Figure 2.10). With the use of the matrix, the position of the stationary beacons relative to each other was shown together with an indicating colour. The colour shifted from red to white when the calibration had been successful. Thereafter it was possible to freeze the beacons position hence creating the area within which gathering of data was to take place.

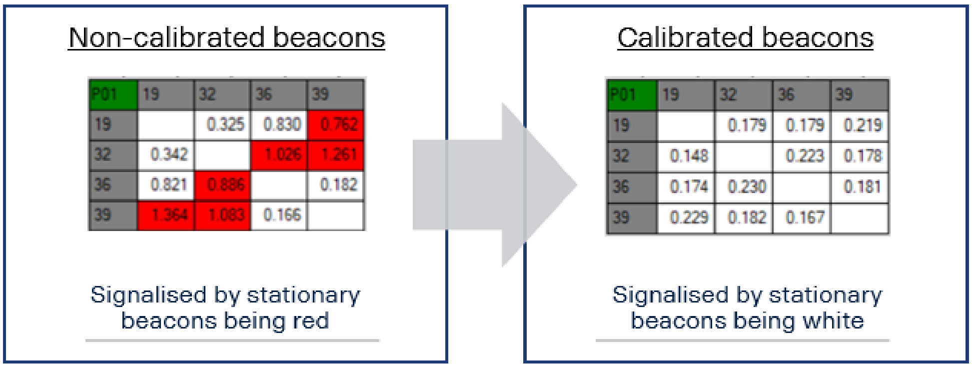

Figure 2.10: Calibration of stationary beacons (Marvelmind Dashboard).

In the tool, the location of the mobile beacon was visualized during tracking sessions. Depending on the quality of the tracking, the colour of the mobile beacon would change. To clarify, the tracking quality directly refers to the degree of line of sight between stationary and mobile beacons. A blue colour on the mobile beacon indicated a good quality and stable tracking, orange indicated poor quality and unstable tracking and grey indicated no connection.

The dashboard was also a useful tool for aftermath analysis since it was possible to playback a tracking session and replay it in real time.

2.7. Analysis of data

Provided in this section is a description of how the collected data have been analysed. Different activities such as Excel analysis, workshop discussions and visualization in various software tools have been performed.

2.7.1. Visualization of gathered data

One way of analysing the gathered data was to visualize it in the software (Gazpacho) provided by Virtual Manufacturing. Via the Gazpacho tool it was possible to visualize and replay the data as heatmaps, spaghetti flowcharts and height-axis diagrams. In the software, a fitting background image could be inserted to reflect the actual physical setting. Also, the beacons were mapped out accordingly to scale. From there, it was possible to visualize the tracking session i.e., the movement of the tracked object. Furthermore, the software also provided the total distances travelled during the tracking period and timestamps.

With the visualization as a tool, it was possible to compare different heatmaps and spaghetti flowcharts that have been obtained. This regarding the question if the visualization reflected the actual movement. More importantly the visualization was presented and discussed in workshops that were carried out with Scania employees. This would allow for Scania to determine whether the test had been successful or not.

2.7.2. Signal-disturbance analysis

A signal-disturbance analysis was also executed on the gathered data. The purpose of this was to investigate to what extent signal disturbances occurred because of poor radio transmission. This analysis would also aid in identifying appropriate areas.

In order to carry out the analysis, the starting point was to collect data with the RTLS equipment and save the gathered data in log files. The log files were of usual Microsoft Excel format (.csv to be more specific). The appearance of the log files is provided in Figure 2.11. For each data collection section lasting for about four to five minutes, approximately 1000 to 2000 rows of data were generated. As shown in the figure, the data stored in each row followed a certain pattern from which the distance from each stationary beacon to the mobile beacon could be read. Also, a time stamp as well as position in a XYZ coordinate system for the mobile beacon was provided. However, some rows in the log file were incomplete hence indicating a faulty signal caused by interruptions or disturbances. The portion of rows with complete data (i.e., as row six in Figure 2.11) could be compared with incomplete rows (i.e., as row seven in Figure 2.11).

What indicates row seven to be incomplete is that not all four stationary beacons (number 19, 32, 36 and 39 in this case) are expressed in the row. As shown, it is only possible to extract information regarding the stationary beacon 19. This implies that signal interventions have occurred which causes the system to not determine the position of the mobile beacon (number 34 in this case).

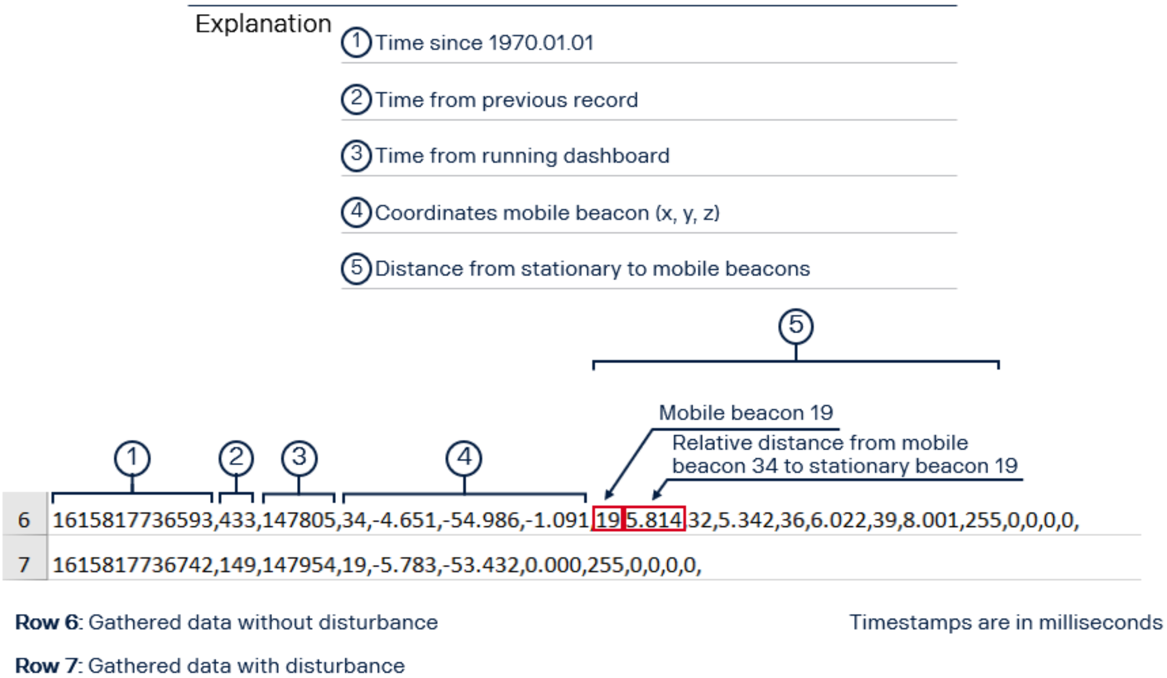

Figure 2.11: Outcome of log files.

The approach described above was performed for all the four stationary beacons at all different setups where the kit was tested. This would allow for a systematic and standardized course of action.

2.7.3. Qualitative data analysis

The qualitative data was gathered from workshops and discussions with Scania employees that were involved in the project. The purpose of this was to also cover the “softer” aspects of implementation management as the previous ways of gathering data mainly focused on the technical aspects. Therefore, a questionnaire was developed with inspiration from RQ1 results as well as from the researchers’ own reflections. Triangulation was achieved since both authors took part in the development. The outcome from the workshop was then used to connect practice with theory and to discuss the framework according to Scania’s environment.

Data was also collected from workshops focusing on what the employees consider to be a successful test of RTLS. These rating workshops were conducted in a similar way as the one in the paragraph above. To facilitate the understanding amongst the readers, Figure 2.12 provides an example of how the criteria were given an *Importance score* as well as a *Primary criteria score*. These two scores contributed to the final *Criteria score* which then was used to evaluate RTLS suitability.

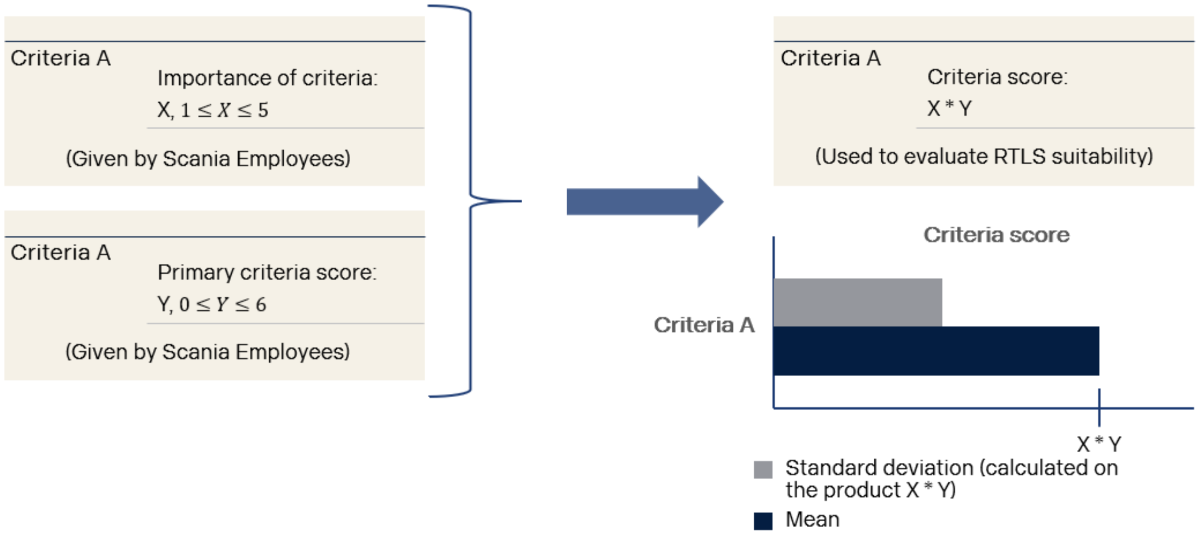

Figure 2.12: Criteria evaluation and scoring process.

To further clarify, the qualitative ratings were rated from employees by using the playback function in the Gazpacho software. This in order to, in real-time, illustrate the tracking session in the heatmaps and spaghetti diagrams that were developed.

2.8. Summary of methodology

This subsection aims to provide an overall view of the methodology approach (see Figure 2.13). Firstly, the research approach was selected to be the abductive one. This was followed by a research strategy consisting of a literature review for the first research question together with a case-study review for the second research question. Additionally, one unit of analysis was chosen to fit both attributes of RTLS and the usage of RTLS for different applications.

Moreover, the research data collection was constituted by literature reviews, interviews, observations and finally gatherings from systems. The credibility of the study was ensured via the triangulation principle along with continuous consultations and progress follow-up meetings with target groups. Further, the RTLS execution consisted of both standardized equipment and software handling. Finally, the research analysis was performed where signal-disturbances, heatmaps and criteria ratings were looked into.

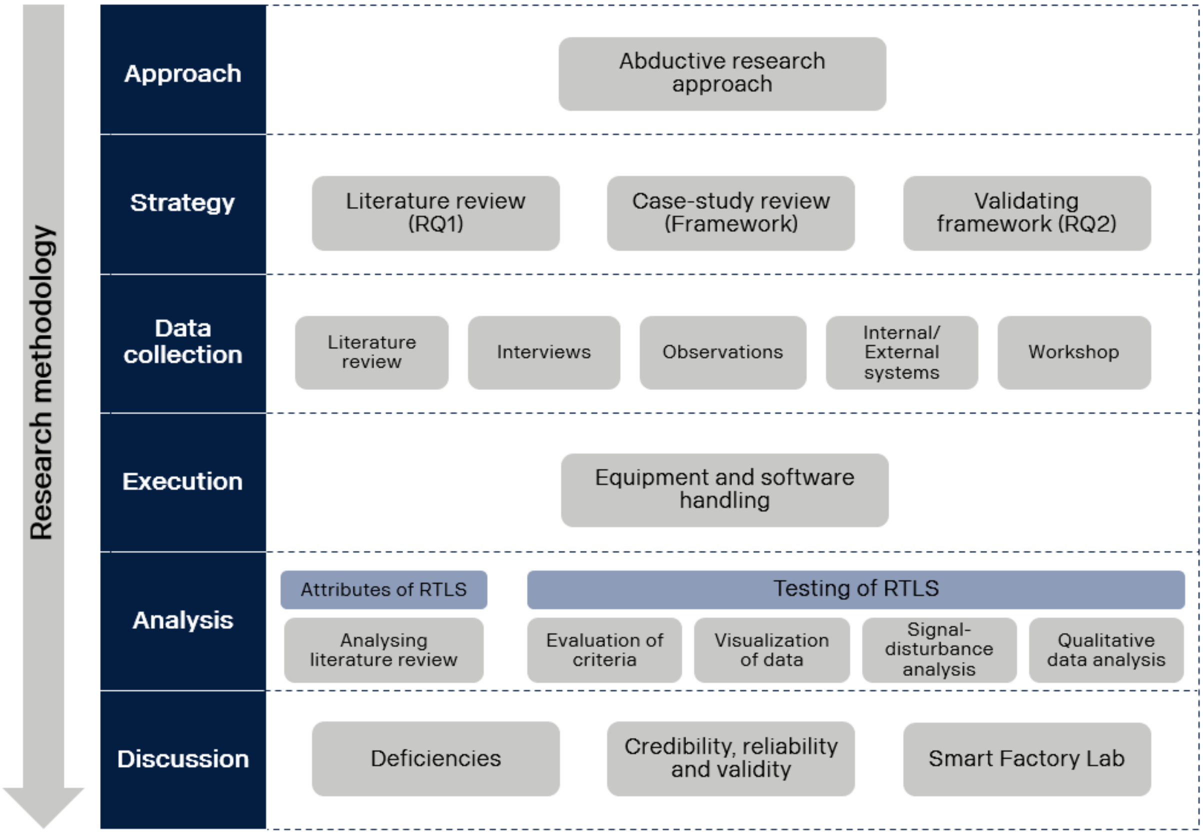

Figure 2.13: Summarization of research methodology.

3. THEORETICAL BACKGROUND

This chapter aims at answering the first research question while also introducing the reader to characteristics and general knowledge on the technology of RTLS. Starting broad, terms such as Industry 4.0, Lean manufacturing and Kaizen are being described to thereafter narrow down into the RTLS technology. RFID is also discussed and compared with RTLS. Lastly a case-study review is conducted in order to develop a conceptual framework.

3.1 Theoretical background

Provided in this section is a theoretical background on the topics of Industry 4.0, Lean manufacturing and Kaizen. Also, a brief comparison between RTLS and RFID is presented.

3.1.1. Industry 4.0

Presented as part of Germany's high-tech strategy to prepare its industrial sector for the production requirements of the future, the term Industry 4.0 was first expressed in the year of 2011. Industry 4.0 was introduced as the idea of a fully integrated industry with the purpose of handling the increasing requirements regarding efficiency, flexibility, adaptability, stability and sustainability. Additionally, it is argued that participating in the Industry 4.0 initiative is necessary to remain successful. This, as the rapid technology progress in recent years has opened for a range of new business potentials and opportunities. Moreover, Hofmann and Rüsch (2017) stated their definition of the fourth industrial revolution to be (see Figure 3.1):

Industry 4.0

"The Fourth Industrial Revolution can be best described as a shift in the manufacturing logic towards an increasingly decentralised, self-regulating approach of value creation, enabled by concepts and technologies such as CPS, IoT, IoS, cloud computing or additive manufacturing and smart factories, so as to help companies meet future production requirements."

Figure 3.1: Definition of Industry 4.0 (Hofmann and Rüsch, 2017).

The concepts and technologies described in Hofmann and Rüsch's (2017) definition of Industry 4.0 are further strengthened in a case study conducted by Hermann et al. (2016). In their research they found that in the identified publications on Industry 4.0, CPS, IoT, IoS and smart factories were four out of the ten most frequently used phrases. Therefore, a more in depth description of these phrases is provided in Table 3.1 below.

Table 3.1. Industry 4.0 key components (Hofmann and Rüsch, 2017).

Industry 4.0 key components	
Cyber-physical systems (CPS)	Industry 4.0 brings the physical and virtual world together. For instance the physical shop floor and the virtual computational space are synchronized (Hofmann and Rüsch, 2017). Moreover, Cwikla et al. (2018) mentioned the integration of these systems as a key to enable failure prediction and adaptation to changes.
Internet of Things (IoT)	IoT refers to a world where all physical things are "smart things". This by featuring them with small computers that are connected to the internet (Hofmann and Rüsch, 2017). Dardari et al. (2015) concluded that IoT will become a large dynamic network of devices, sensors and objects that will find many applications in various settings.
Internet of Services (IoS)	The IoS will allow companies and private users to offer, create and combine new kinds of value-added services. This by making services easily available though web technologies (Hofmann and Rüsch, 2017).
Smart factory	The integration of IoT and CPS constitutes the ides of the smart factory. This factory is context-aware while assisting people and machines in executing their tasks (Hermann et al., 2016). Furthermore, Hofmann and Rüsch (2017) described that the smart factory will contribute to high flexibility, cost-efficient and individualised mass production.

There are nine technological advances that build the basis of Industry 4.0. These nine advances, provided in Figure 3.2, should constitute the basis in the transformation to a connected value chain. When integrating such systems, the term cyber-physical production systems (CPPSs) come in hand. By allowing the CPPSs to directly communicate with each other it is possible to gather data and information across machines and systems. Consequently, a more flexible, faster and more efficient chain is achieved (Cwikla et al., 2018). To enable smart logistics for Industry 4.0, tools such as RTLS can be utilized to further reduce lead times and manage various assets on the shop floor (Rácz-Szabó et al., 2020).

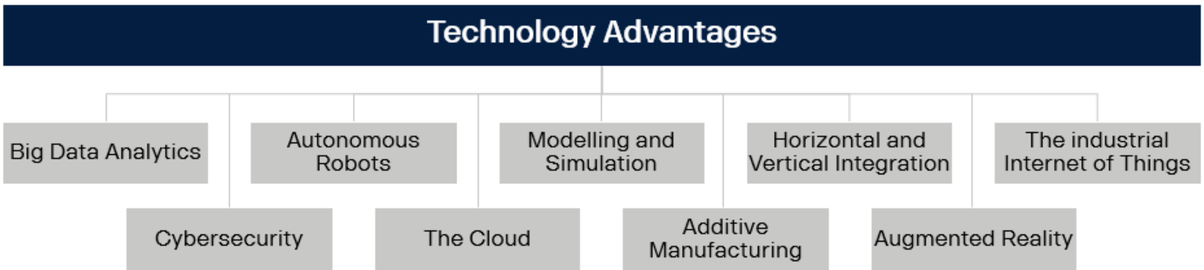

Figure 3.2: Technology advantages building the basis of Industry 4.0 (Cwikla et al., 2018).

3.1.2. Lean manufacturing

The birth of the lean practice was in the 1940s at Toyota's production system in Japan. This production system was based around the idea of producing in a continuous flow which opposed the western world's mass production at that time (Melton, 2005; Gupta & Jain, 2013). In lean practices, inventory is seen as waste and the overarching goal is to reduce such waste. Moreover, Scania is operating according to lean principles. With the aid of RTLS, waste can be reduced resulting in enhanced lean operations. Therefore, it is of a both strategic and operational interest for Scania to invest in this type of technology. As discussed in the upcoming sections, it is clear that RTLS can contribute to reducing waste.

3.1.3. Kaizen

Originating from Japan, Kaizen indicates continuous improvement and is commonly used in today's industries (Manos, 2007). The term involves the two concepts: *Kai* (change) and *Zen* (for the better). Such improvement is a core strategy and crucial for enterprises to remain competitive which is why the process calls for endless effort (Dean & Robinson, 1991; Malik and YeZhuang, 2006). In the case of Scania, Kaizen permeates the enterprise and is a tool used for continuous improvements which is partly why this thesis is carried out. To increase the knowledge about RTLS and where it has potential.

3.1.4. A comparison between RTLS and RFID

Since the technology of RTLS is relatively new and immature, there are not many research projects on this topic. On the contrary, academia is full of research regarding RFID which is a technology similar to RTLS in many ways. Moreover, as this thesis will rely on RFID research as well, it is relevant to compare differences and identify similarities between the two technologies. A search on the search engine Google Scholar showed a remarkably lower number of articles using the keyword RTLS than with RFID as keyword. Thus, it is strengthened to claim that RTLS is a relatively new research topic for academia. Provided in Figure 3.3 are the number of publications on Google Scholar on the topic of RTLS and RFID for the last 40 years.

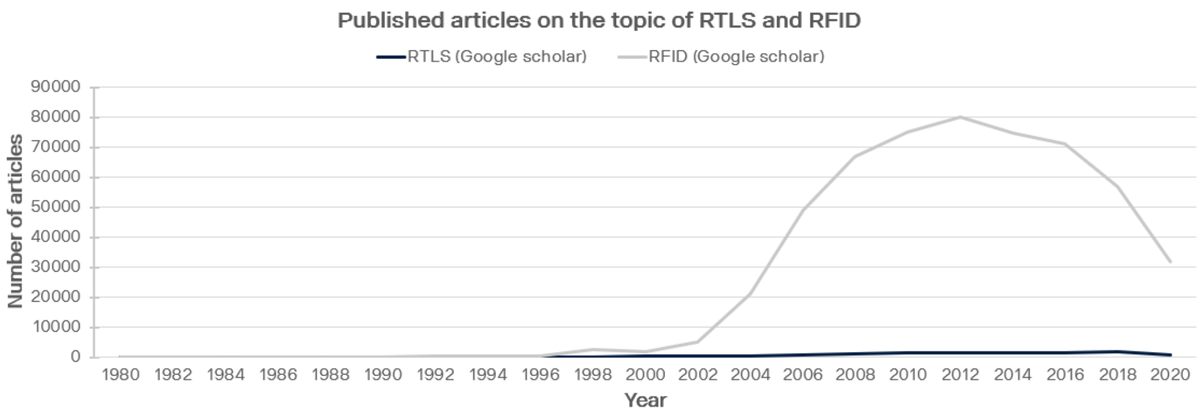

Figure 3.3: Published articles on the topic of RTLS and RFID.

When investigating the similarities and differences between RTLS and RFID, the primer was first introduced in 1998 while RFID had its prelude already in the 1960s (Sakpere et al., 2017; Landt, 2005). Thus approximately 40 years of experience and usage differs between the technologies. Further, both RFID and RTLS are included in the umbrella term AutoID technologies. Moreover, both technologies consist of tags, antennas, readers and modems (Cyplik & Patecki, 2011). The application of the technologies is found in similar industries and fulfil similar purposes. Regarding the differences, RTLS provides better location accuracy while RFID is in general less power consuming. Lastly, the data being provided from RTLS is updated in real-time while RFID is usually not capable of this. A brief comparison between RFID and RTLS is summarized below (see Table 3.2).

Table 3.2: Brief comparison of RTLS and RFID.

Attribute	RFID	RTLS
Start of technology	1960s	1998
Type of technology	AutoID	AutoID
System components	Tags, antennas, modems, beacons	Tags, antennas, modems, beacons
Application areas	Wide variety	Wide variety
Location accuracy	Imprecise	Precise
Power consumption	Less	More
Supply of data/information	Actively/Passively	Real-time

3.2. Real-Time Location System

The term RTLS was first coined around the year of 1998. The idea behind the concept was to describe and differentiate the emerging technology from the already existing RFID technology. RTLS would differ in the way that it would not only be able to automatically identify tags but would also include the ability to view the location in real time on a screen. Despite the technology having been around for some years prior to 1998, it was not deemed for commercial use due to the expensive prices. Since then, technology has emerged, competition has risen, and prices have declined.

3.2.1. Defining Real-Time Location Systems

According to The International Organization for Standardization (ISO), a technical standard for Real-Time Location Systems is as (see Figure 3.4):

Technical standard for Real-Time Location System

"Real-Time Location Systems are wireless systems with the ability to locate the position of an item anywhere in a defined space (local/campus, wide area/regional, global) at a point in time that is, or is close to, real time. Position is derived by measurements of the physical position of the radio link."

Figure 3.4: Definition of Real-Time Location System (International Organization for Standardization, 2014).

In the definition of Real-Time Location System, the meaning of *real time* might not be obvious to the reader which is why the definition provided by the ISO/IEC 19762:2006(en) will be used (see Figure 3.5):

Definition real time

"Real time - level of responsiveness that a user senses as sufficient immediately or that enables a device to keep up with some external processes."

Figure 3.5: Definition of real time (International Organization for Standardization, 2016).

Furthermore, ISO gave four conceptual classifications of RTLS's ability to locate which are provided below.

Conceptual classification of RTLS locating

- Locating an asset over a terrestrial area using terrestrial mounted receivers over a mounted area, e.g., cell phone towers. Corresponding level of accuracy is 200 meters.

- Locating an asset via satellite. Corresponding level of accuracy is 10 meters.

- Locating an asset in a controlled area, e.g., airport, warehouse or campus. Corresponding level of accuracy is 3 meters.

- Locating an asset in a more confined area. Corresponding level of accuracy is tens of centimetres.

Stated by Cwikla et al. (2018, p3), RTLS is defined as a combination of both a software and a hardware which is used to locate objects in real time within an area. Objects to track can be persons, material or equipment and the information gathered can be used for real-time purposes as well as for further analysis. Gladysz and Santarek (2017) put attention to the practitioners' interpretation of RTLS to be a positioning system for indoor applications. Typically, logistics middle and top managers refer to the system as "an indoor GPS".

Despite there being slightly different ways of interpreting the technology and defining it, there are several different techniques that can be used within the technology. Addressed in the following sections are the more functional sides of the technology.

3.2.2. Structure and functionality of RTLS

Deak et al. (2012) established a classification of the indoor application of RTLS to differentiate between active and passive systems. While the former requires the person or object to be tracked to carry an electronic device sending signals to a positioning system, the latter estimates the location based on the variance of a measured signal.

The purpose of RTLS varies depending on the user's intention, whether it is to real-time locate, track or navigate objects. Either it can be used as a tool for collecting data to analyse or serve a more real-time reliant purpose. Dardari et al. (2015) stated that localization is the most basic objective of a RTLS where an object's location is determined via a coordinate reference frame. Moreover, the tracking function is described as a sequence of position estimations where not only the position of an object is determined but also its trajectory is predicted in real time. Thus, tracking objects offers the possibility to estimate the velocity and acceleration. Lastly, navigation has the purpose of following a predetermined path. This by controlling the course and the current position of an object (Dardari et al., 2015).

Even though the infrastructure of RTLS differs on a detailed level it can still be generalized. Consequently, four main components (tags, locating device, location engine and user application and interface) create the system (see Figure 3.6) (Gladysz and Santarek, 2017).

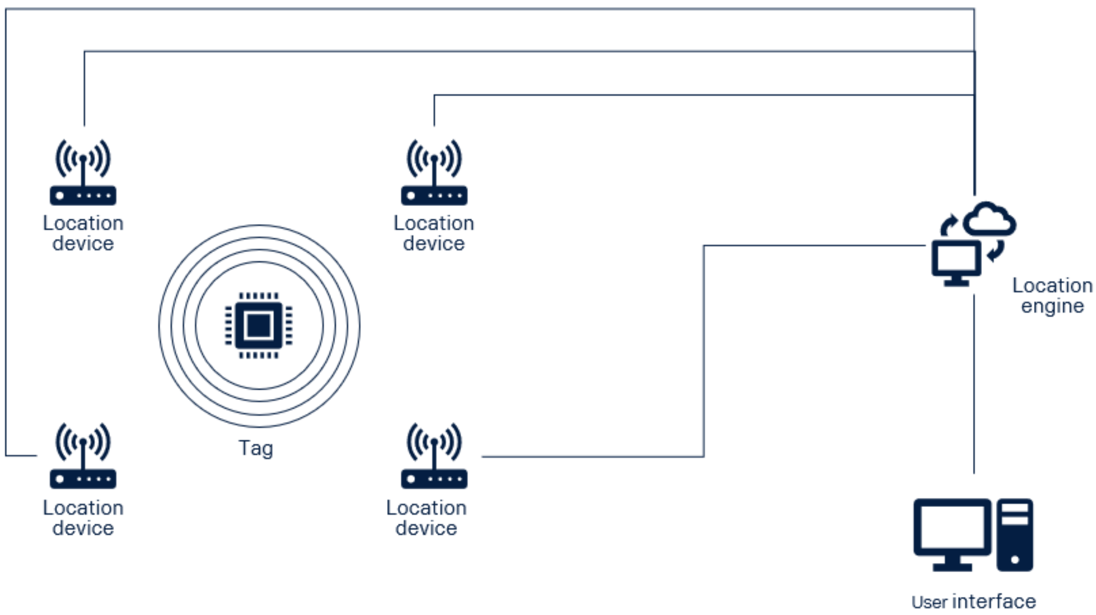

Figure 3.6: The general infrastructure of Real Time Location Systems (Gladysz and Santarek, 2017).

Tags

The tag is attached to the object that is being tracked. It collects data in real time and then transmits it. The gathering, storing and processing of data is carried out via a small chip while both receiving and transmitting data is achieved via an antenna. Currently there exists two variants of tags: active tags containing its own power source (e.g., battery) and passive tags without a power source. As active tags have their own power source, they usually have a larger range of operations than the passive ones. When comparing the prices between the two types of tags it is reasonable that the passive one comes at a lower cost. Despite the passive tags having a smaller range of operation, they are still more popular since their life span is longer (Zhu et al., 2012).

Locating devices

In comparison to the mobile tags, the locating devices are fixed and positioned within the particular area in which the objects are moving. Via the locating devices, wireless communication between the tags and location engine takes place (Gladysz and Santarek, 2017). Additionally, the type of information that is exchanged between the tags and the locating devices can include anything from data summarizing the contents of a carton to manufacturing details of goods, naturally dependent on what type of system that is being used.

Location engine

The location engine is a software that calculates the position of the tags based on data received from the locating devices. Further, it is stated that the complexity of the location engine has a broad spectrum. There exist cases where a simple personal computer or modem is sufficient while in other cases an entire networked enterprise management information system is required (Gladysz and Santarek, 2017; Wu et al., 2006).

User application and interface

In order to integrate RTLS with backend systems, user applications and interfaces are necessary. Further on, the number of features of RTLS are almost unlimited. Accordingly, RTLS may offer a solution for several industries and different kinds of challenges, all suited accordingly to the user (Gladysz and Santarek, 2017).

3.2.3. Measurement types

There exist different ways of measuring data when tracking. Consequently, a classification according to the one created by Dardari et al. (2015) could be used. In their paper on the topic of indoor tracking they created a framework by categorizing three types of measurements. However, only the geometric-related measurement type is of interest here as it concerns the technology that the researchers will test.

Geometric-related measurements
According to Dardari et al. (2015) the measurements are directly related to the geometric constraints between nodes. In practical systems, a pragmatic but suboptimal two-step approach is used. This approach contains a first estimation of geometric quantities and then a tracking estimator using these values. Examples of geometric related measurements are: (1) Received Signal Strength (RSS) which estimates the distance based on received signal strength, (2) Angle of Arrival (AoA) which measures the angle of arrival of signals arriving at the node, (3) Phase Difference of Arrival (PDoA) which measures the phase difference at the node.

3.2.4. Technologies used for RTLS

Declared by Gladysz and Santarek (2017), there are many different technologies that can be applied within RTLS. According to the authors, some of the commonly used technologies are Ultra-Wide Band (UWB), Radio Frequency (RF), Wi-Fi, ZigBee, Bluetooth (BT), Infrared (IR) and Ultrasound (US). Furthermore, there also exist hybrids of technologies such as IR-RF and IR-US. While the above-mentioned technologies are categorized as active systems there also exists several technologies used for passive systems. Among these are Device-free Passive (DfP), Differential air pressure and Computer vision (Deak et al., 2012). Provided in Figure 3.7 is a structural classification of these technologies.

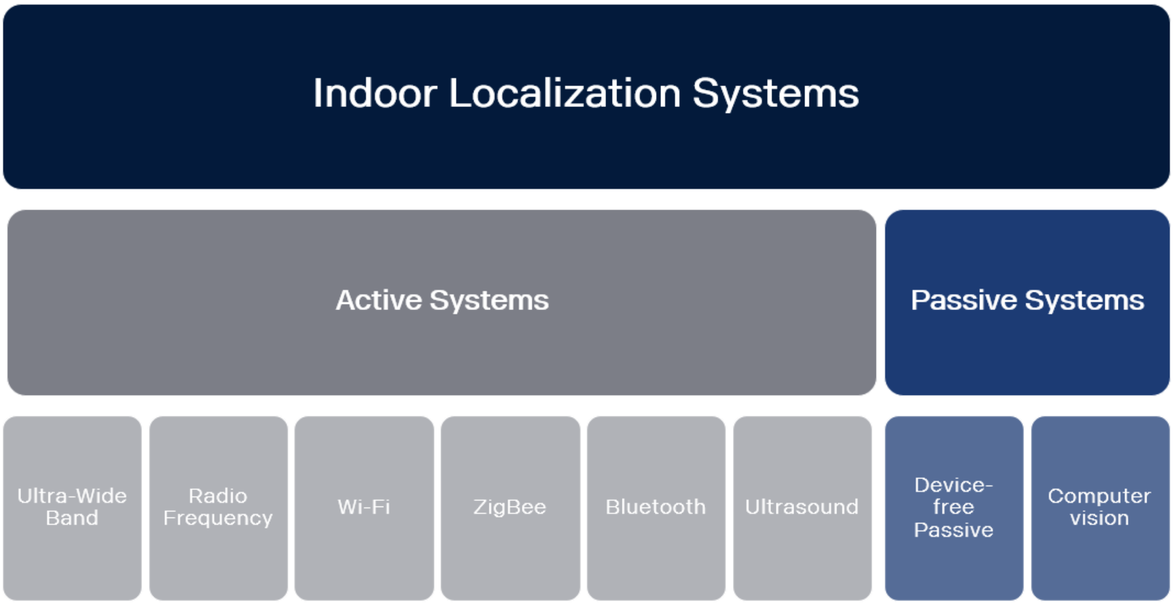

Figure 3.7: Classification of RTLS techniques (Adopted from Cwikla et al. (2018)).

Active technologies used for RTLS

Provided below is a more in-depth description of some of the active indoor localization systems.

Ultra-Wide Band (UWB)

UWB communication systems use short duration pulses on the order of a nanosecond. The short pulse modulation allows the estimation of position with a fine resolution thus commonly used for high-definition indoor tracking (Dardari et al., 2015). Deak et al. (2012) proved this high precision resolution and gives an approximately accuracy of 15 cm for 95% of the readings. This technology has been evaluated in Smart Factory Lab, Scania Södertälje.

Radio Frequency (RF)

According to Curran et al. (2011), RF is today used across many different applications. However, most of these applications only use data regarding objects' position rather than including timestamps. Deak et al. (2012) declared that RFID uses radio frequencies to locate objects and gives the possibility to achieve great resolution and accuracy. Ding et al. (2008) brought up further advantages of RFID to not requiring line-of-sight to the objects.

Wi-Fi

Stated by Curran et al. (2011), the Wi-Fi location determination technologies use modulated Wi-Fi transmission signals to detect the presence of an object. Ding et al. (2008) declared one advantage of this technology to be the lack of requirements on complex cabling distribution. This since it is a wireless network and consequently can make use of existing Local Area Network (LAN). Though Cwikla et al. (2018) revealed that the Wi-Fi technology provides less accurate location then systems specialized for determining the location. Therefore, one needs to investigate the trade-off between high accuracy and more complex set up of the system.

ZigBee (based on IEEE 802.15.3)

The ZigBee technology has low power consumption, comes at a low cost and has an operational range between 10 to 75 meters. Most of the time the ZigBee spends its time deactivated and consequently two AA batteries are sufficient to run the ZigBee for two years (Ergen, 2004). Further stated by Dardari et al. (2015) is that the ZigBee was not developed for localization and tracking purposes thus its positioning performance could be rather poor.

Bluetooth (BT)

According to Cwikla et al. (2018) the operational range for Bluetooth is restricted to approximately 10 meters. They further stated that base stations (access points) need to be installed. Moreover, suitable application areas for Bluetooth are where high location accuracy is not a requirement. Deak et al. (2012) highlighted the advantage of Bluetooth to be the possibility to locate any Bluetooth mobile device without the need of any additional hardware. This technology has also been evaluated in the Smart Factory Lab.

Ultrasound (US)

Sound and navigation ranging relies on ultrasonic and sound as signal. Sound is not a favourable transmission due it being easily disturbed. Positions are accurately identified with the aid of ToA (Time of Arrival). The ToA method measures the time it takes for a signal to propagate between two antennas (Liu, 2005). This is the principle used in the RTLS kit provided by Marvelmind.

Passive technologies used for RTLS
Provided below is a description of the passive indoor localization systems.

Device-free Passive (DfP)
The Device-free Passive localization technique has the purpose of identifying a person's location without any use of sensors. This as the human body contains more than 70% water thus the body reacts as an absorber of signals. (Deak et al., 2012)

Computer vision
According to Deak et al., (2012) the computer vision technique has similarities with DfP in that the tracked object does not carry any device or tag. This technique could be used in cases where one is aiming for transforming a regular environment into an intelligent environment whereas it is possible to switch on devices if a user is around.

Although there exist a large variety of technologies used for RTLS, there are problems with obtaining precise location in complex environments. To cope with these challenges, it is possible to combine two or more techniques creating a hybrid location system (Cwikla et al., 2018). Furthermore, Deak et al. (2012) opined that the next-generation systems can be considered as hybrid systems which already are implemented today for mapping, vehicle navigation and robot navigation.

In the case of this thesis, no passive technologies will be investigated further into. Therefore, that information solely fulfils an informative purpose.

3.2.5. Applications for Real-Time Location System

In Gladysz and Santarek's (2017) literature review they described several different application areas for RTLS. They further stated that there are almost an unlimited number of application areas stretching over various industries. Examples of industries where its application was brought up were in the healthcare, home and building automation, public safety, agriculture, retailing industry, travel and tourism industry, food and restaurant industry (Gladysz and Buczacki, 2018 ; Zhu et al. 2012). Zhu et al. (2012) put a remark on further research directions in the field of RTLS applications and highlighted new applications on item level to be investigated as well as exploring supply chain efficiency improvements like reducing the bullwhip effect.

Moreover, the application of the technology depends on what object to track. As provided below, one can see Table 3.3 listing potential objects and assets.

Table 3.3: Potential objects and assets to track (Cwikla et al., 2018).

Potential objects and assets to track	Mobile assets
	Workers
	Products
	Work In Progress (WIP)
	Materials
	Key components
	Means of transportation
	Containers

Applications for Real-Time Location System in Logistics and Production Settings
Cwikla et al. (2018) discussed RTLS applications for production systems. Among several options, the following were listed: (1) RTLS was used in car assembly system where the technology was applied for both vehicles and tools, (2) RTLS was used to track vehicles as they come “off-line” and move through specific process stages and (3) RTLS was used to allow process monitoring across multiple factory sites and to automatically update ERP systems. An additional classification (see Figure 3.8) of the application of RTLS was presented by Ma and Liu (2011). This was based on their study on the application of Wi-Fi RTLS in Automatic Warehouse Management System.

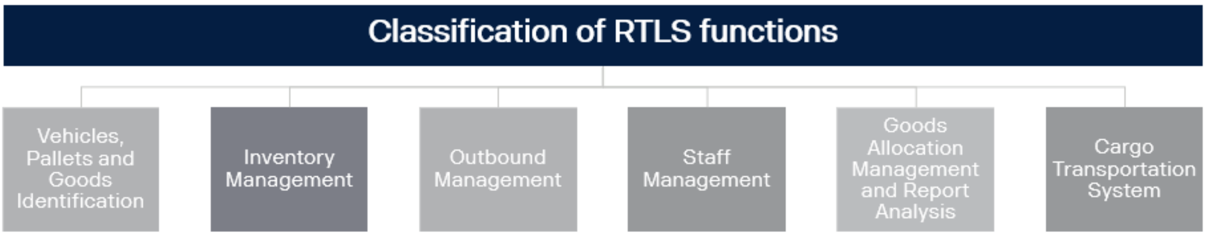

Figure 3.8: Classification of RTLS functions (Adopted from Ma and Liu (2011)).

Summarized in the findings by Ma and Liu (2011), it was clear that RTLS could be applied to solve the management of warehouse related information. It was also concluded that when enterprises seek to improve productivity, RTLS probably will find an appropriate application. Moreover, Jachimczyk (2019) stated that in warehouse and storage settings RTLS can be applied to facilitate the movement of goods through the logistics chain-by-chain visibility. RTLS will further enable modern agile organizations to respond rapidly to changes in demand.

In the conceptual paper by Attaran (2007) the application of RFID in the manufacturing sector was presented. According to him, to ensure accuracy, manufacturers are using RFID for product tracking. Furthermore, RFID helps manufacturers with their scheduled just-in-time (JIT) assembly lines. Also, Attaran (2007) provided that tags can be used to keep track of availability, usage, location and maintenance of the material handling equipment. Dai et al. (2012) stated that in recent years RFID has been employed by a number of leading vehicle manufacturers. This in order to facilitate manufacturing shop-floor management. Examples brought up are establishment of an RFID system on racks in paint shops to achieve continuous production. In another paper written by Huang et al. (2010) it was expressed that RFID is an effective tool for collecting and processing field data from manufacturing machines. Consequently, responsive production planning and control is enabled. Moreover, in one case at a high-performance car manufacturer, RFID tags were used to track the location of vehicles as they move though the final steps in the manufacturing process. This to ensure that the vehicles were produced according to the customers’ demands.

3.2.6. Market analysis of RTLS

Provided in this section is a brief market analysis that has been performed on the technology of RTLS. The market analysis has taken the shape as a SWOT analysis and is summarized below (see Figure 3.9). The reason for presenting the analysis in this chapter is to establish and convey background information to the situation of RTLS today.

Looking at the current situation, RTLS is a promising newcomer to the world of information and identification technologies. Market forecasts point in the direction of RTLS to grow rapidly and continuing to do so. Furthermore, due to the flexibility when using the technology it has and is widely being used within many different industries. The technology is also fairly easy to use and can in many instances be customized and mounted to suit the specific needs of the users.

On the other hand, the technology requires technology competence, maturity as well as willingness to adapt and learn. Furthermore, RTLS can in general be considered to be rather sensitive to signal interferences and disturbances since the technology is mainly based on radio waves and ultrasound. Lastly, RTLS is currently rather expensive when compared to similar technologies, both in maintenance and installation costs.

Regarding the opportunities, besides showing great potential, the need to track and trace assets and objects is continuously increasing. The spread of the Covid-19 virus has also increased the need for contact-tracing solutions where RTLS can play a key role. When looking at threats, RFID and other similar technologies outcompete RTLS when it comes to price. Lastly, RTLS is a fairly new subject to industries which also currently inhibits its potential due to the lack of knowledge about the technology's existence.

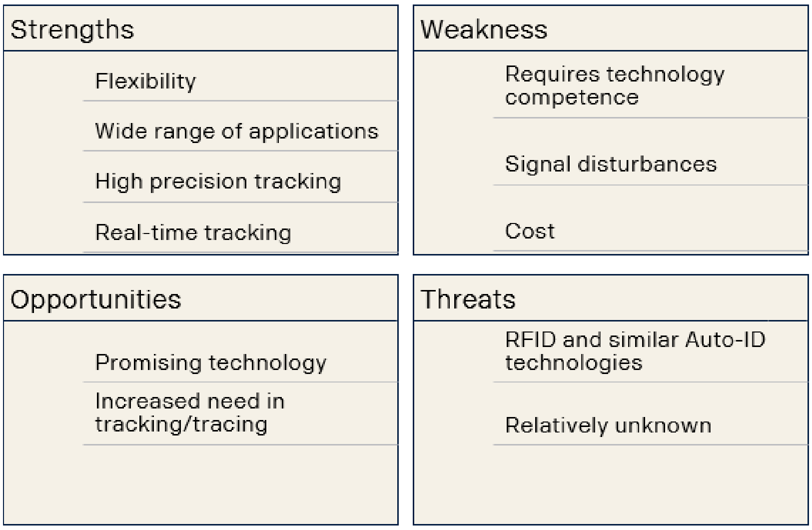

Figure 3.9: SWOT analysis of RTLS.

3.3. Attributes of Real-Time Location System

Addressed in this section is this study's first research question. What advantages, challenges, risks and requirements that RTLS entails. For each of the four attributes, the terms are firstly defined and thereafter context is provided. To clarify, both technical as well as qualitative aspects with RTLS and Auto-ID technologies will be addressed.

3.3.1. Advantages of Real Time Location System

In order to state advantages that RTLS entail it is necessary to define what is meant with the term advantage (see Figure 3.10).

Definition of advantages
For this thesis, the term advantage is meant to imply the following; (1) Include better and more efficient manufacturing techniques, (2) The ability to develop new innovative approaches and solutions and (3) Reduce waste.

Figure 3.10: Definition of RTLS advantages.

Improved inventory control, asset utilization and reduced lead times

When it comes to the technical advantages that RTLS entail, Gladysz and Santarek (2017) addressed some in a paper regarding RTLS selection approaches. There it is stated that by applying RTLS in logistical contexts, one can better control and reduce inventory through smoother information handling. This is also strengthened by Zhu et al. (2012) who claimed that besides reducing ordering lead times, RTLS enables improved inventory control, increases accuracy of inventory information which mitigates the risk of stock outs. Furthermore, asset tracking and improved asset utilization is also addressed (Gladysz & Santarek, 2017).

On the topic of controlling and reducing inventory, Ma and Liu (2011) presented the possibility of solving issues concerning item searching by using RTLS in logistics. According to Hardgrave et al. (2009) RFID is a technology that contributes to improved inventory accuracy. They further discussed that unnecessary inventory in the form of excessive safety stock can be reduced thus decreasing tied capital.

Increased efficiency

Another advantage is that the production efficiency can also be improved. In a case study conducted by Gladysz et al. (2018) they investigated how RTLS could increase production efficiency via the use of dynamic spaghetti diagrams. From the pilot implementation they concluded that, by acquiring data efficiently, RTLS can support lean initiatives when for example conducting spaghetti diagrams. Zang and Wu (2010) also highlighted that adopting RTLS in logistics can save the manpower cost by 30-40%. This since the traditional way of scanning can be done automatically.

Improvement of safety

Beyond the previously mentioned advantages of RTLS, Zhang and Hammad (2012) concluded in their research that RTLS improves safety aspects and prevents delays caused by unforeseen factors. They emphasized that real-time collision avoidance can be achieved by providing increased awareness of the situation through better and more accurate communication.

Better supply chain cooperation and improved information sharing

In a paper by Delen et al. (2009) it was stated that with identification technologies, the information at different organizational levels can be distributed in real time thus eliminating the delay in information sharing. Moreover, one of the keys to an efficient and effective supply chain is inventory accuracy (e.g. ordering and replenishment are based on an accurate inventory count). In a more general perspective, RTLS can be used to share information with different stakeholders in the supply chain. Prajogo & Olhager (2012) mentioned that real-time inventory positions can for instance be shared with suppliers so that they more accurately can plan replenishment and delivery schedules which results in better service levels and reduced inventory costs.

General advantages
Furthermore, technology innovations and acquisitions permits greater control of more decentralized organizations while at the same time enabling information to give managers substantive decision-making authority (Marquardt, 2011). Marquardt (2011) went on to argue that acquiring innovative technologies can provide companies with strategic advantages, or as he put it "*/../ being first can make all the difference between achieving success and failing.*". Furthermore, leveraging technology helps companies stay ahead of competition. It is essential for value creation and capturing new market opportunities (Bowonder et al. 2010). The article lists FedEx implementation of RFID as an example of this. More and more companies are using technology foresight to create business values and gain a strategic advantage. By using RTLS, one contributes to realizing digitization and intelligence management which promotes enterprise development.

3.3.2. Challenges with Real-Time Location System

In order to state challenges that RTLS entails it is necessary to define the term challenge (see Figure 3.11).

Definition of challenges
Potential challenges to address when implementing systems or technologies can be referred to as implementation barriers. Therefore a barrier is meant as an obstacle that prevents or limits a given way an instrument is being implemented.

Figure 3.11: Definition of challenges.

The challenges can be divided into technical ones and more general ones. Challenges that are related to the technology are divided into several subcategories such as environmental constraints, cyber security challenges etc. Lastly, on a more general note, challenges that are related to the implementation of IT technologies are addressed.

Environmental challenges
In a research conducted by Fisher and Monahan (2012) they assessed the implementation and use of RTLS in the hospital industry. They found that the environment as well as the surrounding in which RTLS was installed and used in would greatly affect its functionality. The reason for this is since material and obstacles could either reject or reflect the signals from the tags. This is also the case for manufacturing industries. A complex flow of goods can greatly affect the quality of the signal transmissions. Additionally, it is emphasized that the environment to implement RTLS in must carefully be considered (Budak & Ustundag, 2015; Wu et al., 2006).

Cyber security challenges
In a study analysing security challenges with IoT it was observed that systems can be exposed to different types of attacks (Hinai & Singh, 2017). These can be either passive attacks: monitoring the network without affecting or interrupting the performed service, and/or active attacks: a complete stop of the performed service. These can further be categorized to correspond to the three IoT layers; perception, network and application layer. Since auto-identification technologies are reliant on sensors, connectivity and processes it is fair to consider RTLS an early stage of IoT.

The network layer, which transmits data, deals with DoS, passive monitoring and eavesdropping attacks. This leads to difficulties in maintaining data privacy and ensuring safe identity authentication (Hinai and Singh, 2017). Moreover, Attaran (2007) concluded in his research that there are some important security concerns to consider where he mentioned data confidentiality, integrity and availability as some.

Storage capacity and system delays
Dai et al. (2012) pointed out challenges related to the storage capacity of the technology. Since the storage capacity is limited there is a challenge concerning overflow of tag memory. Secondly, when several tags are read simultaneously the responsiveness of RFID readers can be slow. This means that the responsive time for a large number of data that is being transmitted among tags, readers and databases can be poor. Attaran (2007) also highlighted RFIDs' difficulty to manage large volumes of data sets.

Battery/energy challenges
Lohan and Singh (2017) stated in their review of challenges associated with IoT that long lifetime and energy efficiency of sensors are very important. They further described the problem of power consumption with RTLS readers. Since many RTLS technologies are run on batteries, they require to be charged every once in a while which is a challenge to cope with. However, there are some technologies that have life-long operating time but the precision tends to be poor for those sets. Fisher and Monahan (2012) brought up the challenge with battery capacity. According to them, even though many RTLS vendors provide functions that could send alerts to users to warn of low battery, it was found that these warnings were ignored by users in practise.

Change management
As stated by Pryor et al. (2008), once organizational leaders realize the need for change they face challenges in successfully implementing initiatives. In order to provide the reader with the bigger picture, it is necessary to also address the more qualitative barriers related to implementations of new technologies and systems. As for all implementation projects and changes in organizations, there are forces which govern the transformation and its outcome. Since the RTLS is to be applied on a more shop-floor level and implemented by middle and upper management, it is of high relevance to present challenges with change management and implementation of technologies.

Forces against change can be of individual or group character. Kotter and Schlesinger (2008), refer to the following elements as such forces (see Table 3.4).

Table 3.4: Forces against change (Kotter and Schlesinger, 2008).

Forces against change	Personal interest not connected to the organization interest
	Errors in understanding the implications of organizational change
	Different situation assessment especially between the management and the workers
	Low tolerance to change generated by the distrust to the capacity to adapt

In order to mitigate the forces above and to fully reap the benefits acquired by change, it is important to align the individual and collective interests in organizations (Loloiu et al., 2015).

Acquisition challenges and costs
Huang et al. (2010) listed challenges regarding the adoption of identification-based systems. Firstly, the cost of adopting such systems is perceived as being rather high which tends to lower the interest for the technology. Moreover it is also rather difficult to determine potential cost savings from investing in track and trace technologies which makes it difficult to justify an investment. Since RTLS is part of Industry 4.0 and a core pillar in the development of IoT there is a lot of research put into the technology. Therefore, it is difficult for users to decide whether or not it is the right time to invest since there is a rapid development and growing market for the technology. However, if cost is an issue, one can share this with other stakeholders in order to overcome this obstacle which is known as incentive alignment (Huang et al., 2010; Simatupang and Sridharan, 2005).

Staff competence
Adopting such technologies also puts pressure on acquiring and having the right staff with the right competencies. Implementing highly technical products naturally requires the staff to have the right competencies and more importantly, the willingness to learn. Lastly if workers are not well educated and their awareness of IT systems in general is poor, the risk of human errors increases. Therefore Dai et al. (2012) discussed the aspect of educating workers before systems are implemented.

Resistance to change
The challenges regarding workers' resistance to change was strengthened by Zhu et al. (2012) who stated people's attitude to be one management issue in regards to RTLS. As with all complex technology, there is also naturally a risk related to human errors. During the implementation phase of RTLS, Dai et al. (2012) found one particular challenge that was brought up by people. Workers' resistance to change as they have been accustomed to their individual habits and ways of doing their work.

3.3.3. Risks related to Real-Time Location System

Risk is a common terminology used in many instances, especially within Information System technology and as Ahlan and Arshad (2012) clarified, there are many different definitions currently being used. Therefore the definition of a risk might intervene with what a challenge is and vice versa. With this in mind, it is obvious to the authors to define what a risk is in this paper (see Figure 3.12).

Definition of risks

Due to nature of the report, revolving around an IT technology as RTLS, the definition is adopted from Ahlan and Arshad (2012), where they state the following:

"/../ the definition of IT risks being the uncertainty that a foreseeable loss or damage can result from such uncertain probabilistic events."

Figure 3.12: Definition of risks.

Security risks
Using RTLS causes security and network concerns. All mechanisms regarding the security have to be well implemented in order to protect the network from unauthorized access and eavesdropping (Ilie-Zudor et al., 2010). Even though this article is focusing on the closely related RFID technology, the security concerns are very similar for RTLS. With the information

being transmitted via radio frequencies, classified information might be exposed. Ilie-Zudor et al. (2010) went on to list additional risks regarding the security aspect (see Table 3.5).

Table 3.5: Security risks with RTLS. (Ilie-Zudor et al. (2010)).

Altering network traffic	Stated by Ilie-Zudor et al. (2010) was the interception and altering of messages by the intruder. Typically, the intruder uses this type of attack to for injecting align code into the system which may either cause damage or leak out confidential information.
Altering label information	Nowadays, more information than the unique identifier is stored on the tags. In this case the data on the tags may be exposed to security threats (e.g. data may be corrupted for sabotage by the intruder). (Ilie-Zudor et al., 2010)

Privacy risks
One relevant risk associated with the implementation of RFID is customer privacy. Today, RFID tags can be scanned by anyone with an appropriate scanner and consequently access the data. In order to manage this issue, national legislation and guidelines for goods handling are established. Additional arrangements are features such as attaching shielded cover to the chips thus making it harder to read the contained information (Zhu et al., 2012).

Communicational risks
According to Gladysz and Santarek (2017), it is important to carefully consider the communicational aspects with RTLS. If the system is not properly studied and designed, risks are likely to occur. Such risks are summarized in Table 3.6.

Table 3.6: Resulting risks from problems of communication (Gladysz and Santarek, 2017).

Risks	Designed improperly
	Encoded incorrectly
	Distorted in communication channel
	Not sent
	Not transferred
	Not received
	Decoded incorrectly
	Interpreted incorrectly

Equipment risks and signal interventions
When it comes to the actual equipment of RFID two main types of risks are reader and tag collision (Zhu et al., 2012). The former happens when the coverage area of one RFID overlaps with another reader thus resulting in signal interference. The second occurs when a large number of items with RFID tags are energized by the RFID reader at the same time. In certain environments, radio waves of some devices can interfere with the transmission of RFID radio signals. (Zhu et al., 2012) Furthermore, Van der Togt et al. (2008) therefore suggested onsite electromagnetic interference (EMI) tests and updates of international standards.

Cultural and organizational risks
Some more qualitative risks that touch the topic of IT implementations can be found in an article by Baccarini et al. (2004). Any change or action that involves human behaviour comes with risks. In the article, the authors addressed implementation risks with IT projects. Naturally, Baccarini et al. (2004) listed personnel shortfalls and poor quality of staff as such two. If staff is not properly trained and motivated when setting new standards of work, lack of experience affect the quality of the operating systems. Another factor resulting in failure of implementation is the corporate culture not being supportive as well as weak management support. Also there are risks related to unrealistic expectations. This has been highlighted as a key criterion for implementation success which is why communication is crucial.

3.3.4. Requirements related to Real-Time Location System

In order to state requirements that RTLS entail it is necessary to define the term (see Figure 3.13). This since the term is easily misinterpreted as a challenge or risk.

Definition of requirements
Adopted from Jackson (1997), a requirement is defined as something that is compulsory for a necessary condition.

Figure 3.13: Definition of requirements.

When using RTLS, the requirements seem to rely on the specific situation. As noted earlier, the application areas can vary a lot hence creating difficulties in generalizing what requirements are needed. For instance, there are no standard RTLS and the selection process comes down to the type of environment to track as well as the speed, cost and accuracy required by the user (Adler et al., 2015; Cwikla et al., 2018; Budak and Ustundag, 2015).

Technology maturity
Looking at identification systems, there are some requirements that are necessary to have in place prior to implementing the technology. In order for identification systems to work efficiently, an appropriate IT infrastructure is required since the technology relies heavily on data and transmissions (Zhu et al., 2012). Naturally technical competence is also required within the staff or else it is difficult to use the system.

System requirements
The requirements also depend on the functionality of the identification-based operations. What can be found is that from tracking-based operations, Ilie-Zudor et al. (2010) mentioned that the ability to uniquely identify each item is key. Also to associate the location and time with the given identifier. Another characteristic Jachimczyk (2019) discussed is that the tag or location device must be as easy as possible to handle, since the weight, colouring or size simply can make a significant difference in the output. In the case of radio devices, the way a user wears the tag can greatly affect the efficiency and as discussed previously, maintenance of the RTLS must be simple and user-friendly to lower the barrier of entry for when adopting the technology (Ma & Lui, 2011; Zampella & Seco, 2013; Moreno-Salinas et al., 2013).

Jachimczyk (2019) provides a design frame for when adopting RTLS. The stakeholders' requirements are divided into non-functional and functional ones. The non-functional requirements are defined as performance and quality criteria but also factors of the system operation and investment costs. Such requirements can include for instance the compatibility aspect of the RTLS with other systems in use such as WMS, TMS and ERP systems. The functional requirements on the other side, relate to the main functionalities of the system which influences the system architecture, services, protocols etc. Such parameters are required to adjust accordingly in order to make the system dynamic (Jachimczyk, 2019).

Collaboration between stakeholders

When it comes to the user’s requirements, there needs to exist a close cooperation between the designer, the future user and all involved stakeholders in order to identify the user’s desires. Characteristics such as human interface features need to be addressed. It is also desirable to avoid affecting the user's working environment as much as possible which is why emphasis is on communication and collaboration.

Environmental requirements

Since the environment can affect the radio transmissions, an environmental analysis is crucial and needs to be carried out in detail. The layout, building structure, furnishings and other equipment can impact the system's performance greatly. Metal walls can for instance influence, reflect and disturb radio transmissions (Jachimczyk et al., 2016). Therefore Jachimczyk (2019) listed the following aspects that should be looked into when investigating a suitable environment (see Table 3.7):

Table 3.7: Aspects when investigating the environment (Jachimczyk, 2019).

Aspects to consider when investigating the environment	Working conditions such as humidity, pressure, temperature etc.
	Density and mobility of people
	Interactions and dynamics of moving persons and vehicles

Leadership management and staff involvement

Lastly, as argued by Pryor et al. (2008), it is important that management exercise leadership and act role models to the rest of the staff. Management needs to send positive messages about the change as this greatly affects the employees willingness to learn and adapt. This is in line with social learning theory and that people learn through observations. Therefore emphasis is put on having a motivational approach where staff is involved as implementation of technologies will likely require changes of the organization's cultural elements, norms, values and procedures (Loloiu et al., 2015). Without the willingness from employees to learn and adapt to the technology, an implementation is not feasible.

4. EMPIRICS

This chapter provides empirical background to the thesis with the aim of giving context on the case company. The study object of Scania and its relevant logistics and material flows will be described more in depth. Additionally, assigned to this chapter is also background information on the RTLS technology and external systems that have been applied.

4.1. Case company

This master thesis has been conducted in collaboration with Scania who is a world leading provider of transport solutions with a global presence in about 100 countries. Founded back in the year of 1891, Scania's purpose is to drive the shift towards a sustainable transport system, creating a world of mobility that is better for businesses, the society and environment. With its headquarter in Södertälje, Sweden, Scania today employs around 51 000 employees worldwide (see Figure 4.1) who together are researching, developing and promoting sustainable solutions for cleaner and safer transport of people and goods.

Figure 4.1: Scania global presence (Scania, 2021).

Research and development activities are mainly concentrated in Sweden, with branches in Brazil and India. Moreover, production takes place in Europe, Latin America and Asia. For a few years, Scania has been part of Traton Group. Under this umbrella the brands Scania, MAN and Volkswagen Caminhões e Ônibus work closely together with the aim to turn Traton Group into global champions. Depicted in Figure 4.2 is the product line of Scania. (Scania, 2021).

Figure 4.2: The product line of Scania (Scania, 2021).

In Sweden, Scania holds three production sites (see Figure 4.3) divided between the cities Oskarshamn, Södertälje and Luleå. At the former site the cab production takes place. This is also where this master thesis has been conducted. The facility at Oskarshamn is divided between Manufacturing Body (MB) and Manufacturing Cab (MC). These are the two main production units at the site in Oskarshamn and will be addressed in more detail in section 4.2. (Scania, 2021).

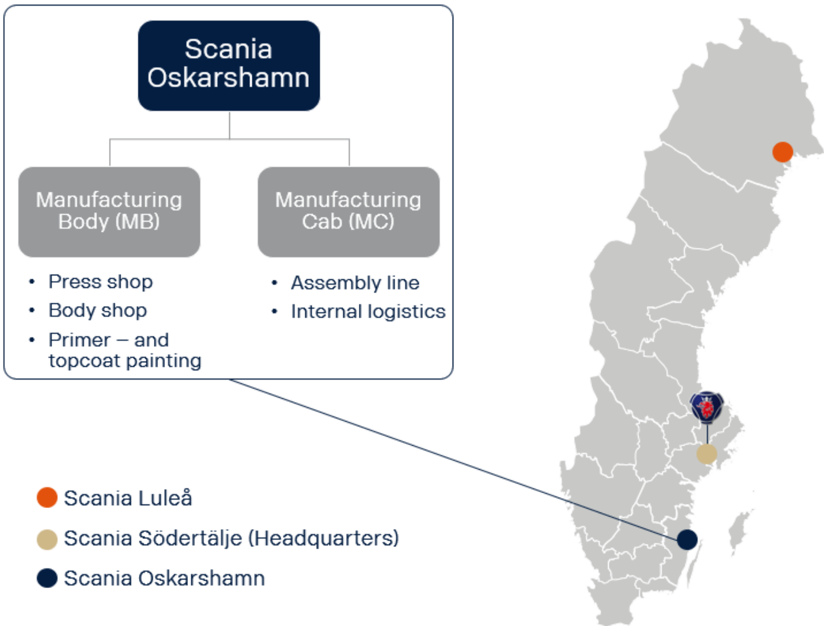

Figure 4.3: Scania production sites in Sweden (Scania, 2021).

4.2. Mapping of relevant logistics flows

This section will provide a general overview of the Scania facility in Oskarshamn including its material and logistics flows. The aim of presenting this is to generate a basic understanding of the operations taking place and in what way RTLS will be applied.

In several processes (see Figure 4.4), divided between press workshop, body shop, primer - and topcoat painting and assembly workshop, steel coils are successively transformed into cabs. The cabs are then delivered to one of the chassis workshops in Södertälje (Sweden), Zwolle (Netherlands) or Angers (France) for final assembly. Thereafter the truck is completed and delivered to the customer.

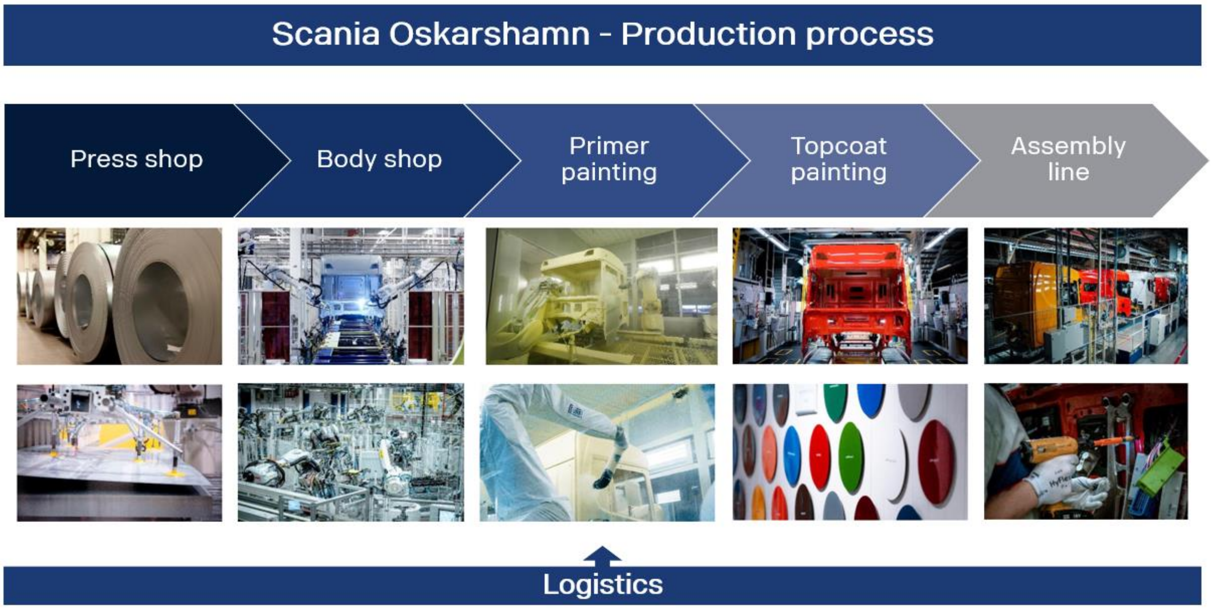

Figure 4.4: Scania Oskarshamn production process (Scania, 2021).

Below follows a detailed description of MB and MC. Since focus has been on applying RTLS to the latter, it is therefore presented more in depth.

4.2.1. Manufacturing Body (MB)

MB constitutes the first manufacturing unit at Scania Oskarshamn. Here the process is in general divided into two workshops, the press workshop and the body shop. At the former, steel coils are cut into pieces followed by pressing processes where different articles are pressed.

From the press shop, articles are transported to the second workshop at MB which is the body shop. Here, the articles are successively transformed into the body frame of the cab. A few years back, Scania invested in a completely automated body workshop hence enabling the transformation from steel articles into a complete body frame to be fully automated. Various operations such as welding, gluing and partial assembly are performed by the robotics. Unfortunately, the application of RTLS will not take place in MB, but due to the chain connection, it is still worth including. It is also worth mentioning that the paint shop is included in MB, where layering and top coating are being performed on the cabs.

4.2.2. Manufacturing Cab (MC)

MC constitutes the second manufacturing unit at Scania Oskarshamn. Here the production process is in general divided into the assembly line and logistics. After MB, the cabs are transported into the final production process which is the assembly line. At the assembly line, various components are assembled to the cab depending on the customer order. This part of the production process is the most workforce intensive one since many employees are required to perform all assembling activities as well as the supply of material to the lines. In the facility, the assembly line is divided into nine sub-lines. Depicted in figure 4.5 is a conceptual layout of the assembly line.

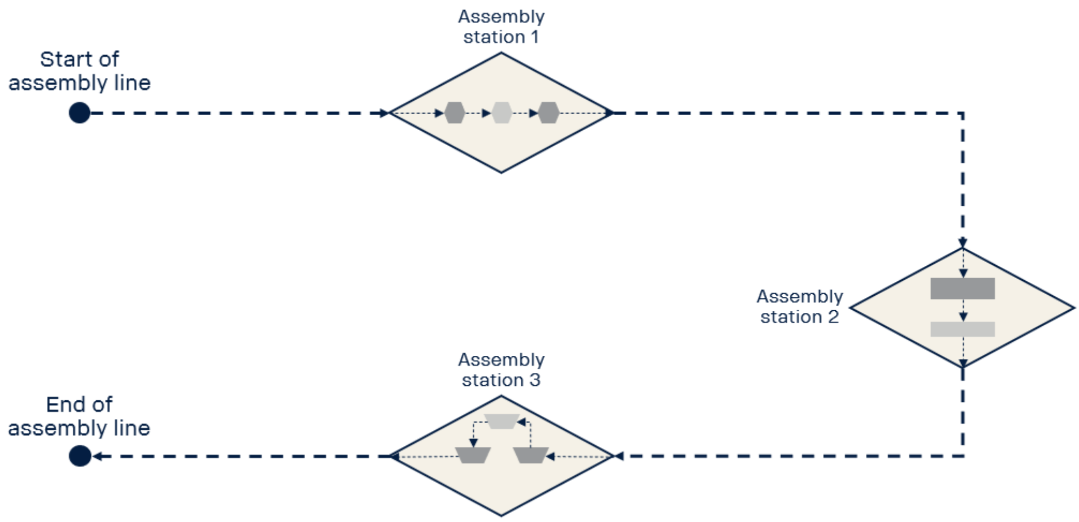

Figure 4.5: Conceptual layout of the assembly line (Scania, 2021).

4.2.3. Logistics Centre (OLO)

A third unit is the logistics centre called OLO. At OLO, material from Scania's external suppliers is arriving and stored in a larger warehouse. Also, partial assembling activities are taking place as well as regular warehouse activities such as retrieving, storing, picking and moving material within the warehouse. From OLO there is a continuous flow of material to the main facility (see Figure 4.6). This material flow consists of internal truck transportations with a distance of approximately two kilometres. On average, every eight minute, transportations depart from OLO. Once arrived at the main facility, material is stored in various warehousing setups such as narrow-aisle high shelves and/or in a fully automated warehouse.

Figure 4.6. Material flow between OLO and manufacturing site (Scania, 2021).

4.2.4. MC Operations

Assembly line
No application of RTLS has been performed at this part of the material flow. This was mainly due to time restrictions. However, providing some background information on the assembly line was deemed to be relevant in order to facilitate the understanding of upcoming sections.

At the assembly line, it is of high importance that the right material is being supplied at the right time and at the right place. If not, the line might have to come to a halt causing delay in the production schedule. Further, modifications in the cab assembling order is taking place with the purpose of better balancing the line with regards to assembling activities. Providing the assembly line with cab beds and shelves is the so-called CU-forklift. This forklift is of interest as it is chosen to be studied for this thesis, more on this the following chapters.

Platform and kitting operations
For each of the assembly lines, a separate platform is assigned (see Figure 4.7) with the purpose of supplying material to the respective line. Via different picking methods, material is picked from pallets and placed in a transportation unit called racks. For such picking processes, there is a need from Scania's point of view to track and gather data on what picking method is the most efficient. Therefore, this area is of interest for investigating the suitability of RTLS.

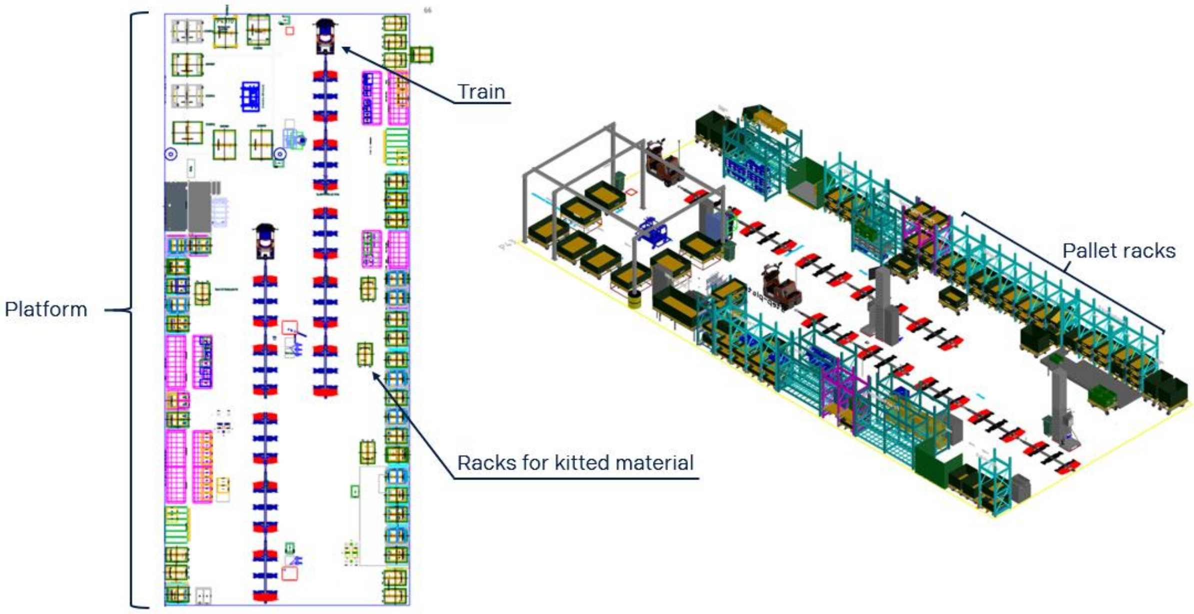

Figure 4.7: Top - and 3D view of a platform (Scania, 2021).

Box storage
In narrow aisles (see Figure 4.8), small size boxes are stored in different zones. The material flow of boxes is initiated at the logistics centre OLO or from external suppliers. In the case of the former, boxes are delivered to the main facility via internal truck transportation. Once arrived, boxes are unpacked from pallets and prepared for storage. Before put-away, the boxes are assigned a manual printed paper label and thereafter placed in racks using man-up forklifts.

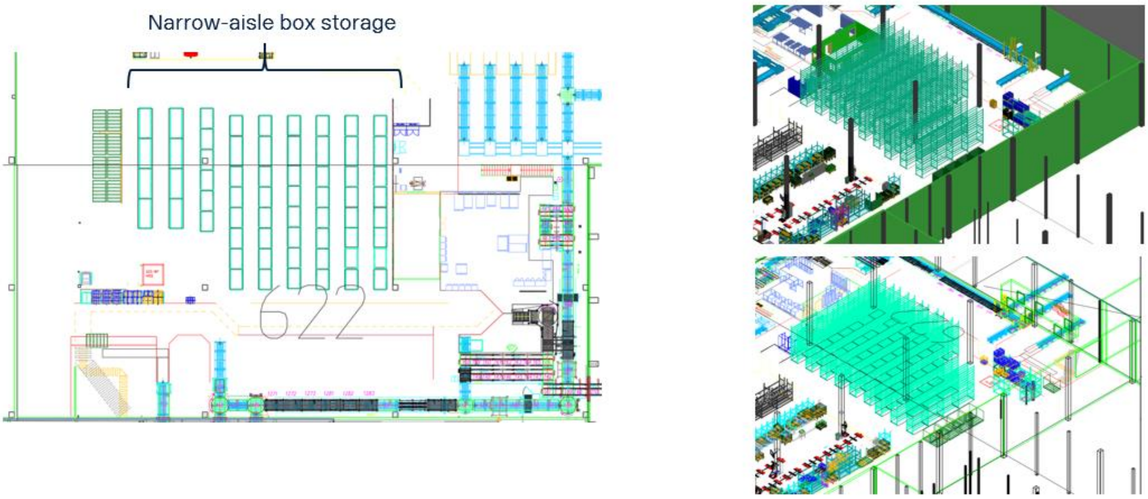

Figure 4.8: Top - and 3D view of box storage (Scania, 2021).

The box storage has a height of approximately 5 meters and contains SKUs of maximum 10 kg. Thus, both replenishment and picking activities are time consuming since the pickers move up and down the racks. Therefore it is an interesting area for RTLS application, more on this in Chapter 5.

High storage warehouse

In close connection to the assembly lines and platforms there exists an automated storage / retrieval system (ASRS). The physical layout of material flow for incoming pallets is provided in Figure 4.9. Via an automated setup, the pallets are put away into the ASRS warehouse for intermediate storage. Supported by a warehouse management system, pallets are automatically picked from the ASRS warehouse and transferred via conveyor belts to a certain area nearby called *Direkten*. From *Direkten*, pallets are picked by forklifts and delivered to different platforms for material replenishment.

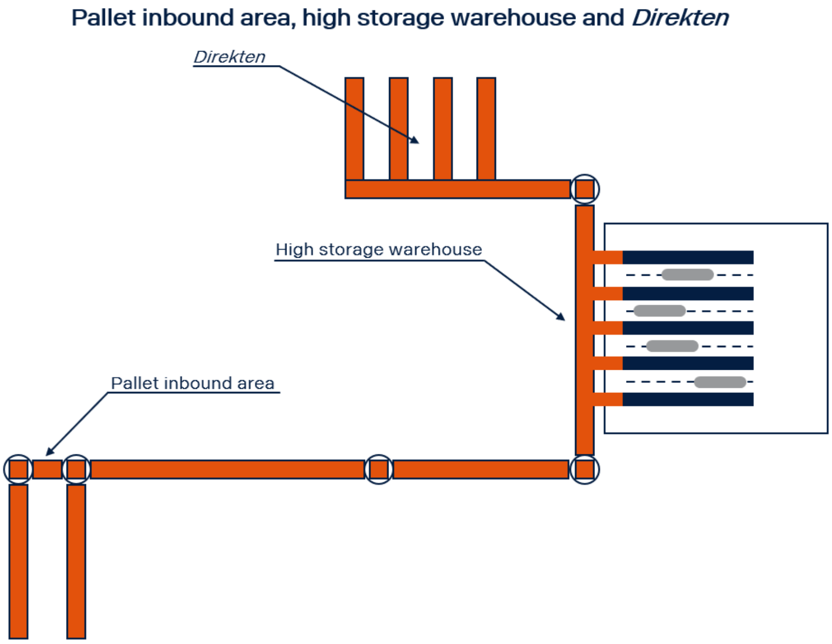

Figure 4.9: Detailed view of pallet inbound area, high storage warehouse and Direkten (Scania, 2021).

For this research, the operations taking place at *Direkten* have been identified as an interesting area for RTLS application due to safety concerns.

4.3. External systems

Throughout the thesis, various external systems have been used in order to visualize and analyse the gathered data. Firstly, both hardware and software provided by Marvelmind Robotics have been applied in the data gathering phase as well as in the visualization of the data. Secondly, another software (also known as Gazpacho) provided by Virtual Manufacturing was used as an additional tool for visualization. Aside from this, Excel interpretations and analytics were carried out. Provided below is a brief description of two first mentioned systems.

4.3.1. Marvelmind Robotics

The supplier of the RTLS equipment to be tested at Scania is Marvelmind Robotics. Marvelmind Robotics is a company manufacturing indoor positioning systems for industrial applications. Their technology is a combination of ultrasonic pulses and radio waves, which as mentioned in section 3.5.4, can be considered a hybrid of transmission technologies. With the aid of the two, a precision of +- 2 cm is achieved. Furthermore, their offering consists of a wide variety of mixes, ranging from deployable robots to customized systems and starter kits for indoor navigation systems. The RTLS being provided by Marvelmind Robotics is today used by companies in the automotive as well as other industries with customers such as Nasa, Amazon and Porsche (Marvelmind, 2020).

Marvelmind's RTLS equipment usually consist of tags, beacons and modems and since the locational data is streamed in a native GPS format, external devices (such as phones) are easily integrated and connected to the system. With the aid of the stationary ultrasonic beacons, the mobile location is determined on a propagation delay of the signals using trilateration. Trilateration is also known as time of flight, which is based on how long it takes for the signals to reach its object. Due to the high precision, the technology is more suitable in some settings. For instance in warehouse or industrial environments where there is a desire for better precision than "room-level" accuracy. Marvelmind lists a few more practical examples such as people tracking for productivity and safety aspects in industrial environments but also forklift and vehicle tracking to optimize routing and movements (Marvelmind, 2020).

Despite the technology being very precise, the ultrasonic transmission has its drawbacks and requirements. Allowing such accuracy requires a clear line of sight between the mobile beacon and the stationary ones as well as a shorter measuring distance (preferably below 30m). Furthermore, it is prone to errors since objects such as walls, concrete, glass, metal and shelves can cause signal disturbances. Therefore it is favourable to have an unobstructed sight by a mobile beacon of three or more beacons simultaneously and an unobstructed sight between three or more stationary beacons simultaneously (Marvelmind, 2020). The modem however, communicating via radio, does not need a clear line of sight. In Figure 4.10 the RTLS equipment used for this master thesis is provided. The kit consists of one modem, four stationary beacons and one mobile beacon (the one to be located on the tracked object). Furthermore, a snapshot of the software interface is provided in Figure 4.11.

Figure 4.10: Image of the RTLS equipment (Marvelmind, 2021).

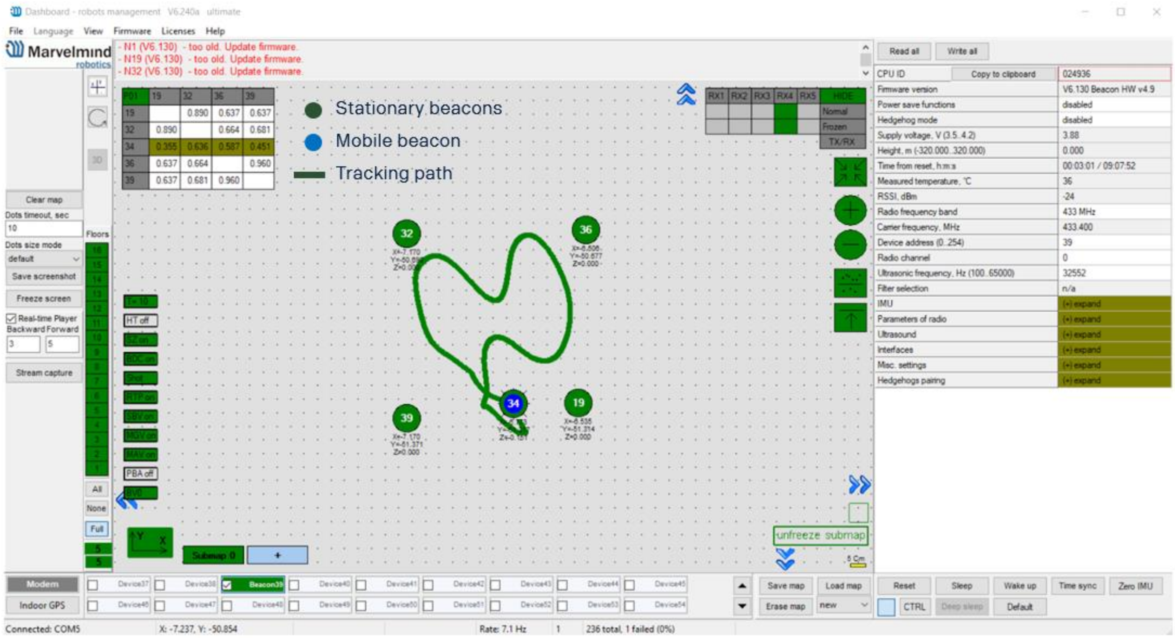

Figure 4.11: Picture of the interface of the dashboard in the Marvelmind software (Marvelmind Dashboard, 2021).

4.3.2. Gazpacho

Having extracted a log file from a tracking session, it was possible to upload it into the Gazpacho tool (see Figure 4.12). With the use of this tool it was possible to study the tracking session via heatmaps, spaghetti flowcharts and height diagrams. The Gazpacho has an option to insert a background image of the physical layout where the tracking was performed. This in order to facilitate the analysis. This tool was proven to be useful when illustrating and visualizing the data. Furthermore, the software did also provide data on the duration of a tracking session and total distances travelled.

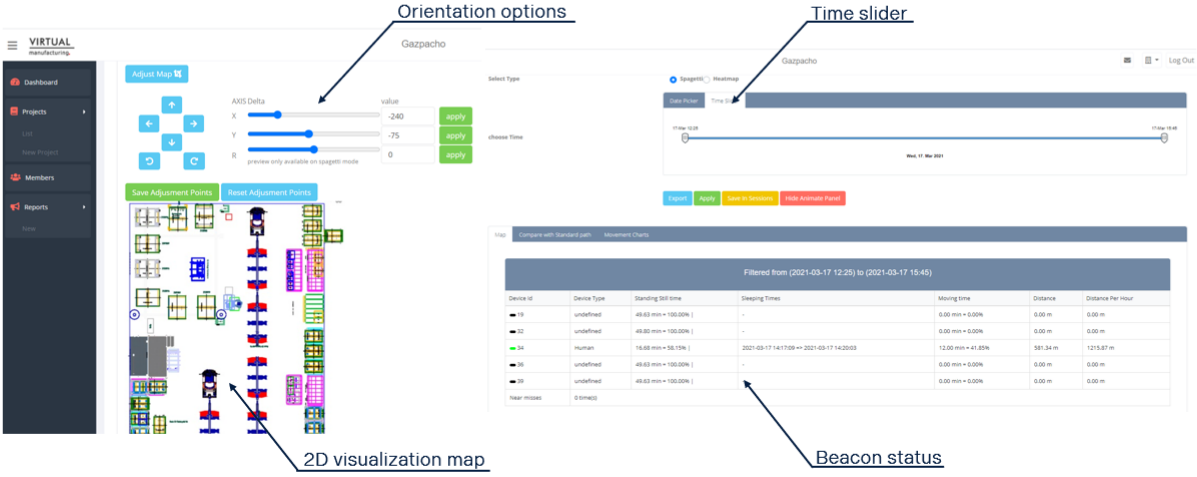

Figure 4.12: Snapshot of the interface of the dashboard in the Virtual Manufacturing software (Virtual Manufacturing, 2021).

5. ANALYSIS

This chapter provides the findings in regards to this master thesis' first and second research questions. The structure of the section is as follows: Firstly the theory from Chapter 3 - Theoretical background is summarized in order to answer RQ1. Thereafter the outcome of the RTLS implementation case study is presented along with the establishment of the conceptual framework. Furthermore, the identified areas that RTLS was tested in are addressed followed by findings related to RQ2.

Provided in Figure 5.1 is the structure on how the findings will be presented.

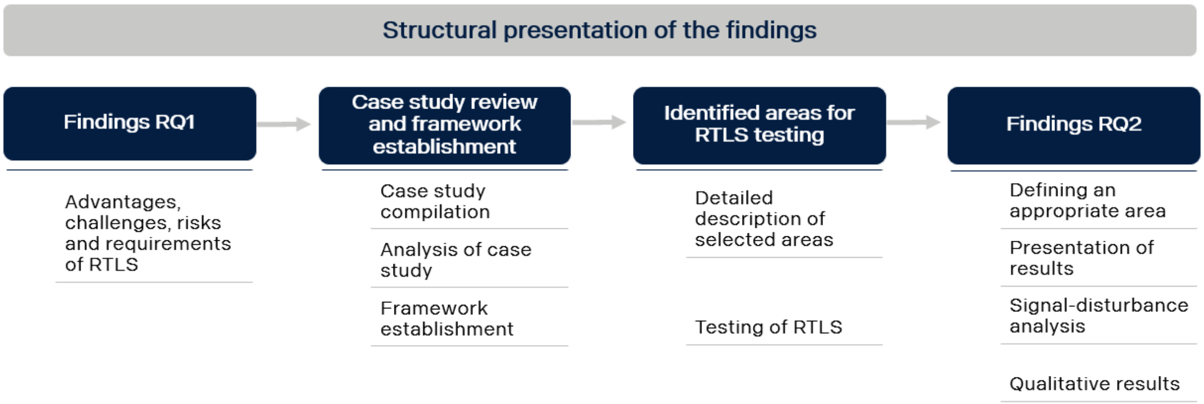

Figure 5.1: Structural presentation of findings.

5.1. Findings related to RQ1

By a systematic literature review it was possible to answer this study's first research question which was already addressed in chapter three. The findings are summarized in each subsection below. For each of the attributes (i.e., advantages, challenges, risks and requirements), both technical and general aspects have been identified (see Figure 5.2).

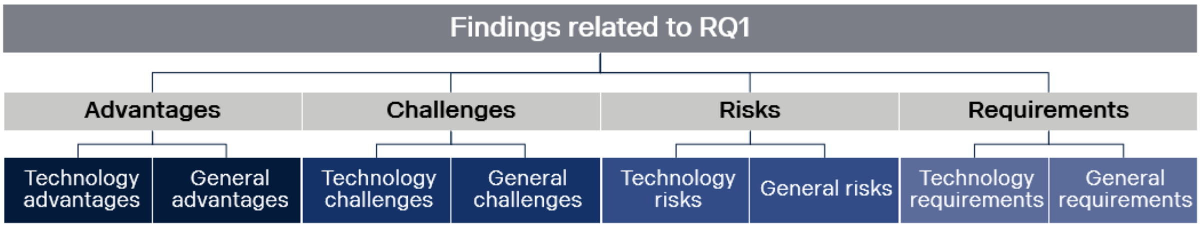

Figure 5.2: Findings first research question.

5.1.1. Identified advantages

Provided in Figure 5.3 are the advantages identified from the conducted literature review on RTLS.

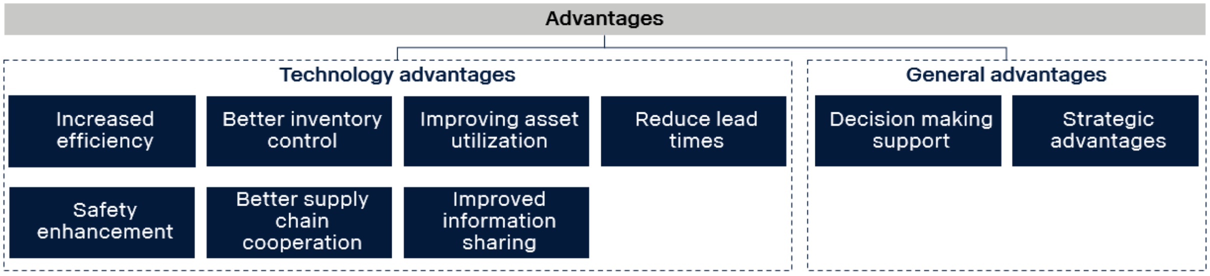

Figure 5.3: Identified advantages.

Presented in Figure 5.3, RTLS entails various advantages. The findings indicate better asset control and/or improving production efficiency as some. There are also possibilities to improve decision making processes with the use of the technology. This by gathering unbiased data hence supporting objective decision making. Furthermore, the findings revealed the potential for organizations to improve safety in operations by implementing RTLS. This both regarding collision avoidance between forklifts, forklifts and operators or simply to prevent operators from entering risk zones.

The findings showed that RTLS also can improve the performance throughout the supply chain. The well-known bullwhip effect could be mitigated while real time tracking, tracing and information sharing with supply chain partners improves visibility and transparency.

Furthermore, acquiring and leveraging innovative technologies results in business value creation for companies. This also results in enterprises staying ahead of competition and opening up new market possibilities.

5.1.2. Identified challenges

Provided in Figure 5.4 are the challenges identified from the conducted literature review on RTLS.

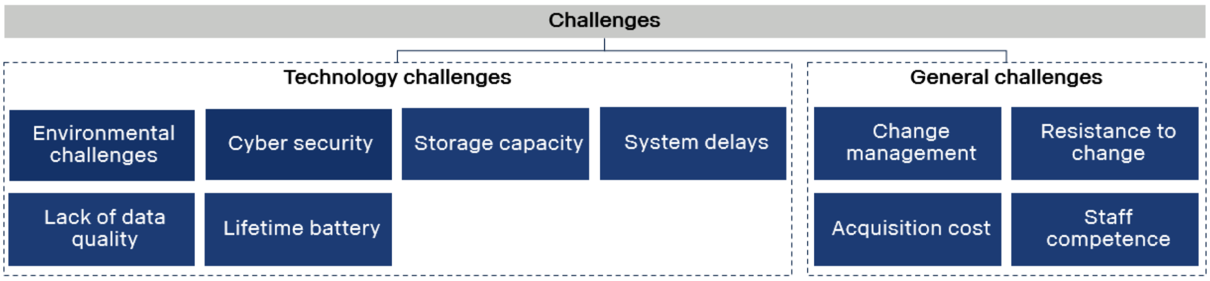

Figure 5.4: Identified challenges.

Firstly, the findings indicated that there are challenges to deal with in terms of the physical setting of where RTLS is to be implemented. This since the technology is dependent on radio transmissions, where obstacles can easily reflect, intervene and disturb the outcome. Secondly, there are challenges related to the cost aspect of the technology. This both regarding adopting and maintaining RTLS. Moreover, the result emphasized various technological challenges such as technical competence to be embedded in the organization. Also in many cases, when acquiring RTLS, it has to be integrated with other previously established systems such as ERP, WMS or MES which naturally poses another challenge in adopting the technology. Thirdly there are challenges related to the organizational aspects. Employee resistance was identified to be such a challenge. Thus effort in change management is essential for a successful adaptation of RTLS. The findings revealed external cyber-attacks, the exposure or leaking of data to inaccurate receivers as an additional challenge to overcome.

Lastly, other forces against change and implementation of new technologies have been identified. These are, personal interest not connected to the organization interest, errors in understanding the reason for change, differing levels of situation assessment between shop-floor employees and management as well as low tolerance to change.

5.1.3. Identified risks

Provided in Figure 5.5 are the risks identified from the conducted literature review on RTLS.

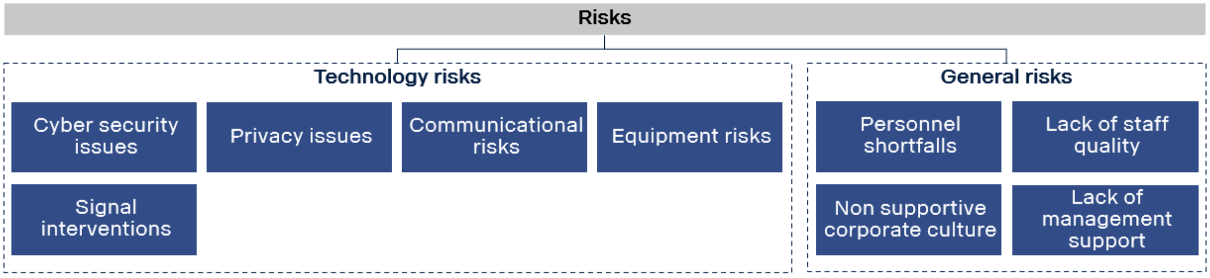

Figure 5.5: Identified risks.

Indicated in the result, RTLS implementation implicates risks of various characters. The review brought up risks of reader or tag collision as well as signal interferences. Along with this, identity theft and manipulation of data was also discussed. Additional risks identified were dealing with the communication aspect. To ensure a flawless application of RTLS the result underlined to also keep in mind how the information is transmitted. Moreover, privacy and security risks could also be found where it is important to consider the reliability and readability of acquired data. Lastly, the findings revealed external cyber-attacks and exposure of data as another potential risk to cope with.

The more qualitative risks were staff shortfalls and poor quality of staff. Lacking the proper background, motivation and training are risks to consider when setting new standards. Weak management support and unrealistic expectations are also important to consider.

5.1.4. Identified requirements

Provided in Figure 5.6 are the requirements identified from the conducted literature review on RTLS. As mentioned previously and in contrast to the other attributes, the requirements depend more heavily on the specific situation, but presented are some general findings.

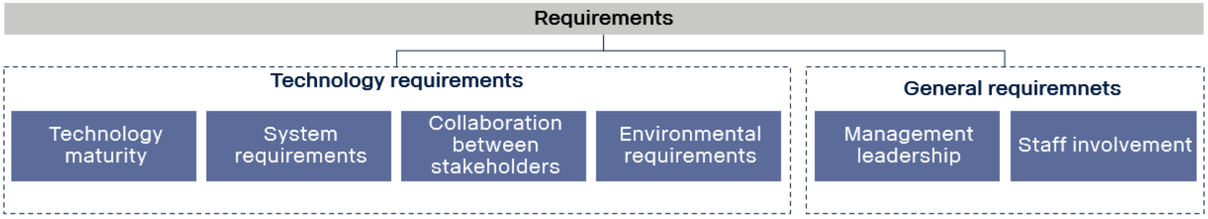

Figure 5.6: Identified requirements.

The findings show that the RTLS implementation is not possible without an established IT infrastructure. Along with this, similar to the challenges, technical competence is required within the staff. Another requirement is the willingness from employees to both learn and adapt to the technology. Furthermore, establishment of system standards when implementing in a more full-scale scenario is necessary. The literature review also indicated that user preferences such as cost, accuracy and usability is another requirement aspect to take into account.

When developing a more tailor-fitted solution, the findings revealed close cooperation between the stakeholders to be crucial. This also facilitates when it comes to the environmental requirements. Humidity, obstacles, temperature and the physical environment could also play a role when using the RTLS.

Lastly, it is important that a positive message is sent regarding the change. This requires managers to act role models in the implementation project as well as have the ability of involving and motivating workers.

5.2. Case study review results and framework establishment

In order to develop a conceptual framework, several RTLS implementation cases were looked into. This with the idea of exploring and determining areas as well as for what purposes where RTLS is proven to be feasible to implement. The case compilation can be found in Appendix D.

5.2.1. RTLS implementation case-study

Provided in this subsection is a brief summary of the cases studied where relevant parameters were identified and investigated for each case. This provides a structured approach which is also aligned with how Rowley and Slack (2004) reason. The identified parameters can be found in Table 5.1.

Table 5.1: Definition of developed parameters.

Definition parameters	***Author*** The author/s of the case
	Industry What industry the case study was performed in
	Purpose The purpose of conducting the case
	Reliance of RTLS use The what extent the operations are reliant on the information provided from RTLS (e.g. real-time reliance, aftermath analytics or both)
	Object What object that is being tracked

The 16 cases that were looked into are briefly presented in Table 5.2. For the curious reader, a more in-depth compilation is provided in Appendix D as noted earlier.

Table 5.2: Summarization of RTLS implementation cases.

Authors	Area	Purpose	Reliance of RTLS	Object
Hellmich et al. (2017)	Healthcare industry	Evaluate differences in conventional and new tracking technology with the hope of improving visibility and traceability	Both real-time support and as a tool for analysis	Human
Park et al. (2006)	Container terminal	Improve working efficiency and performance	Real-time use	Container
Ding et al. (2008)	Warehouse operations	Realize warehouse automation, intelligence and digitalization management	Both real-time use and a tool for analysis	SKU
Gladysz et al. (2018)	Cold chain warehouse	Save time from drawing spaghetti diagrams and reflecting the true dynamics of logistics	Tool for analysis	Forklift
Zhang et al. (2012)	Construction industry	Prevent potential collisions	Real-time use	Construction equipment/objects
Meunier et al. (2017)	Livestock farming	Explore biological information and behaviour by monitoring	Tool for analysis	Animal
Halawa et al. (2020)	Warehousing operations	Demonstrate how RTLS can enhance warehouse safety and operational efficiency	Both	Mobile entities such as forklifts
Fang et al. (2016)	Construction industry	Improving asset management	Real-time reliance of system	Construction equipment/objects
Rizzi and Romagnoli (2017)	Fashion retailer	Locating garments and automate inventory stock-taking processes	Real-time reliance of system	Garments
Nawotarski et al. (2017)	Construction Industry	Improving renovating processes	Real-time reliance	Equipment and material
Maleki and Meiser (2011)	Logistics	Improving visibility in supply chain	Tool for analysis	Containers
Bendavid et al. (2011)	Healthcare industry	Improving efficiency	Discrete real-time reliance	High-value products in healthcare
Huang et al. (2020)	Healthcare industry	Improving visibility and transparency	Both	Human
Bowen et al. (2010)	Healthcare industry	Improving service efficiency and response times	Real-time reliance	Human
Baslyman et al. (2014)	Healthcare industry	Tracing of hygiene compliance	Tool for analysis	Human
Slovak et al. (2019)	Manufacturing industry	Monitor material flow	Tool for analysis	Material

Once the cases were in place they were categorized with the purpose of classifying them into different branches. The idea behind this principle was to facilitate the development of the conceptual framework. The categorization of the cases is presented in Table 5.3.

Table 5.3: Categorization of RTLS implementation cases.

Purpose	Industries	Number of cases	Objects	Reliance of RTLS
Operational efficiency evaluation	Warehousing operations Construction industry Healthcare industry Fashion retailer	10	Human SKU Forklift Construction equipment High-value products in healthcare	Both
Monitoring purposes	Elderly care Healthcare industry Container terminal Agriculture Fashion retailer Logistics Manufacturing industry	6	Container Animal Garments Human Material	Both
Safety evaluation	Construction industry Warehousing operation	2	Forklift Construction equipment	Both
Regulation compliance	Healthcare industry	1	Human	Analytical

As noted, there are four recurring "themes" or purposes that the cases in general would cover. It was discovered that RTLS was used in many industries as a tool to evaluate operational efficiency. Moreover, in other cases there was no clear connection to what the tracking data was going to be used for. However, for such cases, a similar purpose was fulfilled, monitoring the tracked objects. Therefore, these were put into a separate category. This for instance was common in the elderly care industry where one would want to monitor the clients location at all times. The third category concerns safety aspects such as risks of collision, accidents etc. Lastly, regulation compliance deals with the process of understanding to what extent people are complying with regulations or not.

5.2.2. Framework establishment

From the case study review, it was possible to initiate the establishment of a conceptual framework (see Figure 5.7) which would aid the researchers when identifying suitable areas for RTLS testing.

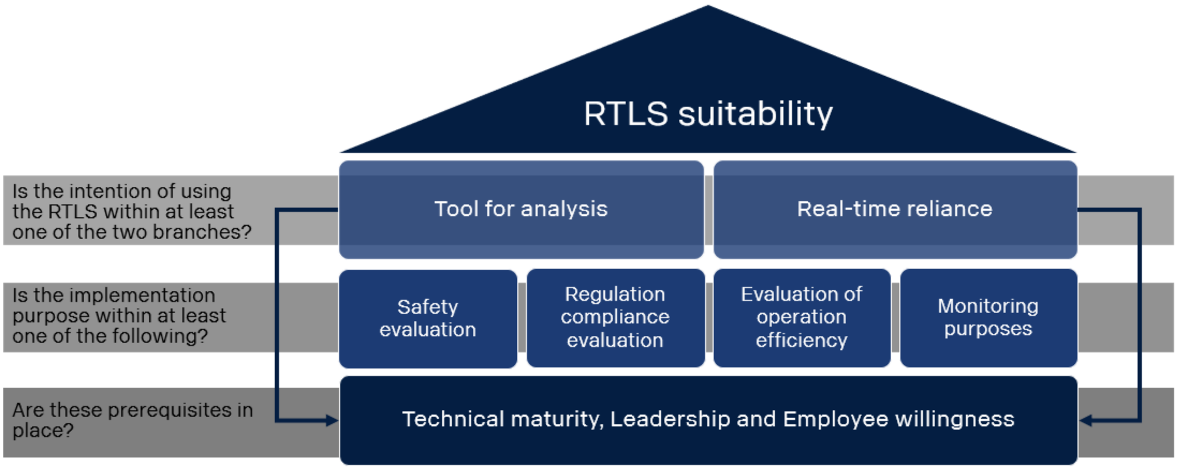

Figure 5.7: A conceptual framework developed from the case study collection on RTLS implementation suitability.

The conceptual framework is built on the core function of having necessary prerequisites in place which constitutes the bottom layer in the figure. These include technical maturity, project leadership as well as employee willingness.

The second level of the framework addresses the purpose of implementing RTLS. Throughout the case studies it was identified that the studies either addressed one of four categories; safety, regulation compliance, operational efficiency and monitoring purposes or in some instances, several of these at the same time.

The third level deals with the application of the technology, or to what degree to rely on the data provided by RTLS. In some cases the data provided was solely used for analytical reasons, in other instances continuous real-time data was necessary to acquire desired results. Therefore, it branches out in the two different approaches (analysing data and/or real-time reliance) and these can also be used simultaneously. At this level, one must really ensure that the technical prerequisites are in place prior to implementing the technology which is why there are arrows pointing back to this foundational layer. This to also ensure that the company is on-board with the suggested intention of the implementation.

These so-called "building blocks" constitute the conceptual framework. The RTLS suitability rooftop completes the house. The idea is that reaching the rooftop should indicate suitability for testing of RTLS. Worth mentioning is that the proceeding to the framework's top can differentiate among the frames depending on the specific situation. The framework is also intended to fit both long-term implementations and short-term testing's of RTLS since this is what the case studies addressed which is a good fit for this thesis's testing.

5.3. Identified areas for RTLS testing

This section presents the identified areas at Scania where RTLS was deemed suitable for testing. The chosen areas were derived from the previously presented funnel approach in section "*2.4 - Identifying interesting areas at Scania*". From the start, 12 areas were of interest, however, due to limitations in time, resources and practical settings, only four were chosen to advance further with (see Table 5.4). These four areas were selected based on the evaluation process applied (see Figure 5.8).

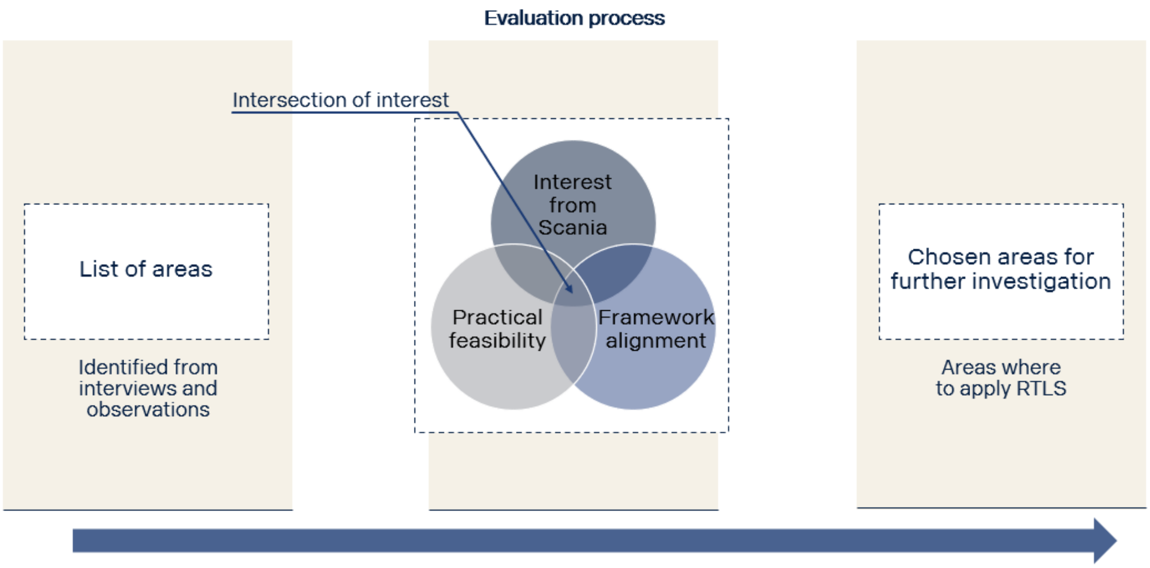

Figure 5.8: Evaluation process for further investigations.

Table 5.4: *The four identified areas.*

Identified issues	Purpose
Deviations in platform kitting	Operational efficiency
Intense forklift traffic concern causing for safety and regulation compliance	Safety, Compliance, Monitoring
Storing inefficiencies in the box storage	Operational efficiency
CU-forklift inefficiencies	Operational efficiency

Provided in this subsection is a more detailed description of the selected areas for RTLS testing. In Figure 5.9 one can see the locations of interest for these. A summary of all the 12 areas can also be studied in the Appendix E.

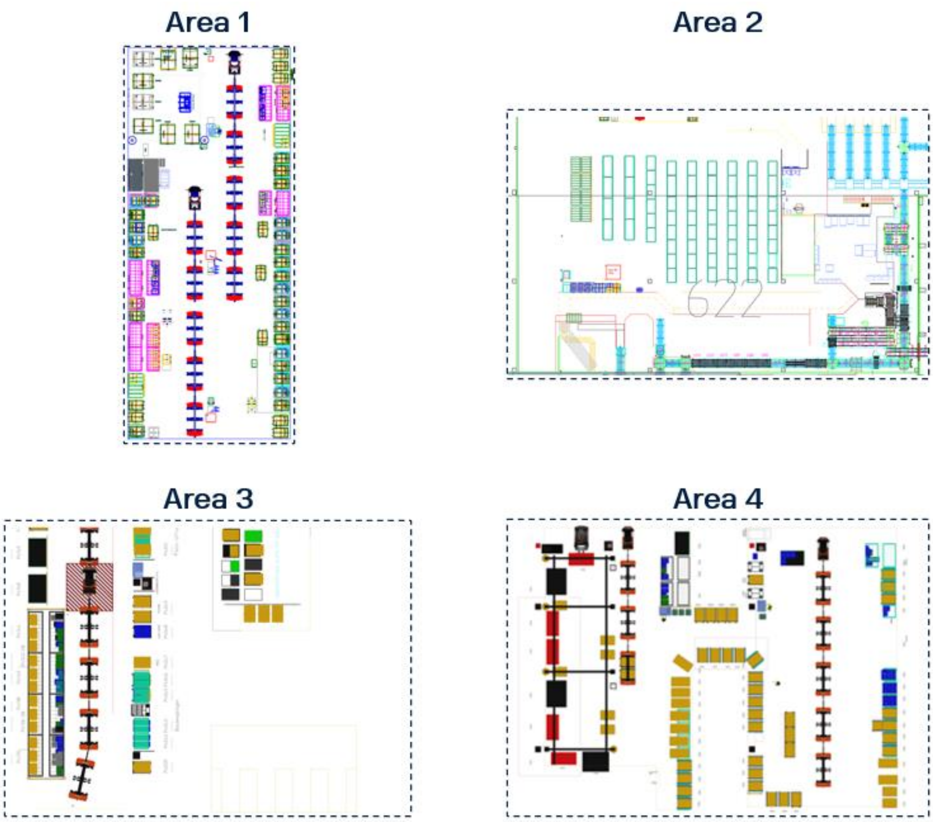

Figure 5.9: The four areas for RTLS application.

5.3.1. Area 1: Deviations in platform kitting

Since Scania sees potential in gathering data to objectively analyse different picking methods, this area was of interest. Therefore, it was interesting to see whether RTLS was suitable or not. Further, the purpose concerns the “efficiency improvement” block from the conceptual framework hence being aligned and the setting was also realistic. The two different mounting setups of the RTLS can be seen in Figure 5.10.

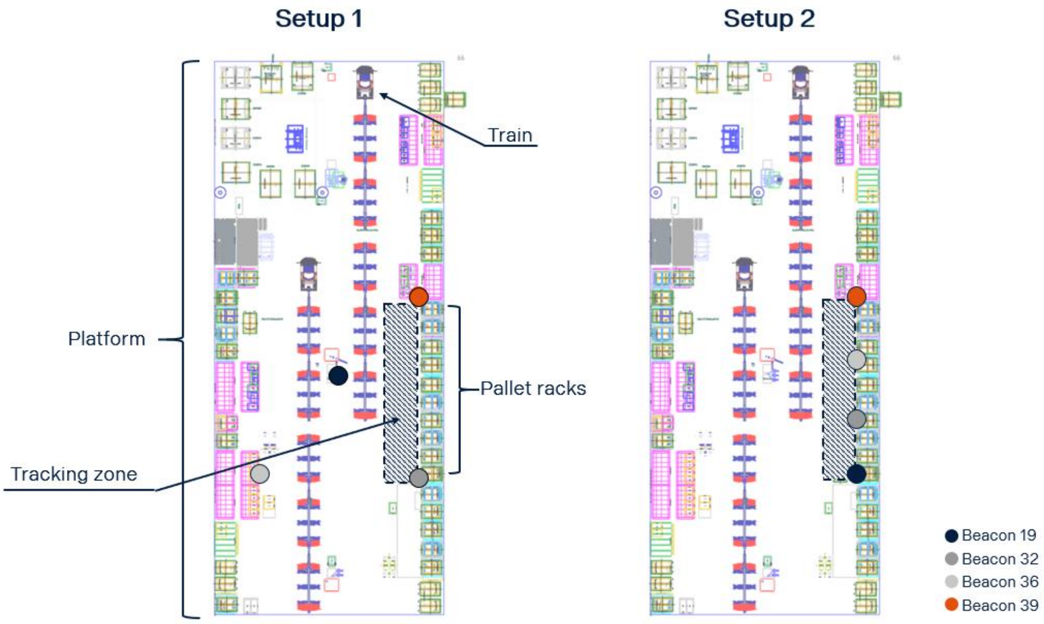

Figure 5.10: Top view setup 1 and setup 2 (Source: Scania).

5.3.2. Area 2: Storing inefficiencies in the box storage

It was of interest to see if RTLS would enable for future analysis on vertical forklift movement in this area. Furthermore, since today's operations lack proper information on these activities, minor concerns have risen for excessive forklift movement caused by non-optimal SKU placement. With the interest from the case company, the conceptual framework alignment and physical setting this area was selected. The RTLS equipment was mounted as below (see Figure 5.11) where the setups cover two different aisles.

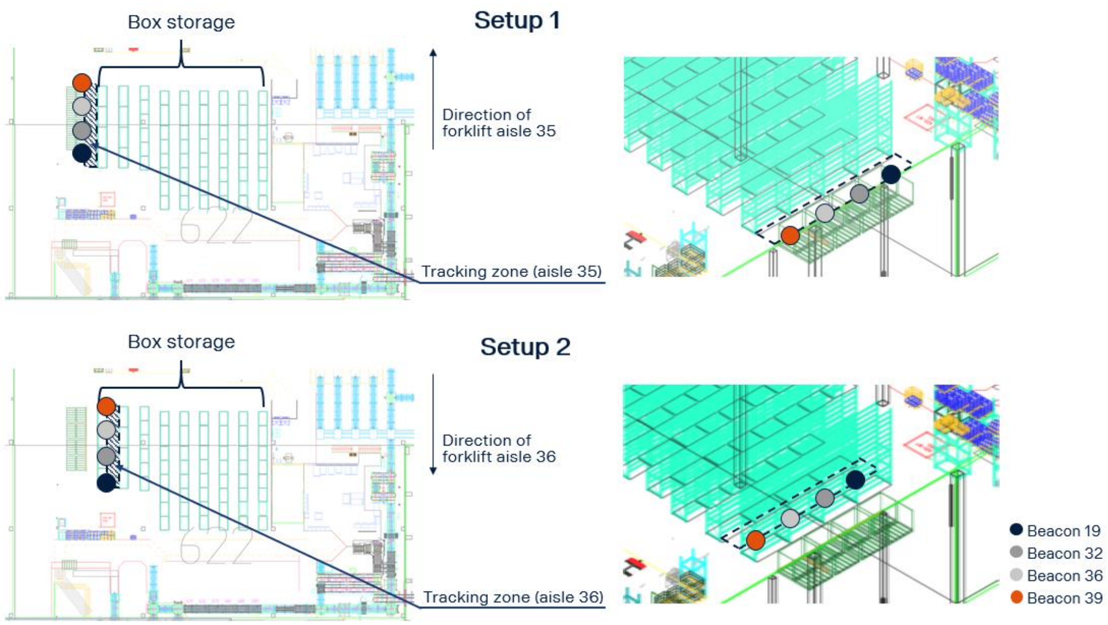

Figure 5.11: Top - and 3D view setup 1 and setup 2 (Source: Scania).

5.3.3. Area 3: Intense forklift traffic at *Direkten*

Despite safety being a top priority at Scania, concerns have been raised regarding the intense forklift traffic at *Direkten*. In general there are seven forklifts constantly moving around in this area picking pallets from the high-bay warehouse which then are delivered to the platforms. Further, Scania did show a great interest to track the movement of the forklifts. Also, the physical setting was rather open hence deemed suitable and the safety aspect covered in the framework as well. The setup of the RTLS equipment can be seen in Figure 5.12.

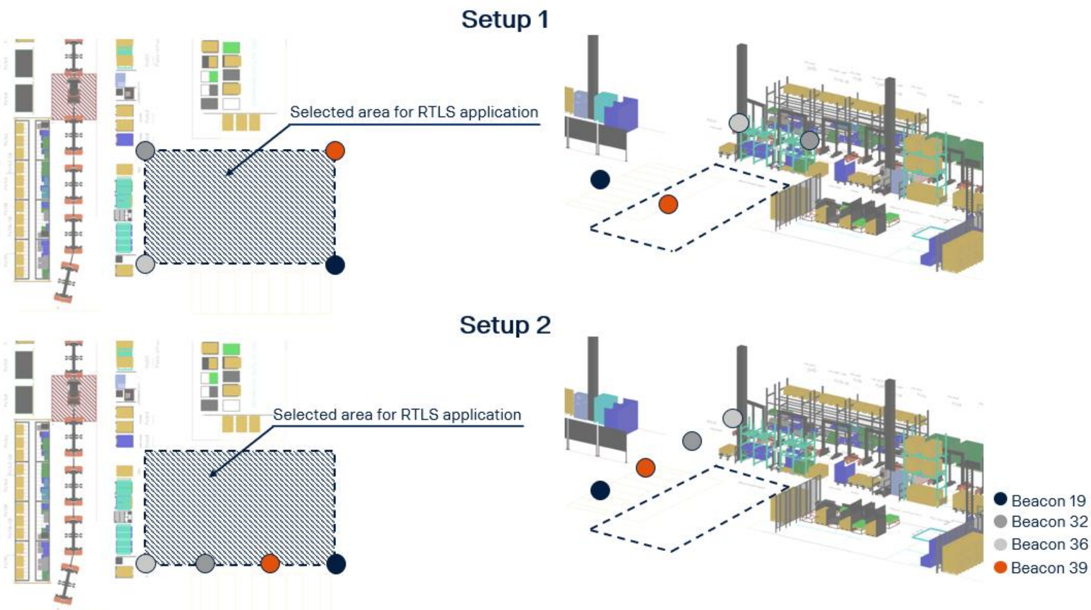

Figure 5.12. Top - and 3D view of setup 1 and setup 2 (Source: Scania).

5.3.4. Area 4: Utilization of CU-forklift

The last area was concerning the utilization of the so-called CU-forklift. This forklift supplies the assembly line with goods and if given extra time, other material handling tasks are to be carried out. The reason for the name "CU-forklift" is to differentiate it from the ordinary forklifts. The origin of interest to track here is to investigate the operational efficiency which unfortunately also is out of this thesis scope. However, it is still interesting to see if this area is suitable or not. The setup of the RTLS equipment can be seen in Figure 5.13.

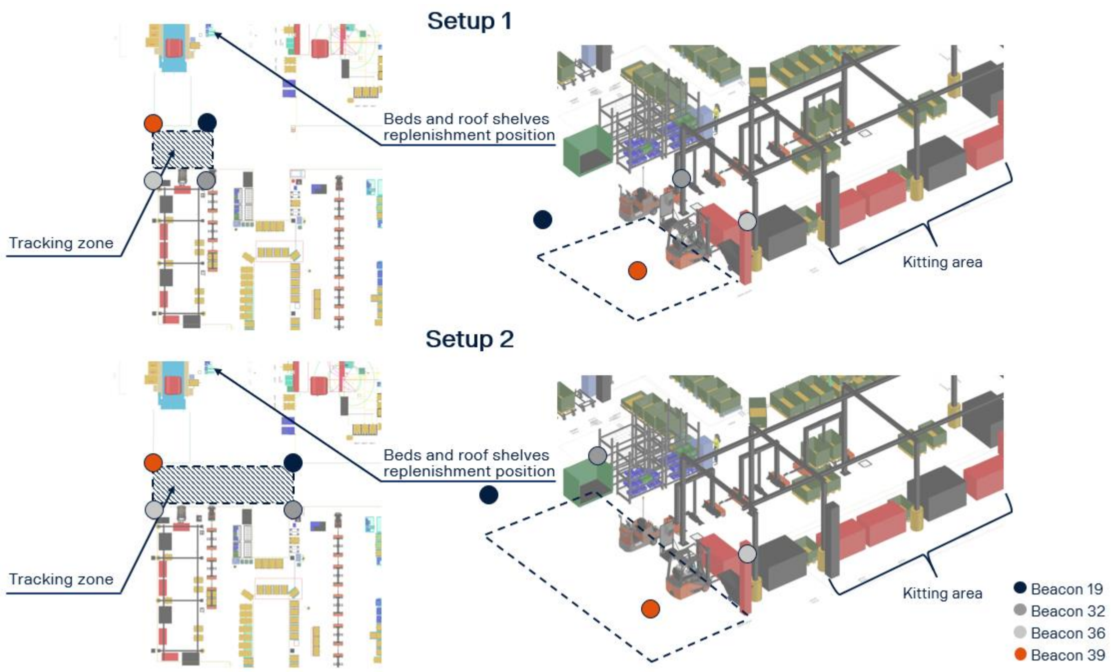

Figure 5.13: Top - and 3D view setup 1 and setup 2 (Source: Scania).

5.4. Findings related to RQ2

Provided in this section are the findings related to the second research question. The structure of the subchapter is shown in Figure 5.14. Firstly, Scania's perception of important criterions for RTLS testing is presented. Secondly, the gathered data is visualized in heatmaps, spaghetti flowcharts and height diagrams along with how Scania employees rate the outcomes of the tests. Thirdly, a signal-disturbance analysis is provided which lastly is followed by qualitative aspects.

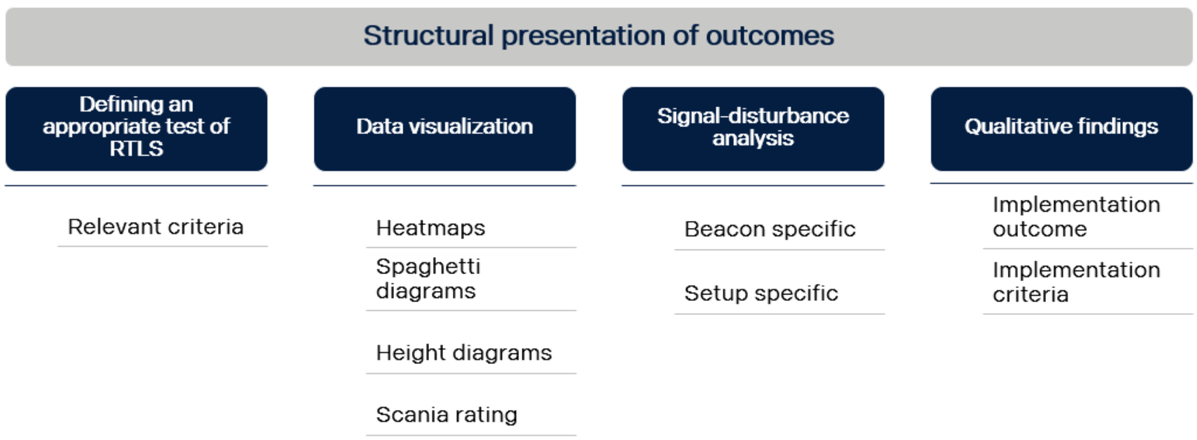

Figure 5.14: Structural presentation of outcomes.

5.4.1. Defining an appropriate test of RTLS

Workshops were conducted with Scania employees in order to determine relevant criteria for a successful RTLS implementation for each area. This since an area's suitability is dependent on the purpose of tracking. Summarized in Table 5.5 are the all of the developed criteria which were later weighted by Scania employees in order to find out how successful the testing has been for each area.

Table 5.5: Developed criteria from workshop with Scania employees

Criteria	Explanation
Track relevant areas	E.g. is it possible to cover the areas that were of interest of tracking?
Picking precision (ability to clearly see start/end points)	E.g. is it possible to get desirable precision of movement?
Extract distances travelled	E.g. is it possible to extract the distance travelled during a tracking session?
Understand unexpected stops in the tracking	E.g. was is possible to understand the reason why a worker/forklift has stopped?
Retrieval of timestamps	E.g. is it possible to retrieve timestamps?
Precision of movement (height axis)	E.g. is it possible to get desirable precision of vertical forklift movement?
Integrate tracking data with external systems (e.g., combine tracking with platform cycle times)	E.g. is it possible to combine tracking data with external data? E.g. do you see potential in combining tracking data with external data?
Integrate tracking data with picking data (e.g., to see where certain SKUs are placed and when these are being picked)	E.g. is it possible to combine tracking data with picking data? E.g. do you see potential in combining tracking data with picking data?
Track several objects at the same time	E.g. is it possible to track multiple objects (human/forklift) at the same time?
Track for longer periods of time	E.g. is it possible to track for several days or more?
Identify whether picking occurs on the right/left side of the box storage shelves	E.g. is it possible to distinguish the right from the left shelf when picking in the box storage?
Measure forklift intensity in aisles	E.g. is it possible to determine traffic intensity in the aisles?
Optimize picking routes	E.g. is it possible to optimize picking route with the data?
Extract distances between objects (e.g., forklifts, critical zones etc.)	E.g. is it possible to obtain information of distance between objects?

5.4.2. Visualization of gathered data

Provided follows snapshots from heatmaps, spaghetti flowcharts and height diagrams for respective areas. These have been extracted from either Marvelmind's dashboard or the Gazpacho tool. Furthermore, the criteria developed by Scania employees are presented in a weighting format as well as given a score. The former depicts the importance of each criteria per area and is weighted between 1 (not important at all) to 5 (very important). The latter corresponds to how well these criteria were achieved for each area. In order to generate this, each Scania employee gave a primary criteria score ranging between 0 (not satisfied) to 6 (completely satisfied) which was later multiplied by respective weight. Hence, the overall criteria score was based on both the importance of each criteria but also how well it was fulfilled. This was deemed to provide a fair evaluation of the areas. The heatmap and spaghetti illustrations were rated by using the playback function in the software to, in real-time show the employees how the tracking session looked like.

Area 1: Deviation in platform-kitting

Provided in Figure 5.15 and 5.16 are randomly selected heatmaps and spaghetti diagrams from the Area 1 testing's as well as Scania's ratings on the area. It is worth mentioning that the employees only rated one of the setups due to lack of time.

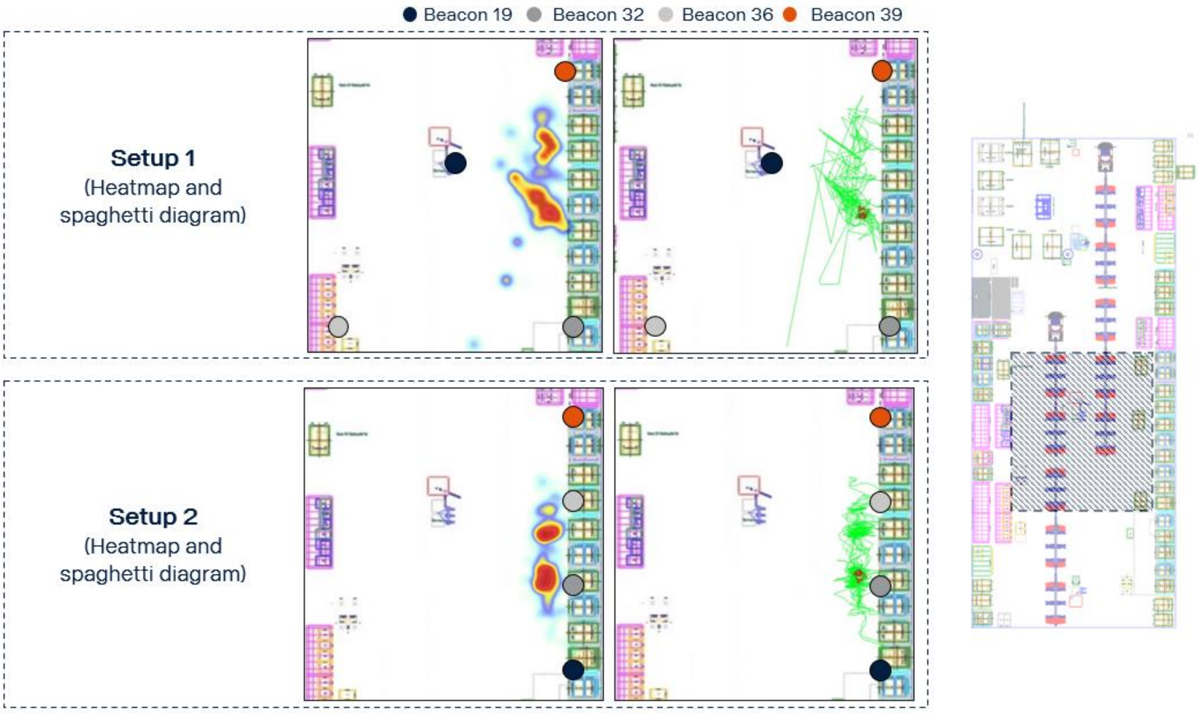

Figure 5.15: Heatmap and spaghetti diagrams from two different tests on kitting suspension bellows at platform 7. Note that setup 1 (the top) has different beacon placement than setup 2 (the bottom).

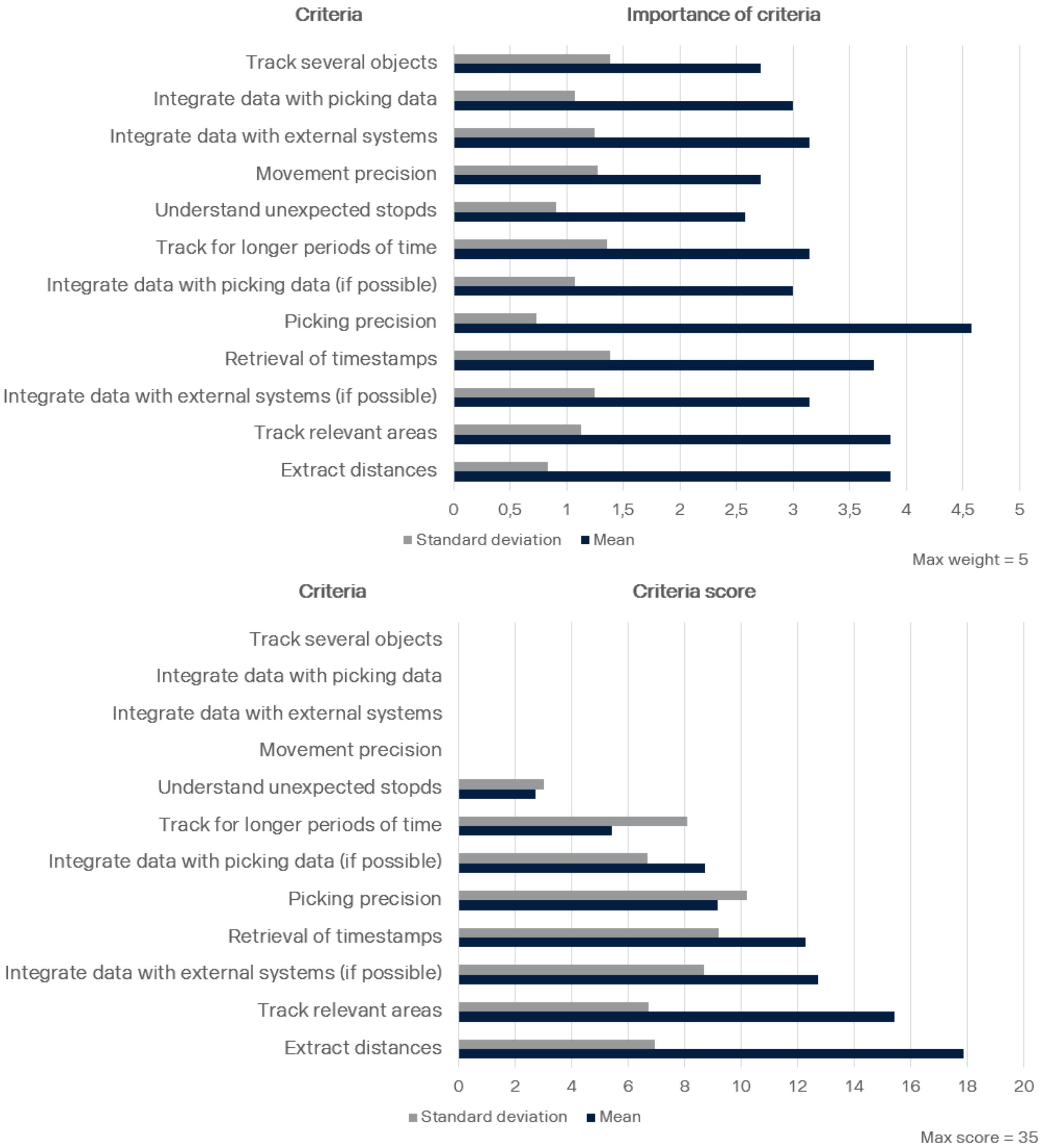

Figure 5.16: Importance - and score diagram for criteria.

The findings show that the RTLS equipment can be used to visualize the kitting process. This both with the use of heatmaps and spaghetti diagrams. However it was found to be quite difficult to interpret the current figures (i.e. determine the actual movement of the person). In the Gazpacho tool, it was possible to video preview the gathered data for every second. This with the purpose of visualizing it more in detail.

According to the Scania employees, the top two criteria for Area 1 were *Extracting distances* and *Tracking relevant areas*. Also, if it would be possible, the Scania employees did see potential in integrating the tracking data with external systems such as platform cycle time. The gathered data was also deemed suitable for retrieval of timestamps.

Moreover, it was found that the highly scored criteria were also being prioritized (i.e. importance of criteria). This implies that Area 1 somewhat fulfils certain criteria being highly weighted while at the same time it lacks to meet all the important criteria.

Additionally, the findings indicated uniformity in regards to the weight of the criteria. This as the standard deviation was low in regards to the mean. However, for some of the criteria score, the uniformity was not that well aligned amongst the Scania employees. This implies that some employees deemed the gathered data to be appropriate while others did not.

Area 2: Storing inefficiencies in the box storage

Provided in Figure 5.17 and 5.18 are spaghetti - and height diagrams and Scania's ratings for Area 2. The reason for the spaghetti diagram not being extracted from Gazpacho was because the height (z-axis) was studied with Marvelmind's technology. At the time of conducting this thesis, there is not yet an option in the Gazpacho tool to extract this more than presenting the height in a regular z-axis vs timestamp diagram. The spaghetti diagrams are presented with the height on the y-axis along the vertical movement on the x-axis.

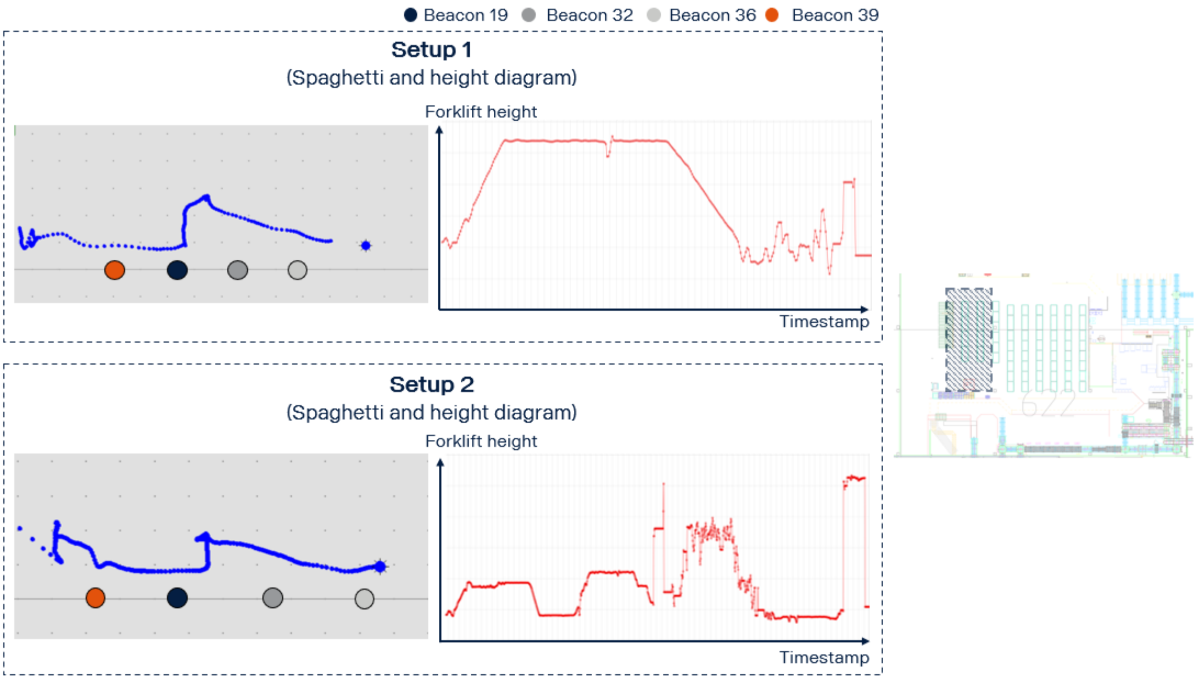

Figure 5.17: Spaghetti - and height diagrams from two different tests on the box storage. Note that setup 1 and setup 2 are in two different aisles.

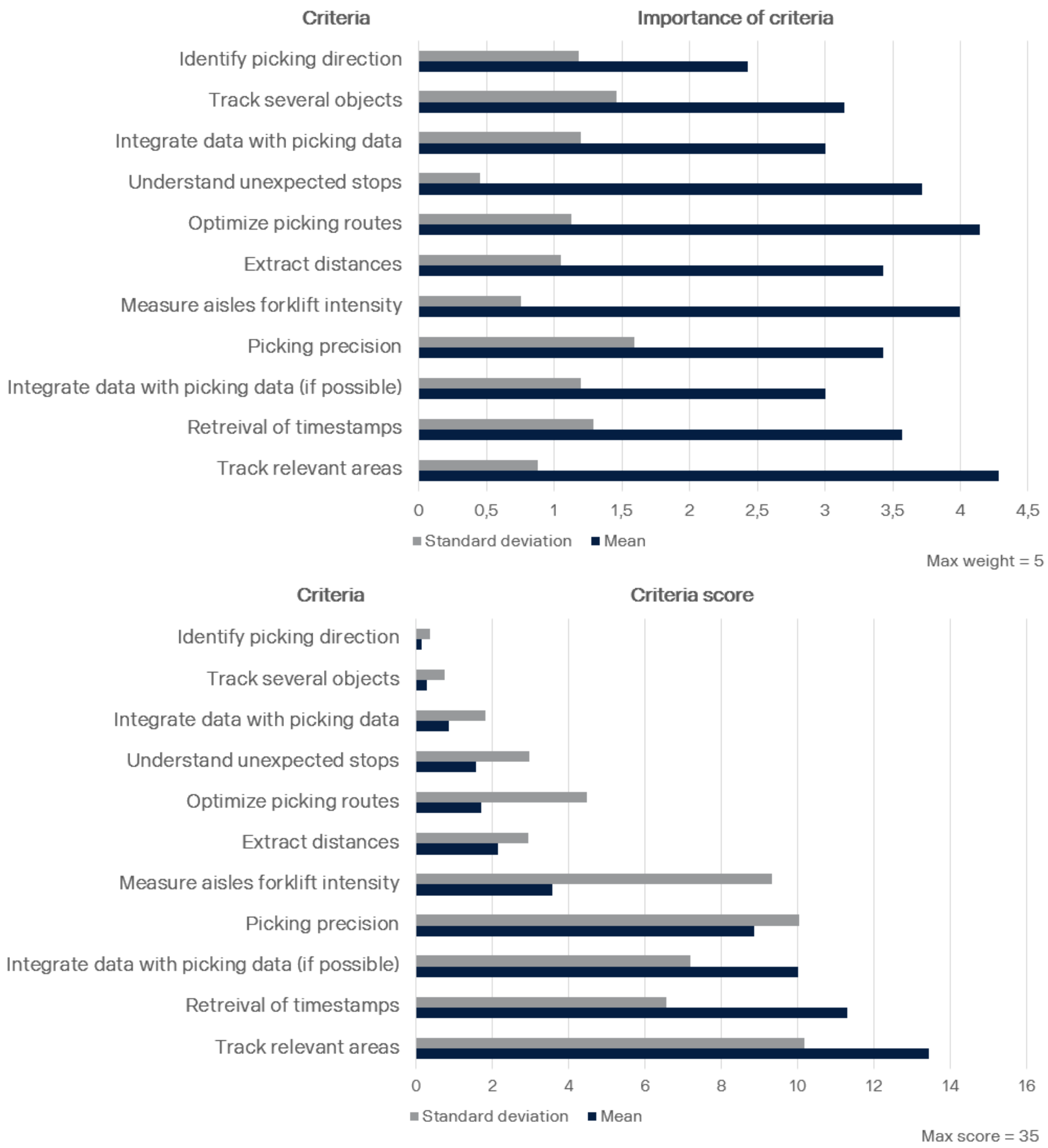

Figure 5.18: Importance - and score diagram for criteria.

The findings indicate that the RTLS equipment can be used to visualize the vertical forklift movement. However it was found to be very challenging to interpret and understand the figures. The void background did not facilitate this either.

For Area 2, criteria such as *Track relevant areas*, *Retrieval of timestamps*, *Integrating data with picking data (if possible)* as well as *Picking precision* scored higher. However, from the result these four criteria were found to have a high standard deviation compared to their means. This implies that Scania employees did not have one common view of the appropriateness in the gathered data.

It was found that approximately half of the highly weighted criteria were given a relatively high score. This implies that the gathered data partly satisfied what Scania employees considered to be important for Area 2, but looking at the overall picture, it is deemed challenging to use this data. Since not all high weighted criteria were given a high score it is clear that Area 2 lacks in appropriateness and does not fulfil all criteria. Further, for the weighted criteria, the low standard deviation compared to the mean implies uniformity amongst the Scania employees.

Area 3: Intense forklift traffic at Direkten

Provided in Figure 5.19 and 5.20 are heatmaps and spaghetti diagrams for Area 3 as well as Scania's ratings on the criteria. Once again the employees only rated one of the setups, which was setup 1 in this case, due to lack of time.

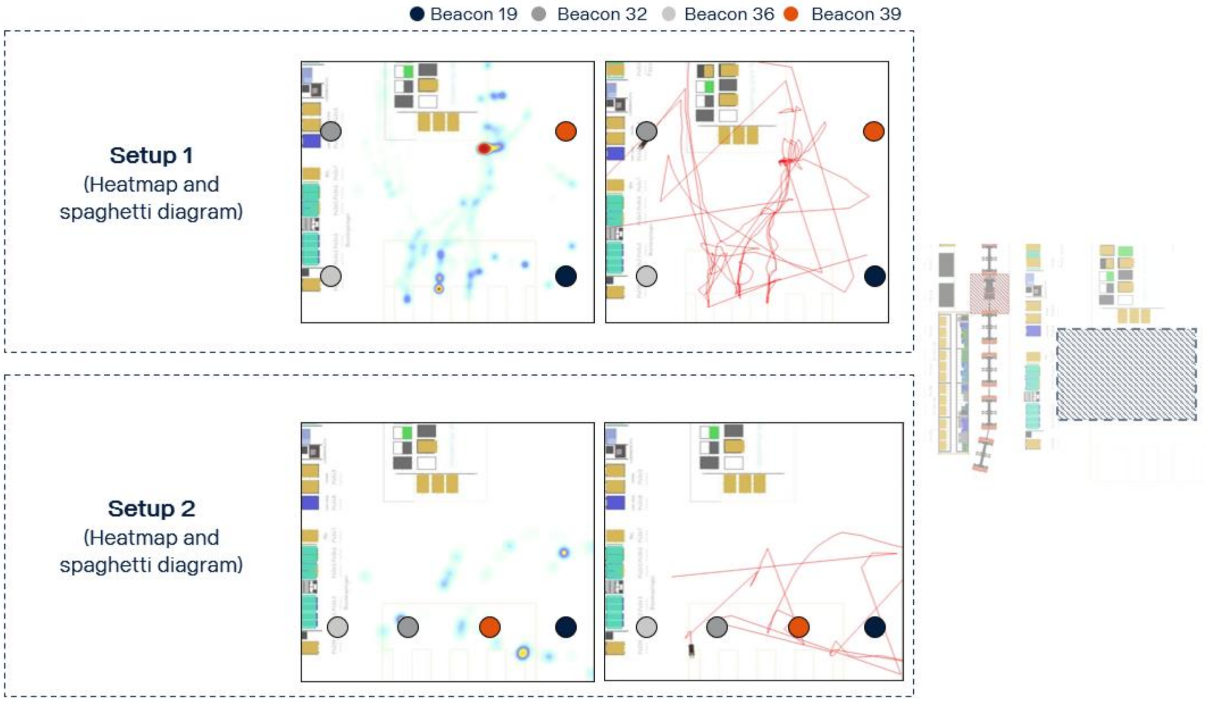

Figure 5.19: Heatmap and spaghetti diagrams from two different tests at Direkten. Note that setup 1 (in the top) has different beacon placement than setup 2 (in the bottom).

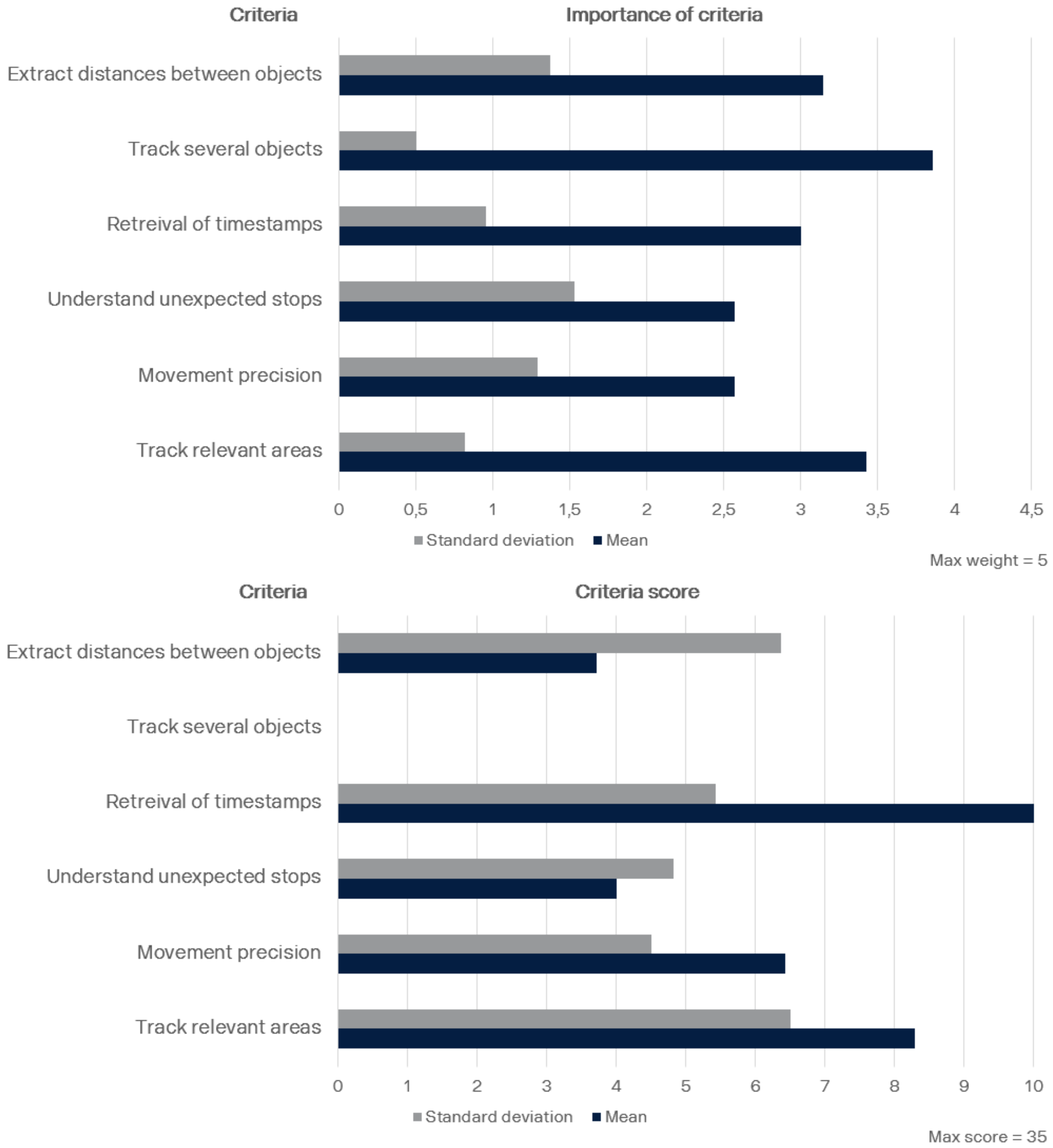

Figure 5.20: Importance - and score diagram for criteria.

From the results it is difficult to visualize the forklift traffic. A general pattern of the movement can perhaps be provided from setup 1, however, it is far from accurate. Setup 2 is completely incapable of delivering any result. Regarding the criteria, *Retrieval of timestamps* retrieved the highest score. However, looking at the most important criteria being *Track several objects*, this scored zero as it was not possible. This is a textbook example of where the main purpose is not possible to study due to the lack of tracking capabilities. For this area, the traffic intensity is only useful to study when more mobile beacons or tracking devices are installed. Furthermore, the criteria scoring standard deviation is relatively high for some of the criteria which implies uncertainties in the findings. It indicates that the Scania employees do not have a common view of the technology's suitability.

To sum it up, since the highest score reached 10 out of 35, it is determined that this area did not perform well with the RTLS kit. However, as for the other areas, it has potential to deliver better results in the future.

Area 4: Utilization of CU-forklift

Provided in Figure 5.21 and 5.22 are heatmaps and spaghetti diagrams for Area 4 as well as the ratings. For setup 1 a smaller area was tested. Once again, only one of the setups were discussed in the workshops due to lack of time.

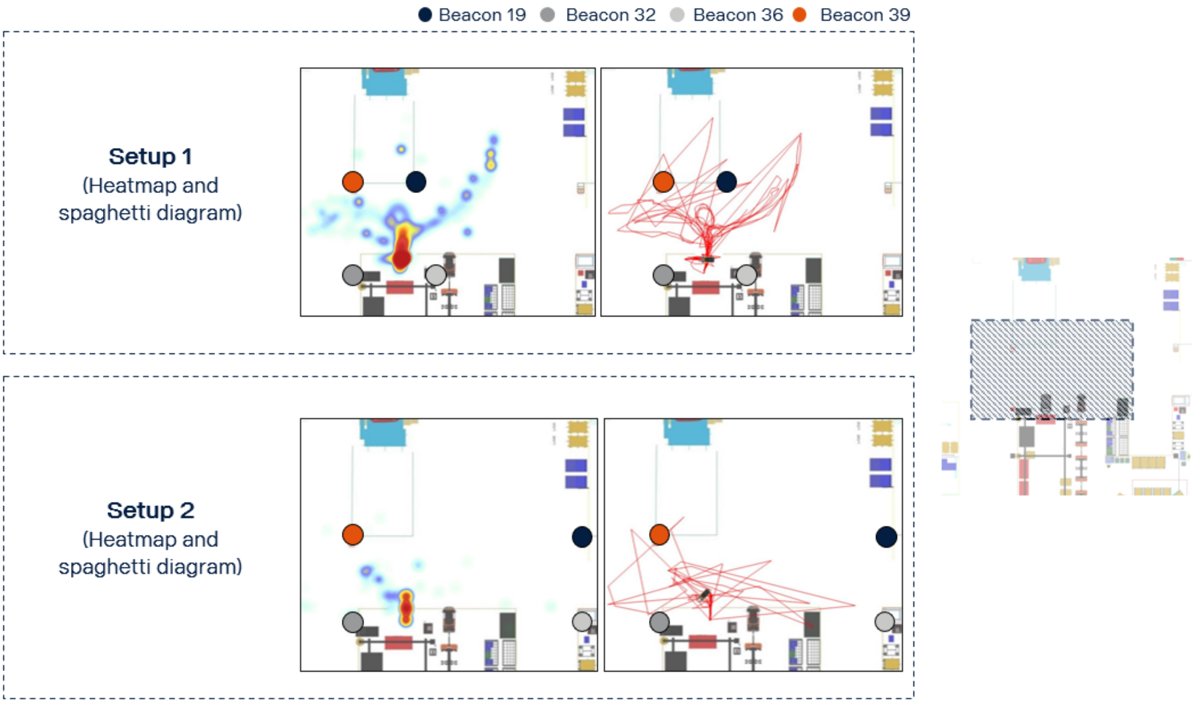

Figure 5.21: Heatmap and spaghetti diagrams from two different tests on the CU-forklift. Note that setup 1 (in the top) has different beacon placement than setup 2 (in the bottom).

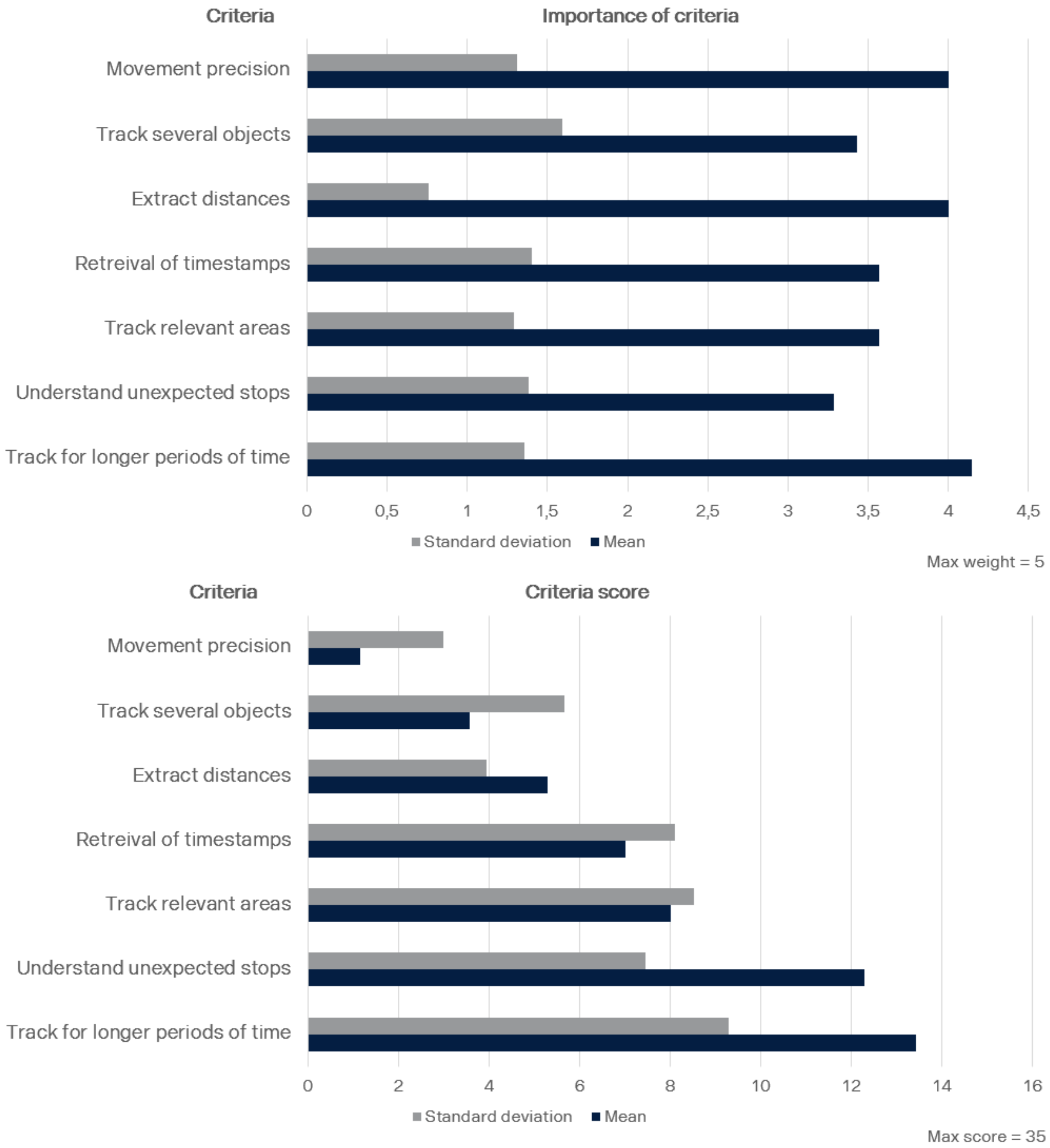

Figure 5.22: Importance - and score diagram for criteria.

The findings revealed that RLTS can be used to visualize the forklift movement. However, it can be seen that the tracking is spiking a lot more in setup 2 compared to setup 1. This is likely either due to a larger area being covered or environmental constraints or both. Interestingly enough, for setup 2, the distances between the beacons are still within what the supplier claims to be an acceptable operating range.

The findings show that it appears to be more challenging for the RTLS equipment to get high quality data of the movement when expanding the tracking area. Likely, more beacons are needed to offset this.

According to Scania, Area 4 was scored high for criteria such as ability to *Track for longer periods of time* and *Understand unexpected stops*. However, due to the relatively high standard deviation in regards to mean this implies some uncertainty in these scores. Moreover, approximately one third of the highly weighted criteria was given a high score. Thus the gathered data does partly fulfil the important considered criteria.

Furthermore, for the weighted criteria, the low standard deviation in regards to their mean indicates uniformity in regards to what is deemed important criteria for Area 4.

5.4.3. Signal-disturbance findings

Provided below follows a signal-disturbance analysis for the stationary beacons. This is of interest since the beacon positioning can affect the quality of data. The analysis has been conducted for each of the four areas. The degree of disturbance is presented as a mean as well as standard deviation. What is meant by signal disturbance is provided in Figure 5.23 below.

Definition signal disturbance
"Any kind of disturbance causing the signals not to be successfully transmitted between the stationary and mobile beacons. The disturbance takes the shape as a nullified row in the extracted .csv files".

Figure 5.23: Definition signal disturbance.

It is worth to quickly mention that for the tracking sessions, the disrupted signals were ranging between anything from 8 % to 81 %.

There were two branches of analysis that have been performed regarding the signal quality which are described in Table 5.6 below.

Table 5.6: The two types of signal-disturbance analysis performed.

Signal-disturbance analysis	**Signal-disturbance analysis – entire setup** Presents the proportion of no established connection with the tracking device. This for at least two stationary beacons. No connection implies that there is no possibility in determining the position of the mobile beacon.
	Signal-disturbance analysis – beacon individual Presents the proportion of no connection out of all the signals transmitted for each stationary beacon. This is of interest as it indicates the location appropriateness for each stationary beacon.

Area 1: Deviation in platform-kitting

Provided in Figure 5.24 is the signal-disturbance outcome for the entire setups 1 and 2 for Area 1.

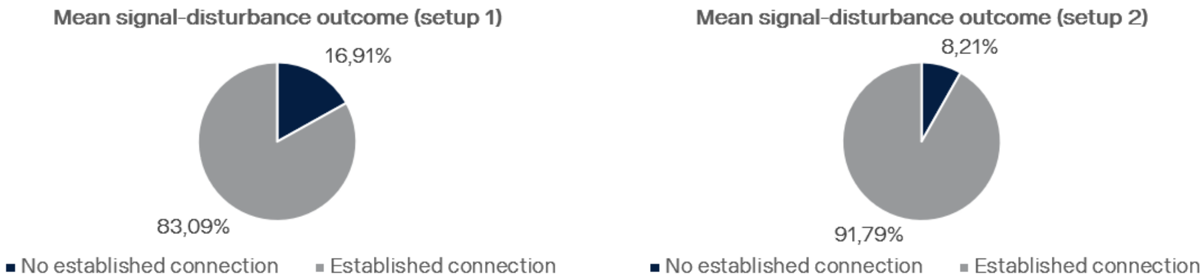

Figure 5.24: Mean signal-disturbance analysis - entire setup 1 and 2.

The analysis shows that setup 2, compared to setup 1, provided better connection establishment to the tracking device. This since a mean of 17% (standard deviation of 6%) of the gathered data from setup 1 had no connection to the mobile device while 8% (standard deviation of 1%) accounted for the same in setup 2. For both setups, the low standard deviation compared to their mean implies credibility of the data. The outcome indicates the deployment of RTLS in setup 2 to be suitable for a more successful gathering of data than for setup 1. If more time was given it would have been interesting to let the employees at Scania score the criteria for both setups to see if this is in line with what they experience as well.

Provided in Figure 5.25 is the signal-disturbance outcome for each individual beacon for setup 1 and 2.

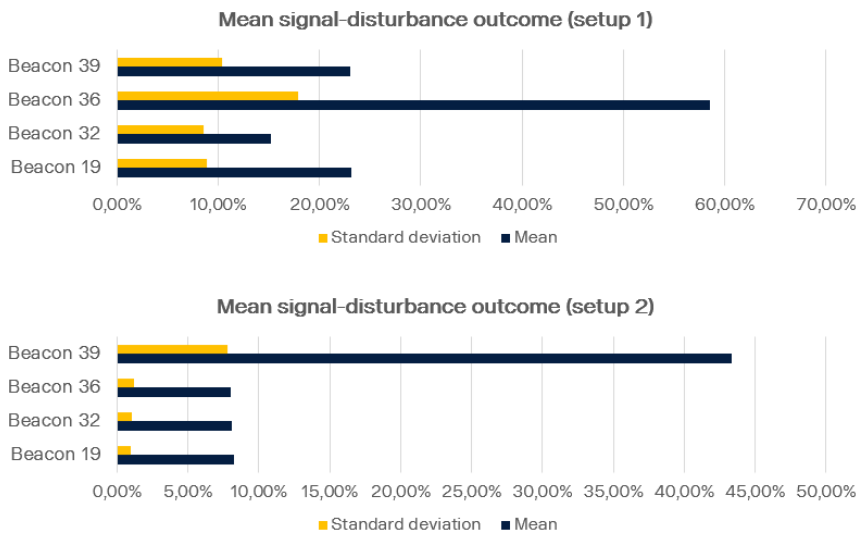

Figure 5.25: Mean signal-disturbance analysis - beacon individual for setup 1 and 2.

The outcome indicates that for setup 1, beacon 36 distinguishes from the other beacons with 59% of its signals being nullified. This is approximately three times the amount of disturbance when compared to the remaining beacons for setup 1. The findings show a more stable mean for beacon 19, 32 and 39 compared to beacon 36.

For setup 2, the analysis shows beacon 39 to distinguishes from the other with 43% on its signals being disturbed. This while beacons 19, 32 and 36 were all relatively equal regarding disturbance. The analysis indicates a stable mean for all four beacons.

Area 2: Storing inefficiencies in the box storage

Provided in Figure 5.26 is the signal-disturbance outcome for the entire setups 1 and 2 for Area 2.

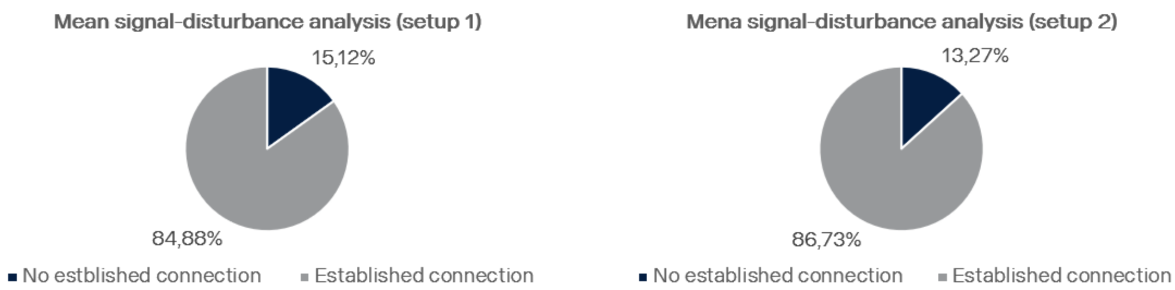

Figure 5.26: Mean signal-disturbance analysis - entire setup 1 and 2.

The outcome shows that the amount of disturbance is relatively equal for both setup 1 (15%) and 2 (13%). Both setups appeared to have a low standard deviation in comparison to their mean which ensures good quality of data. This shows that the deployment of the stationary beacons to be more or less suitable for both setups.

Provided in Figure 5.27 is signal-disturbance outcome for each individual beacon for setup 1 and 2.

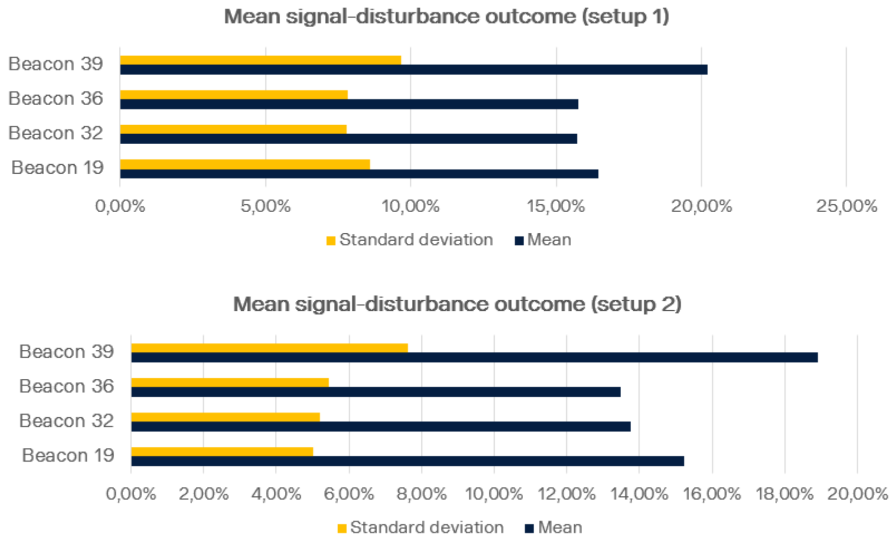

Figure 5.27: Mean signal-disturbance analysis - beacon individual for setup 1 and 2.

For setup 1, the analysis indicates the amount of disturbance per beacon to be relatively similar. This both in regards to mean and standard deviation. However, the standard deviation in relation to its mean, was relatively high which implies the data to be less trustworthy. The analysis for setup 2 is fairly similar to the one for setup 1. Consequently, the beacons were almost equally suitably positioned in both setups; just in different aisles.

Area 3: Intense forklift traffic at Direkten

Provided in Figure 5.28 is the signal-disturbance outcome for the entire setups 1 and 2 for Area 3.

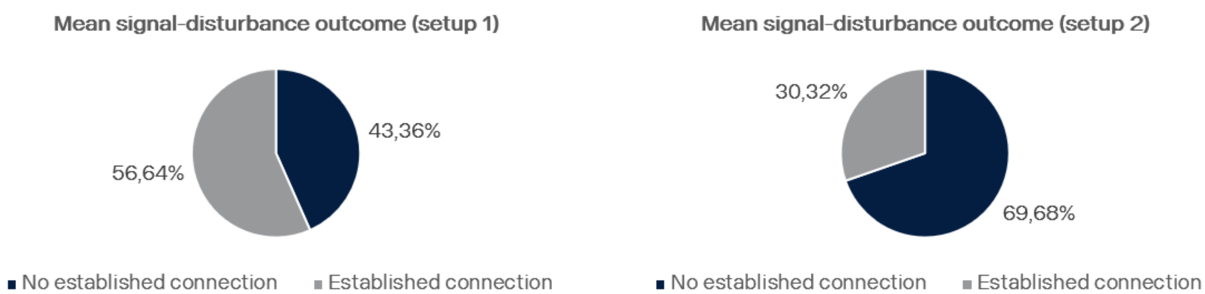

Figure 5.28: Mean signal-disturbance analysis - entire setup 1 and 2.

The outcome shows the degree of disturbance to be considerably larger for setup 2 (70%) than for setup 1 (43%). Both setups have a low standard deviation in comparison to their mean which should indicate the data being rather trustworthy. From this it can be concluded that the application of RTLS for setup 1 was more appropriate in regards to connection establishment than for setup 2.

Provided in Figure 5.29 is signal-disturbance outcome for each individual beacon for setup 1 and 2.

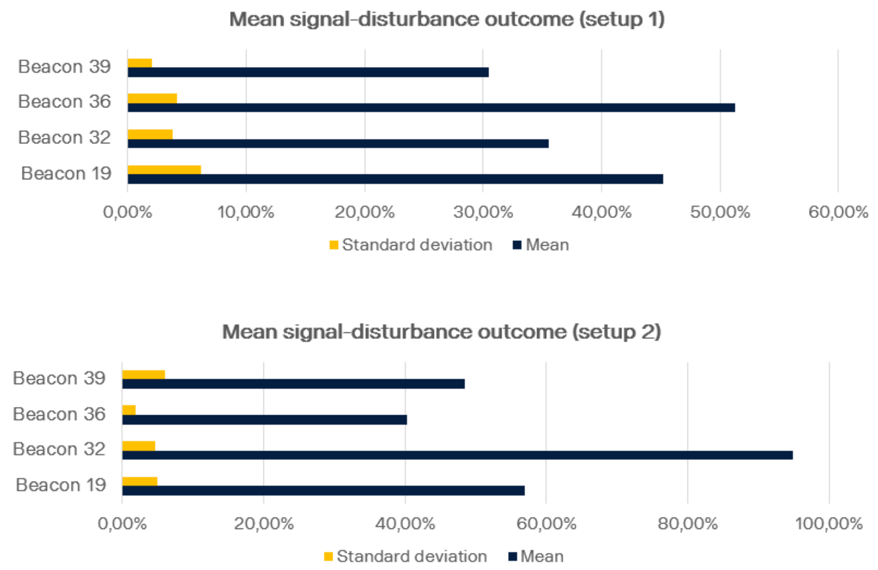

Figure 5.29: Mean signal-disturbance analysis - beacon individual for setup 1 and 2.

For setup 1, the outcome indicates all four stationary beacons to be equally well positioned. However, beacon 36 appeared to have slightly less connection which implies its positioning to be somewhat less appropriate than the others. Moreover, all the beacons had a low standard deviation in comparison to their mean which implies the data to be trustworthy.

For setup 2, it is quite obvious that beacon 32's placement is not optimal. Compared to setup 1, all beacons performed worse except for beacon 36. When looking at the mean and standard deviation values, it is fair to say that the data should be reliable.

Area 4: Utilization of CU-forklift

Provided in Figure 5.30 is the signal-disturbance outcome for the entire setups 1 and 2 for Area 4.

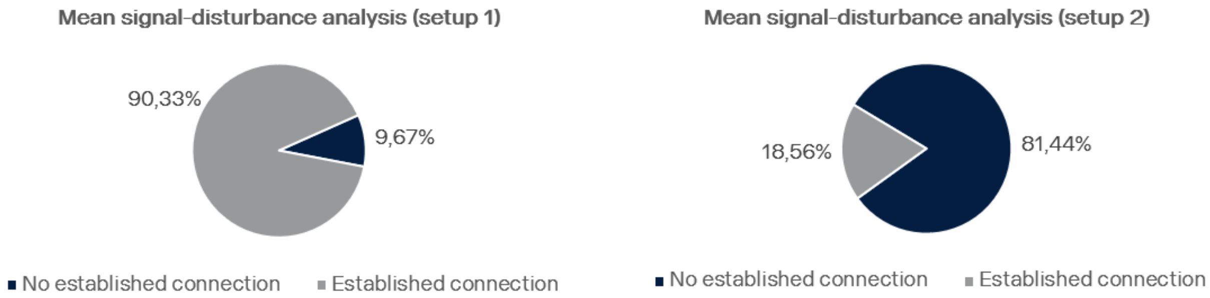

Figure 5.30: Mean signal-disturbance analysis - entire setup 1 and 2.

From the outcome it is clear to see a considerable difference between the setups. For setup 1, 10% (5% standard deviation) of the signals were disrupted compared to setup 2 where the corresponding number was 81% (4% standard deviation). This indicates the deployment of the RTLS equipment to be more appropriate for setup 1 than for setup 2.

Provided in Figure 5.31 is the signal-disturbance outcome for each individual beacon for setup 1 and 2 with the same principle as for the previous areas.

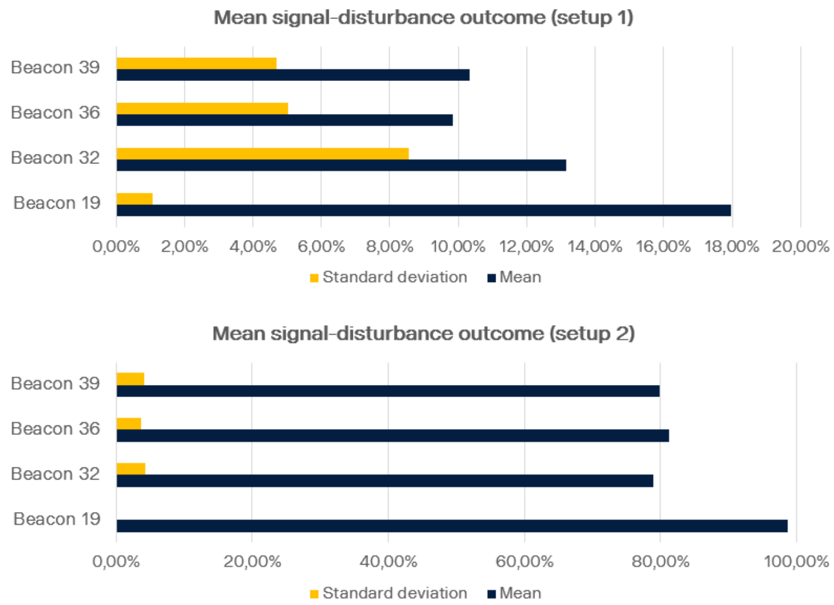

Figure 5.31: Mean signal-disturbance analysis - beacon individual for setup 1 and 2.

For setup 1, most of the beacons indicated the same outcomes, however, beacon 19 was less suitably positioned due to its amount of disturbance being 18%. For setup 2, the analysis indicates that all four beacons have a high amount of disturbance i.e. less suitably positioned. The worst positioned was the beacon 19 with almost 99% of signal transmissions being nullified. The best positioned was the beacon 39 with 80% disturbance. The standard deviation was almost the same for all beacons indicating reliable data.

5.4.4. Qualitative findings

From workshops it was concluded that employees at Scania are positive to the usage of RTLS. The questions that were approached can be found in Appendix C. It was found that the technology was praised for its potential on evaluating and improving efficiency in logistics operations. However, there were some minor drawbacks. These were expressed when addressing the outcomes and potential challenges with the RTLS testing. In some instances, it was desirable to extract more precise data to better investigate ergonomics. In others, not everyone had a positive view on being tracked, especially older employees who did not want to participate in the testing.

On a more general note, when implementing new technologies, the group leaders rated the following criteria on a scale from 1-10 (1 - not important and 10 - very important). See Figure 5.32 for ratings. It is of great relevance to include this since it provides the case company with concrete values on what to pay attention to if advancing further with RTLS testing.

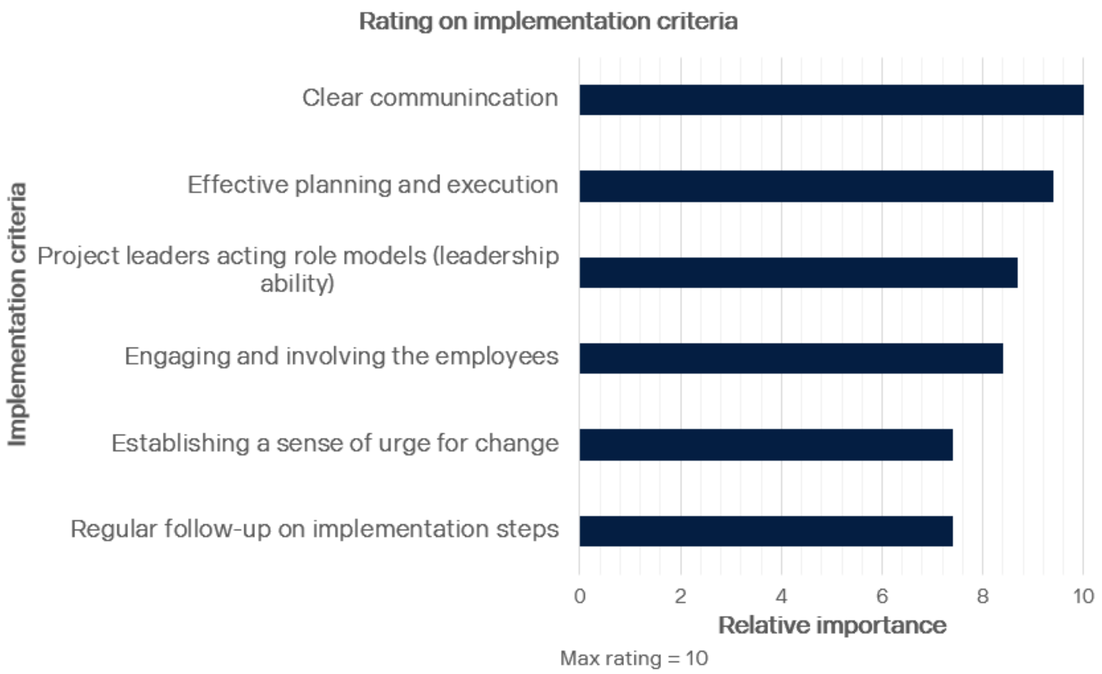

Figure 5.32: Illustrating what arbitrary Scania group leaders within logistics in Oskarshamn consider to be important when implementing new technologies.

It was found that effective planning and execution as well as clear communication was scored as important criteria when implementing new technologies. Moreover, the third top rated criteria was that project leaders should act role models during the implementation. From a general perspective, the findings revealed that all criteria were scored above 7, which indicates that all of them are impactful.

6. CONCLUSION AND RECOMMENDATION

This chapter provides conclusions and recommendations drawn from the findings. It is aimed at discussing the results in order to finally suggest recommendations for Scania. Additionally, this chapter also revises the developed conceptual framework with additional insights gained from the testing of the RTLS technology. Finally, suggestions for further studies are addressed.

Provided in Figure 6.1 is the structure on how the discussion and conclusions will be presented.

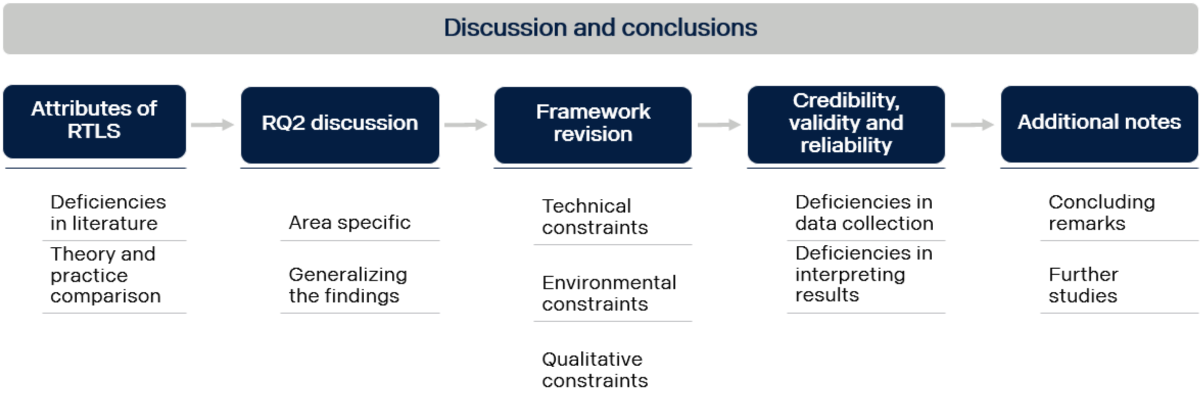

Figure 6.1: Discussion and conclusions.

6.1. Discussing the attributes of RTLS

The literature review revealed that organizations acquiring RTLS will face a variety of advantages, challenges, risks and requirements. Although the literature review was executed from a broad base of resources, it is important to consider RTLS being a newly emerging technology. Consequently, the existing literature covered by the academic probably does not cover the full picture as there are likely to be additional aspects that have not yet been discovered. This since the technology is fairly new to the market.

In the conducted literature review, the closely related RFID technology was looked into and therefore those attributes might differ from RTLS. Also the literature review consisted of searching through 51 articles, expanding the literature base even further might reveal additional aspects in regards to the technology. Another deficiency in the literature conduction is that some sources were more than 20-30 years old which means that what was written 30 years ago might not be accurate today.

Beyond what has been discussed above, additional aspects were discovered during the testing of the technology. In order to even be able to track objects, or people, negotiations with the union had to be in place. Even though Scania accounted for the negotiations, it could be something organizations should consider when adopting the technology. Moreover, contradictions and agreements were faced in regards to what the literature revealed to be environmental requirements. When applying the RTLS technology provided by Marvelmind, working conditions such as humidity, pressure and temperature was not an aspect to consider on a remarkable level. However, on the other side, interactions and dynamics between moving persons and vehicles was a crucial aspect to investigate prior implementation for all areas.

Additionally, what the academia stated to be challenging in regards to the battery capacity for the RTLS readers was not really encountered during this project. This since relatively short tracking sessions were performed with the RTLS equipment. Once again, there are contradictions with the existing literature and the lessons learned from the testing of RTLS, however such challenges are general and perhaps more obvious in other instances than in for this study.

A practical finding that was confirmed in the literature review was that the researchers faced some resistance to change when testing. From certain employees, there was a lack of interest in the technology which highlighted the importance of management leadership.

When it comes to the advantages of RTLS, these were not as apparent as other findings. For instance, the authors could not see a direct improvement in efficiency nor safety being enhanced when testing. This is because the technology was used as a tool for investigating its suitability in production and not for evaluating and improving daily operations. Therefore, it would be interesting to see future work when using the technology as an evaluation tool and draw conclusions on how it is similar and differs from existing literature.

Consequently, from above mentioned it is possible to conclude that the identified aspects in literature might not be equally clear to the organization. This since the application of RTLS is heavily dependent on how it is used and for what purpose. For instance, in the case of this research, since RTLS was used as a testing tool with the purpose of exploring its suitability, some attributes were more apparent than others.

6.2. How can Scania Oskarshamn use RTLS?

In order to answer the second research question this section aims at addressing each of the areas where RTLS was tested. The outcome from the tests will be discussed and thereafter a more general conclusion is presented. Thereby, how Scania can use RTLS is being provided and for what applications.

6.2.1. Discussion for Area 1 – *Deviation in platform-kitting*

In the case of platform kitting, what could be extracted from the results is that the important criteria scored relatively low. The most important criteria being *“Picking precision”* did not perform too well. When conducting the workshops however, some participants claimed that it might still be good enough. Looking at the best rated criteria, it is very possible to extract distances when tracking in this area. The reason for the relatively low score was since some participants desired the ability to extract distances at particular instances from the tracking which was not possible. When relating back to the root causes for tracking in this area, it was identified that there is no common agreement on what picking method is most effective. Since the total distance travelled for a kitting session can easily be extracted, it is reasonable to say that one can evaluate this issue with the aid of RTLS. Once again, the purpose of tracking shows how much it affects the suitability.

It is also worth pinpointing that there might be better ways of gathering higher quality data which in turn could improve the criteria scoring. For this thesis only two different methods of mounting were tested. From the signal-disturbance analysis it is possible to conclude that mounting the beacons closer to the mobile device will greatly improve the data quality. On the qualitative aspect, there was minor resistance being met when tracking the staff in this particular area, but this did not pose a threat since there were many more employees being willing to participate.

With this in mind, it is concluded that what Scania deems important to track in this area is not completely fulfilled, however, some criteria alone should be good enough. If in the future, the company is deciding to track in a similar area with similar circumstances, it is important to consider the distances between the beacons.

6.2.2. Discussion for Area 2 – *Storing inefficiencies in the box storage*

When looking at the results from the box storage area, many criteria were weighted and prioritized highly. At the same time many were scored rather low. When comparing with the previous area 1, looking at the relation between the importance of criteria and how well they performed, this area performed worse. Signal-disturbance wise there was little to no difference between the mounting setups, and it is clear to say that mounting in between aisles, which was believed to provide worse quality of data, did not convey this message.

Since there are future plans to rearrange the box storage, RTLS could perhaps still be useful. For instance, the criteria named *"Retrieval of timestamps"* performed better which indicates that there are possibilities to use RTLS. However, it is important to further clarify that it is not justified to look at a single criteria in this case since the evaluation is only useful when one can study the synergy between several criteria. To give an example, *"Retrieval of timestamps"* is first useful when combining with data such as picking data. In that case, one can see how optimal the SKU placement is as well as how much time is being spent on picking frequent SKUs for instance. Regarding the qualitative side there was no resistance being met when tracking in this area.

Considering the circumstances for this thesis in relation to the results, this area performed not so well. But, just as discussed, with more beacons at hand to track several objects and multiple aisles, this conclusion will likely be different. Therefore, with the current RTLS setup, it is not an optimal area to use the technology within.

6.2.3. Discussion for Area 3 – *Intense forklift traffic at Direkten*

In this area it is very apparent that tracking several objects is of a central importance for Scania. This is tied to the purpose of tracking here which relates to the traffic intensity and safety aspects. The criteria of *"Tracking several objects"* was not possible to investigate here due to the limitations in RTLS equipment which is why it scored a zero. Adding additional beacons would probably increase this criteria's score as the purpose would be more fulfilled. But this is only a speculation and needs confirmation. From this research, it is not possible to make any conclusions regarding this.

Because the area to track in was rather large with many objects moving in and out, it was obvious that the quality of data would be lacking. Almost half of the collected data was not able to be interpreted for setup one and for the second setup a clear majority of the signals were not usable. The spaghetti flowcharts for this area clearly shows how chaotic the data can be. What is of interest here is that despite confining the tracking area and trying to mount the beacons accordingly to what was more successful for Area 1, mounting the beacons closer in a line, did not show the same outcome in this case. Therefore, it is also of importance to perhaps consider what materials that are being mounted on. Also, the interrelations of forklifts and objects within the tracked area and more importantly the range of visibility between the beacons.

Since the purpose behind the tracking is not possible to investigate, it is decided not a good area to test RTLS in.

6.2.4. Discussion for Area 4 – *Utilization of CU-forklift*

For this area, the criteria of *"Understanding unexpected stops"* was highly weighted. It is further interesting that for this area, the number of important criteria is less than for the others. This, once again, indicates that the potential of the technology is heavily dependent on each specific situation.

Testing RTLS for this area was originally initiated with the purpose of investigating forklift idle time. Hence, as the criteria above mentioned scored relatively high there is eventually some potential to apply the technology for its primary purpose. However, as discussed for Area 2, in order to fully understand the situation, it might be necessary to combine *"Understanding unexpected stops"* with additional criteria such as *"Track several objects"*. In that case, a more complete and fairer picture of the situation is revealed where the traceability of the surrounding objects can be studied. Since the later criteria did score relatively low this indicates RTLS to be somewhat less suitable for this case.

What can be found from the signal-disturbance analysis is that expanding the area of tracking affected the quality of data greatly. Thus, it is suggested to use more beacons when tracking in areas with similar circumstances as this. With additional beacons the entire movement could be tracked, which was the case for Area 1 where the *"Tracking relevant areas"* scored high. With the above in mind, it is concluded that there is potential for tracking here but since the full movement is necessary to have in order to fulfil the tracking purpose, it is not very suitable.

6.2.5. Trying to generalize the findings

As shown, it is rather challenging to compare the selected areas with each other since the results are somewhat contradictory. In some instances, expanding the tracking area would provide worse quality of data and in others the opposite. What could be the reason for this is the area interrelations. A high degree of disturbing objects would still cause signal interferences despite decreasing the size of the tracking zone. However, what can be compared, is the relation between the weighted criteria and scorings but since there is no common relation between these it is difficult to draw any conclusions on this. What can be said though is that it all comes down to the purpose of tracking as this will determine whether an area is suitable or not. If the purpose requires a large area to be tracked, the findings indicate that the number of beacons to use is important. It is clear that the purposes that are portrayed in the conceptual framework needs to be looked into on a more detailed level when adapting RTLS to the organization. Consequently, additional research is required in order to draw any trustworthy conclusions.

Another interesting aspect is that despite some criteria being better fulfilled, others might not. Therefore, the question to ask is, what is good enough? As the tested areas completely vary in purpose, physical setting and employee mindset one must consider each area for itself as it is not possible to draw a general conclusion. Despite difficulties in generalizing a suitable area, the discussion of the conceptual framework aims at addressing this but on a more overall level. It is also interesting to address what is considered being a poor result when looking at the percentage of signals that were interpretable and not. As seen in Figure 6.2 below, the lowest percentage of disrupted signals in Oskarshamn was during kitting which achieved 8,21% (seen pie chart to the left) while the most was 81,44% (the middle pie chart) which was for Area 4, the utilization of CU-forklift. Provided at the very right is the quality of data when testing a kitting session in a near-optimal lab environment at Scania Södertälje. With this in mind, achieving 8,21% in a realistic environment is considered being good since 6,89% was achieved in a less disturbed area. But once again, for the other areas and tracking purposes, it is difficult to say that e.g., 20% or 40% is good enough or a terrible outcome. It all comes down to how much data that is sufficient in order to investigate what is being asked for. For instance, there are situations where millisecond refresh rates from the tags are necessary to look closely at movements whereas in other instances it could suffice with a refresh rate of every 10th second.

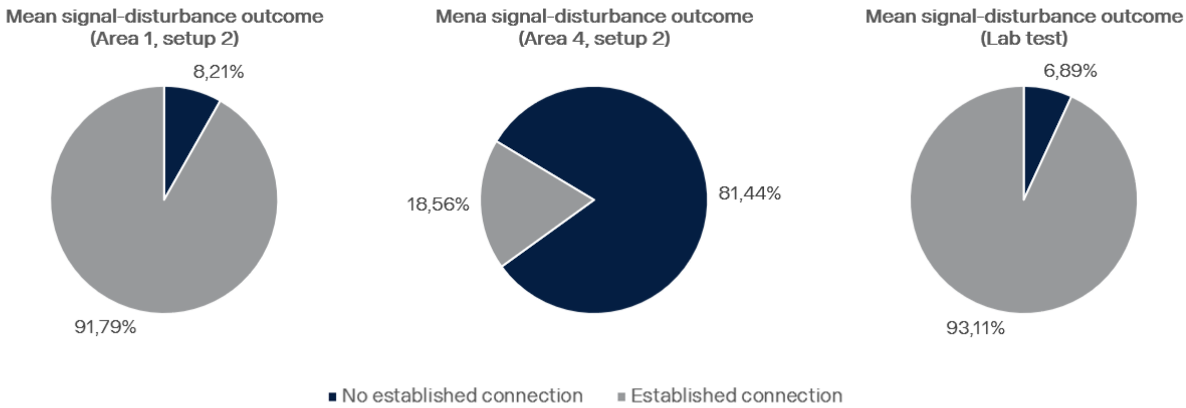

Figure 6.2: Comparison of signal quality for Area 1 and 4 (Scania Oskarshamn) and in a Lab test environment (Scania Södertälje).

Regarding the qualitative findings it showed that Scania Oskarshamn employees were positive to the usage of RTLS. This indicated that the company should be able to leverage the technology's potential due to the organization's positive attitude. The encouragement amongst Scania employees also facilitated the data gathering phases. This implies that the organization is ready for RTLS. However, it is still worth mentioning on a more general note, that the technology might not fit other companies and industries.

What can be said is that the outcome of the testing did not fulfil the purposes of the tracking, however, the outcomes were successful in the way that one could identify what is lacking and what to consider in order to ensure more successful testing. Therefore, key aspects to address are summarized in the Figure 6.3 below.

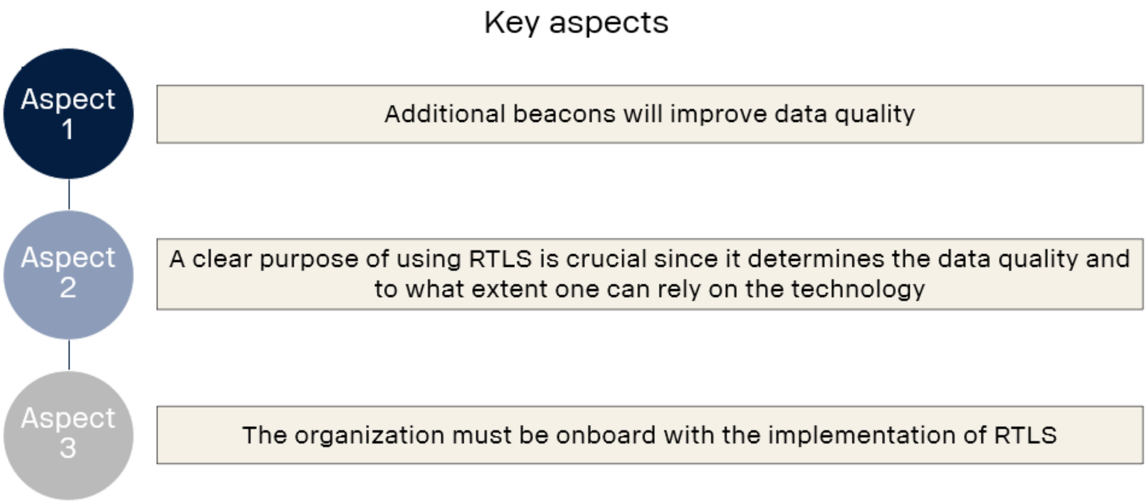

Figure 6.3: Key aspect to address.

6.3. Revising the conceptual framework

Initially, the framework constituted from case study learnings. Progressing through the thesis, it quickly became apparent that there are additional dimensions to include in order to ensure a successful test of RTLS. It was obvious to the authors that qualitative aspects and additional theory requirements discovered from the theoretical background chapter could play a part in the framework. Since the technology was new for Scania Oskarshamn, a trial-and-error approach had to be followed which is why many discoveries were made during the testing phase. Furthermore, as only four stationary beacons were available, it was difficult to test the technology on larger scales. The learnings can be summarized as follows (see Figure 6.4 for summarizing process).

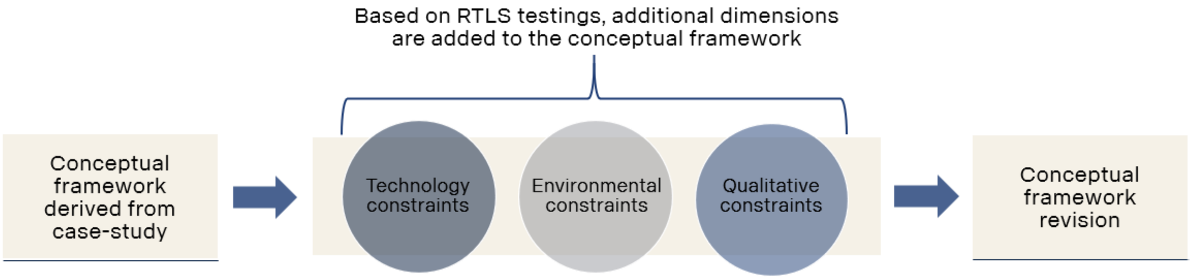

Figure 6.4: Summarizing process leading to the revising of the conceptual framework.

6.3.1. Technology constraints

Manuals were provided from Marvelmind where it was clearly informed how to properly mount the tags for best results. It is claimed that best results are achieved when the beacons are mounted so that the antennas are pointing towards the mobile device. Ideally, the tags should also have been mounted on a sticker, but since this was not available, improvisations had to be made thus duct tape was used to mount the beacons. The tape would sit in front of the transmission sensors since it was the only feasible way to place the beacons. This might eventually have caused signal interruptions thus impacting the quality of data. Consequently, signal-disturbances that were thought to be caused by the environmental setting might instead have occurred due to the usage of tape.

In connection to a visit at Smart Factory Lab, Södertälje, a possibility was given to further test and evaluate the RTLS technology provided by Marvelmind. Though, in a laboratory setting. In the lab, the situation similar to Area 1 was simulated. Also, the beacons were mounted on stickers with the purpose of investigating if differences in signal quality occurred. From data gathering and analysis it was found that the signal quality appeared to be better (Figure 6.5 to the right) when using stickers compared to tape (Figure 6.5 to the left). However, the laboratory environment in which the tests were performed did cover a smaller area with near to optimal settings.

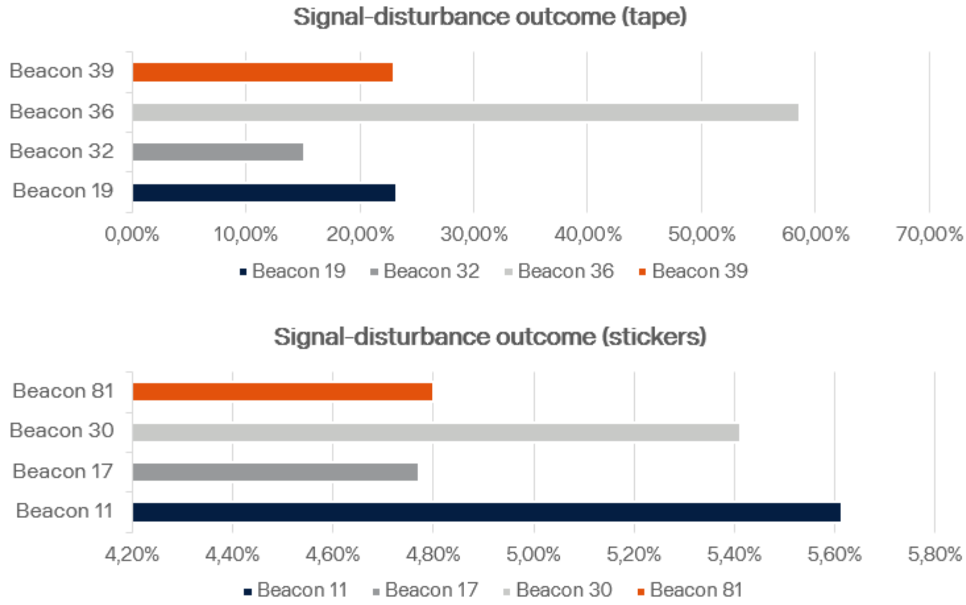

Figure 6.5: Comparison of beacon mounting - tape vs stickers.

It is also worth mentioning that mounting the beacons optimally might not be possible in all instances which is why one must consider this aspect as well when deciding to track an object.

Since the RTLS beacons provided by Marvelmind are active, they need to be charged after circa 20 hours of use. When tracking for longer periods, they consequently need to be connected to some sort of energy source which is not possible when tracking a moving person for longer periods of time. The technology type therefore plays a role. Interestingly, when in the Smart Factory Lab, other technologies were also experimented with where one of those for instance had a life-long battery. By simulating a kitting process (like Area 1), it was possible to investigate and compare different RTLS technologies on how they performed in gathering data on this criterion. Later, the outcome from this was also rated amongst the Scania employees, but, as seen in Figure 6.6 below, despite the technology with life-long battery (Supplier A) performing well in the battery aspect it did lack in many other categories.

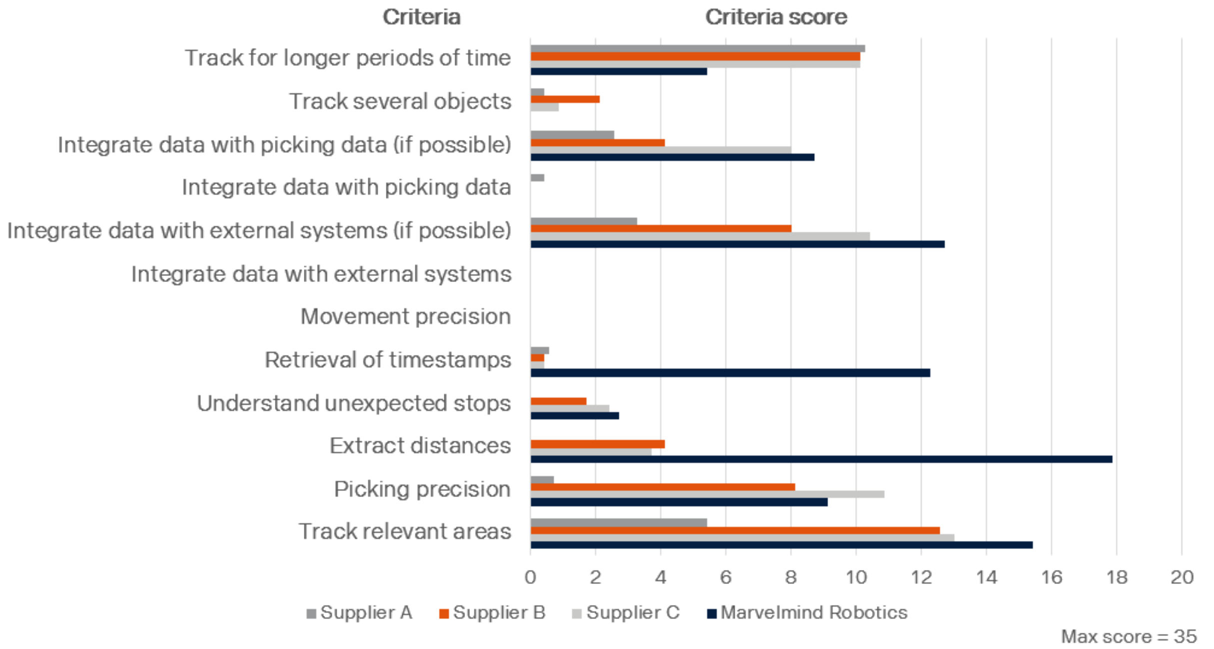

Figure 6.6: Comparison of different RTLS technologies.

For the curious reader, Supplier A's technology is Ultra-Wide band based but it is pinging its location every 10th second, Supplier B uses Bluetooth-low energy transmissions and supplier C uses Ultra-Wide band with refresh rates of around a couple of seconds. When choosing appropriate technology, it all comes down to the many aspects to consider such as precision, cost of acquisition, how easy it is to handle and so forth. While some offer longer operating capabilities others have better precision etc. In this case, according to what is considered important to Scania, it is safe to say that Marvelmind's offer is the better choice when comparing the technologies that were tested in Figure 6.6 above. However, it once again comes down to what purpose the technology is used for.

Lastly at Smart Factory Lab, it was possible to add an additional mobile beacon to the Marvelmind equipment. This with the purpose of investigating whether the quality of data was affected by the number of mobile beacons in use. As seen in Figure 6.7 below, the impact of adding more devices to be tracked is negligible. Hence giving an indication that RTLS might be applicable and suitable for tracking several forklifts at Area 3. However, additional testing would be advised to conduct in order to draw a more well supported conclusion.

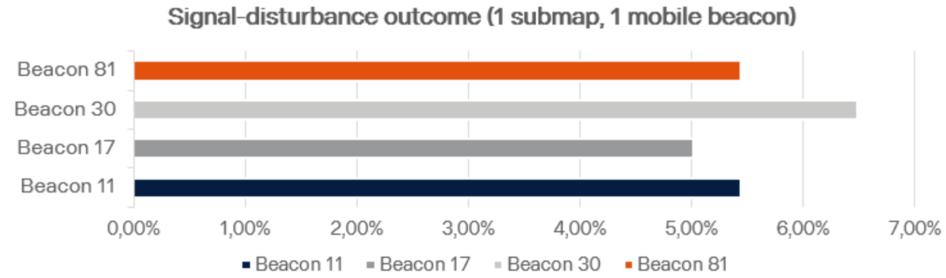

Figure 6.7: Comparison of one versus two mobile beacons.

Provided in Figure 6.8 is the layout from the RTLS testings at Smart Factory Lab, Scania Södertälje.

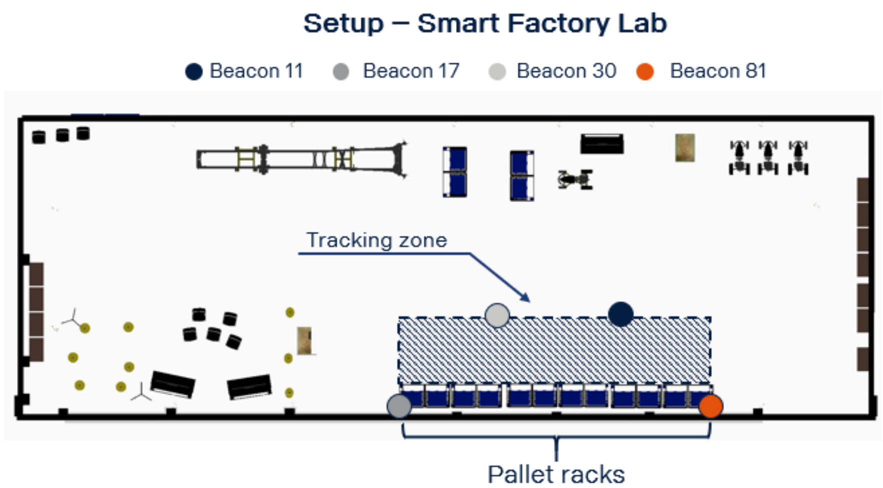

Figure 6.8: Layout of tracking zone when experimenting with one and two tracking devices.

6.3.2. Environmental constraints

Having tested the RTLS technology it was realized that the larger the area, the more important it is to consider the number of beacons available. However, whether the disturbance was caused by too large distances between the beacons, or if objects in between the beacons were the source of disturbance, was hard to conclude. Still, it is reasonable to say that both factors play a key role in the quality of data.

At the visit in Smart Factory Lab, Scania Södertälje, a Marvelmind setup like Area 1 - *Deviation in platform-kitting* was tested. Though, the simulated area had almost optimal settings which means that there was a very low degree of disturbance and it was an open and small area with tags mounted very visible to one another. This to confirm whether less intense area interrelations would increase the quality of data. The outcome from this testing is provided for each individual beacon and is compared to the similar kitting process tested in Oskarshamn (see Figure 6.9). As shown, there is a difference in the quality of data. However, since the circumstances of the two settings investigated were not near each other, it is not fair to make this comparison. It is also worth pointing out that the test in Oskarshamn might not have been the most successful test.

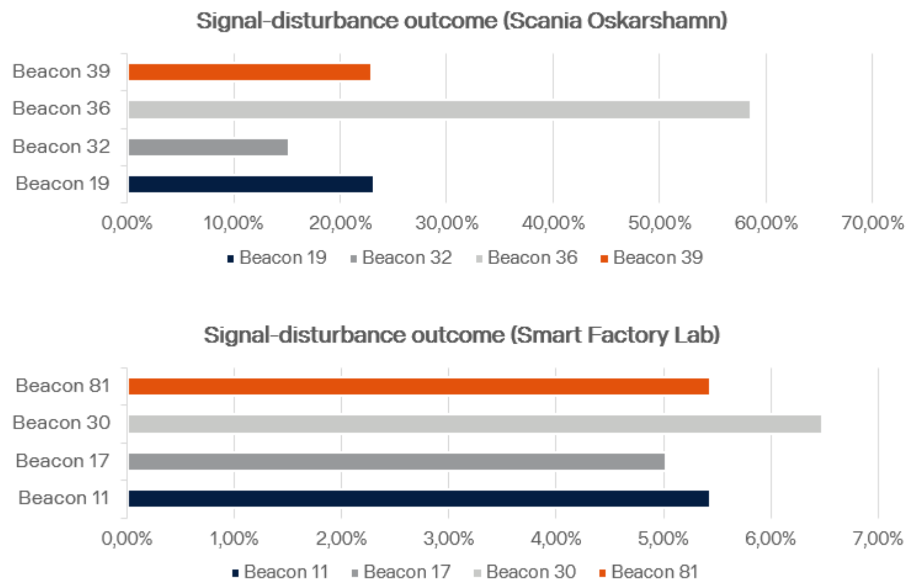

Figure 6.9: Investigating the effect of environmental constraints.

Another constraint that became apparent in the production in Oskarshamn was the lack of time to mount, adjust and experiment with the beacons. When determining areas to track in, one would ideally want to be granted the opportunity to study the area and its interrelations more closely. This to find out and experiment how to best mount the beacons. However, since the production is up and always running, there are only very few 10-to-30-minute breaks each day, which resulted in lack of time to mount. This means that more complex and perhaps, better ways of mounting might not be possible to do. Since this aspect is very specific to the case company, it is chosen to be excluded from the framework as it covers a more general view. However, this is taken into consideration for the checklist that is provided later in section "*6.3.5 - Applying the framework in industry*".

6.3.3. Qualitative constraints

As presented and discussed, there are also qualitative aspects to consider in the framework. With no commitment from management nor employees, it is not suitable to implement RTLS. In the case for Scania, it is not seen as a real barrier due to the positive response from the workshops. However, just as discussed, the workshop results do not capture the full picture and despite the case for the company, it needs to be addressed in one way or another in the framework. However, since the bottom layer takes this consideration into account there is no need to add another layer concerning this topic.

A reason for the minimal qualitative constraints is likely because small-scale testings were conducted. When one seeks to implement RTLS on a larger scale, it is reasonable to expect more pushback. It is also worth pointing out that in order to track people, negotiations with unions must be held which is another constraint, that is very dependent on the organization.

6.3.4. Conceptual framework revision

With all the above in mind, the framework can be revised and additional two layers are to be added as seen in Figure 6.10 below.

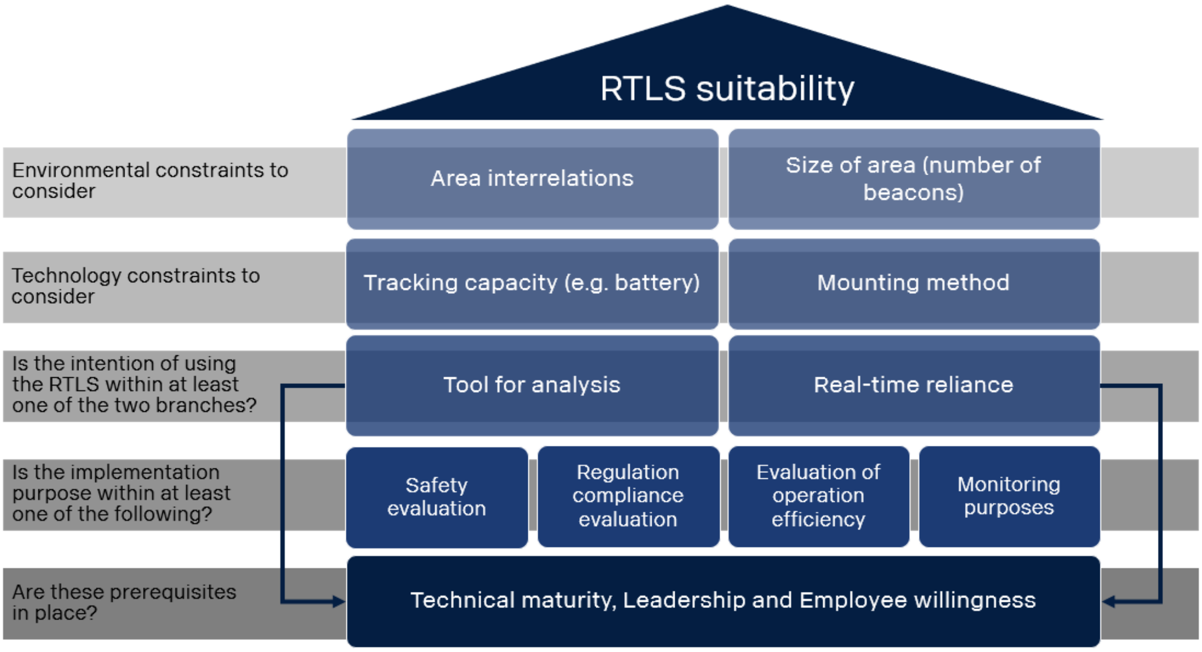

Figure 6.10: Revised conceptual framework.

6.3.5. Applying the framework in the industry

Since the framework covers a more general perspective of the technology, it is decided to concretize this for the sake of providing the case company with a more concrete value. The following checklist is believed to be useful when Scania seeks to test or implement RTLS in their operations. Keep in mind that this list is developed in an early stage of Scania's RTLS implementation phase and therefore it is likely to not capture the full picture.

The checklist is also developed to be of a binary character hence the questions are to be answered with either yes or no. Answering yes means that one can proceed with the next question in number. Answering no means that one must address the follow up questions which are provided directly below each main question. The questions should be read and discussed from the top to the bottom. Following through all points successfully (by answering yes) should pave the way for a successful implementation of RTLS. Prerequisites such as technical maturity, leadership, employee willingness and the ability to conduct the testing are assumed to be in place prior to addressing the checklist. Please note that answering no on some questions does not mean you shall not proceed with the implementation but rather carefully consider and reflect upon the reasons why you answered no as the data quality is likely to be affected.

A remark is put on that the checklist was developed in accordance with the prerequisites for Marvelmind's technology. Hence, when applying other RTLS technologies, the checklist might have to be adjusted to better fit the prerequisites for respective technology.

Lastly, it is worth mentioning that this checklist only accounts for when using RTLS as a tool for aftermath evaluation purposes and not in instances where real-time reliance is used to conduct daily operations. Furthermore, the accuracy of the list might differ depending on what industries and circumstances one wishes to test.

To further clarify, Figure 6.11 shows how to proceed with the checklist to retrieve best results.

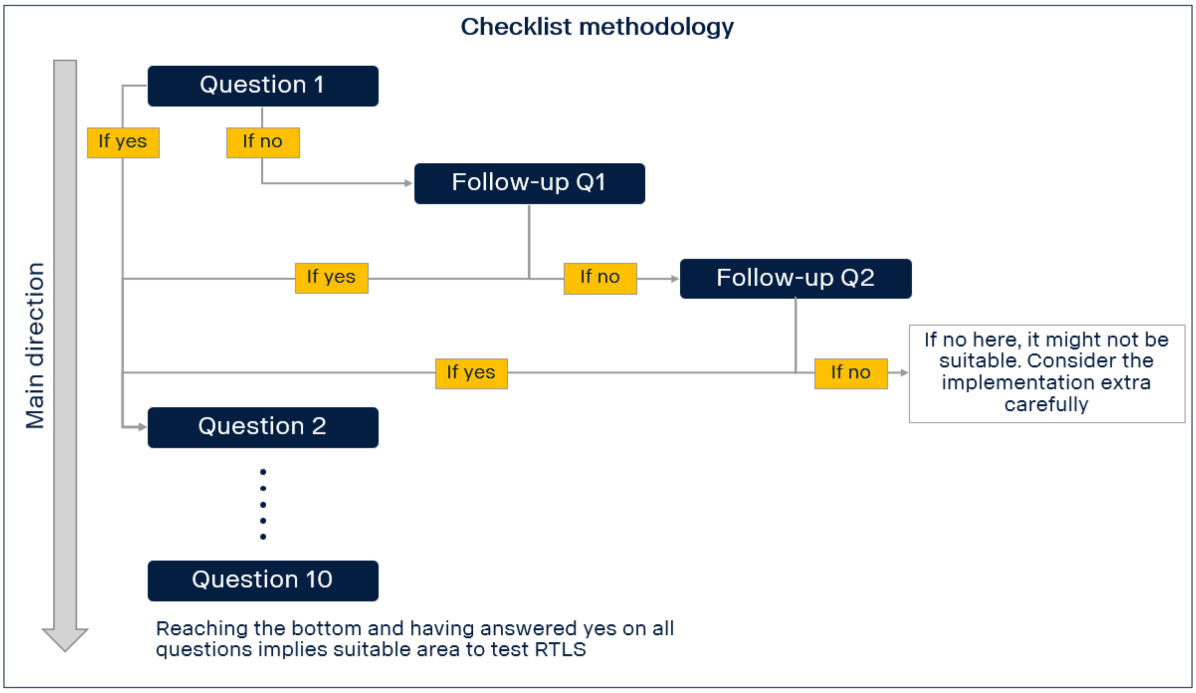

Figure 6.11: Depicting checklist methodology.

Provided below are the 10 checklist questions.

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1. Does the technology's battery capacity allow for tracking for the required amount of time (there is a maximum lifetime battery for approximately 20 h)?
    a. Can we supply power to the beacons?
        i. Can we divide the tracking session into several subparts?

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2. Is it possible to cover all relevant areas to track with the stationary beacons? This implies obtaining distances no longer than 10-15m between adjacent stationary beacons.
    a. Is it possible to mount in a different way that would allow for the relevant areas to be covered? For instance, the line-mounting method (see Figure 6.12).
        i. Is it possible to increase the number of stationary beacons?
            1. Is it possible to divide the area into "subsections" and track these separately?

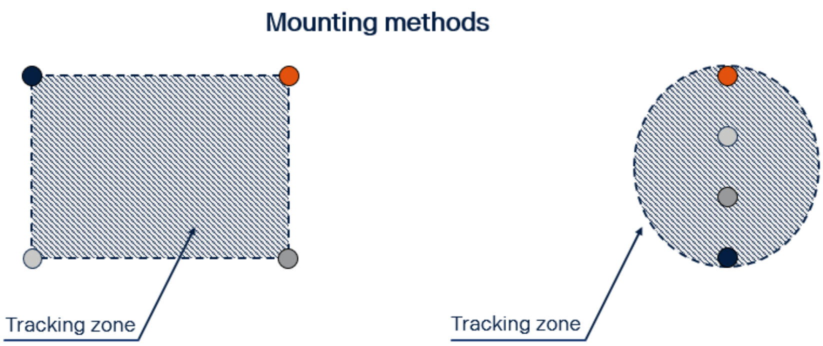

Figure 6.12: E.g. of different beacon mounting setups.

3. Is it possible to achieve line-of-sight between the stationary beacons?
    a. Is it possible to remove potential objects that cause no line-of-sight?
        i. Is it possible to move the beacons to achieve line-of-sight, by for instance mounting higher or reworking the positioning?
            1. If not, pay attention to the Marvelmind Dashboard matrix when creating the room to track in.

4. Is it possible to establish line-of-sight between tracking devices and at least three stationary beacons when tracking AND maintaining distances of 10-15m between tracking devices and stationary beacons?
    a. Is it possible to remove potential objects that cause no line-of-sight?
        i. Is it possible to move the beacons to achieve line-of-sight, by for instance mounting higher or reworking the positioning?
            1. Is it possible to add more beacons so that line-of-sight is achieved?

5. Is it possible to mount the stationary beacons so that the transmission outputs are not covered?
    a. Is it possible to mount the stationary beacons so that as few as possible transmission outputs are not covered?
        i. If not, reflect upon the Marvelmind matrix indications when setting up the system.

6. Is it possible to mount the mobile beacons so that the transmission outputs are not covered?
    a. Is it possible to mount the mobile beacons so that as few as possible transmission outputs are not covered? If not, be aware that data quality might be affected.

7. Is it possible to position the stationary beacons so that their transmission angle (see Figure 6.13) points to where the mobile device is moving and vice versa? This means to angle the antennas towards each other.
    a. Is it possible to change the location of the mounting point?

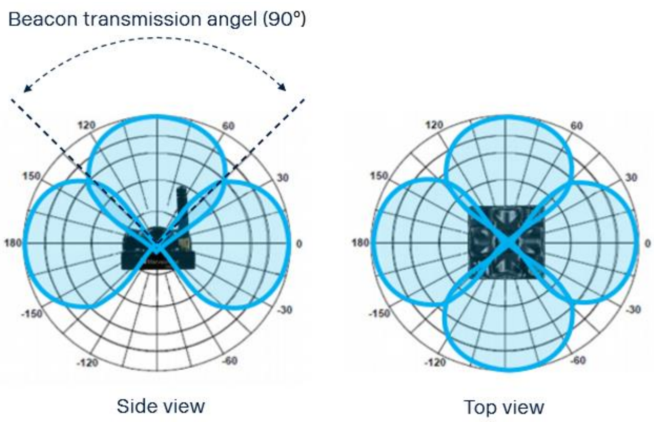

Figure 6.13: Beacon transmission angle. The right one provides better range (Marvelmind, 2021).

8. Have you allocated necessary time to synchronize the mounting and installation with the production schedule?

9. Is the computer modem within at least 100m from the beacons? Note that there is no requirement for line-of-sight between the modem and beacons.

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10. If you wish to track more than one object simultaneously, do you have enough tracking devices?
    a. If not, do you have extra stationary devices? These can be converted to tracking devices.

6.3.6. Risk assessment when using the conceptual framework/checklist

Provided in this section is a risk assessment matrix on the application of the conceptual framework as well as the presented checklist. This is addressed with the purpose of contributing to the case company with relevant risks to consider.

As seen in Figure 6.14, there were two identified risks when using the models. The first is misinterpretations amongst the users using the framework and/or the checklist. The probability of this risk was deemed to be medium, but it depends on who the user is and the level of experience and competence. The impact of misunderstanding the framework or the checklist is high. This is because a prerequisite of using the models is to understand how to use them. Using the checklist differently than intended will likely result in a poor execution of the RTLS. The mitigation strategy that is being proposed is to allow for transparency and have open discussions with other users and/or persons involved. To share insights and thoughts and include more people into discussions on how to apply it.

A second risk identified with using the framework or the checklist is that it can be misleading depending on what industry and under what circumstances RTLS is tested in. This risk is obvious as this thesis did not have the ability to cover a larger scope. However, the framework is still more on a general level. The probability of the risk occurring is medium as there were many different areas identified at the case company where RTLS could be used. Since the checklist is inspired from testing in only four areas, the probability of this risk is high. However, looking at the impact, it is believed to cause less troubles than misunderstanding the list. The checklist should be able to relatively accurately cover other areas as well as it has been developed with aid from the framework. Lastly, the mitigation strategy proposed is to allow for more research and investigations into this matter as well as encourage users to question the model/checklist.

Risks Assessment Matrix
(Associated with the application of conceptual framework and/or checklist)

Identified risks	Probability	Impact	Mitigation strategy
User misinterprets the conceptual framework/checklist	Medium	High	Allow for transparency when using the tools, share and discuss thoughts
Conceptual framework/checklist is misleading due to lack of scope	High	Medium	Allow for more research, dare to question the model

Figure 6.14: Risk assessment on conceptual framework and/or checklist.

6.4. Credibility, validity and reliability of study

Throughout the thesis there were aspects that affected the credibility of the study. All of these are addressed and discussed in this section.

6.4.1. Deficiencies in data collection

Provided in Table 6.1 are some deficiencies in data collection that might have had an impact on the results.

Table 6.1: Deficiencies in data collection.

Deficiencies in data collection	Number of tests (was necessary to limit due to the restricted time frame)
	Length of tests (last for five to 10 minutes)
	One RTLS technology was mainly tested (Marvelmind Robotics)
	Tracking humans affect their way of working (does not directly have an impact on this thesis's outcome nor purpose)
	Number of employees included in workshops (was difficult to get in touch with more employees)

It was discussed throughout this thesis that other technologies could perhaps provide better suitability for certain areas or instances. Fortunately, during the Södertälje visit, other RTLS technologies were at hand. A tracking session was conducted with three different technologies (the same as previously presented in Figure 6.6) to see how well they all performed in relation to one another. For the curious reader, this comparison can be found via the QR-code below (Figure 6.15).

Figure 6.15: QR-code for video of the RTLS comparison. Please discard the background images shown for supplier A and B as it is outdated. Supplier B's technology is pinging every 10th second which is why it is difficult to see any movement compared to the other two.

6.4.2. Deficiencies in interpreting results

Provided in Table 6.2 are two deficiencies in data collection that might have had an impact on the results.

Table 6.2: Deficiencies in interpreting results.

Deficiencies in interpreting results	Limited knowledge on visualization tools
	Criteria rating (interpreted differently amongst Scania employees)

6.5. Concluding remarks

Regarding the circumstances for this thesis, it is clear to say that the technology does not meet the requirements set by Scania. This since what the RTLS kit is capable of is not in line with the purposes of using the technology. However, RTLS could still be used when testing in areas where the purpose is more fit to the technology’s capabilities, i.e., in smaller areas and where the degree of disturbance is lower. It is important to highlight that the perfect fit between testing areas at Scania and Marvelmind’s RTLS was not discovered by the authors. One cannot therefore stress enough the importance of Scania’s continuous effort to investigate this. There might be areas that are perfectly suitable. For RTLS to be more suitable regarding the purposes investigated for this thesis, additional beacons are likely needed to improve the outcomes. Therefore, it is recommended to investigate the possibility of testing with more beacons.

Regarding what type of RTLS technology to use, Marvelmind scored highest overall amongst the one that were tested in Smart Factory Lab. It is not possible to draw a conclusion on this though since the technologies were compared under different circumstances which is why it is recommended that Scania further investigates this.

To answer RQ1, RTLS entails a wide variety of attributes. These range from technological ones to more general ones. For RQ2, Scania can use RTLS for any application if the purposes of tracking are in line with what the RTLS technology is capable of.

6.6. Suggestion for future studies

During the thesis, several potential areas to further advance with were identified. It would be interesting to include more tracking devices as it was realized that a lot of valuable information is left out due to the lack of this. With additional tracking devices, more objects can be tracked simultaneously. It would also be interesting to narrow down the scope and perhaps focus on one or two areas with the use of RTLS. To see how these can be improved with the technology. Further, to use the technology as an evaluation tool and draw conclusions on how it is similar and differs from existing literature would also be interesting.

In this study, several environmental constraints were identified and elaborated on. What would have been interesting is for further studies to focus on the appearance of signal interruptions. This regarding in what circumstances disturbance is caused by either; (1) Exceeding the distances between the beacons and/or (2) Objects in between beacons disturbing the signals. This was hard to conclude from this research and further research might provide a more evident interpretation on this.

Finally, most literature covered the implementation of RFID and with the growing interest in RTLS it is highly recommended to continue evaluating the possibilities with the technology. Also, how to best adapt to changes in order to leverage the full potential of the technology.

Allowing for RTLS to expand, it would be interesting in a couple of years to do a systematic review of the appropriateness of RTLS depending on the industry and organisational setting. Another interesting academic development would be to conduct a survey among firms that have implemented RTLS to investigate prerequisites like the ones that have been developed in this thesis framework, to see how well the conceptual framework performs in practice.

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Appendix A - Exploratory/informal interview questions

The list of questions below were used during the exploratory/informal interviews with Scania employees.

Q1: Who are you and what do you do at Scania?
Q2: What are your thoughts on RTLS?
Q3: What challenges do you encounter today?
Q4: How do you work in order to achieve efficiency?
Q5: Do you work with track and trace? If not, do you see a need for this?
Q6: Do you think implementing RTLS is feasible in your area of knowledge?
Q7: Do you currently use any AutoID technology?
Q8: Do you suggest or have any recommendation on other persons we should contact?

Appendix B - List of interviewed persons

The persons listed in Table B-1 were interviewed throughout the master thesis.

Table B-1: List of interviewed persons.

Interviewed persons	
	Karl Hammerin, Logistics Developer, Scania Oskarshamn
	Philip Skarheden, Logistics Developer, Scania Oskarshamn
	Claudia Kopf, Logistics Developer, Scania Oskarshamn
	Eva Rockner, Logistics Technician, Scania Oskarshamn
	Johan Bågfeldt, Logistics Developer, Scania Oskarshamn
	Rickard Bengzon, Logistics Developer, Scania Oskarshamn
	Lars Gustafsson, Senior Logistics and Material Handling, Scania Oskarshamn
	Erik Karlsson, Project Leader, Scania Oskarshamn
	Lars Hanson, Project Engineer, Scania Södertälje
	Lennart Lundgren, Senior Engineering Advisor, Scania Södertälje
	Jose Maria Sabater, Project Engineer, Scania Södertälje

Appendix C - Change management questionnaire/workshop

The list of questions below were used during the change management questionnaire/workshop.

Q1: What is your perception and attitude regarding the usage of RTLS as a tool for collecting digital data?

Q2: Do you consider the technology promising or are there perhaps any “threats/risks” to consider?

Q3: What was your experience of the RTLS testing? Was it complex and difficult to participate in the study? If, why?

Q4: What would you say are the biggest challenges when implementing new technology at Scania, at shop floor level?

Q5: Were there any obstacles or barriers that you encountered when providing us the possibility of testing the technology?

Q6: How did you experience that the group’s attitude was to participate in the study?

Q7: How did the persons involved react to being tracked? Positively or negatively? Why?

Q8: Is there anything that we could have done differently in order to ensure a more positive experience when testing the technology?

Q9: On a scale from 1-10, where 10 is very important and 1 not so important, where would you rank the following factors in the case of implementing RTLS:

Table C-1: Ranking factors in the case of RTLS implementation.

Factors	
	Clear communication
	Implementation leaders acting role models (leadership ability)
	Engaging and involving the employees
	Establishing a sense of urge for change
	Regular follow-up on implementation steps
	Effective planning and execution

Q10: In general, is there anything that you want to add, perhaps something to think more on for future implementations?

Appendix D - Case-study compilation

Provided is a brief description of the 16 cases that constituted the case study. Cases from a broad range of industries such as warehousing operations, manufacturing - and healthcare industry were investigated.

Hellmich et al. (2017) - Contact tracing with a real-time location system: A case study of increasing relative effectiveness in an emergency department
In the healthcare environment, conducted by Hellmich et al. (2017), it is concluded that RTLS can effectively be used to track and sustain contact information regarding disease spreading. RTLS can provide improved and more reliable information than conventional systems. Here conventional systems are referred to as electronic medical record (EMR) which is a method used for contact tracing.

Park et al. (2006) - RFID-Based RTLS for Improvement of Operation System in Container Terminals
Park et al. (2006) performed a RFID based RTLS study in the context of container terminal operations. Their study was conducted with the purpose of investigating the technology's impact on productivity in container terminals. Productivity is an important aspect where RTLS can be used to reduce the turnaround time for shipping companies at ports.

Ding et al. (2008) - Application of RTLS in Warehouse Management Based on RFID and Wi-Fi
The purpose was to implement RFID and Wi-Fi based RTLS in warehouse management. Ding et al. (2008) developed, tested and evaluated a model to be used in an automobile manufacturing enterprise. Along with this, they also identified improvements and benefits with RTLS in the case company. The identified improvements were such as greatly improved efficiency of warehouse operations, reduced management costs and considerable economic benefits.

Gladysz et al. (2018) - Dynamic Spaghetti Diagrams. A Case Study of Pilot RTLS Implementation
Gladysz et al. (2018) performed a pilot project where they studied the impact of dynamic spaghetti diagrams in a cold chain warehouse. More specifically they set up the tests within dispatching and high rack storing. From their pilot project they concluded that RTLS can support lean initiatives by efficient and effective acquisition of data.

Zhang et al. (2012) - Crane Pose Estimation Using UWB Real-Time Location System
Crane pose estimation can aid the operator in predicting potential collisions. In the study conducted by Zhang et al. (2012) they used real-time location data of the crane components to compute the pose of the crane which is tested in a case environment. The results from their research are promising.

Meunier et al. (2017) - Image analysis to refine measurements of dairy cow behaviour from a real-time location system
Meunier et al. (2017) performed a case study where RTLS was used to track animal behaviour. This with the purpose of enabling engineers in developing precision livestock farming tools. From the research it was concluded that using visual observations, activity profiles can be developed and extracted.

Halawa et al. (2020) - Introduction of real time location system to enhance the warehouse safety and operational efficiency
Via a real warehouse case study, Halawa et al. (2020) aimed to demonstrate how RTLS can be leveraged to enhance the warehouse safety and operational efficiency. RTLS was integrated with other existing warehouse operation systems (e.g. WMS).

Fang et al. (2016) - Case Study of BIM and Cloud-Enabled Real-Time RFID Indoor Localization for Construction Management Applications
In this case study, Fang et al. (2016) introduced building information modelling (BIM) and cloud-enabled RFID localization systems. This is tested in a full-scale implementation on a construction site. The study indicated that the localization system has great potential when it comes to site security control, safety management, asset management and productivity monitoring.

Rizzi and Romagnoli (2017) - Testing and Deploying an RFID-Based Real-Time Locating System at a Fashion Retailer: A Case Study
Rizzi and Romagnoli (2017) deployed an RFID-based RTLS at a fashion retailer. Strengths and weaknesses of the implementation were concluded and resulted in promoting the future benefits of RTLS implementation.

Nawotarski et al. (2017) - RTLS systems as a Lean Management tool for productivity improvement
In the case study, Nawotarski et al. (2017) used Bluetooth based RTLS for checking the possibility of locating objects (equipment or materials) in existing buildings.

Maleki and Meiser (2011) - Managing Returnable Containers Logistics - A Case Study. Part II - Improving Visibility through Using Automatic Identification Technologies
In this paper, Maleki and Meiser (2011) researched the capabilities of auto identification technologies to improve visibility throughout the supply chain. They performed a case study at an assembly and manufacturing company which resulted in improved visibility.

Bendavid et al. (2011) - RFID-Enabled Traceability System for Consignment and High Value Products: A Case Study in the Healthcare Sector
Bendavid et al. (2011) evaluated RFID-enabled traceability systems in the healthcare sector. From their case study it was concluded that end-to-end traceability of medical products in the healthcare supply chain can be significantly enhanced.

Huang et al. (2020) - Providing Proximity Safety Alerts to Workers on Construction Sites Using Bluetooth Low Energy RTLS
In a case study, Huang et al. (2020) investigated BLE RTLS on a construction site. The study revealed that BLE RTLS can provide accurate positioning in large sites.

Bowen et al. (2010) - Real-Time Location System (RTLS) to Improve Fall Detection
In a case study conducted by Bowen et al. (2010) it was found that RTLS may improve staff response time, patientcare and reduce healthcare costs associated with falls in later life.

Baslyman et al. (2014) - Towards an RTLS-based Hand Hygiene Notification System
In this paper, Baslyman et al. (2014) proposed an RTLS-based approach to track hand hygiene regulations in healthcare. Thus, infection rates could be reduced.

Slovák et al. (2019) - RTLS tracking of material flow in order to reveal weak spots in production process

Slovák et al. (2019) used RTLS together with a simulation software to monitor material flow. Also, to provide a view of the problems of weak spots in the production process.

Appendix E - Identified areas at Scania for RTLS implementation

Provided is a brief description of the 12 areas that were identified for testing RTLS at. Out of these 12, four areas were then selected for further investigations and finally RTLS testing.

Cold temperature exposure of cabling equipment causes non-ergonomic assembling solutions

It has been identified that during wintertime when cabling equipment is transported between OLO and MC, the cables often arrive at low temperatures. This causes stiffness in the cables and therefore unfavourable conditions at the assembly line when assembling this equipment. Temperature measurement devices have recently been mounted into the transport unit carrying the cabling equipment. This with the purpose of, via continuously measuring the temperature, identify where in the material flow from OLO to MC the temperature drops below accepted levels.

This area was of great interest but due to the requirement of tracking in large physical settings, it was not feasible.

Non-objective data on forklift flows affect the evaluation of material flows

In a constant manner, forklifts are shipping goods causing an intense and dynamic aspect in the workplace at MC. It was identified as a certain interest from Scania to collect and analyse data on specific material flows and processes. Current data lacks the ability to capture the full picture in certain material flows. Thus, it is challenging to collect data in order to evaluate key performance indicators such as picking frequency, distance travelled and so forth. Consequently, data is not being fully accurate nor reliable which affects decisions being based on such metrics.

In regard to the presented lack of reliability in material and forklift flows, RTLS could potentially contribute to process improvement. The technology would enable tracking of the forklift and its driver’s behaviours. Hence improving quality and reliability in data. Similar to the area above, it was deemed not possible to apply RTLS in such a large setting.

Deviations in platform kitting

It was identified that depending on which shift that was working, various knitting strategies were performed at the platforms. This for the same kitting process. It was also found that there is currently no commonly agreed method to apply in order to determine the most efficient and ergonomic kitting strategy in an objective way. Here kitting strategy is referred to in what sequence to pick and place material in racks. On one hand, some argue that batch picking is the most efficient. On the other hand, some mean that picking all the articles for one cab at a time is a more successful strategy.

Considering the deviations in kitting strategy applied, RTLS could objectively determine the most efficient kitting strategy. One process that was promising is the kitting of suspension bellows at platform seven. This area was prioritized since it was realistic to evaluate RTLS in this physical setting.

Assembly line-picking deviations
It was identified that RTLS could be used to measure picking efficiency at the assembling line. From Scania's point of view there was a great interest for further investigations into this area. This since it is apparent that the pickers efficiency deviates hence RTLS could potentially provide a better understanding why such phenomena occur. Unfortunately, negotiations have not yet taken place which would allow for tracking employees at the line which is why this is not feasible to investigate further into.

Excessive use of forklifts
An additional aspect that was identified during the first round of interviews was that certain forklifts are likely being used for non-value adding activities. Thus, waste is created which is undesirable for Scania and a top priority to eliminate to as large extent as possible.

Here, RTLS could be used to further investigate this topic. With the technology, it is possible to track forklift movements hence generating heatmaps and spaghetti flowcharts. Unfortunately, since forklifts are moving around in large and complex areas, it was not possible to study this with the RTLS kit that has been provided.

Rack location uncertainty
The units of shipment used for material transportation between the logistics centre OLO and the main facility are so called racks. From the interviews it was identified that it is very important to control this particular material flow. The reason being is because this flow is completely independent of the cycle time of the assembly line. Consequently, if the assembly line is put to a complete stop the rack material flow will continue. Moreover, since the racks are used in a circular manner, the racks must be shipped back to the logistics centre OLO.

With this in mind, it is apparent that the rack material flow plays an important role. With no racks at OLO, the supply of material to the main facility will be put to halt. Due to this, Scania showed a great interest in tracking the racks, hoping for increased material flow control. Once again, the material flow covers a too large range to evaluate with the RTLS kit provided.

Intense forklift traffic causes concerns for safety and regulation compliance
Despite safety being a top priority at Scania, it was identified from the interviews that minor concerns have been raised regarding the intense and congested forklift traffic at *Direkten*. When forklifts are picking outbound pallets from the high-bay warehouse there is a risk for collisions. This is due to close-proximity movements. Consequently, harshness in breaking or rapid acceleration could potentially also cause collisions.

In general, there are seven forklifts constantly moving around in this area. Therefore, Scania did show a great interest to track the movement of the forklifts and to determine whether they are complying with the safety regulations and standards set such as following dashed lines and lanes. This area was deemed fit due to the realistic physical setting.

Creating spaghetti flowcharts is time consuming
From interviews it was found that many potential benefits could be exploited via spaghetti flowcharts. In today's operations, such diagrams are being plotted manually resulting in the process being rather time demanding. In addition to the process being perceived as tedious and slow, there is also a lack of understanding the potential such diagrams could provide. This results in the process being carried out rarely.

Here, the application of RTLS did show a great potential for process improvements. Since this action takes place at many instances throughout the operations, it was rather difficult to branch down and identify more concrete, smaller areas of interest. Also, since spaghetti flowcharts are being extracted from Marvelmind's software, this issue was automatically covered when testing the technology in the most favourable places.

Inefficiencies in pre-shipping operations
When reaching the end of the assembly line, the cabs are finished and ready for shipment for Scania's other manufacturing sites. Prior to the shipment, the complete cabs are being temporarily stored outside the assembly line building under a canopy.

In order to perform a smooth loading process of the cabs on trailers, the cabs need to be arranged in a specific sequence. Consequently, this results in forklifts having to rearrange the cabs which is time consuming and rarely value adding. Thus, RTLS was identified to provide insights into this process via tracking the movement of forklifts. However, this problem was not selected to advance further since it was outside of the authors testing scope.

Storing inefficiencies in the box storage
From observations it was identified to apply RTLS in the box storage. This in order to generate spaghetti flowcharts of the vertical movement of forklifts in the storage area. As stated in section 4.2.2., the replenishment and picking activities related to the box storage requires intensive time consuming moving up and down along the racks. Also, today's operations hold no data or information on these activities hence unnecessary movement caused by non-optimal placed boxes is very likely to occur.

Applying RTLS in this situation, the vertical movement of the forklift could be monitored, gathered and analysed. Thereafter, further actions could be taken with the purpose of improving picking efficiency in the box storage. This area was deemed fit due to the realistic physical setting.

Excessive forklift speed
An additional issue was identified from a combination of observations and literature review since RTLS could potentially enable forklift speed monitoring. Hence, applying RTLS in various settings at MC, would allow for the identification of maximum forklift speed exceeding. Once again, due to this being extremely large and non-concrete for the authors to dig deep into, it was not of main interest.

CU-forklift inefficiencies
Another potential issue Scania wanted to investigate was the utilization rate of the so-called "CU-forklift". The main task of the CU-forklift is to replenish a certain type of material (beds and roof shelves) that do not go with the usual material flow via platforms and trains. If spare time is given, the driver is supposed to take on other tasks (e.g., pallet return flow in parallel with the bed shipping. How many tasks that are being executed in parallel is very dependent on the person driving the forklift. Therefore, it is of interest to gather objective data on this concern.

From observations, the physical setting was deemed appropriate and therefore this area was further investigated into.
