JÖNKÖPING UNIVERSITY
School of Engineering

Real-Time Locating System (RTLS) Applicability for ERP Integration

Guidelines for Applicability and Barriers and Enablers for RTLS and ERP Integration

PAPER WITHIN: *Production systems, specialization in Production Development and Management*

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This final thesis has been carried out at School of Engineering at Jönköping University within the main area production systems. The work is a part of the Master of Science program Production Development and Management. The authors are responsible for the opinions, conclusions and results herein presented.

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Scope: 30 credits (second cycle)

Date: 2022-06-15

Abstract

Purpose. Real-time Locating Systems (RTLS) are used to identify and locate physical assets in real-time. Essentially, the aim of RTLS is to increase process visibility and thus provide accurate process data concerning for example, lead times, cycle times and inventory control. Today, process visibility is one of the most critical aspects for manufacturing companies in their quest for higher quality and shorter lead times. Since the introduction of Industry 4.0, RTLS has received an upswing in attention in the literature. However, despite the technical advances, enterprises are struggling to fully comprehend the entire impact of RTLS. Further, when integrating RTLS and other IT systems, such as the ERP, business operations can be carried out based on real-time information, providing more value than a standalone RTLS. Enterprise Resource Planning (ERP) system is the core IT system for enterprises. The ERP is in turn divided into several modules: Manufacturing, Warehouse, Human resources, Sales & Distribution, and Finance & Accounting. Evaluating the applicability for each module will provide a holistic view on RTLS and ERP integration that has a wider perspective than previous studies on the topic. Consequently, the purpose of this study was to examine and evaluate the applicability of integrating RTLS with the various ERP modules and present a set of guidelines for RTLS and ERP integration. The guidelines will be created based on the following research questions. **RQ1:** How can the various ERP modules utilize RTLS data? **RQ2:** What barriers and enablers are there when integrating RTLS and ERP?

Research method. An extensive literature review and interviews with industry experts were conducted. Thematic analysis and thematic narrative analysis were applied to extract relevant information form the literature review and industry expert interviews. Thematic synthesis was applied to synthesize the information received from the result of the thematic analysis and thematic narrative analysis, thence answer the research questions, and create the guidelines.

Findings. Applicability was found for all ERP modules and the main barriers identified was lack of mature processes, knowledge, and cost. The guidelines created in the study included five main steps. 1) organizational enablers, 2) IT structure enablers, 3) ERP module applicability, 4) knowledge and understanding, and 5) business case generation. The guidelines were presented in text and as a picture.

Contributions. This study has contributed to research by expanding the perspective on RTLS and ERP integration further than previous studies on the topic. The study showed that all ERP modules can utilize the RTLS data to provide value for that particular module. This study contributes to industry by providing guidelines that can be utilized by managers and decision makers in their process of evaluating RTLS implementation Managers and decision makers can use these guidelines to create a fundamental understanding of how RTLS can create value for all ERP modules. This knowledge is a key to create profitable business cases. The guidelines will therefore facilitate enterprises to overcome the initial knowledge barriers and thus, contribute to the acceleration of the RTLS expansion within the industry.

Keywords. Real-time Locating System (RTLS), Enterprise Resource Planning (ERP), Industry 4.0

Acknowledgments

We would like to express great appreciation towards our supervisors Pontus Rosengren and Daniel Nilsson at Virtual Manufacturing for providing support and guidance on our research purpose and research process. Secondly, we would like to send our warmest acknowledgments to our supervisor Alexander Vestin at School of Engineering at Jönköping University. Alexander has helped us by developing our thoughts and concepts throughout the study. Moreover, by simply offering cues and tools Alexander has challenged us to solve issues ourselves, thereby developing our individual knowledge and expertise. Lastly, Alexander's academic expertise and guidance have challenged us to continually take the additional step for increased academic attainment.

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Table of Contents

Table of Figures

Table of Tables

1 Introduction

1.1 Background

As the customer requirements on quality and short lead times are constantly increasing, process visibility has become a critical factor for manufacturing companies all over the world. Therefore, traceability and visibility of physical assets will be a key characteristic for future manufacturing and supply chain success (Samir et al., 2019). A common term used among manufacturing companies regarding process visibility is asset tracking. Asset tracking refers to the ability to identify and locate goods, material, humans, vehicles, and other form of assets. Essentially, the aim of asset tracking is to increase process visibility and thus provide accurate process data concerning for example, lead times, cycle times and inventory control (Thiesse & Fleisch, 2008).

The ability to identify and track assets originates back to the World War II. During the war, the British Royal Airforce developed a system called Identification of Friend or Foe (IFF) that was able to distinguish friendly aircrafts from enemies. The IFF system later developed into what is now known as Asset Tracking. As the Radio Frequency Identification (RFID) technique started to become cheaper and wider standardized, asset tracking started to gain increasing interest in the 1990´s. Since then, asset tracking via RFID has been widely used within for example military, retail, security and Supply Chain Management (SCM) (Khattab et al., 2017). Nowadays, modern technologies can provide real-time, dynamic positioning with higher accuracy and including environmental data, thus enabling asset tracking in real-time. Consequently, asset tracking today is most often referred to as Real-Time Locating Systems (RTLS) (Frankó et al., 2020).

An RTLS system consist mainly of two parts: hardware for the tracking itself (tags, sensors, anchors etc.) and an IT system that receives and process the data to prepare it for other applications within the IT structure (Thiede et al., 2021). The RTLS software can provide companies with analytics such as trajectory of assets and real-time production monitoring, thus providing process visibility (Yang et al., 2016). This process visibility can be utilized by companies to facilitate manual process improvements. However, the next-level benefits can be achieved only by integrating the RTLS with the existing IT structure (Siemens, 2021). Kohn et al. (2005) emphasize that a traditional ERP cannot consider unexpected events. However, with RTLS data, the ERP, or similar systems, can retrieve real-time data and adjust activities such as planning and scheduling to real world events. Consequently, the RTLS data needs to interact with other software in the existing enterprise IT structure to facilitate real-time decision making and thus provide maximum value to the business processes (Ding et al., 2008; Franz & Franz, 2010; Geier & Bell, 2001; Husak et al., 2021; Kohn et al., 2005; Siemens, 2021; Thiede et al., 2021; Yang et al., 2016).

One of the most important IT systems for enterprises is the Enterprise Resource Planning (ERP) system. ERP systems has for long been the center of operational data management within the industry and have played an important part of streamlining processes and improving business performance (Tavana et al., 2020). The ERP consists of several core modules. These modules differ from system to system, but the basic functionality is similar. Fundamentally, an ERP system consist of the following core modules: Manufacturing, Warehouse, Human resources, Sales & Distribution, and Finance & Accounting (Hossain, 2003; Parthasarathy, 2007; Zabukovšek et al., 2020).

One of the most important industry trends that is predicted to facilitate future development and expansion of RTLS is Industry 4.0 (Chao et al., 2020; Huang et al., 2017; Řezáč & Soušek, 2018). Since the introduction of Industry 4.0, RTLS has received a significant increase in attention from researchers (Cwikla et al., 2018; Frankó et al., 2020; Řezáč & Soušek, 2018). Industry 4.0 was introduced by the German government in 2011. The purpose was to inspire German industries to adapt new technologies to strive for higher efficiency and productivity (Frank et al., 2019). Industry 4.0 can be described as a manufacturing philosophy that incorporates next generation production technologies that utilizes and exchanges data to facilitate more agile production systems and customized products (Oztemel & Gursev, 2020). RTLS is evidently one of the next generation production technologies and thus, Industry 4.0 can be considered an enabler for RTLS and the other way around. As Industry 4.0 is becoming more and more established, the landscape around ERP is changing as well. Sensors and devices can process and transfer real-time data to the ERP concerning products, quality, and transportation. Thus, increasing process visibility (Tavana et al., 2020).

1.2 Problem Statement

A decade ago, Qu et al. (2012) established that there are three main obstacles for implementing asset tracking: high hardware cost, high risk due to lack of standardized solutions and rapid technology development, and technical threshold. However, as the technology are getting cheaper and more reliable, new opportunities have emerged to elevate asset tracking within the industry 4.0 paradigm (Chao et al., 2020; Halawa et al., 2020; Huang et al., 2017; Řezáč & Soušek, 2020).

Even though the topic of RTLS is hot within literature, Řezáč and Soušek (2018) states that enterprises are hesitating to implement RTLS and there has yet been no greater expansion within the industry. The main reason for the hesitancy is lack of knowledge and experience of implementing and managing RTLS within the industry (Geier & Bell, 2001; Řezáč and Soušek, 2018). Further, many of the benefits retrieved from RTLS are so called spillover effects. Hence, implementing RTLS for one function might lead to positive effects in other areas of the enterprise (Ferrer et al., 2011). Some benefits of RTLS-ERP integration might therefore be hidden and thus the entire impact of RTLS implementation is somewhat difficult to comprehend. Today, managers and other decision makers are struggling with understanding the purpose of implementing RTLS and integrate it with the ERP system.

Several studies have established a distinctive connection between RTLS and existing IT systems, such as Manufacturing Execution Systems (MES) (Huang et al., 2018; Rácz-Szabó et al., 2020; Tran et al., 2021a; Yang et al., 2016), Warehouse Management Systems (WMS) (Bin et al., 2008; Halawa et al., 2020; Ma & Liu, 2011), and Enterprise Resource Planning (ERP) systems (Kohn et al., 2005; Ruppert & Abonyi, 2020; Tran et al., 2021b). These studies have generally been technology centred and built upon specific cases and contexts. Only a few studies have applied a more holistic approach. In a literature review on the topic of RTLS within production management, Rácz-Szabó et al. (2020) identified six applications areas for RTLS: production control, logistics, quality management, safety, efficiency monitoring and operator tracking. Thiede et al. (2021) also performed a holistic study as they performed a survey on nineteen people that had limited experience of RTLS. The study intended to investigate the industry´s perspective on potential application areas for RTLS within a manufacturing context. Even though these studies are holistic, they both focus on utilization of RTLS data in a production management perspective, only including integration towards MES (Rácz-Szabó et al, 2020) or no integration at all (Theide et al., 2021). The novelty of this study lies in expanding the view on RTLS integration beyond MES (corresponding to the Manufacturing ERP module) and WMS (corresponding to the Warehouse ERP module) by investigating the impact of RTLS in all core modules of the ERP.

In summary, since the introduction of industry 4.0, the opportunities for real-time tracking of assets are greater than ever. However, despite the technical advances, enterprises are struggling to fully comprehend the entire impact of RTLS and how to utilize the data to improve existing business operations. When integrating RTLS and ERP, business operations can be carried out based on real-time information, providing more value than a standalone RTLS. This lack of knowledge result in a hesitancy among companies and retains the greater expansion of RTLS.

1.3 Purpose and Research Questions

Based on the problem statement, this study can be considered as two-folded.

First, the majority of the studies on the topic of RTLS are technology centered and carried out in unique manufacturing environments. As a result, there has been few studies considering integration between ERP and RTLS on a holistic view.

Second, enterprises within the industry tends to be tentative towards adapting RTLS. A set of guidelines presenting applicability, barriers and enablers can act as decision foundation and a driver for manufacturing enterprises to start implement and fully benefit from the RTLS and ERP integration.

Consequently, the purpose of this study is to examine and evaluate the applicability of integrating RTLS with the various ERP modules and present a set of guidelines for RTLS and ERP integration.

To fulfill the purpose, two research questions has been established.

RQ1: How can the various ERP modules: manufacturing, warehouse management, human resources, sales & distribution, and finance & accounting utilize RTLS data?

RQ2: What barriers and enablers are there when integrating RTLS and ERP?

“Barriers” is defined as reasons for tentativeness and resistance to investing and implementing RTLS. “Enablers” is defined as prerequisites for success when implementing RTLS and integrating with ERP.

1.4 Delimitations

This study will not consider technical details regarding RTLS, e.g., which sensors or tracking technology is used. However, the systems included are all real-time, and thus non-real time tracking systems will not be included. This study is performed within a manufacturing context. Other industries, such as healthcare or retail, or cultural aspects will not be considered.

Also, the identified core modules might differ in various ERP systems. Some specialized ERP systems have additional modules that otherwise are applied as external applications, for example Customer Relationship Management, (CRM). These modules will not be considered in this study.

1.5 Outline

The rest of this thesis is structured as follows. In chapter 2 – Theoretical background, the reader will be introduced to fundamental theories and concepts that are related to this study. In chapter 3 – Research method, the methodology of the study will be presented. In chapter 4 – Findings and analysis, a summary of the findings from the empirical studies will presented and the findings from the literature review will be presented. The findings from the literature review and the empirical data are then compared and presented together to answer the research questions and synthesize the guidelines. In chapter 5 – Discussion and conclusion, comparison to other studies, discussion of findings and discussion of methods are presented. Lastly, the conclusion and further research is presented.

2 Theoretical Background

In this chapter, theoretical background is presented to introduce and educate the reader on the relevant topics of this study. First, the main topic, Asset tracking (including RTLS) will be introduced. Then, the other main topic of this study, ERP, will be presented, including architecture of control systems (mainly MES and WMS). At last, the infrastructure of the combination of RTLS and ERP is presented.

2.1 Asset Tracking

Asset tracking refers to the identification and positioning of various physical assets. According to the asset management standard ISO55000, an asset is described as an item, thing or entity that has potential or actual value to an organization. Assets could be either physical or financial. In an industry context a physical asset could for example be a product, tool, human, or a carrier (Dempsey, n.d.). Asset tracking originates from the Identify Friend or Foe (IFF) technique developed by the Royal British Airforce during World War II which was based on standard radar technique. The IFF further developed into the Radio Frequency Identification (RFID) technique, which is the most common and well-known tracking techniques until date (Khattab et al., 2017). Nowadays, asset tracking is widely used in different kinds of industries, such as healthcare, security, logistics and manufacturing. Within manufacturing, asset tracking is most used for tracking of work-in-progress (WIP), production scheduling and material planning (Huang et al., 2017).

2.1.1 Real-time Locating Systems (RTLS)

When tracking assets in real-time, the term RTLS is most used. An RTLS system can be defined as “a combination of software and hardware used to automatically determine the coordinates of an object in real time within an instrumented area (e.g., person, materials, or equipment), allowing tracking and management” (Cwikla et al., 2018, p. 3). Fundamentally, an RTLS system consist of two parts: hardware for the tracking itself (tags, sensors, anchors etc.) and an IT system that receives and process the data. A basic design on an RTLS is presented in Figure 1 (Thiede et al., 2021).

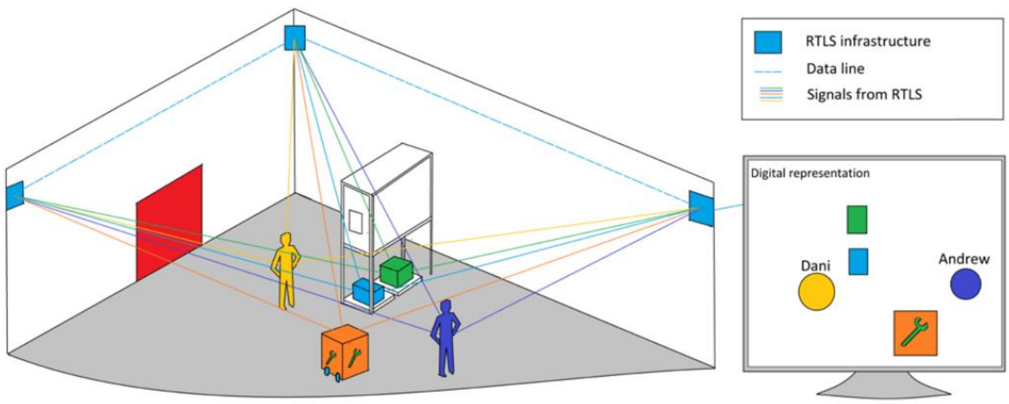

Figure 1. General design of an RTLS system (Thiede et al., 2021).

2.1.2 Tracking Technologies

Asset tracking can be enabled by different kinds of technologies. The most traditional methods being barcodes and RFID which allows items (assets) to be labeled and identified via electronic signals (Haddud et al., 2015). In recent years however, more technologies have been developed, offering different kind of solutions for different kind of scenarios. In a comparative study, Ahmed et al. (2020) created a framework for different tracking and positioning technologies. According to the authors, the basics of a tracking device consist of two key components: an identification unit and a positioning unit and depending on the demands and purpose of the tracking, different technologies have different advantages and disadvantages. For example, the RFID technology is cheap, but consist only of identification and must be detected by sensors to deliver a position. Bluetooth or Ultra-Wide Band (UWB), on the other hand, can both provide identification and real-time positioning but comes with a much higher cost. The technologies compared includes RFID, Bluetooth Low Energy (BLE), Ultra-Wide Band (UWB), Wireless Fidelity (Wi-Fi), Long Range Wide Area Network (LoRa WAN) and Global Positioning System (GPS) and are presented in Table 1. Summary of tracking and positioning techniques based on Ahmed et al. (2020

Table 1. Summary of tracking and positioning techniques based on Ahmed et al. (2020).

	RFID	**BLE**	**UWB**	**Wi-Fi**	**LoRa WAN**	**GPS**	**Image**
Operation	Identification	Identification	Identification and positioning	Identification and positioning	Identification and positioning	Identification and positioning	Identification
Range	< 1 m	5-50 m /reader	20-100 m /station	< 150 m	> 1 km	Unlimited (outdoor)	Depends on interferences
Accuracy	< 10 cm	2-3 m	< 30 cm	< 15 m	> 500 m	< 10 m	Depends on resolution
Smartphone compatibility	No	Smartphone readable tags	Smartphone readable tags	Yes	Yes	Yes	Yes
Installation	Expensive compared to BLE and UWB	Simple, plug-and-play	Simple, plug-and-play	Difficult, plug-and-play	Difficult, plug-and-play	None	Expensive
Tag cost	Ca 50 cents (passive tags)	\$5 - \$100	>\$100	>\$100	-	\$25-\$50	-
Power consumption	Low (Passive tags)	Low, but more than UWB and Wi-Fi	Low	Low	Low	Low	High

Further, Ahmed et al. (2020) emphasize that no tracking technologies are better than the other and that a combination of different solutions often is preferred. Generally, GPS and Wi-Fi are most suitable when range is important, UWB is the most accurate one and if infrastructure cost is mostly considered, UWB, BLE and RFID are the most preferred solutions.

There are several studies where different tracking techniques has been combined, developed, and tested. For example, Huang et al. (2017) and Frankó et al. (2020) both developed hybrid systems of UWB and RFID. To compensate for the lack of real-time positioning of RFID, the authors in both studies developed used UWB to enable real-time tracking while maintaining a relatively low price (compared to using UWB only). Similarly, Kao et al. (2017) developed a hybrid system using BLE and Wi-Fi where the accuracy of BLE was considered a suitable complement to the wide range of Wi-Fi.

In recent years, researchers have realized and investigated the impact of asset tracking in smart factories within the industry 4.0 paradigm. Konstantindis et al. (2018) developed a vision-based system for real-time tracking of products in a Cyber-Physical System (CPS) where product can be visualized in real-time in a virtual reality environment. Ahmed et al. (2020) underlines that just as outdoor tracking solutions, such as GPS, has revolutionized Supply Chain Management (SCM), indoor tracking solutions, RFID, BLE, UWB etc., will have a significant effect on the design of Smart Factories within Industry 4.0. It is evident that since the introduction of Industry 4.0, RTLS has received a significant increase in attention from researchers (Cwikla et al., 2018; Frankó et al., 2020; Řezáč & Soušek, 2018).

2.2 Industry 4.0

Industry 4.0 was introduced by the German government in 2011 and was introduced to inspire German industries to adapt new technologies to strive for higher efficiency and productivity (Frank et al., 2019). The term Industry 4.0 is somewhat fuzzy (Vestin et al., 2020). Fundamentally, it is characterized by complex integrations of assets through digitalization which will facilitate increased flexibility and productivity in the production processes (Lu, 2017). Despite the fuzziness surrounding Industry 4.0, Oztemel and Gursev (2020) presented an Industry 4.0 definition.

"Industry 4.0 is a manufacturing philosophy that includes modern automation systems with a cretin level autonomy, flexible and effective data exchanges encoring the implementation of next generation production technologies, innovation in design, and more personal and more agile in production as well as customized products." (Oztemel & Gursev, 2020, p.166).

One of the cornerstones within Industry 4.0 is the digital twin (Samir et al., 2019). A digital twin is a virtual reality of a factory that is fully integrated with physical assets in the production system. Sensors on the shop floor feeds the digital twin with real-life data that can be processed and simulated in the digital twin. In contrary, the digital twin can transfer data to the physical object to optimize the real-life operations (Tran et al., 2021b). A central component of Industry 4.0 is real-time capability, referring to the ability to collect and process data in real-time. Real-time capability is vital for creating an accurate digital twin (Schleich et al., 2017). Consequently, there is a relationship between the digital twin and RTLS.

2.3 Enterprise Resource Planning (ERP)

Enterprise resource planning (ERP) is a term used to describe software that support business-management. An ERP system facilitates information flow between all business functions and manages connections to outside stakeholders. Using a common database, an ERP system provides a continually updated picture of fundamental business activities. It is an integrated application which enable collection, storing, managing and interpretation of data from organizations daily business activities. An ERP system allow data to be shared across various departments (manufacturing, purchasing, sales, accounting). The shared data derive from tracking business resources: cash, raw materials, production capacity and of business commitment: orders, purchase orders and pay roll (Zabukovšek et al., 2020).

The evolution of ERP started right after the development of hardware and software systems. During the 1960s, centralized computing systems were designed, constructed, and implemented by most businesses, the majority of which used inventory control (IC) packages to automate warehouse inventory control system (Tavana et al., 2020). In the 1970s, Material requirement planning systems were created which mostly combined part requirements according to a predefined production schedule. Later, Manufacturing resource planning (MRP II) was created based on the MRP to optimize the material and production requisites in manufacturing processes. MRP II incorporated new functions such as shop floor, distribution management, project management, finance, human resource, and engineering (Kasem et al., 2017). In the late 1980s and the early 1990s, the first ERP systems appeared based on the technological foundations of MRP and MRP II, see Figure 2. It enabled enterprise-wide inter-functional coordination and integration, providing accessibility, visibility, and consistency across the enterprise (Hossain, 2003).

The functional areas in ERP systems are generally called ERP modules and during the 1990s ERP system vendors added more modules and functions as "add-ons". These gave birth for the extended ERP which include advanced planning and scheduling, customer relation management (CRM) and supply chain management (SCM) (Hossain, 2003). According to Kasem et al. (2017) does different ERP system vendors present systems with different features, however most packages are similar in core functionality.

2000s	Extended ERP
1990s	Enterprise Resource Planning (ERP)
1980s	Manufacturing Resources Planning (MRP II)
1970s	Material Requirements Planning (MRP)
1960s	Inventory Control Packages

Figure 2. ERP evolution (Hossain, 2003).

2.3.1 ERP Modules

An ERP system serves many purposes and thus, the system is commonly divided into sub-systems, also referred to as modules. There are several definitions of what a module is and what the different modules includes. Hossain (2003), Parthasarathy (2007) and Zabukovšek et al. (2020), all presented frameworks for the various ERP modules. Many similarities can be identified but also some differences. For example, Parthasarathy (2007) argues that there are only a few (4) core modules and that some of the core modules are built up of several sub-modules. In contrary, Zabukovšek et al. (2020) and Hossain (2003) argues that there are significantly more core modules (10-11). Yet, it is evident that some core modules are represented by all authors in some way, even though the level of details are different. Those are:

- Finance & accounting
- Manufacturing and Material management
- Warehouse Management
- Human Resource
- Sales & distribution

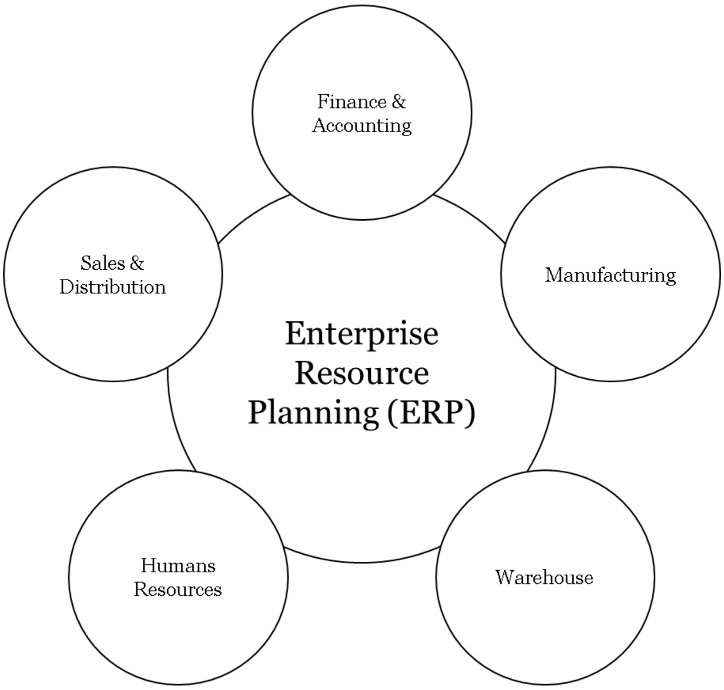

Figure 3. ERP core modules outline based on Hossain (2003), Parthasarathy (2007) and Zabukovšek et al. (2020).

Based on Zabukovšek et al. (2020), areas of data management for each module are presented in Table 2. The findings from the literature review will be placed in the most suitable module and presented accordingly.

Table 2. ERP modules data management based on Zabukovšek et al. (2020).

Manufacturing	• Corresponding to MES functionality • Managing data concerning the manufacturing process, from raw material to finished goods, excluding transportation of raw material, WIP´s and finished goods • Includes for example, Bill of Materials (BOM), work orders, scheduling, capacity, and workflow analyses
Warehouse	• Corresponding to WMS functionality • Managing data concerning internal transportation of raw material, WIP´s and finished goods and inventory management • Includes for example, planning and inventory management
Sales & Distribution	• Managing data concerning the sales processes from the sales of a product to delivery of the product • Includes for example, order processing, pricing, and delivery times
Human Resource	• Managing data concerning humans • Includes for example, training, pay and safety
Finance & Accounting	• Managing data concerning the enterprise finances and cost management • Includes for example, value of assets, and budgeting

2.3.2 Integration of ERP and Control Systems

The traditional ERP system is business centered and therefore not suited to manage manufacturing and warehouse operations on a more detailed level. Thus, it is common to use other applications that operates closer to the shopfloor (Yang et al., 2016). In a manufacturing context, these systems are referred to as Manufacturing Execution Systems (MES) and in a warehouse context, it is referred to as Warehouse Management Systems (WMS). Both the MES and the WMS can be placed in the third level of the ISA-95 pyramid (Kardos et al., 2013). The ISA-95 pyramid is a standard for describing the interfaces of control functions in an automated environment The third level refers to systems that operates close the shopfloor performing planning and scheduling on an hourly basis. In contrary, the ERP operates on a daily or sometimes even a monthly basis. (International Society of Automation [ISA], 2006). A construction of the ISA-95 pyramid together with ERP, MES, and WMS is presented in Figure 4.

MES

The MES was introduced to close the gap between the ERP and the shopfloor. The main objective of the MES is to manage shop-floor operations such as scheduling, control, material deliveries and consumption. Since the ERP is operating in a more long-term horizon that includes both internal requirements and external demands, the MES and the ERP should be integrated to support each other. The ERP supplies the MES with long term manufacturing plans whilst the MES perform short-term planning and reports back to the ERP (Yang et al., 2016).

WMS

Similar to the MES, the WMS can act as a bridge between the ERP and the warehouse operations. Modern warehouses are more than just places for storing goods and thus, they need an advanced system for warehouse management. The main objective of the WMS is to manage warehouse operations such as storage, order picking, packaging, and shipping (Halawa et al., 2020).

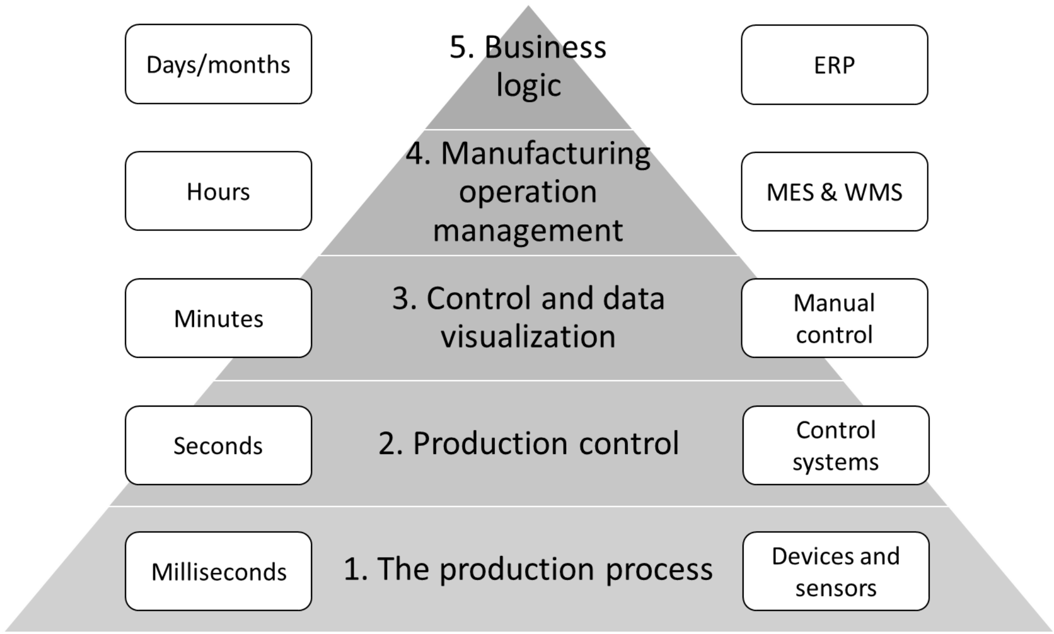

Figure 4. ERP, MES, and WMS displayed in the ISA-95 pyramid, based on Kardos et al. (2013) and ISA-95 (n.d.).

2.4 RTLS and ERP Infrastructure

An RTLS system consist mainly of two parts: hardware for the tracking itself (tags, sensors, anchors etc.) and an IT system that receives and process the data to prepare it for other applications within the IT structure (Thiede et al., 2021). Several records suggest that the RTLS needs to be integrated with the existing IT structure to facilitate companies to fully utilize the RTLS data to provide maximum business benefit (Husak et al., 2021; Kohn et al., 2005; Siemens, 2021; Thiede et al., 2021; Yang et al., 2016).

Ding et al. (2008) suggest that the RTLS structure includes four levels: the physical level, the operation level, the management level, and the application level. Similarly, Yang et al. (2016) also suggests that the RTLS structure consist of four levels: the shop-floor level, the object perception level, the information integration level, and the application services level. Siemens (2021) on the other hand suggests that there are three levels: shopfloor, locating infrastructure and ERP-layer. A combination of these three RTLS structure frameworks is presented below, see Figure 5.

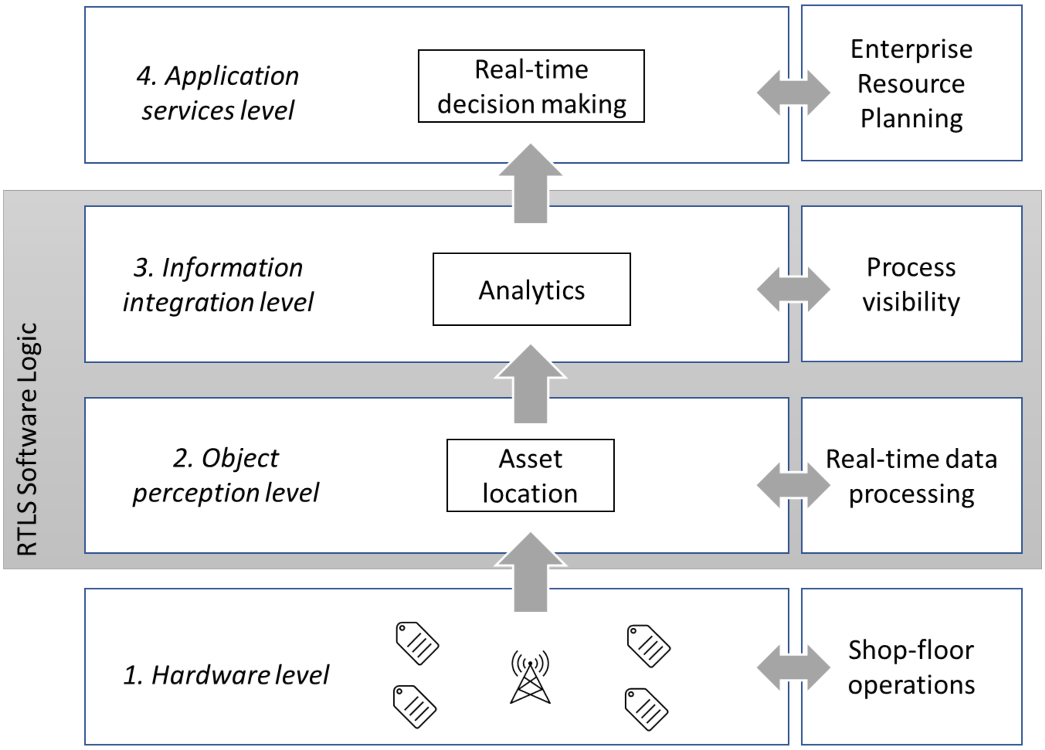

Figure 5. RTLS and ERP infrastructure based on Ding et al. (2008), Yang et al. (2016) and Siemens (2021)

1. In the hardware level, the hardware collects identification and location data.
2. In the object perception level, raw data from tags and sensors is transferred to IT servers that interpret the data to generate scattered position points of the objects and attach the ID of the tag to a physical object, for example a WIP or a human.
3. In the information integration level, the RTLS data can be presented as current location and identification of objects, thus providing process visibility. The system can also present history and future predictions of trajectory curves that can be used for analytics. According to Siemens (2021), this is where the initial business benefits are retrieved since manual improvement activities can be performed based on real-time data. However, to reach what they refer to as "next-level benefits", the RTLS must be integrated with other applications.
4. In the application services level, the processed RTLS data is utilized by other applications in the IT infrastructure. Systems such as MES, WMS and ERP can retrieve data from the RTLS and facilitate intelligent decision making, based on facts, in real-time. According to Siemens (2021), this is where companies can retrieve even greater efficiencies and business value. Kohn et al., (2005) emphasize that a traditional ERP cannot consider unexpected events. With RTLS data, the ERP can retrieve real-time data and adjust activities such as planning and scheduling to real world events.

3 Research method

This chapter presents the methods used in this study, including data collection methods together with data analysis and synthesis to answer the research questions and create the guidelines. First, the research process is presented. Secondly, the data collection methods and data analyses are presented and lastly, the data synthesis is presented.

3.1 Research Process

To answer the research questions and create the guidelines, the following research process been completed. The research process is illustrated in Figure 6.

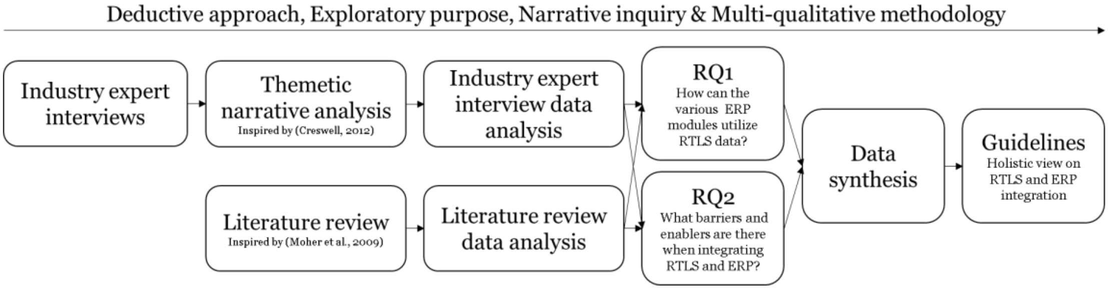

Figure 6. Research process.

The research process consisted of three main parts: the industry expert interviews, the literature review, and the data synthesis.

The first part of this study was the industry expert interviews, which account for the empirical data of this study. Thematic narrative analysis was applied to establish narrative themes raised in the interviews. The narrative themes were analyzed in the "Industry expert interview data analysis" stage to answer the research questions with empirical data.

The second part of this study was the literature review, which account for the theoretical data of this study. The purpose of the literature review was to organize applicability areas of RTLS to the various ERP modules and built themes of barriers and enablers. The theoretical data gathered were analyzed in the "Literature review data analysis" stage to answer the research questions with theoretical data.

The third part of this study was the data synthesis. In the data synthesis, answers for the research questions from both the empirical and literature side were synthesized to create the guidelines. The first research question provided the applicability areas of RTLS for the various ERP modules. The second research question provided barriers and enablers for the integration, thus presenting prerequisites for a successful RTLS and ERP integration.

This study takes a deductive research approach. The study has its origin in theory (the literature review) which is analyzed with theory (the ERP modules definitions by Zabukovšek et al. (2020)) which is assessed with empirical data (the industry expert interviews). Thereby, this study attributes from the generalized to the specific to create knowledge.

This study is of an exploratory nature. It is regarded as exploratory due to the formulation of the research questions. This study wishes to clarify the understanding of a certain issue or problem; the RTLS and ERP integration, thus concerning exploratory purposes. Furthermore, this study has conducted what is suggested by Saunders et al. (2016) to do in exploratory research: literature search and in-depth interviews in semi-structured form with experts in the subject. Additionally, in accordance with Saunders et al. (2016), the study's research process is of multi-method qualitative study due to its two data collection techniques.

Since this study collects qualitative data and uses interpretative style data analysis and synthesis it is regarded as qualitative research. The study has attempted to create a rigorous research process by being transparent, used established research methods and specified the contribution of the study. This is vital considering the methodological variation that qualitative research is characterized by (Saunders et al., 2016).

As the research process is considered qualitative, narrative inquiry was chosen as research strategy. Since both in-depth semi-structured interviews and literature reviews require interpretation of raw data in a specific context, narrative inquiry was suitable. In this study, raw data were considered as stories or narratives. Hence, extracting the data as codes, regardless of the context, could have provided misinterpretations of the raw data. Therefore, the thematic narrative analysis strove to interpret the data before extraction. Consequently, in line with Saunders et al. (2016), no raw data was extracted out of its context.

3.2 Industry Expert Interviews

As previously stated, conducting industry expert interviews were appropriate since it suits the exploratory purpose of the study. Also, conducting industry expert interviews were preferred since it provides a more efficient and concentrated data gathering method compared to, for instance, systematic quantitative surveys (Bogner et al., 2009). The strength of the industry expert interviews lays in the experience and knowledge provided by fewer, but more appropriate, respondents.

The sampling plan for respondents was settled together with the company that has initiated and supported this study: a production- and logistics development solutions provider. The sampling plan aimed to acquire respondents knowledgeable in RTLS, ERP systems or managing production development. Moreover, the sampling plan aimed to acquire respondents with manager experience or respondents currently managing manufacturing enterprises. The purpose was to provide comprehensive business knowledge and thereby provide holistic insights in RTLS areas of applicability for the various ERP modules and the industry's view on barriers and enablers for RTLS and ERP integration.

Four interviewees were selected from the production and logistics development solutions provider's network of contacts. The industry experts had numerous years of industry experience, both from their previous and current roles. The first industry expert worked at a Swedish shop fitting manufacturer large enterprise, LE) as a logistics consultant and has worked as a consultant for 9 years. The second industry expert worked at a Swedish ERP supplier (LE) as Managing Director for 9 years. The third industry expert worked at an Italian RTLS supplier (small/medium sized enterprise, SME) as a COO for 13 years. The fourth industry expert worked at a Swedish manufacturer (SME) as a CEO for 7 years.

The collection of empirical data attempted to offer perspectives from both system users and system providers to acquire a broader view to RTLS and ERP integration. The attempt to acquire a broader view of the subject investigated was to realize the transferability of the results.

Before the interviews, an interview guide document was sent out to the interviewees, see Appendix 1. The interview guide contained a presentation of the forthcoming interview questions together with basic theory on the topic of RTLS. The interview guides were sent to the interviewee to ensure that the interviewee was prepared and up-to date in the topic questioned. However, the information concerning applicability and barriers and enablers for an RTLS and ERP integration found in literature was limited in attempt to minimize the influence from the authors explanation to the subject. Before sending out the interview guide documents, it was presented to, and evaluated by, the study's supervisor in effort to make the interview guide as comprehensible as possible.

Each of the interviews were performed in Microsoft Teams and both authors were present during all interviews. The responsibilities of each author were predetermined. One was responsible for making sure all the questions were assessed and the other took annotations of the answers. This was done to ensure fuller data collection and be able to discuss and establish a common picture of the data. Moreover, the interviews were video recorded to ensure that no information was forgotten, thus enable the possibility to return to the original data and not solely rely on annotations.

Each interview started with an explanation of the content of the interview and an introduction to the topic, connecting back to the interview guide document. These actions were selected to increase credibility in data to support trustworthiness. In line with semi-structure interviews, certain themes and questions were required to be answered (Saunders et al., 2016) and both closed- and open-ended questions were included, which is characteristically for semi-structured interviews (Adams, 2015). However, during the interviews, the interviewees were encouraged to speak freely, and the authors intentionally avoided to interrupt the industry experts. This was done to obtain answers with as little involvement from the authors as needed and thus, avoid affecting the industry experts and thereby influencing the empirical data. Moreover, "digging questions" were asked during the interviews to obtain a richer answer from the industry experts. The digging questions were not systematically applied throughout the interviews. Instead, they were presented spontaneous and based on the current context of the interview to richen the industry expert answers. The digging questions had their basis of 5W, which are: Who, What, Where, When and Why. The interviews conducted are presented below, see Table 3.

Table 3. Conducted interviews.

Interview	Date	Company	Role	Duration
1.	2022-04-01	Manufacturing company 1	Logistics consultant	60min
2.	2022-04-06	ERP supplier	Managing Director Southeast Asia	80min
3.	2022-04-20	RTLS supplier	COO of Operations and Supply Chain	70min
4.	2022-04-26	Manufacturing company 2	CEO	40min

3.2.1 Thematic Narrative Analysis

The thematic narrative analysis was chosen because of the few but rich, in-depth interviews and the semi-structure approach of the interviews. Moreover, to maintain significance in the interview data and create transparency and traceability in the research process, the context of the interview data was regarded as important. Therefore, thematic narrative analysis was chosen due to its purpose to identify analytical themes within narratives (Saunders et al., 2016).

The thematic narrative analysis was structured with inspiration from the qualitative content analysis scheme by Creswell (2012). Since the study was of exploratory purpose, the industry experts were encouraged to speak freely with support of the questions in the interview guide document. This resulted in rather unstructured raw interview data, which required assessment to make sense of the transcript. On that part, the qualitative content analysis scheme by Creswell (2012) was utilized to break down the interview data and building it together to make logical and relevant presentation of the empirical data. Connecting back to narrative inquiry, the decomposing of the interview data and building it together was carefully executed to ensure that no context or narrative was lost. The qualitative content analysis scheme by Creswell (2012) is presented below, see Figure 7.

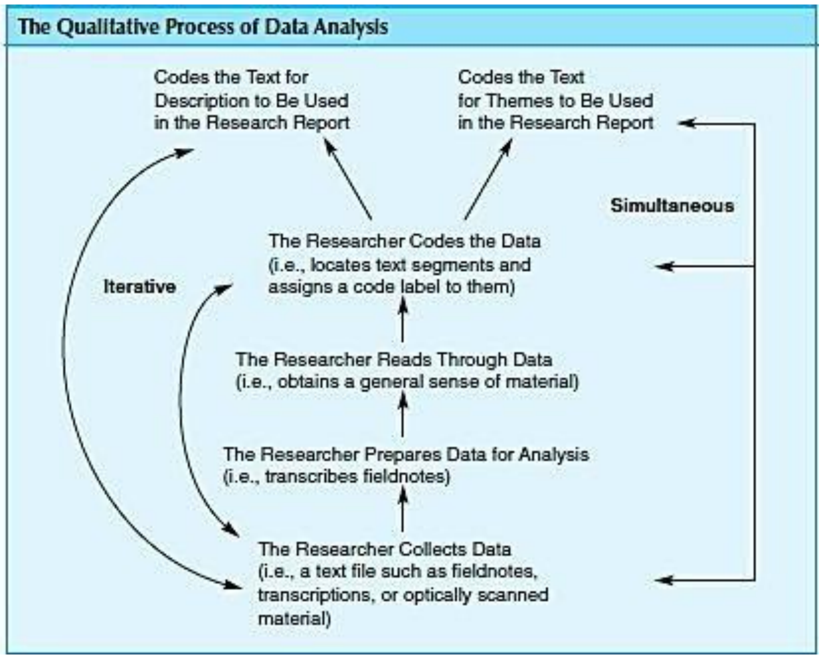

Figure 7. Qualitative content analysis scheme (Creswell, 2012).

Following the scheme by Creswell (2012), transcripts were collected through the video recording of the interviews with the industry experts. Each transcript was read-through by both authors together with the video recording to ensure that the transcript was correct and to make both authors familiarized with the interview data. Once the transcripts were read-through, segments and sentences of the transcripts were coded. The codes later allowed building data together to create narrative themes that each industry expert discussed, thus provide a clearer presentation of the empirical findings. The analysis process of the interview data was, in accordance with Creswell (2012), iterative to ensure that no relevant information was left out. The result of the thematic narrative analysis is presented in Appendix 2. The process of extraction and building of data together is presented below, see Figure 8.

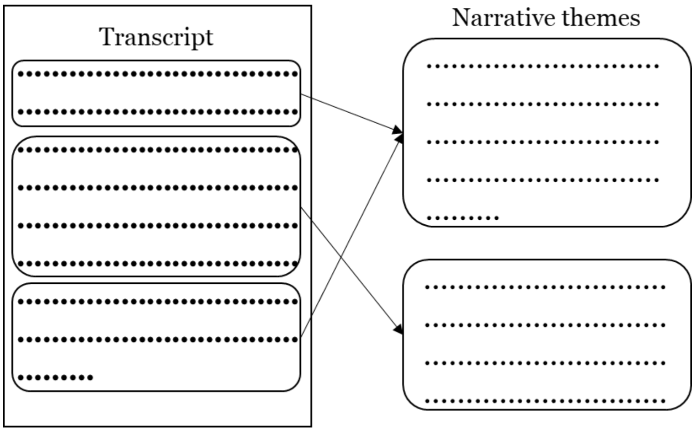

Figure 8. Narrative extraction.

3.2.2 Industry Expert Interview Data Analysis

The information required to be collected for answering the research questions was predetermined: the applicability areas, and barriers and enablers for RTLS and ERP integration. In other words, how RTLS can be utilized in the integration with ERP and what the barriers and enablers there are for RTLS and ERP integration. To obtain this information, the narrative themes were analyzed to organize applicability areas of RTLS to the various ERP modules and extracting barriers and enablers.

The interview expert data analysis consisted of two steps. In the first step, areas of applicability and barriers and enablers was extracted from the narrative themes, displaying the findings for each industry expert. The areas of applicability were organized based on Zabukovšek et al. (2020) definitions on ERP modules. Still, most connections between areas of applicability and the various ERP modules were provided by the industry experts during the interviews. Hence, less interpretation was required to organize the areas of applicability.

In the second step, the extracted applicability areas, and barriers and enablers, from all the industry experts were merged into a shared empirical view, answering the two research questions. Further, to be able to answer the second research question, the barriers and enablers from the shared empirical view were organized into themes established from the literature review. This way, the empirical data could be compared to the theoretical data in the data synthesis stage. The industry expert data analysis process is presented below, see Figure 9.

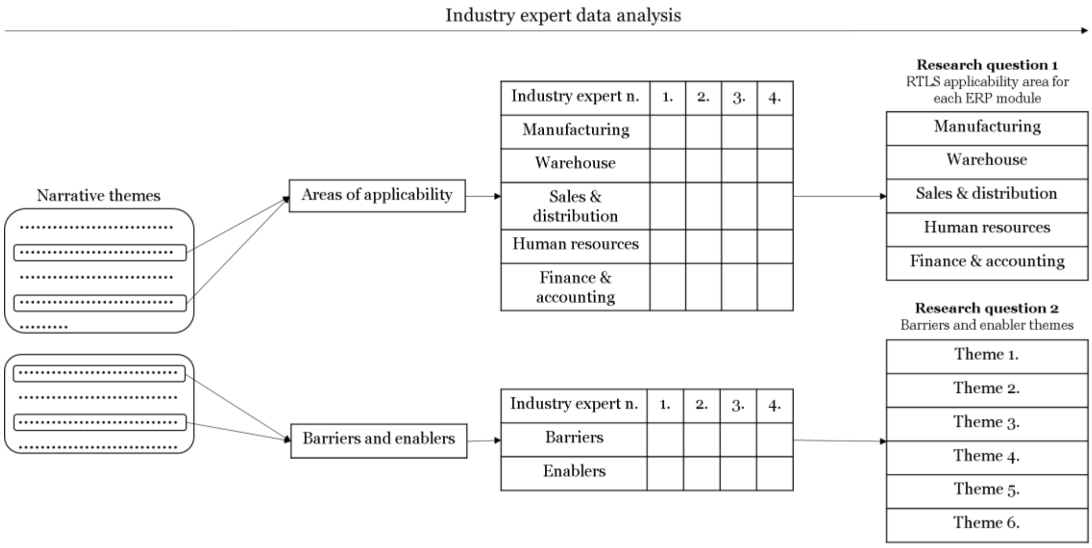

Figure 9. Industry expert data analysis.

3.3 Literature Review

This study covers RTLS and ERP module integration which is poorly covered in the research community. Therefore, the literature review is crucial since it examine what is already known and outline gaps in the research knowledge (Easterby-Smith et al, 2018). The systematic literature review was chosen due to its practice to discover established literature, assess the contribution, analyze, and arrange the findings and determine conclusions about what is known and, also, what is not known (Saunders et al., 2016). The purpose of performing a systematic literature review was, in accordance with Denyer and Tranfield (2009), to create an approach which is replicable, scientific, and transparent to minimize bias. This contributed to the rigorousness of the research process.

The literature review was conducted using the indexing database Scopus. Scopus was chosen as search database because it delivers the broadest coverage of any interdisciplinary abstract and citation database. Thus, using Scopus reduced the risk of unwanted exclusion of relevant information in the literature review. First, synonyms of RTLS were identified to decide the keywords in the search string. The identification of synonyms was completed by skimming through RTLS articles in Scopus before the systematic literature review. This was crucial to ensure that no relevant literature was missed by not including the necessary keywords.

It is crucial to be open and explicit about the processes and methods applied in the systematic review (Denyer & Tranfield, 2009). Therefore, to demonstrate how the literature review was conducted, a collection procedure was created. The collection procedure created was inspired by the flow diagram for systematic reviews by Moher et al. (2009), see Figure 10.

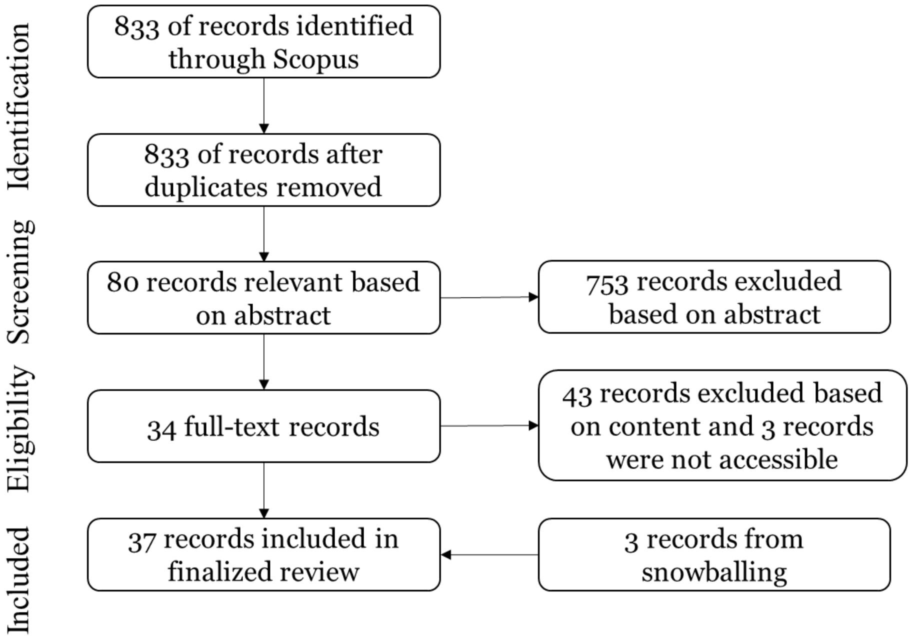

Figure 10. Literature collection procedure.

The first step in the literature collection procedure was identification. The literature search string applied in Scopus included five keywords searching in article title, abstract and keywords. The five keywords identified are presented in the search string below. The wildcard character was added to "locat" and "positio" in the keywords to include differences in spellings and endings recognized during the skimming of RTLS articles before the systematic literature review.

TITLE-ABS-KEY ("real time locat system" OR "real time positio* system" OR "real time asset tracking" OR "real time indoor positio* system" OR "real time indoor locat* system")*

The formulation of the search string intended to obtain relevant articles and to exclude articles that simply did not mention any of the keyword in its text. The first step of the literature procedure identified 833 records. Since only one database was used, there was no duplicates to remove.

The second step in the collection procedure was the screening of all records found. All abstracts of the records were read trough to determine relevance. During the screening, the records were exported from Scopus to an Excel sheet where the records were categorized as relevant or irrelevant. The relevance of the records was determined by the following inclusion and exclusion criteria.

Inclusion criteria:

The paper must be an article, a conference paper, or a review.

The language must be English.

The purpose, or actions to fulfill the purpose, of the record is to propose, develop or/and test an RTLS.

The purpose, or actions to fulfill the purpose, of the record is to review proposals, developments or/and tests of an RTLS.

The purpose, or actions to fulfill the purpose, of the record is to obtain industry and/or industry expert view on RTLS.

The RTLS is applied in a manufacturing context or in a manufacturing company.

Exclusion criteria:

The purpose of the record is exclusively technology focused, e.g., “the purpose is to improve accuracy” or “developing an algorithm”

Context not related to manufacturing or applicable to manufacturing companies. Excluded contexts:

- Hospital/healthcare
- Construction
- External logistics/transport (air, sea etc.)
- Office spaces
- Surveillance/security industry

The screening phase resulted in 80 relevant records and exclusion of 753 records. The third step in the collection procedure was to determine eligibility. Out of the 80 records, 10 records were not available to open for full text through Scopus. These 10 records were requested through the library of Jönköping University. Out of the 10 records, 7 records could be found through the library’s service. One of the records accessed through the library’s service was found to have been removed from Scopus. The removed record was excluded from the literature review to assure that all included records met the scientific requirements from Scopus. To settle eligibility, the full text of the 76 records were skimmed through. The eligibility was determined based on the previous inclusion and exclusion criteria and non-relevant the records were excluded. The eligibility phase resulted in 34 relevant records and 43 excluded records. The fourth step in the collection procedure was executed during the thematic analysis. The technique “backwards snowballing” was applied on the 34 records found in the eligibility phase. The backwards snowballing suggested tracking interesting references and the references of interest were chosen based on their information about ERP connection. During the fourth phase, 3 records was found and finalized the total records in the literature review to 37 records. Number and type of record is presented below, see Figure 11 and Figure 12.

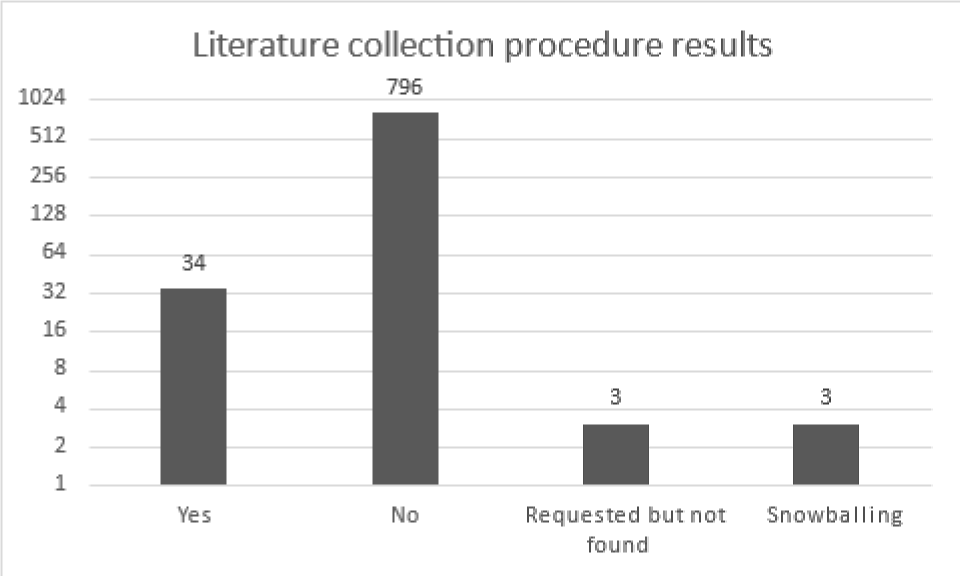

Figure 11. Result of the literature collection procedure.

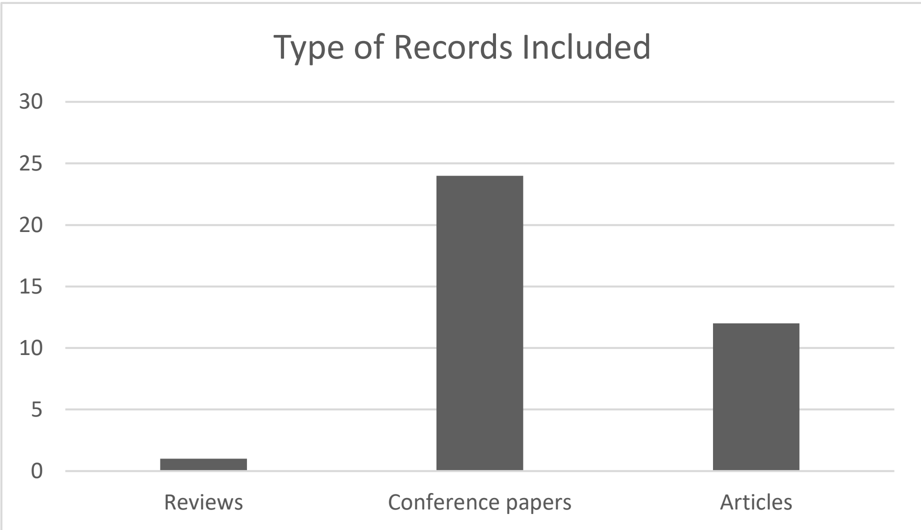

Figure 12. Type of records included.

3.3.1 Literature Data Analysis

The information required to be collected for answering the research questions was predetermined: the applicability areas, and barriers and enablers for RTLS and ERP integration. In other words, how RTLS can be utilized in the integration with ERP and what the barriers and enablers there are for RTLS and ERP integration. First, the finalized records were familiarized by reading through and highlighting data concerning areas of applicability and barriers and enablers for ease of extraction. Secondly, the highlighted data on areas of applicability were organized to each ERP module. The process of organizing the highlighted data was based on Zabukovšek et al. (2020) definitions on ERP modules. The highlighted data of RTLS applicability were interpreted and organized by both authors to organize the applicability areas to each ERP module. In contrast, the organizing of data on barriers and enablers did not have previous categories. Therefore, themes of the highlighted data were constructed during the literature data analysis. The literature data analysis process is presented below, see Figure 13.

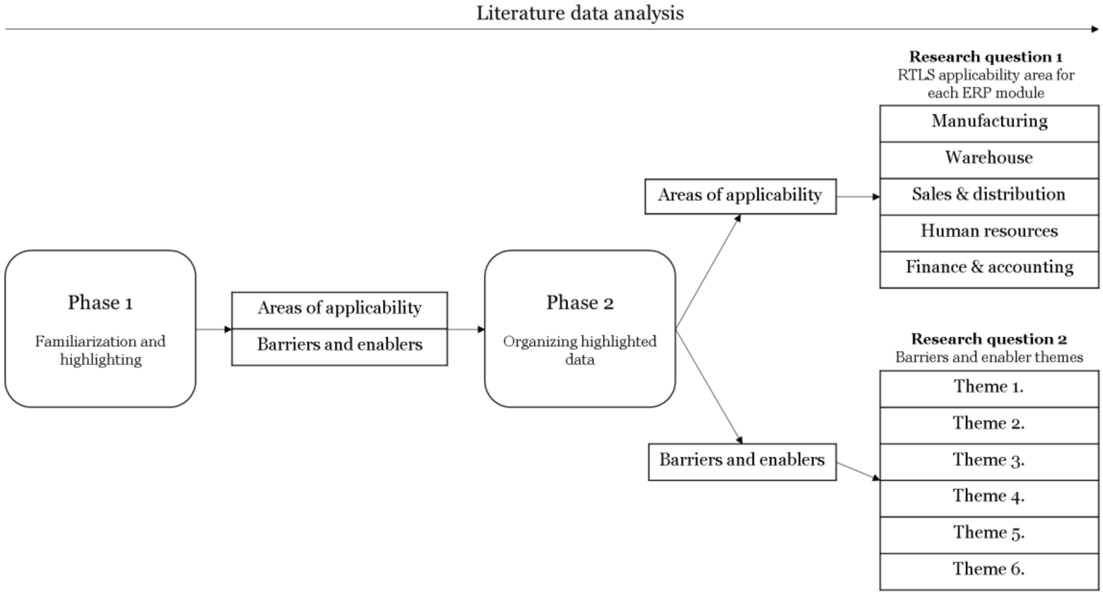

Figure 13. Literature review data analysis.

3.4 Data Synthesis

The data synthesis combined the knowledge gained from both empirical and theoretical results to create the guidelines of RTLS and ERP integration. From the first research question, applicability areas of RTLS for each ERP module is used to display the potential advantages of integrating RTLS and ERP. From the second research question, the barriers and enablers are presented as fundamentals or prerequisites for an RTLS and ERP integration.

First, the content in each ERP module from both the industry experts and literature review were synthesized into one guideline step. Secondly, the content in each barrier and enabler's theme from both the industry experts and literature review were synthesized into four guideline steps. Thirdly, the five guideline steps were determined to which order the steps will arise. The order of the guideline steps was determined through iterative discussion, justification, and interpretation of the five steps. The industry expert narrative themes helped to grasp the context to which the barriers and enablers arose, therefore eased justification of guideline step order. The data synthesis and creation of guidelines process is presented below, see Figure 14.

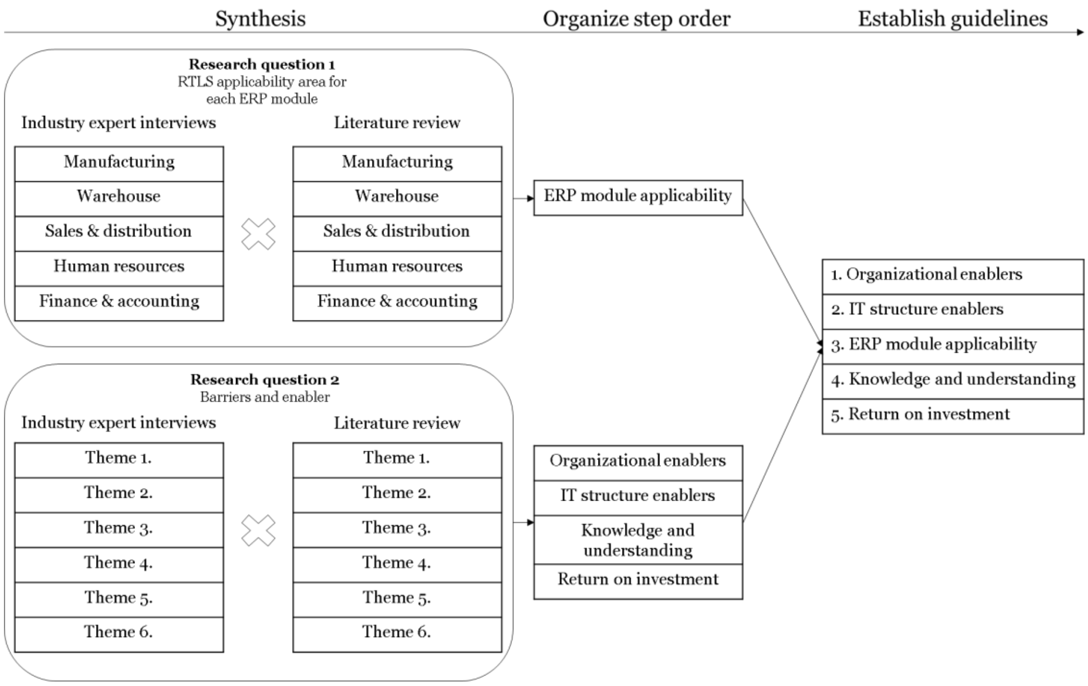

Figure 14. Data synthesis and creation of guidelines.

3.5 Research Quality

This study is considered of qualitative focus, since it is of interpretative character where logic is pursued by the researchers (Saunders et al., 2016). With a qualitative focus, the research quality encompasses the entire research process (Patel & Davidson, 2016). Since this study is a qualitative study, trustworthiness is considered rather than conventional terms, such as internal and external validity, reliability, and objectivity (Hoepfl, 2000). Lincoln & Guba (1985) introduced the concept trustworthiness, including four evaluation criteria: Credibility, Transferability, Dependability and Confirmability.

Credibility

Credibility refers to confidence in the truth of the findings. Credibility in information sources is the most significant criteria for trustworthiness. Without credibility in the information sources, the reader will not be able to identify the findings, discussions, and conclusions as credible (Lincoln et al., 1985). To address credibility, this study has used data collection triangulation and researcher triangulation. This was done in accordance with Saunders et al. (2016) to overcome fundamental biases and offer a more balanced explanation to the reader. Moreover, an interview guide was sent to the interviewees before the interview to give them time to prepare and receive basic up-to-date information on the topic. Furthermore, peer debriefing has been held during the research process to review the information presented. Additionally, in accordance with Lincoln and Guba (1985), data sources are clearly identified from where the data originates from. More specifically, data is punctiliously referenced for each industry expert and record from the literature review to support credibility.

Transferability

Transferability refers to generalizability, showing that the findings are applicable to other contexts. In line with Lincoln and Guba (1985), this study has attempted to provide a thick description of the research object to enable transferability of the findings. As a result of the purpose and choice of methods, this study access transferability. The purpose aimed to present broad knowledge, hence reach transferability. Furthermore, the choice of interviewing industry expert enabled the study to receive data which are less company specific rather more industry's view on the RTLS and ERP integration, thus supporting transferability. Moreover, this study's extensive literature review connects the result to already established literature, thus supporting transferability.

Dependability

Dependability refers to the findings being consistent and possible to repeat. Too realize dependability, the research process is required to be logical, traceable, and clearly documented (Tobin & Begley, 2004). This is achieved by thorough description of each step in the research process in accordance with (Tobin & Begley, 2004), such as providing the search string, clear inclusion and exclusion criteria, presenting the interview guide and context of the industry experts. Moreover, each step (including the content) of the systematic literature review is presented, thus aid transparency and traceability. Some dependability may be left out by not including interview transcripts in appendix. However, this action was not considered necessary. Then again, presenting the industry expert narrative themes allow insight in data interpretation and analysis, thereby supporting dependability.

Confirmability

Confirmability refers to neutrality or establishment that the interpretations and findings clearly derive from data. According to Guba & Lincoln (1989), confirmability is achieved when credibility, transferability, and dependability, are fulfilled which is previously addressed. Moreover, Tobin & Begley (2004) states that to realize confirmability, demonstration is needed of how the interpretations and conclusions were reached. To achieve confirmability in this study, in line with Koch (1994), each step in the research process has not only been presented, but also justified to be transparent with decisions taken in the study. By pursuing all previous aspects of trustworthiness, the realization of confirmability has been supported. Neutrality in interpretations and findings to achieve confirmability has been attained by both authors assessing all issues together and utilizing peer-briefing during the research process for evaluation. Neutrality have also been attained by executing the literature review before the interviews were held. This is in line with Bogdan (1998) since the literature review offered more knowledge to the subject. Therefore, the quality of the interviews could be increased, prejudices avoided, and biases decreased. Additionally, the study has presented how interpretations and conclusions have been reached through the descriptive research process, which is desired to realize confirmability (Tobin & Begley, 2004).

3.6 Ethical Considerations

This study has considered the following ethical principles by Saunders et al. (2016), that was found relevant for this study.

Integrity and objectivity of the researcher

To achieve integrity and objectivity, the authors have acted openly and truthfully. This principle is also coupled with the minimizing of bias, striving to present accurate collected data and result where both correspondence and non-correspondence in findings and result is presented. Additionally, to help this principle, both authors were involved in all actions in the research process to receive more accurate interpretations.

Furthermore, peer debriefing was applied to help interpretation of data and research process quality.

Avoidance of harm

To achieve avoidance of harm, the research process was formed to minimize risks for negative effects of the well-being of the interviewees. The risks have been minimized by assuring anonymity of the interviewees. In addition, a voluntary nature to participation and the semi-structured interviews allowed the interviewees freedom and they were not forced to answer certain questions.

Informed consent of those taking part

This principle is coupled with *Voluntary nature of participation and right to withdraw* (Saunders et al., 2016). The respondents in this study were asked to participate voluntarily and their part to this study was explained. The interview guide document was sent out before the interview helped the respondents to grasp the scope of the study and consent if they wanted to participate or not. Moreover, the interviews were video recorded with consent from all respondents.

Responsibility in the analysis of data and reporting of findings

This principle is coupled with *Privacy of those taking part and Ensuring confidentiality of data and maintenance of anonymity* (Saunders et al., 2016) of those taking part. To achieve anonymity of those taking part, names of the industry experts and their employers have been left out. There are however some personal information provided about the industry experts and their employers since it intends to give context and justification of why they were chosen as respondents. Confidentiality is supported by not sharing the interview video recordings with anyone but the author. The analysis and reporting of findings also rely on the integrity and objectivity of the authors. As previously stated, accurate findings and result of both correspondence and non-correspondence and clear acknowledgement of data source has been presented. Additionally, the industry experts' interests (depending on if they were suppliers of RTLS or users of RTLS) were in consideration whilst interpreting the data. This ensured awareness of biases in the perspectives given from the different industry experts.

4 Findings and Analysis

The findings and analysis chapter begin with a summary of the data found in the industry expert interviews for each expert, followed by a presentation of the findings from the literature review. Later, the empirical and theoretical answers to the first and second research question are displayed. Lastly, the result from the data synthesis resulting in the guidelines is presented.

4.1 Empirical findings

The findings from the industry expert interviews on RTLS applicability for the various ERP modules, and barriers and enablers for an RTLS and ERP integration is presented in this section.

The RTLS applicability areas for the various ERP modules were extracted from the narrative themes and organized for each industry expert. Consequently, the industry experts represent a column each, and ERP module represent a row each, see Table 4.

Table 4. Summary of RTLS applicability areas for each ERP module per industry expert interview.

	Ind. Ex. 1	**Ind. Ex. 2**	**Ind. Ex. 3**	**Ind. Ex. 4**
Role	Logistics consultant	Managing director	COO	CEO
Business	Industry	ERP supplier	RTLS supplier	Industry
Manufacturing *(WIP, humans, tools)*		- Automatic production order timestamps - Measuring non-value adding time - Tool localization and registration - Human tracking for productivity purposes - Scheduling based on real-time data		-Automatic production order timestamps -Continuous current state analysis
Warehouse *(vehicles, material)*	- Tracking of forklifts to locate bulk batches (WIP), e.g., gravel/bricks or other large batches, e.g., barrels in a brewery - Real-time and automatic stock-taking	- Automatic stock transfers	- Logistics analytics (heat maps & spaghetti diagrams) - Mission scheduling optimization - Forklift guidance system (FGS)	
Sales & distribution	- Track and predict lead times of outgoing goods	- Goods tracking		-Automatic production order timestamps
Human Resources	- Track effective work time	- Human and forklift tracking for safety purposes		-Automatic employee timestamping
Finance & accounting	- Real-time automatic stock-taking			

The barriers and enablers for an RTLS and ERP integration were extracted from the narrative themes and organized for each industry expert. Consequently, the industry experts represent a column each, and the barriers and enablers represent a row each, see Table 5. As mentioned earlier, “Barriers” is defined as reasons for tentativeness and resistance to investing and implementing RTLS. “Enablers” is defined as prerequisites for success when implementing RTLS and integrating with ERP.

Table 5. Summary barriers and enablers for RTLS and ERP integration per industry expert interview.

	Ind. Ex. 1	**Ind. Ex. 2**	**Ind. Ex. 3**	**Ind. Ex. 4**
Barriers	- Cost for large volumes of goods - Conventional ERP systems cannot interpret RTLS data - Difficult to make profitable ROI´s - Lack of standardized IT interfaces	- Undeveloped production systems and IT structure in some parts of the world	- Cost - Difficult to make a business case - Technology inaccuracy - Difficult to create interfaces between outdated IT systems	-Cost for integration -Lack of experience about solution -Resistance towards tracking
Enablers	- Operational processes needs to be mature and efficient - Up-to-date and standardized IT systems - Understanding of how to utilize the RTLS data - Important to have a WMS or specialized ERP to fully benefit from the RTLS	- High cost for manual labor (geographic location) - Company maturity - Up-to-date IT structure - Integration is simple - Their ERP is specialized towards manufacturing (similarly to MES)	- Up-to-date and specialized IT systems - Important to integrate with WMS - Suggests a digital twin for processing and visualization of RTLS data	

4.2 Literature review

In this section, the findings from the literature review will be presented. First, a summary of the findings on RTLS applicability for each ERP module is presented. Then, a summary of identified barriers and enablers is presented. Next, all RTLS applicability for each ERP module will be presented in detail. At last, the barriers and enablers will be presented in detail.

The RTLS applicability areas received from the literature review were organized to the various ERP modules based on Zabukovšek et al. (2020) definitions. Therefrom, the ERP module represent a row each and the RTLS applicability areas from the literature review represent the column, see Table 6.

Table 6. Summary of theoretical findings on RTLS applicability areas for each ERP module.

ERP modules	**RTLS applicability areas from literature review**
Manufacturing	- Asset localization, including tools, WIP´s and carriers - Automation of manual tasks, including automatic order status checks and automatic production order timestamping - Dynamic production scheduling (scheduling based on real-time data) - Dynamic performance analysis, including dynamic VSM, performance measurements (cycle times, waiting times etc.), workflow analyses (e.g., heat maps) and identification of non-value adding activities
Warehouse	- Asset localization, including WIP/carriers and vehicles - Automation of manual tasks, including automatic stock-taking and stock-transfers - Vehicle productivity analyses, including spaghetti diagrams and heat maps - Route optimization - Vehicle guidance systems, including AGV´s and manually driven forklifts
Human Resources	- Tracking of worker productivity, including work time tracing - Worker safety, including tracking of forklifts and humans to prevent collisions and location of humans in dangerous zones
Sales & Distribution	- Real time customer order status, including expected lead time and time of arrival - Increased after-sales services
Finance & Accounting	- Real-time inventory control, including real-time automatic stock-taking

The barriers and enablers received from the literature review were organized and grouped into themes. Therefrom, the themes represents a row each and the barriers and enablers from the literature review represent a column each, see Table 7.

Table 7. Summary of barriers and enablers found in the literature review.

Barrier & Enabler Themes	**Barriers**	**Enablers**
IT Structure and Integration	- Lack of standardized IT interfaces	- Integrating RTLS with specialized IT systems such as MES and WMS - Industry 4.0, including cheaper and more accurate technology - Having a visualization tool such as a digital twin
Knowledge	- Lack of knowledge	- Training and education
Process Maturity		- Adaption of operational changes and production system
Enterprise Characteristics	- Low value of the assets - More difficult to find ROI for SME´s	- High value of the assets - Easier to find ROI for large enterprises
Privacy	- Privacy issues when tracking humans	- Activate tracking of humans only when entering the shop floor (suggestion)
ROI	- Cost of hardware and software and integration - Difficulties in calculating savings	

4.2.1 Manufacturing Module

Asset localization is considered applicable for the manufacturing module due to its management of capacity, work orders and scheduling. Thiede et al. (2021) suggest that tools can be shared and used over the whole factory and thus, location of the tools is of interest. The status and availability of the tools is also of interest and can be extracted. Kelepouris and McFarlane (2010) showed considerable time savings by tracking shared tools within production facilities. Searching time was reduced for all tools, however RTLS were justified for more frequent used and smaller tools compared to larger and less used tools. Nian et al. (2014) points out that the result if tools and measuring tools etc. cannot be found in time is that operators cannot conduct the scheduling plan in MES, therefore should tools be located and tracked. They simulated a dynamic production scheduling system connected with RTLS, which showed significant improvement of cycle times and machine utilization especially when product variants increase. Similarly, by knowing the location and status of critical asset, RTLS will enable proactive management over the production flow, prioritize tasks and optimize asset utilization (Cwikla et al. 2018). Likewise, RTLS enabled shop floor operations to react to circumstances such as rushed orders, machine downtimes and delayed raw materials at truly short notice to adjust the situation (Nian et al., 2014). RTLS tracking tools and equipment can also prevent losses, thereby saving time and avoiding purchase replacements (Geier and Bell, 2001). According to Cwikla et al. (2018), users of RTLS can identify the location and status of every product etc. Thiede et al. (2021) explained that the value adding material flow is usually connected to work orders, therefore it is of interest to know the status. Being aware of the location and status allow decision making based on real-time data, elimination of manual production status checks, automatic identification, and location of process performance issues.

Dynamic scheduling is considered applicable for the manufacturing module due to its management of capacity, work orders, scheduling, and material management. Several authors discussed improved scheduling as a benefit from utilizing an RTLS (Cwikla et al., 2018; Ferrer et al., 2011; Nian et al., 2014; Thiesse & Fleisch, 2008). Nian et al. (2014) simulated a dynamic production scheduling system connected with RTLS, which showed significant improvement of cycle times and machine utilization especially when product variants increase. If WIP's, cannot be found in time, operators cannot carry out the scheduling plan in MES. The RTLS enabled shop floor operations to react to circumstances such as rushed orders, machine downtimes and delayed raw materials at noticeably short notice to adjust the situation. Similar outcomes were found by Gorldt et al. (2007) which presented a possible solution of tracking cars in a variable storage area. The solution always provided exact position of each car which removes the need of searching and therefore leads to time reduction. The solution resulted in increased transparency in the process. Likewise, tracking load carriers to be able to locate specific orders and determine the status of the carriers to remove the time-consuming search for the carriers (Gutewort et al., 2021). Ferrer et al (2011) simulation showed moderate improvements in flowtime by knowing the components' location for reducing search time, however not all parameters could be considered in the simulation.

Moreover, RTLS enables proactive management over the production flow, prioritize tasks and optimize asset utilization (Cwikla et al., 2018). Similarly, Thiesse and Fleisch (2008) emphasized the strategic relevance of flexibility that RTLS can provide in unguided manual processes and the process control capacities of traditional automation technology. Better performance indicators can assist companies in their production planning and control, for example optimization of dispatching rules, in complex and flexible production systems. In conclusion, flexibility in production of controlling and coordinating a wide range of variants can be supported by RTLS. Ferrer et al. (2011) consider that the accurate worktimes provided by RTLS have given businesses the opportunity for better scheduling and therefore enabling cost savings.

To improve scheduling, Řezáč and Soušek (2018) used zoning and RTLS to monitor and predict the workload in different workplaces at an assembly hall at a car manufacturer. Every workplace was represented by a zone and the cars (the WIP´s) were each tracked individually. By visualizing the workplaces (the zones) and all the cars, management personnel could identify bottlenecks as some zones was exceeding its capacity or predict future occupancy of zones depending on the next destination of the cars, see Figure 15.

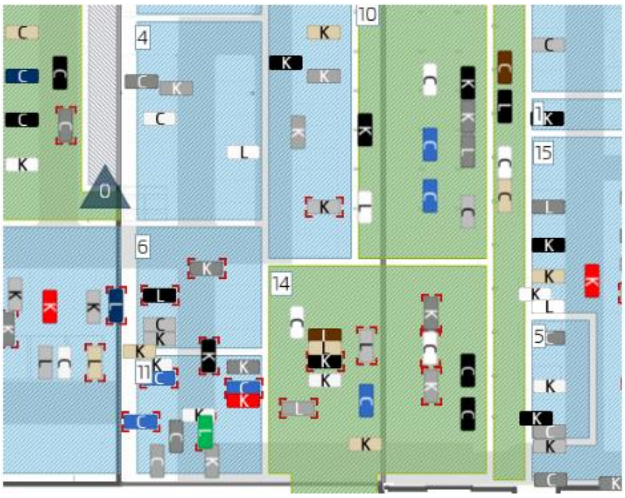

Figure 15. Visualization of assembly zones (workplaces) and cars (WIP) at an assembly hall (Řezáč & Soušek, 2018).

Dynamic performance analysis is considered applicable for the manufacturing module due to its management over workflow analyses. Several authors mention RTLS in WIP analysis purposes. Arkan and Van Landeghem (2013) used RTLS to create a spaghetti diagram of WIP´s to detect bottlenecks. Ruppert et al. (2020) demonstrated dynamic spaghetti diagrams and heat maps of WIP's in a dedicated production line. The authors argue that by tracking accurate time and location of WIP´s, KIP´s such as cycle times and waiting times can be accurately measured. The authors found that when the product mix contains many variants with unique cycle times, the dynamic spaghetti map and heat map are suitable tools for optimization of production planning and utilization of equipment. The dynamic spaghetti diagram and heat map is illustrated below, see Figure 16.

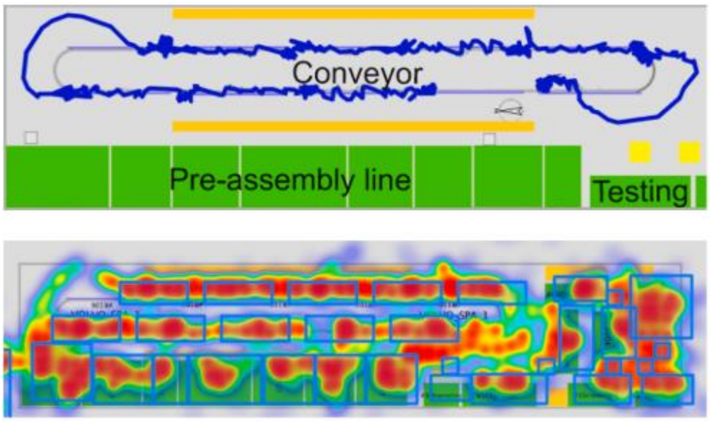

Figure 16. Dynamic spaghetti diagram and heat map of WIP´s (Ruppert et al., 2020).

Tran et al. (2021a) created a similar diagram where semi-finished products, WIP´s, were tracked to map both movements, waiting time and cycle time. In the study, the authors aimed at explaining how RTLS can support improving lean and thus eliminates wastes. By identifying movement, waiting time and cycle time, unnecessary movements and waiting could be identified in real-time. The diagram shown in Figure 17.

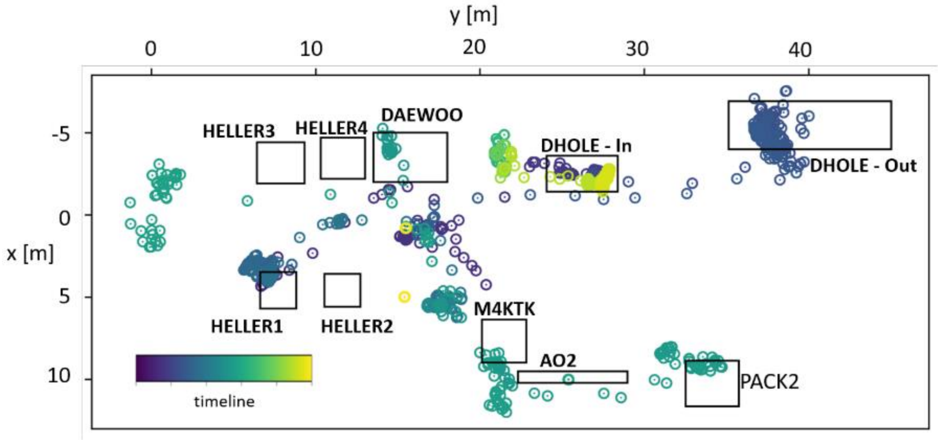

Figure 17. Spaghetti diagram of a product (WIP) that indicates both movement pattern and time spent in different buffers or operations (Tran et al., 2021a).

In a literature review on RTLS in production management, Rácz-Szabó et al. (2020) "RTLS-based efficiency monitoring" is mentioned as a key application area. Along with improved lean-based metrics and dynamic spaghetti diagrams, human resource efficiency monitoring is highlighted. By measuring cycle times for WIP in different workstations (zones), and simultaneously identifying which operators has been working on the different workstations, operator performance is measurable. Tran et al., (2021a) also used zoning to mark workstations at the shop floor. The RTLS could define starting time and end time of WIP´s entering and leaving that zone (representing the workstations) and thus measure actual cycle time. Furthermore, the Rácz-Szabó et al. (2020) mention "production control with RTLS" as another key application. By knowing the exact product sequence and combining that with Key Performance Indicators (KPI´s) such as cycle times, lead times, and number of defects. Therefore, the RTLS can support advanced production control for manufacturing companies. Additionally, Arkan and Van Landeghem (2013) defined four KPI´s for the quality control process: time, speed, quality, and efficiency. By using RTLS to measure these KPI´s accurate data on cycle times, transportation speed of material, defect/scrap rate, and WIP levels could be determined. In the experiment, the authors proved the shop floor visibility improved significantly by applying RTLS.

Tran et al. (2021a) and Rácz-Szabó et al. (2020) both argues that RTLS tracking of humans can be useful to find WIP related KPI´s. By dividing the shop floor into zones, where every zone represents a workstation, the RTLS can determine when a human is entering a zone and hence starts working on that workstation. Knowledge on the exact time an operator has been working on a certain workstation can enable accurate calculations of for example cycle time, lead time. Both authors suggest that the RTLS should be tracking WIP´s simultaneously and thus receive data on both WIP´s and operators' arrival and exit from the workstations.

Ramadan et al. (2012), Ahmed et al. (2014) and Tran et al. (2021a) all argues that RTLS can facilitate improved Lean activities. Ramadan et al. (2012) and Ahmed et al. (2014) applied RTLS to a traditional Lean tool: The Value Stream Map (VSM). The authors argue that a problem with traditional VSM (or other lean tools) is that the current state is evaluated, but there is no continuous follow-up. By applying RTLS, the VSM becomes dynamic as the position of assets is tracked continuously. Tran et al. (2021a) suggest that performance indicators measured in real-time can be an important enabler for lean 4.0. By measuring cycle times, waiting times and queuing times, value adding and non-value adding activities can be accurately measured and thus provide a foundation for waste reduction within a lean-industry 4.0 context.

4.2.2 Warehouse Module

Asset localization is considered applicable for the warehouse module due to its planning and management of inventory. RTLS adoption can decrease the risk of rework and errors, enable traceability and efficiency (Cwikla et al., 2018). Comparable outputs were displayed by Bottani and Montanari (2013) in their evaluation of three different tracking systems for warehouse management in terms of technology and economic payback time. The tracking systems were applied to error-proof pallet movements, error-proof labeling, error-proof picking, automatic inventory counting, automatic shipment checks and remove manual system update. Removal of manual system was also suggested by Bin et al. (2008), which proposed an RTLS connected to the WMS to increase the synchronization between stocking and production departments with material supply. The functions of the RTLS and WMS connection provides automatic stock-taking, checking and warehouse positioning. The connection results in reduction of loading and unloading times, savings in manpower and increased accuracy of operations. Additionally, it realizes automation and information management of warehouses. Similarly, Huang et al. (2018) developed an RTLS solution for warehouse management. Carriers were tagged with passive RFID, and a reader was placed in the carrier shelf system. This will help to ensure carriers are not misplaced and reduce lost items. Huang et al. (2018) mentions that the proposed solution can be connected to the data base to manage inventory based on the RTLS.

Zang and Wu (2010) presented adaptions and utilization of RTLS within Supply chains. Adaptation by manufacturers, in logistics and by retails are discussed. Manufacturers will receive real time feedback to respond to rapid changes in supply and demand which facilitates inventory reduction. They also stated that RTLS can lead to significant improvements in cycle time and machine utilization. Moreover, loss and theft of products will decrease. RTLS in logistics will reduce cost of manpower through scanning and checking goods automatically which also increases stock information accuracy and decreases losses and theft due to mistake proofing.

Vehicle productivity and route optimization is considered relevant for the warehouse module due to management of internal material movement. Real-time tracking of vehicles can provide historical analyses where vehicle moving patterns are visualized and analyzed to improve vehicle productivity, optimize routes, and provide accurate KPI´s based on real-time data (Ghosh et al., 2011; Gladysz et al., 2018; Halawa et al., 2020). Ghosh et al. (2011) used RTLS to track movement and utilization of forklift trucks at an aluminum manufacturing site. By tracking the trucks in real-time, the authors could calculate actual utilization rate, identify bottleneck areas, and develop an optimization model for calculation of optimal number of trucks and optimization of routes. Similarly, Gladysz et al. (2018) used moving pattern identification to create a dynamic spaghetti diagram for forklifts. The authors explain that a spaghetti diagram is used to identify activities of different assets to detect unnecessary movements and thus optimize routes. However, a traditional spaghetti diagram is static and time consuming to draw. By applying RTLS, the authors were able to not only visualize a dynamic spaghetti diagram but also provide real time status (idle, moving or out-of-reach) and real-time KPI´s (average speed, real-time OEE and more) of the forklifts. The result is presented in Figure 18. Halawa et al. (2020) also implemented an RTLS system for tracking of forklifts, but in comparison to Ghosh et al. (2011) and Gladysz et al. (2018), the system was more complex. For example, the authors explain that the system can be used to analyze relation between moving patterns, congestions in aisles in Figure 19 and cornering behaviors in Figure 20.

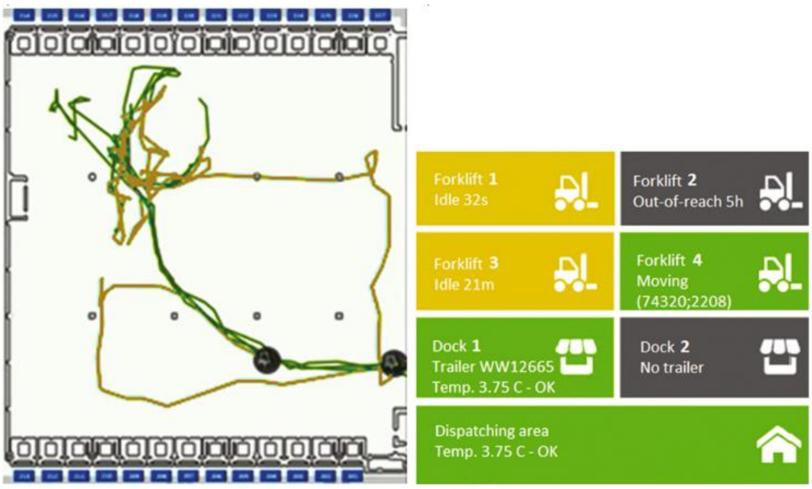

Figure 18. Dynamic spaghetti diagram and real-time forklift status (Gladysz et al., 2018).

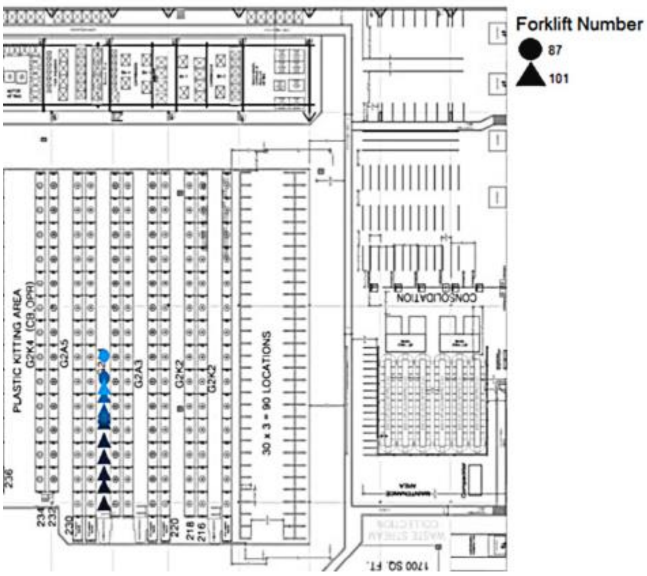

Figure 19. Congestion map showing two trucks that are blocking each other paths (Halawa et al., 2020).

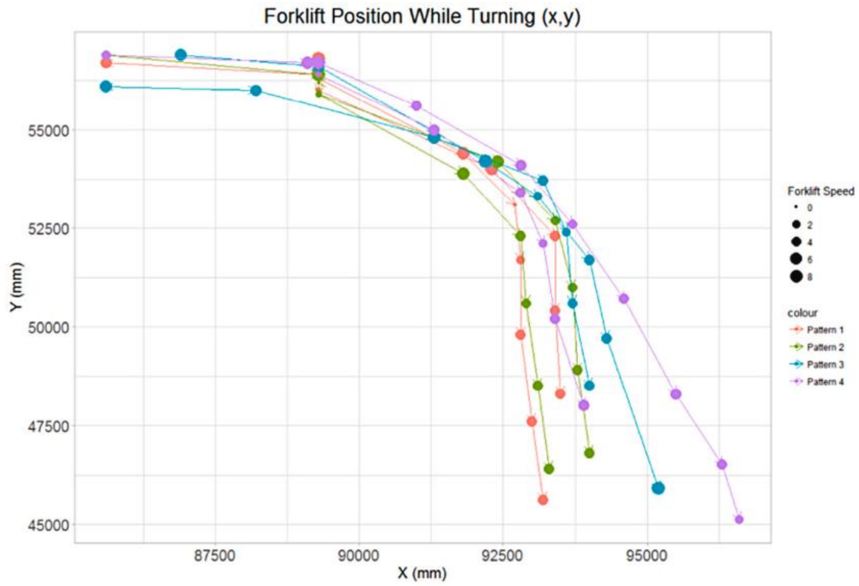

Figure 20. Detailed analysis of cornering positions of forklifts indicating position and speed (Halawa et al., 2020).

In difference to Ghosh et al. (2011) and Gladysz et al. (2018), Halwa et al. (2020) also presents several safety applications in their model. For example, the system was able to measure speed in dangerous zones, forklift faults and accidents. The authors explain that this data could be used to increase overall safety by limiting forklift speed in dangerous areas and analyze root causes of forklift accidents.

Vehicle guidance systems is considered relevant for the warehouse module due to management of internal material movement. Both Jiang et al. (2014) and Huang et al. (2017) discussed vehicle guidance systems as a potential application for RTLS. In an experiment, Jiang et al. (2014) applied a system to raise a concept of "Coordinated Guided Vehicles". By using RTLS on miniature autonomous trucks, the trucks could move in optimal routes considering the real location of humans and material (which were also attached with RTLS tags). Compared to a traditional Automated Guided Vehicle (AGV), RTLS guided vehicles have a higher flexibility since AGV´s must travel along a fixed route. Thus, RTLS guided vehicles can preferably be used in complex, low-volume industries by transporting small batches much more efficient than AGV´s or manual trucks. Huang et al. (2017) supports this theory by including guidance of autonomous vehicles as a potential application area for RTLS in a RTLS framework.

4.2.3 Sales & Distribution Module

Real-time customer order status and increased after sales services is considered applicable for the sales and distribution module due to its management of sales, order processing and delivery of products. Real-time WIP tracking can provide companies, real-time status on a customer order (Cwikla et al., 2018; Franz & Franz, 2010; Gutewort et al., 2020; Thiede et al., 2021). According to Cwikla et al. (2018) users of RTLS are able to know the location and status of every product. Ramadan et al. (2012) and Ahmed et al. (2014) suggested that a dynamic VSM should be integrated with the ERP system and the supply chain, including suppliers and customers. This way, the dynamic VSM can continuously measure current lead time. Tracking of WIP´s will help to determine where and which state products are in (warehouse, transportation, or distribution). RTLS will help to assess the warranty authentication and increase post-sales service. Manufacturers will receive real time feedback to respond to rapid changes in supply and demand and thereby increase the responsiveness and service level through the Supply chain and thus increase efficiency in the distribution of products (Zang & Wu, 2010). In addition, Thiesse and Fleisch (2008) tested several dispatching characteristics in a manufacturing process through simulation. They found that the use of RTLS provided increased process visibility and control in comparison to traditional material tracking systems.

4.2.4 Human Resources Module

Tracking of worker productivity is considered applicable for the human resource module due to its management of data concerning the employees, such as training and pay. Tran et al. (2021a) and Rácz-Szabó et al. (2020) both argues that RTLS tracking of humans can be useful to measure operator performance and thus worker productivity. By dividing the shop floor into zones, where every zone represents a workstation, the RTLS can determine when a human is entering a zone and hence starts working on that workstation. Knowledge on the exact time an operator has been working on a certain workstation can enable accurate calculations of operator productivity. In contrast, Cheng et al. (2021) used RTLS to measure more accurate movements. The authors argued that RTLS tags can be attached to different body parts, for example, thighs and arms. This way, the RTLS system can identify human activities such as sitting, walking, and standing.

Increased worker safety is considered applicable for the human resource module due to its management of data concerning the employee's safety. Anderson et al. (2019), Slovák et al. (2021) and Cwikla et al. (2018) all suggest that utilization of zones and RTLS tracking of humans can be utilized in a safety purpose. By identifying dangerous zones at the shop floor, human activities can be detected and measured inside those zones. Anderson et al. (2019) emphasizes that it is vital to track other assets those zones as well and hence determine if there is a risk for accidents, for example a collision between an operator and a forklift. The suggested system can detect dangerous situations and warn the operators which can reduce the risk for accidents significantly. Slovák et al. (2021) similarly suggest that other assets should be tracked within the dangerous zones as well. The authors suggest that marking dangerous zones around robots can facilitate safety as the robot will stop if human activities is recognised within that zone, see Figure 21. However, by tracking other assets that are allowed to move close to the robot, for example carriers, the safety system can decide whether to stop the robot or not depending on the type of asset entering the zones. This way, the safety system will not affect the productivity by causing unnecessary stops.

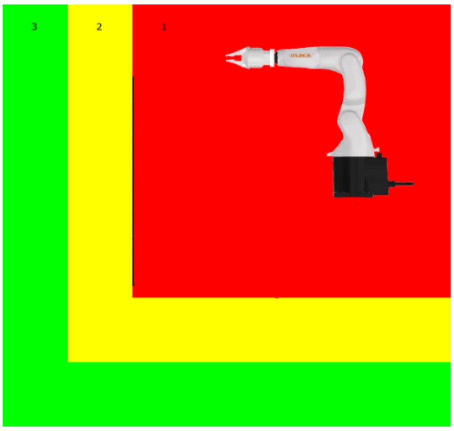

Figure 21. Example of zoning around a robot, representing a danger zone (1), a warning zone (2) and a safe zone (3) (Slovák et al., 2021).

4.2.5 Finance & Accounting Module

Inventory control is discussed by several authors, the inventory control is interpreted applicable for finance and accounting module due to control of value of assets and cost management. Bottani and Montanari (2013) stated that their RTLS solution can provide automatic inventory counting and removal manual system update. Removal of manual system update was also suggested by Bin et al. (2008), who proposed an RTLS connected to the WMS to increase the synchronization between stocking and production departments with material supply. The functions of the RTLS and WMS connection provides automatic stock-taking, checking and warehouse positioning. Similarly, Huang et al. (2018) developed an RTLS solution for warehouse management. The proposed solution could be connected to the data base to manage inventory based on the RTLS. RTLS will increase stock information accuracy through reduction of manual scanning and checking of goods (Zang & Wu, 2010).

4.2.6 Barriers and Enablers

IT Structure and Integration

Several records stated that RTLS itself does not provide any value. The RTLS system consists of two parts: 1) sensors and tags that delivers location and identification data and 2) an IT system that receives and process the data (Thiede et al., 2021). The processed data can in turn be utilized by IT systems that control operational and business-related processes. Consequently, the RTLS needs to interact with other software in the existing enterprise IT structure to provide true value to the business processes (Ding et al., 2008; Franz & Franz, 2010; Geier & Bell, 2001; Husak et al., 2021; Kohn et al., 2005; Thiede et al., 2021; Yang et al., 2016). The three most essential IT systems to integrate with RTLS are MES, WMS, ERP, and visualization systems such as a digital twin.

Kohn et al. (2005) explains that a conventional ERP system is designed to manage data that represents the average behavior of a company. It does not, however, take in account real world unexpected events, for example late arrival of material. Thus, an RTLS-ERP integration can facilitate capacity planning, scheduling and control based on real-time data. Further, Gutewort et al. (2021) highlighted that RTLS-ERP integration can also facilitate automation of previously manually performed processes, for example order tracking in real-time.

Yang et al. (2016) explains that the ERP is fundamentally business-oriented and cannot therefore directly interact efficiently with the shop floor. To bridge the gap between the ERP and the shop floor, the Manufacturing Execution System (MES) was introduced. Yang et al. (2016), Rácz-Szabó et al. (2020) and Huang et al. (2018) all argues that the MES should be integrated with an RTLS to facilitate optimal usage of the MES. Rácz-Szabó et al. (2020) clarifies that the MES provide the shop floor with work instructions and expected cycle times. An RTLS can provide the MES with accurate real-time data and thus facilitate better work instructions and actual cycle times. Yang et al. (2016) underlines the importance of feeding the MES with real-time data from the shop floor as well.

In a warehouse context, the equivalent to MES is the Warehouse Management System (WMS). Like the MES, the WMS can function as bridge between the ERP and the warehouse operations and is fundamentally used to improve warehouse efficiency (Bin et al., 2008). Conventional WMS´s are however only focusing on loading and unloading while other activities such as stock-taking and goods positioning are conducted manually. Bin et al. (2008) and Ma and Liu (2011) suggest that applying RTLS can facilitate automation of these kind of manually performed activities, saving manpower and increasing information accuracy. The importance of integrating RTLS and WMS is further emphasized by Halawa et al. (2020) who argues that an integration can facilitate both safety and efficiency in the warehouse.

It is evident that the RTLS data needs to be collected and processed. However, in many cases it is also necessary to visualize the data. This can be done by applying various visualization tools, for example a holographic workshop map (Huang et al., 2017). A system that can not only visualize, but also collect and process the RTLS data is the digital twin (Ruppert & Abonyi, 2020; Samir et al., 2019; Tran et al., 2021b). Both Ruppert and Abonyi (2020) and Tran et al. (2021b) suggest that a digital twin can be integrated with both the RTLS, MES and ERP. The digital twin can utilize data from the MES (e.g., planned production sequence and BOM list), the ERP (e.g., available resources and delivery time deadlines) and an RTLS system (e.g., real-time process flow and assembly time). This way, the digital twin functioned as a bridge between the RTLS and MES/ERP and the digital twin itself reflected a reliable model of the reality.

Companies should however be aware of the technical limitations of the tracking technologies (Geier & Bell, 2001). The tracking technologies requires to be used selectively due to several reasons, such as unfriendly environments, high hardware and software costs and ROI (Franz & Franz, 2010). Further, Zang and Wu (2010), Singh et al. (2018) and Cwikla et al. (2018) all mentioned lack of standardization as a potential barrier for RTLS implementation, mainly within RFID. Zang and Wu (2010) highlight that lack of standardization could be an issue specifically within a supply chain. The lack of standard between actors can affect manufacturers desire to adopting RTLS technologies since it is difficult to control the integration in the whole supply chain. Similarly, Sing et al. (2018) raises the question of standardized RFID radio frequency differences in various parts of the world, which is a factor that might complicate implementing RTLS in a supply chain. In addition, Jiang et al. (2014) stated that integration between IT systems is fundamentally complicated, for example between ERP and MES.

Industry 4.0 can be considered an enabler for RTLS since it will facilitate the technology getting cheaper and more available. Also, data will be more accessible and easier to analyse (Chao et al., 2020; Huang et al., 2017; Řezáč & Soušek, 2018). Samir et al. (2019), Ruppert and Abonyi (2020) and Tran et al. (2021b) highlights the digital twin as an enabler for RTLS, which is a part of Industry 4.0.

Knowledge

Another barrier frequently mentioned in the literature is the lack of knowledge. Correspondingly, knowledge and education are one of the most vital enablers for RTLS implementation (Geier and Bell, 2001; Gutewort et al., 2021; Thiesse and Fleisch, 2008). Thiesse and Fleisch (2008) and Ferrer et al. (2011) both indicates that knowledge on solely RTLS is not enough. To fully benefit from the RTLS, it is often required to implement major changes in operational processes, reorganizations and sometimes modifications of the whole production system. This in turn requires knowledge, time, and top management commitment.

Process Maturity

As explained by Thiesse and Fleisch (2008) and Ferrer et al. (2011), the operational processes, and sometimes the whole production system, might need to be changed to fully benefit from the RTLS implementation. Thus, the production system must be flexible and able to adapt to fit the RTLS based operations.

Enterprise Characteristics

Gutewort et al. (2021) argues that some barriers, for example knowledge, is more difficult to overcome at small and medium sized enterprises (SME´s). RTLS is mainly found at larger companies since they have the resources to purchase expertise and develop their own versions of RTLS that suits the enterprise context and business model. In contrast, SME´s are having difficulties in acquiring the expertise necessary and they are lacking finances to invest in expensive technology. In addition, Kelepouris and McFarlane (2010) argues that the value of the assets is a critical factor for evaluating the profitability of RTLS. If the value of the assets is low, it will probably not be profitable to place expensive tracking devices on it.

Privacy

Thiede et al. (2021), Singh et al. (2018) and Tran et al. (2021a) mentions that privacy issues can be considered a barrier when applying RTLS on humans. Tran et al. (2021a) underlines that by using RTLS on humans one could track every movement, all the time, which would violate privacy. To overcome this issue, the authors suggest that the RTLS is only activated when an operator enters the shop floor.

Business Case

One of the most critical barriers for RTLS implementation is the cost (Bottani and Montanari, 2013; Cwikla et al., 2018; Lempert and Pflaum, 2011; Nian et al., 2014; Singh et al., 2018). The implementation cost includes both the procurement of hardware, software, and implementation cost. Bottani and Montanari (2013) argues that there are cases when simpler non-real time systems are more profitable than RTLS. The authors argue that RTLS system cost three times more than a non-real time system and depending on the purpose and context, a non-real time system might be more profitable. In addition, Lempert and Pflaum (2011) states that integration between RTLS and other IT systems such as ERP, MES and WMS is expensive and time consuming. Cwikla et al. (2018) and Singh et al. (2018) declares the prices for RTLS technologies are still high and Nian et al. (2014) emphasize that one must consider the trade-off between potential benefits of RTLS and initial cost.

It is evident that cost is a critical barrier for RTLS implementation and thus, to overcome this barrier the calculated savings must exceed the initial costs. However, Ferrer et al. (2011) and Thiede et al. (2021) both argues that finding the savings is complex and thus, enterprises are experiencing problems finding a profitable business case. Ferrer et al. (2011) underline that many of the benefits of RTLS are so called spill-over effects which are often hidden from the traditional payback models.

4.3 Research Question 1

How can the various ERP modules: manufacturing, warehouse, human resources, sales & distribution, and finance & accounting utilize RTLS data?

In this section, the first research question is answered by presenting the empirical and literature review findings of RTLS areas of applicability organized to each ERP module. Accordingly, the empirical findings and literature review findings represent column each and the ERP module represent a row each, see Table 8

Table 8. Summary of RTLS applicability areas for each ERP module.

ERP modules	**Empirical findings**	**Literature review findings**
Manufacturing	- Tool localization and registration - Automatic production order timestamps - Scheduling based on real-time data - Dynamic current state analysis, including measuring non-value adding time	- Asset localization, including tools, WIP´s and carriers - Automation of manual tasks, including automatic order status checks and automatic production order timestamping - Dynamic production scheduling (scheduling based on real-time data) - Dynamic performance analysis, including dynamic VSM, performance measurements (cycle times, waiting times etc.), workflow analyses (e.g., heat maps) and identification of non-value adding activities
Warehouse	- Tracking of vehicles for WIP localization (e.g., bulk batches) - Real-time and automatic stock-taking and stock transfers - Logistics analytics (heat maps & spaghetti diagrams) - Mission scheduling optimization - Forklift guidance system (FGS)	- Asset localization, including WIP/carriers and vehicles - Automation of manual tasks, including automatic stock-taking and stock-transfers - Vehicle productivity analyses, including spaghetti diagrams and heat maps - Route optimization - Vehicle guidance systems for AGV´s
Human Resources	-Automatic employee timestamping for work time tracking - Human and forklift tracking for safety purposes	- Tracking of worker productivity, including work time tracing - Worker safety, including tracking of forklifts and humans to prevent collisions and location of humans in dangerous zones
Sales & Distribution	- Real-time order status, including tracking and prediction of lead times	- Real time customer order status, including expected lead time and time of arrival - Increased after-sales services
Finance & Accounting	- Real-time automatic stock-taking	- Real-time inventory control, including real-time automatic stock-taking

4.4 Research Question 2

What barriers and enablers are there when integrating RTLS and ERP?

In this section, the second research question is answered by presenting the empirical findings and literature review findings of barriers and enablers to an RTLS and ERP integration. The empirical findings and literature review findings of barriers and enablers represent a column each, and the barrier and enabler themes represent a row each, see Table 9. As mentioned earlier, "Barriers" is defined as reasons for tentativeness and resistance to investing and implementing RTLS. "Enablers" is defined as prerequisites for success when implementing RTLS and integrating with ERP.

Table 9. Summary of barriers and enablers.

	Empirical findings		Literature review findings	
Barrier & Enabler Themes	**Barriers**	**Enablers**	**Barriers**	**Enablers**
IT Structure and Integration	- Undeveloped production systems and IT structure - Lack of standardized IT interfaces - Technology inaccuracy	- Up-to-date IT systems, including WMS/MES or specialized ERP - Standardized IT systems that are easy to integrate - Visualization tool such as a digital twin	- Lack of standardized IT interfaces	- Integrating RTLS with specialized IT systems such as MES and WMS - Industry 4.0, including cheaper and more accurate technology - Having a visualization tool such as a digital twin
Knowledge	-Lack of experience	- Understanding of how to utilize the RTLS data	- Lack of knowledge	- Training and education
Process Maturity		- Operational processes needs to be mature and efficient		- Adaption of operational changes and production system
Enterprise Characteristics	- Large volumes of goods	- High cost for manual labor	- Low value of the assets - More difficult to find ROI for SME´s	- High value of the assets - Easier to find ROI for large enterprises
Privacy	-Resistance towards tracking		- Privacy issues when tracking humans	- Activate tracking of humans only when entering the shop floor (suggestion)
ROI	- Cost of hardware and software and integration - Difficulties in calculating savings		- Cost of hardware and software and integration - Difficulties in calculating savings	

4.5 Guidelines

The guidelines intend to provide managers and decision makers with information on RTLS and ERP integration and provide ideas of how it can be utilized to support the core modules of the ERP. By applying these guidelines, companies should be able to understand the basics of RTLS and ERP integration. Also, decision makers can start evaluating if a company is a suitable fit for RTLS implementation, and if not, evaluate which enablers needs to be considered first. In the end, these guidelines can assist companies in creating a business case and thus act as a foundation in a decision-making process.

First, organizational and process related enablers are presented. Second, general recommendations regarding the IT structure are presented. Third, applicability for each ERP module is presented. Fourth, establishment of knowledge and understanding is presented. At last, the creation of the business case is presented.

Step 1. Organizational Enablers

First, one needs to consider enterprise characteristics. Manufacturing enterprises with low volumes and high value assets (products) are prime contesters for RTLS implementation. Further, the labor cost should be relatively high since many of the benefits of RTLS concerns automation of manual tasks. If the labor costs are low, it might be difficult to justify the investment.

The company shall have well developed operational process before considering RTLS. If the operational processes are mature and well developed, RTLS might help to optimize and finetune the processes. However, if the operational processes are less mature, simpler, and cheaper methods will provide more improvement to a lower cost.

Step 2. IT Structure Enablers

For the IT structure, up-to-date and specialized IT systems (such as WMS and MES) is a requirement. In addition, having systems that is easy to interact with other IT systems, through open APIs, is highly recommended and this often goes together with having up-to-date systems. The main topic of this report is RTLS and ERP integration, thus integration (through open API´s) between the RTLS application and the ERP, WMS and MES are essential. Notice that the WMS and MES are often seamlessly integrated with the ERP or built into the ERP. Also, a visualization tool, e.g., a digital twin, is recommended to fully benefit from the RTLS data. A digital twin, which is consider a cornerstone of Industry 4.0, can also be significantly improved by using RTLS data which in turn can help optimizing operations as well.

Step 3. ERP Modules Applicability

All ERP systems are different, and all company business strategies are different. Therefore, it is important to realize that different companies can utilize RTLS data in different ways. In the guidelines, applicability for 5 common ERP modules is presented which facilitates companies to recognize applicability beyond the most researched applicability areas (which is manufacturing and supply chain management). All modules can be accounted for when calculating the business case and the company should decide its applicability based on its unique business environment.

Step 4. Knowledge and Understanding

The last to consider before creating the business case is to create an understanding of the purpose of the RTLS and ERP integration. By knowing the company´s business processes and study the application areas of RTLS, a clear purpose of the RTLS implementation can be established. This is essential for succeeding with the RTLS implementation and a foundation for the business case.

Further, it is vital to inform and educate the employees on the RTLS implementation. Knowledge and understanding among the employees might help overcome resistance since privacy can be a sensitive subject, especially when tracking workers.

Step 5. Business Case

As the initial cost of implementing RTLS can be high, it is important to consider all applicability areas for RTLS from these guidelines, as explained above. However, doing the calculations might still be difficult due to the unique environments of different companies. The initial cost is dependent on the choice of technology, which in turn is dependent on the layout of the tracking area, accuracy requirement and more. Consequently, these guidelines can never generate a business case on its own. It can, however, provide the overall knowledge necessary for companies and decision makers perform an overall applicability evaluation. If the guidelines encourage a company to start considering using RTLS, the next step is to invite RTLS experts for a technical review and thus, lay the foundation for the initial cost calculation. Thereafter, a business case should be built upon the knowledge attained from these guidelines and recommendations from RTLS consultants.

The five steps previously presented make up the guidelines for an RTLS and ERP integration. The guidelines are visually presented below, see Figure 22.

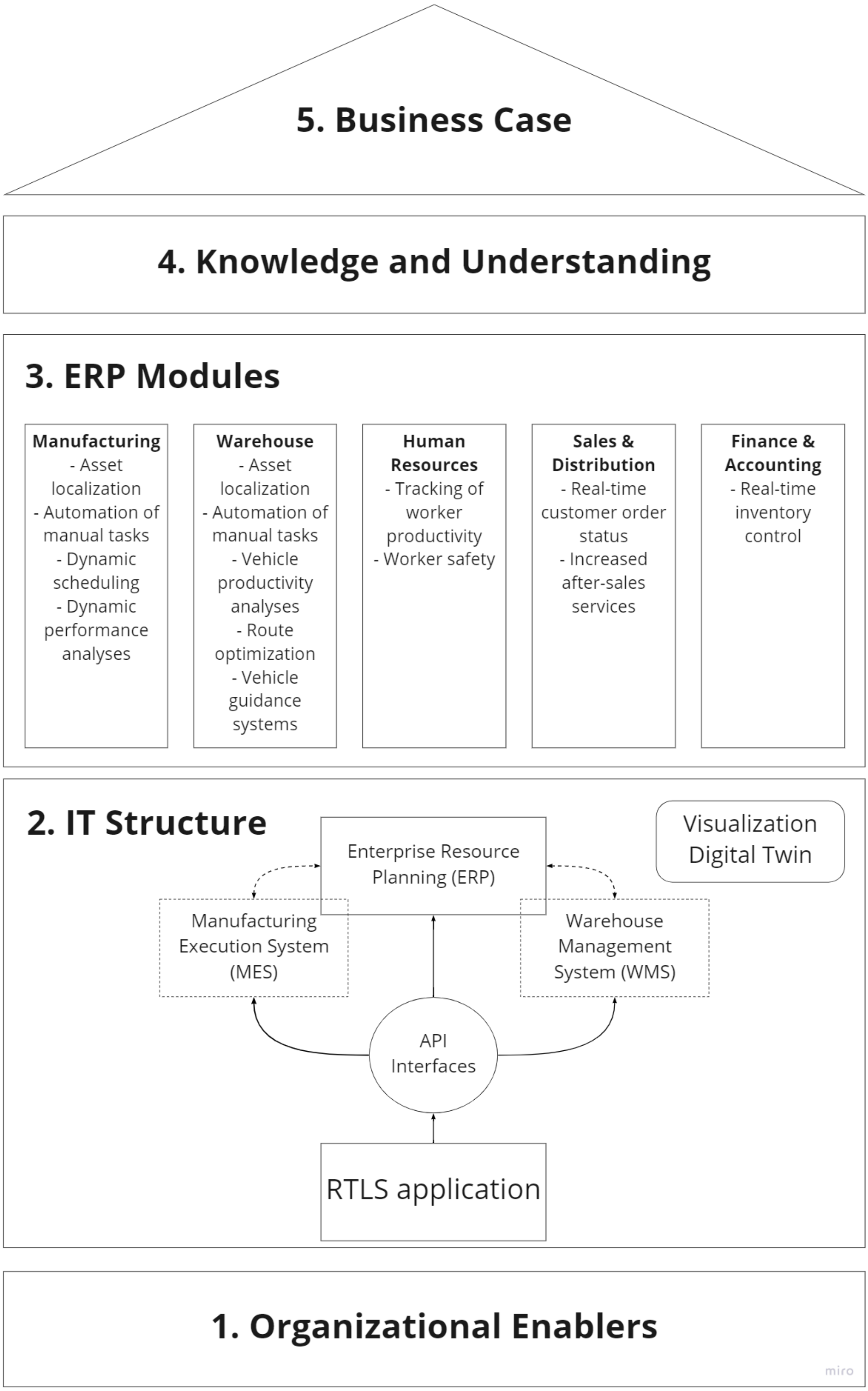

Figure 22. Guidelines for an RTLS and ERP integration.

5 Discussion

In this chapter, three major parts are discussed. The first part is comparison of this study to other studies. The second part is the discussion of empirical and theoretical findings for the two research questions and the guidelines. The third part is the discussion of methods and lastly the study's contribution is presented.

5.1 Study Comparison

During the literature review, two previous studies was found that had similar purposes as this one. Rácz-Szabó et al. (2020) performed a literature on the topic of RTLS within production management and Thiede et al., (2021) performed a survey within the industry to investigate the industry's view on RTLS. Both articles are up to date which makes them both comparable to this study.

Rácz-Szabó et al. (2020) identified several application areas for RTLS. One could argue that all areas are represented in this study as well but in different terms, which increases the credibility and transferability of the findings However, this study included a finance and accounting and sales and distribution perspective which provided an even broader result. Concerning the method, both literature reviews were conducted on a similar topic but included various records. This was interesting and is probably a result of the inclusion and exclusion criteria which in turn is a result of slightly different purposes. For example, Rácz-Szabó et al. (2020) included a technology review in their study while this study is delimited from choice of technology.

Thiede et al., (2021) involved 19 industry persons that had none to low experience with RTLS to perform a survey on 1) which items are most interesting to track and 2) what RTLS use cases that are most interesting to the industry. The identified assets and used cases were all equivalent to the assets and ERP applications identified in this study which increases the credibility and transferability of the findings as well.

5.2 Research Question 1

How can the various ERP modules: manufacturing, warehouse management, human resources, sales & distribution, and finance & accounting utilize RTLS data?

Manufacturing Module

The result of both the literature review and expert interviews indicates that tracking of tools integrated with the ERP system is of interest since those tools can be shared within production facilities (Kelepouris & McFarlane, 2010; Nian et al. 2014; Thiede et al., 2021; Interview expert 2, personal communication, April 6, 2022). Benefit such as reduction of search time for tools (Kelepouris & McFarlane, 2010; Nian et al., 2014; Interview expert 2, personal communication, April 6, 2022), reduce losses (Geier & Bell, 2001) and knowing the status and availability of the tools (Cwikla et al., 2018; Thiede et al., 2021, Interview expert 2, personal communication, April 6, 2022) can optimize tool utilization and improve production scheduling and management (Cwikla et al., 2018; Nian et al., 2014). Additionally, two experts added that RTLS could provide automatic tool registration towards production orders facilitating automatic production order timestamping (Interview expert 2, personal communication, April 6, 2022). In short, automatic time stamping could be based on the arrival and exit of the tool from the workstation and how it is utilized. The automatic tool registration may therefore in the same way, save time, reduce timestamping errors, and remove misses such as employee timestamping and production order timestamping (Industry expert

4, personal communication, April 26, 2022). This exact application was not found in theory, even though tracking of tools and automatic timestamping was and thus confirming the feasibility of the application.

Tracking WIP to enable real time automation was brought up both in the literature and by industry experts. WIP tracking will result in improved operational management and dynamic scheduling (Cwikla et al., 2018; Ferrer et al., 2011; Nian et al., 2014; Řezáč & Soušek, 2018; Thiesse & Fleisch, 2008; Zang & Wu, 2010) and reduction of manual tasks (Gorldt et al., 2007; Gutewort et al., 2020). Manual system updates are not accurate and can therefore be faulty and missed (Industry expert 4, personal communication, April 26, 2022). Similarly, industry expert 2 highlighted that manual system informing can cause issues to the production scheduling when not updated correctly. Both Industry expert 2 and Industry expert 4 discussed that the automatic production order timestamping will remove the need of manual time stamping and provide performance measurements. Real time automation can also be achieved when tracking humans, as mentioned by both literature and two of the industry experts. According to Industry expert 2, automatic production order timestamping can operate by tracking human movement between different dedicated zones at the shop floor. Tran et al., (2021a) did a similar application where zones represented different workstations. Similarly, Cwikla et al. (2018) argued that tracking of humans allows decision making based on real-time data and automation of manual tasks. Automatic production order timestamping could save time, reduce timestamping errors, and remove misses (Industry expert 4, personal communication, April 26, 2022). All combined, real-time automation was widely mentioned in both literature and among the industry experts. However, the automation of production order timestamping was more emphasized by the industry experts than in the literature.

Tracking WIP can enable extraction of real time KPI's to measure performance. This was highlighted in both literature and by industry experts. Besides the KPI's, WIP can be displayed in visual analysis tools, such as spaghetti diagram (Arkan & Van Landeghem, 2013; Tran et al., 2021a; Ruppert et al., 2020) and heat maps (Ruppert et al., 2020). Arkan and Van Landeghem (2013) suggested dynamic VSM to integrate with the ERP system, including suppliers and customers to continuously measure current lead time and value-adding activities. Likewise, Industry expert 2 mentioned that the integration of RTLS and ERP could provide interesting analysis statistics. Industry expert 4 similarly explained that today's performance analyses are simply snapshots of reality, therefore continuous current state analysis provided by the integration are interesting.

Tran et al., (2021a) and Rácz-Szabó et al. (2020) brought up analysis of employee performance and Cheng et al. (2021) presented human body movement analysis. The integration of human performance analysis and ERP was considered interesting by Industry expert 2 for analytics purposes. Therefore, continuous current state analysis of humans provided by the RTLS-ERP integration is interesting from an industry perspective. However, tracking of humans were not as frequently mentioned in the interviews as in the literature and a reason for this might the privacy barrier, which was highlighted by several industry experts 1, 2 and 4 (more on this in section 5.3).

Warehouse Module

Based on both theoretical and empirical findings, it is clear that tracking of WIP and carriers can provide many advantages to the warehouse management module. Knowing the real-time, accurate location of WIP´s and carriers will remove searching times, ensure that no assets are lost, and increase overall inventory transparency (Huang et al., 2018; Gordlt et al., 2007; Gutewort et al., 2020). This was also emphasized by both industry expert 1 and 2. Further, industry expert 1 elaborated on how RTLS can be used to perform automatic stock-taking, comparably to Bin et al. (2008) and Bottani & Montanari (2013). Industry expert 2, on the other hand, highlighted automatic stock transfers as a key application, similarly to Bottani and Montanari (2013) and Zang and Wu (2010).

Several literature records highlighted that real-time tracking of vehicles can provide historical analyses where vehicle moving patterns are visualized and analyzed. These analyses can be utilized to improve vehicle productivity, optimize routes, and provide accurate KPI´s based on real-time data (Ghosh et al., 2011; Gladysz et al., 2018; Halawa et al., 2020). Industry expert 3 confirmed that so called "offline analyses" is one of the most required features when it comes to RTLS within warehousing. This includes for example spaghetti diagrams and heat maps, which are being used to provide analyses on routes and forklift related KPI´s (e.g., utilization rates), just as described in the literature. Further, industry expert 1 mentioned that forklifts can be tracked to indirectly track WIP´s that are not possible to track themselves, for example products that are sold in bulks, such as gravel and bricks. This was however not brought up in the literature, leaving the bulk tracking as a relatively unexplored area, even though tracking of goods in stock and tracking of vehicles was frequently mentioned.

Jiang e al. (2014) and Huang et al. (2017) both argued that RTLS can be used to create vehicle guidance systems. A vehicle guidance system can be used either as a way of creating autonomous vehicles, as suggested by Jiang et al. (2014) and Huang et al. (2017), but also to guide drivers in manual trucks, as suggested by Industry expert 3. He explains that by applying this kind of guidance system, multiple manual tasks can be removed (e.g., scanning of new location). Also, the mission scheduling and route planning can be optimized and thus make the material handling more efficient. Industry expert 3 highlights that a vehicle guidance system is dependent on integration with WMS (or a specialized ERP) since it utilizes data from the WMS. The main difference here is that the literature emphasizes vehicle guidance systems for autonomous vehicles, while the industry expert (3) highlighted the need for guidance systems for manual vehicles. This might be an indication that parts of the industry are not ready to for utilizing RTLS to facilitate autonomous vehicles and that utilizing RTLS to facilitate more efficient operations for manual vehicles might be a more feasible start for some enterprises.

Finance & Accounting Module

During the interviews it became clear that all RTLS applications has a positive impact on the enterprise finances over the long term. However, when it comes to RTLS data that directly improves the daily operations performed at the Finance and Accounting module, there were less applications mentioned.

Only one of the four industry experts could identify a direct connection between RTLS and the Finance & Accounting module. Industry expert 1 mentioned that knowing exact inventory and automatic stock-taking could have a direct impact on the Finance & Accounting module since the Finance department has an interest keeping track of the value of the company´s assets. The topic of automatic stock-taking and inventory control was brought up by industry expert 2, Bin et al. (2008) and Bottani & Montanari (2013) as well, confirming the applicability of automatic stock-taking and inventory control.

Sales & Distribution Module

The applicability area of utilizing RTLS to track customer orders was mentioned in both literature and among the industry experts. Several literature records stated that by applying RTLS to WIP´s, customer order status can be updated in real-time (Cwikla et al., 2018; Franz & Franz, 2010; Gutewort et al., 2020; Thiede et al., 2021). This was also mentioned by industry experts 1, 2 and 4. According to the experts, the real-time tracking of orders can have a massive impact on the Sales and Distribution module. By knowing the exact order status and location, customers can receive continuously updated order status, predicted lead-times, and expected time of arrival. Zang and Wu (2010) highlighted that RTLS for order status tracking can assess warranty authentication and increase after-sales services. Industry expert 2 emphasized that there is highly valuable for customers to receive real-time order status information from the supplier, and thus verifying that there is a potential for increased after-sales services.

Human Resources Module

Two records from the literature review and one of the industry experts elaborated on the topic of safety between vehicles and humans. Both Franz and Franz (2010) and Halawa et al. (2020) suggests that applying RTLS on vehicles (e.g., forklifts), worker safety can increase. For example, Halawa et al. (2020) used RTLS to track forklift speed in dangerous zones and to analyze root causes of forklift accidents. Industry expert 2 mentions briefly that it would be of HR interest to track forklifts for safety reasons.

Anderson et al. (2019), Slovák et al. (2021) and Industry expert 2 all argues that tracking of humans can help establish a safer workplace and reduce the risk of accidents. By identifying dangerous zones, for example close to automation robots, an RTLS can detect human activities within those dangerous zones and establish safety cautions. Anderson et al. (2019) also emphasizes that tracking of other assets (such as forklifts) is vital as well to create a system that can avoid accidents between humans and machines or vehicles. Overall, the topic of safety was more emphasized in literature than among the industry experts. A reason for this might be that it is not obvious that safety can be considered an applicability area for the HR module. There are no obvious RTLS data that can be transferred to the module.

The applicability of applying RTLS on humans for productivity tracking purposes was however more emphasized by the industry experts. Here, the data collected are more tangible and directly connected to HR activities, such as salaries. According to industry experts 1, 2 and 4, tracking of human activities can provide data on actual work times and productivity which can in turn be of interest for the HR department. This was also confirmed by two literature records (Cheng et al., 2021; Tran et al., 2021a). Tracking of human activities for this purpose can however be tricky due to privacy issues (more on this in the section 5.3).

Summary

It can be concluded that all the applicability areas suggested by the industry experts could be found in the literature. It is however a matter of perspective. Some suggestions presented by the industry experts were very specific and thus, there were no equivalent case studies in the literature. During the literature review, specific case studies were organized and categorized in different applicability areas. To be able to compare the cases suggested by the industry experts with the theory, a similar categorization needed to be made (see **Fel! Hittar inte referenskälla.**). Consequently, considering the suggestions as applicability areas, rather than specific cases, all suggestions had equivalent applicability areas found in the literature. Thus, all applicability suggestions from the industry experts could be supported by the theory. In total, the industry experts suggested three specific cases that did not have an equivalent case study within the literature, which therefore needs to be addressed.

1. Tracking of tools to enable automatic order timestamping
2. Tracking vehicles for locating bulk batches (gravel, bricks etc.)
3. Using guidance systems for manual forklifts

First, industry expert 4 suggested that tracking of tools can enable automatic order timestamping. In literature, automatic order timestamping was mentioned but realized through the tracking of WIP´s or humans, not tools. Tracking of tools were however mentioned for other purposes, thus verifying that this suggestion is feasible. Second, industry expert 1 suggested that vehicles can be tracked to pinpoint the location of bulk batches, such as gravel and bricks. In literature, tracking of goods in stock and general tracking of vehicles are frequently mentioned. Thus, this suggestion is feasible, but not confirmed. At last, industry expert 3 suggested that guidance systems based on RTLS can be used for guiding forklift drivers in manual forklifts. In literature, guidance systems are applied to autonomous vehicles rather than manual vehicles. However, the systems appear to be similar, and the base of the guidance system as suggested by industry expert 3: the optimized mission scheduling, is also highlighted in the literature, thus confirming the feasibility of this suggestion as well.

5.3 Research Question 2

What barriers and enablers are there when integrating RTLS and ERP?

Knowledge and Understanding

Knowledge and understanding in investing, applicability, and operation of RTLS was raised both in the literature and the industry expert interviews. Industry expert 1, 2 and 4 brought up the importance of possessing knowledge and understanding why and how to implement an RTLS. Likewise, several authors in the literature review discusses the importance of knowledge and understanding in investing and utilizing an RTLS (Bottani and Montanari, 2013; Ferrer et al., 2011; Geier & Bell, 2001; Gutewort et al., 2021; Nian et al., 2014; Thiesse & Fleisch, 2008). The knowledge and understanding regards applicability and operation of an RTLS. Applicability considers the knowledge and understanding of how an RTLS can be used by the company investing or intending to invest in an RTLS. With the application of RTLS there are benefits which are hidden, therefore are the benefits difficult to measure (Ferrer et al., 2010; Geier and Bell, 2001; Thiesse and Fleisch, 2008; Thiede et al., 2021), thus knowledge about applicability is important.

Operation involves the knowledge and understanding of the RTLS by the employee's using the system. The operation of RTLS was brought up in literature but not in the industry expert interviews, however industry expert 4 emphasized the importance of making sure employees understand the purpose of the RTLS. Implementing RTLS comes with changes and reorganization to the working environment (Ferrer et al., 2011; Thiesse & Fleisch, 2008). The unfamiliar environment and adoption to working with an RTLS requires training and change management to make use of advantages of integrating the real time data and the manufacturing system (Thiesse & Fleisch, 2008). Due to the work environment changes that the RTLS implementation will affect it demands uninhibited commitment from the top management (Ferrer et al., 2011), which ties back to the knowledge and understanding about the business case and why the implementation is important (Industry expert 2, personal communication, April 6, 2022).

Process Maturity

Company and process maturity considers to which extent the company has reached developments in automation and effectivization. All Industry experts raised the maturity of the company and its processes, however it was not mentioned in any of the records in the literature review. Less mature company, with less mature processes does not prioritize or consider RTLS solutions (Industry expert 1, personal communication, April 1, 2022; Industry expert 2, personal communication, April 6, 2022; Industry expert 4, personal communication, April 26, 2022). Companies with less developed processes will prioritize, simpler and more cost-effective development projects compared to an RTLS. An RTLS solution might help to optimize and finetune the processes, an RTLS solution is in general a major investment for a small improvement, therefore the company investing in an RTLS solution ought to have come long in their developments in automation and effectivization (Industry expert 1, personal communication, April 1, 2022).

For example, companies should prioritize to get the basics established, such as lean, before considering an RTLS integration. Since the companies will not achieve much improvement without the basics established (Industry expert 2, personal communication, April 6, 2022). Too conclude, an RTLS adoption is to improve the companies processes the last percentages of an already mature environment (Industry expert 1, personal communication, April 1, 2022).

Enterprise Characteristics

Industry expert 3, argued that the cost of the technology must be competitive compared to labor cost. For example, in developing countries the labor is cheap and thus, automating processes has lower impact on the overall profitability. In line with that statement, Bottani and Montanari (2011) showed that an RTLS implementation can result in labor cost savings. No literature record did however state that low labor cost could be considered a barrier. Further, Industry expert 1 argued that the technology cost might be too high for companies that handles large volumes since every WIP, or pallet must be equipped with a tracking tag. Consequently, the cost for RTLS implementation is a significant barrier for companies that are using cheap labor and manages large volumes of goods. On the other hand, companies that are using expensive labor and managing low volumes might find cost a less significant barrier. The aspects of significance in labor cost and significance of volume of goods was not found in the literature. In addition, Kelepouris and McFarlane (2010) argues that the value of the assets is a critical factor for evaluating the profitability of RTLS. If the value of the assets is low, it will probably not be profitable to place expensive tracking devices on it. This aspect was however not mentioned in any of the interviews.

Since integration between RTLS and ERP is not well developed, the knowledge and experience are required to be created by the company themselves (Industry expert 4, personal communication, April 26, 2022). Larger companies can purchase competence about RTLS and create solutions that fit for their own business. However, SMEs cannot purchase this RTLS competence and develop their own solutions, therefore it is difficult for SMEs to implement RTLS technologies (Gutewort et al., 2021; Industry expert 1, personal communication, April 1, 2022).

Privacy

The issue of privacy was raised both in literature and by industry experts. Industry expert 1, 2 and 4 all mentioned tracking of human activities as a potential application area of RTLS, but at the same time discussed the issue of privacy. In theory, one could track total productivity on workers, including toilet- and smoking breaks. However, that might be a major privacy issue that will create conflicts with the employees, the HR department and worker unions. Singh et al. (2018) also discusses the privacy issue and Thiede et al. (2021) while Tran et al. (2021a) presented a workaround on the issue by applying tracking only when the workers entered the shop floor.

IT Structure and Integration

Several authors in the literature and industry experts emphasized that the RTLS system should be integrated with existing IT systems. The data collected by tags and sensors, or other tracking technologies must be interpreted, processed, and integrated to existing IT structure to provide maximum value and facilitate automate real-time decision making (Ding et al., 2008; Franz & Franz, 2010; Geier & Bell, 2001; Kohn et al., 2005; Lempert and Pflaum, 2011; Thiede et al., 2021; Yang et al., 2016). Industry experts 1, 2 and 3 emphasized this as well.

Industry experts 1, 2 and 3 all mentioned the existing IT structure as a potential barrier. If the existing IT structure are not up-to-date, or insufficient in any other way, it might be complicated to create the interfaces necessary to perform a successful integration. Industry expert 2 highlights that there should be no difficulties integrating RTLS with existing IT structure if there are open APIs. Further, industry expert 3 highlights that deficiency of specialized IT systems is a common barrier. Without those systems, there is a lack of sophisticated data which can be used by RTLS. Several specialized systems were mentioned suitable systems for RTLS integration. This statement is not directly supported by any record in the literature, even though several records highlight the importance of integrations with specialized IT systems, for example, Bin et al. (2008), Ma and Liu (2011), Yang et al., (2016) and Ruppert and Abonyi (2020).

Within a warehouse context, Industry expert 1 and 3 both argues that an integration between the RTLS and the WMS, or a specialized ERP with WMS functionality, is critical to fully benefit from the RTLS data. This statement is supported for example, Bin et al. (2008), Ma and Liu (2011), Halawa et al. (2020), Tran et al. (2021a) and Tran et al. (2021b). Within a manufacturing context, Industry expert 2 explains that in their ERP system, the MES is integrated. Otherwise, if the systems were separate, it would have been relevant to integrate the MES with the RTLS. The importance of integrating RTLS and MES is further emphasized by for example, Franz and Franz (2010), Yang et al. (2016), Huang et al. (2018), Ruppert and Abonyi (2020), and Rácz-Szabó et al. (2020). Further, Industry expert 3 suggests that a digital twin could act as an appropriate bridge between the RTLS and ERP. According to the industry expert, a digital twin can also be used as a visualization tool for the users (in this case the forklift drivers). Huang et al. (2017) used a holographic work map to visualize to RTLS data, while Ruppert and Abonyi (2020), Samir et al. (2019) and Tran et al. (2021b) all suggest an outright digital twin as a visualization tool and thus supports the statement of Industry expert 3.

Consequently, having an up-to-date IT structure with open APIs, including specialized systems for warehouse- and manufacturing control and visualization, is a distinctive enabler for RTLS integration, emphasized by both industry experts and literature.

Business Case

Industry experts 1, 2 and 4 explicitly mentioned cost as one of the main barriers for RTLS implementation. This includes cost for technology (hardware) procurement and system integration. Technology costs have obviously become cheaper over the years. However, not too many years ago, Cwikla et al. (2018) stated that the cost of accurate RTLS is still high as the technology is yet under development. Industry expert 3 also emphasized that cost is the traditional barrier for RTLS integration and predicts that a decreasing in cost for both technology and integration is necessary before RTLS can have its extensive breakthrough.

Several authors have highlighted the importance of making a profitable business case as a major enabler for RTLS (Ferrer et al, 2008; Franz & Frans, 2001; Nian et al., 2014; Thiede et al., 2021), which was also emphasized by industry experts 1 and 3. Industry expert 1 explains that to create a solid business case for an RTLS and ERP integration, it must be clear of what and how parameters affecting the return of investment. Therefore, understanding how the RTLS integration will benefit the company is essential to build a solid business case. This statement is supported by Ferrer et al. (2011) and Thiede et al. (2021), who argues that findings the saving is complex and that many positive aspects of RTLS are spillover effects. Many of the spillover effects are presumably soft values. For example, it is difficult to measure safety in terms of money and add to the ROI calculation. The same goes for measuring the increased customer satisfaction provided by real-time customer order status in terms of money. In that sense, it is important to realize that the ROI, as mentioned by for example industry expert 1, is only a part of the business case since the business contains both financial values and soft values. The ROI itself does only include financial values.

Summary

The perspective of barriers and enablers among the industry expert varied depending on the role of the industry expert. The industry experts on the supplier side (industry expert 2 and 3) tended to be more positive to RTLS implementation in general and thus did not highlight as many barriers as the industry experts on the customer side (industry experts 1 and 4). This was expected and indicated that the perspective of the interview object affects their view on RTLS implementation.

There were three barriers that were emphasized by the industry expert that were not clearly stated in the literature.

1. Lack of specialized and up-to-date IT structure within the industry
2. Low labor costs
3. High volumes of goods

The lack of specialized and up-to-date IT structure was highlighted by industry expert 3 as a barrier for RTLS expansion within the industry. In literature, it was found that lack of knowledge was the main barrier for RTLS expansion within the industry, but it was nowhere explicitly stated that outdated IT systems was a common barrier. Further, industry expert 3 mentioned that having low labor costs, for example in developing countries, can be a barrier for RTLS expansion within the industry. Similarly, industry expert 1 mentioned that enterprises that handles large volumes of goods will find it difficult to cope with the initial costs since a lot of products have to be tracked. This might lead to higher costs since it will require more hardware or more advanced RTLS technology. None of these aspects were clearly mentioned in the literature. All in all, it can be concluded that there is a lack of research for these kind of enterprise characteristics.

5.4 Guidelines

Organizational Enablers

The content of the organizational enablers step originates mostly from the empirical findings and mostly related to the Barrier and Enabler category "Enterprise Characteristics". For example, industry expert 1 emphasized that for RTLS to be beneficial, the labor cost cannot be too low. Similarly, industry expert 3 mentioned that RTLS can be an expensive investment for companies handling large volumes of goods. These barriers were not clearly addressed in the literature and is thus a foundation for future research.

IT Structure

The IT structure step in the guidelines is created from data originating from somewhat equally between the literature and industry expert interviews. Industry experts saw lack of standardization and up-to-date IT structure as a barrier, whilst the literature saw it more as enablers for the RTLS-ERP integration to create more value. The IT structure theme was the largest theme identified in literature, and most industry expert did have resembling answers which indicate that IT structure is of great importance in both literature and industry.

ERP Modules

The RTLS applicability is mostly based on the literature review since the sample of records where much larger than the number of interviews. In addition, all applicability areas identified in the empirical data were all supported by the theory, thus increasing the trustworthiness of the applicability areas presented. The categorization of the applicability areas was however conducted by the authors of this study and the statements from the industry experts.

Knowledge and Understanding

This step was based on both empirical data and theory. Industry expert 1, 2 and 4 brought up the importance of possessing knowledge and understanding why and how to implement an RTLS. Likewise, several authors in the literature review discusses the importance of knowledge and understanding in investing and utilizing an RTLS (Bottani and Montanari, 2013; Ferrer et al., 2011; Geier & Bell, 2001; Gutewort et al., 2021; Nian et al., 2014; Thiesse & Fleisch, 2008). The purpose of the guidelines was to provide basic knowledge on RTLS and ERP integration. Thus, when considering all the applicability areas and understanding the wide potential of RTLS, hidden benefits might reveal and provide knowledge necessary for the next step: creating the business case.

Business Case

The business case was highlighted both among the industry experts and in literature as a key for enabling enterprises to start implementing RTLS. Three out of four industry experts highlighted the business case as the main key for RTLS success. Industry expert 1 highlighted the importance of understanding all benefits of RTLS and how it can affect different parts of the company. This was also supported by Ferrer et al. (2011) and Thiede et al. (2021).

It is however important to realize that the business case can contain soft values, for example increased safety. Some records and industry experts in this study have referred to the business case as a Return of Investment (ROI). There is however a slight difference between a business case and an ROI calculation. An ROI calculation only accounts for financial values which can create a faulty view on the profitability of RTLS-ERP integration and implementation. In difference, a business case accounts for all values, both financial and soft.

5.5 Discussion of Method

To make conclusions concerning the quality of the result of the study it is important to understand the strengths and weaknesses of the study's research method. The research method chapter 3 presents the method choices, reasoning and measures taken to overcome the weaknesses, thus the strengths of the study's methods. Having that said, this section discusses the weaknesses of this study's research method to demonstrate that they and their effects are considered.

The chosen search string and inclusion and exclusion criteria will undoubtedly affect the amount and spread of information included in the literature review. Thus, relevant records could have been missed out even if measures have been taken to diminish this. Likewise, by only obtaining literature through the search engine Scopus, some relevant literature which are not published in Scopus may be missed out. Hence, there is a risk of RTLS areas of applicability and barriers and enablers being missed out. Similarly, there is a risk for incorrect evaluation for relevance of records based on the inclusion and exclusion criteria even though measures have been taken to overcome this risk of inappropriate inclusion or exclusion.

The search string and inclusion and exclusion criteria shaped the literature review to provide as many RTLS areas of applicability as possible. Hence, there are RTLS areas of applicability which to do not necessarily require integration with the ERP to provide value for enterprises. Nevertheless, to support dependability and confirmability of this study, the literature review did not exclude areas of applicability which do not necessarily require integration with the ERP to provide value.

It can be questioned if the ERP modules used in this study provide enough transferability and generalizability due to limiting to these modules and definitions. Having that said, modules will most likely be named differently and have differences in functionality between different ERP suppliers. Thereby, organizing RTLS applicability areas to ERP modules simply aimed to expand the view on RTLS and ERP integration.

The selection of the industry expert interview respondents can be questioned for bias, due to acquiring the industry experts through communication ways by a production and logistics development solutions provider. The production and logistics development solutions provider could push for its own benefits of acquiring knowledge from certain industry experts. Similarly, there are risk for bias in the respondent sampling plan also. A more positive view on the integration from supplier perspective and a less positive view from the customer perspective on the integration are not regarded as a surprise. An RTLS and ERP integration is a business opportunity from the supplier perspective, costly and unexplored by the customer perspective.

The study's utmost weakness is the few numbers of interviews. Hence, the empirical findings may be questioned concerning if the empirical findings truly display the industry's view on current applicability, interest of applicability and barriers and enablers of RTLS and ERP integration. Provided that, this study would have benefited from conducting a greater number of interviews to strengthen empirical findings. A greater number of interviews would help to overcome the high weight of each interview, provide more perspectives and comparison between the interviews.

In conclusion, the choice of methods and actions have supported the fulfillment of the purpose and research questions for the study. The weaknesses in this study have been considered and measures have been taken to counteract these. Again, the part to reflect concerning the research method are the few interviews and its consequences on the result of the study. Having that said, the strength of this study is the extensive theoretical part together with the pursue for a rigorous research process.

6 Conclusion

In this chapter, the conclusion of the study is presented followed by a contribution section and a future research section.

6.1 Conclusion

As the industry 4.0 trend continues to transform the operations within the industry and forces the prices of technology to decrease faster than ever, new opportunities have emerged within the new digitalized era. Asset tracking has since the introduction of Industry 4.0 gained an increased amount of attention within the literature, now in the shape of real-time locating systems, RTLS. Despite the upswing in attention, companies within the manufacturing industry tend to be passive and tentative concerning RTLS implementation. A deficiency of knowledge and experience was identified. Enterprises are struggling to fully comprehend the entire impact of RTLS and how to utilize the data to improve the existing business operations. When integrating RTLS and ERP, business operations can be carried out based on real-time information, providing more value than a standalone RTLS. In addition, there are several hidden positive factors that needs to be accounted for when considering implementing RTLS. If all positive factors can be identified, it will facilitate profitable business cases which is essential to convince managers and decision makers to implement RTLS. The purpose of this study was *to examine and evaluate the applicability of integrating RTLS with the various ERP modules and present a set of guidelines for RTLS and ERP integration*. Two research questions were established: **RQ1**: How can the various ERP modules: Manufacturing, Warehouse, Human Resources, Sales & Distribution, and Finance & Accounting utilize RTLS data? **RQ2**: What barriers and enablers are there when integrating RTLS and ERP?

An extensive literature review and four industry expert interviews were conducted. Literature data analysis and thematic narrative analysis together with the industry expert data analysis were applied to answer the two research questions. Data synthesis was applied to synthesize the knowledge established from answering the two research questions to create the guidelines.

RTLS applicability was identified for all modules which expanded the traditional view on RTLS applicability which mostly concerns manufacturing and supply chain aspects only. In summary, four applicability areas were identified for the Manufacturing module, five applicability areas for the Warehouse module, two applicability areas for the Human resources module, two applicability areas for the Sales & Distribution module, and one applicability area for the Finance & Accounting Module. These are all presented in **Fel! Hittar inte referenskälla.** Barriers and enablers were identified and categorized into six themes: Knowledge, IT structure & Integration, Process Maturity, Enterprise Characteristics, Privacy and ROI. Each category can therefore include both barriers and enablers. These are presented in Table 9. Summary of barriers and enablers.

A set of guidelines was presented to increase the knowledge on RTLS and ERP integration and thus facilitate managers and decision makers to consider implementing RTLS. The guidelines were designed to be applicable for various manufacturing companies and account for all positive effects that may appear when integrating RTLS with the existing IT structure. The guidelines included 1) organizational enablers, 2) IT structure enablers, 3) ERP module applicability, 4) knowledge generation and 5) creation of the business case.

The novelty of this study was the expansion of the view on RTLS and ERP integration beyond the previously researched connections between ERP and WMS or MES. Further, the study contributed to industry by providing guidelines that can be utilized by managers and decision makers to establish basic knowledge prior to their process of evaluating RTLS implementation. In turn, the study can facilitate enterprises to overcome the initial knowledge barriers and thus, contribute to the acceleration of the RTLS expansion within the industry.

6.2 Contribution

This study has contributed to research by expanding the perspective on RTLS and ERP integration further than previous studies on the topic. The study showed that all ERP modules can utilize the RTLS data to provide value for each module. RTLS applicability for the manufacturing and the warehouse management modules has previously been well researched. However, including the rest of the ERP modules provided an even broader perspective.

This study contributes to industry by providing guidelines that can be utilized by managers and decision makers in their process of evaluating RTLS and ERP integration implementation. Managers and decision makers can use these guidelines to create a fundamental understanding of how RTLS can create value for all ERP modules, including spillover effects. This knowledge is a key to create profitable business cases. The guidelines will therefore facilitate enterprises to overcome the initial knowledge barriers and thus, contribute to the acceleration of the RTLS expansion within the industry.

Acceleration of RTLS implementation within industry might facilitate companies to apply Industry 4.0 practices since RTLS is considered an enabler for Industry 4.0. It is well known that Industry 4.0 will provide better working environment and more sustainable manufacturing and thus, this study provides a small contribution to society as well.

6.3 Future Research

The guidelines provided in this study are not tested and verified in practice. Therefore, case studies using these guidelines could help confirming the trustworthiness and user friendliness of the guidelines. Case studies could also provide real business cases and verify that the applicability for RTLS in each ERP module is valid. Further, this study emphasized that it is vital to generate a profitable business case. Future research might therefore also include developing a generalized business case formula for RTLS-ERP integration. This would add significant value to the guidelines. Also, conducting more interviews, thus adding more empirical data, would increase the trustworthiness of the guidelines as well.

Some areas for further research were identified in the discussion chapter. First, three of the suggested application cases (for RTLS) that were found during the industry expert interviews were not fully confirmed by the literature. The three suggested application cases were confirmed to be feasible based on the literature review, but there were no specific case studies to confirm the exact functionality. Therefore, to perform case studies on the following application areas could this verify the empirical studies even further: Tracking of tools to enable automatic order timestamping, tracking vehicles for locating bulk batches (gravel, bricks etc.), and using guidance systems for manual forklifts.

Second, three of the barriers that were identified by the interview experts were not fully confirmed by the literature: Lack of specialized and up-to-date IT structure within the industry, low labor cost, and high volumes of goods. It is already stated that RTLS has yet not had its great breakthrough within the industry. More holistic studies on these general barriers can help understand common barriers and how to overcome them. Mainly, it would be interesting to perform holistic studies on which enterprises are most suitable for RTLS (enterprise characteristics) and how that affects the expansion of RTLS. This would also improve the guidelines in terms of validating the first step: Organizational Enablers, which is mainly based on enterprise characteristics.

7 References

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8 Appendices

Appendix 1 - Interview guide document

Appendix 2 – Thematic narrative analysis of interviews

8.1 Appendix 1 - Interview guide document

In this section, the interview guide document sent to the respondents is presented. The interview guide document offers background and purpose of the study. The interview guide document does also present the questions for each respondent.

Real-Time Locating Systems (RTLS) and Enterprise Resource Planning (ERP) Integration

Preparation before interviews

Hi, we are two students from Jönköping University, currently writing a Master thesis on the topic of Real-Time Locating Systems (RTLS) and ERP integration together with Virtual Manufacturing. This document will be sent out to prepare and inform interviewees on the topic before the actual interview is conducted.

Background

RTLS is an umbrella term for techniques that aims to identify and track assets in real-time. Assets can be, for example, material, products, humans, trucks, and other vehicles. In short, RTLS consists of sensors attached to the asset which will provide the system with accurate and real-time information about identification, position, and other relevant data (for example, temperature and vibrations). An RTLS system provides constant dynamic information such as location of the tracked asset compared to conventional asset tracking which only provides static information when an asset has passed a reader.

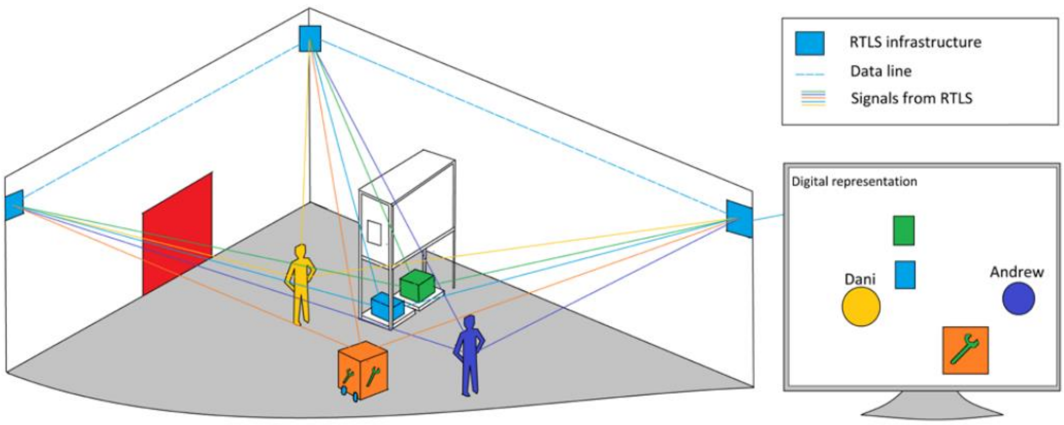

Figure 1. Basic RTLS architecture (Thiede et al., 2021).

So far in this study, we have identified and categorized potential data that can be achieved by applying RTLS in a manufacturing environment. Those are:

- Identify and find assets
- For example, for inventory management
- Identify moving patterns of assets
- Create more efficient moving patterns
- Increase safety

- Process efficiency indicators
- Lead times, waiting times etc.
- Environmental data
- Temperature, vibrations etc.

Also, five core modules of a typical ERP system have been identified. In general, every core module has a corresponding department that utilizes the data provided by that module.

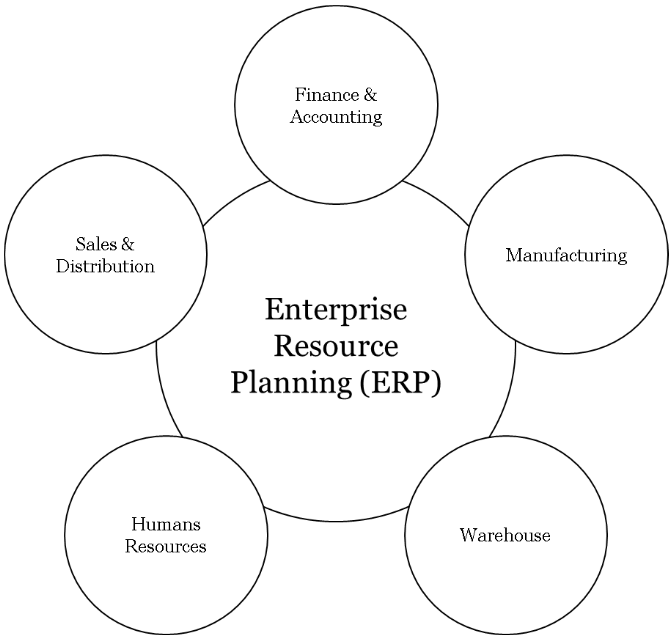

Figure 2. ERP core modules outline based on Hossain (2003), Parthasarathy (2007) and Zabukovšek et al. (2020).

Purpose

The aim of the study is to create guidelines for performing an integration between an RTLS system and an ERP system. RTLS-ERP integration is brought up in literature by some authors (for example, Tran et al., 2021 and Rupert & Abonyi, 2020) and according to X company, this integration is important but has not yet been widely established in industry. Therefore, we need your help to discuss and investigate the enablers, challenges, and benefits of RTLS-ERP integration.

Questions for industry expert 1

- What is your role?
- How many years have you been working at X?
- What ERP system is your company using?
- What is your experience of RTLS/Asset tracking?
- Are you using RTLS/Asset tracking today?
    - If yes, which assets are you tracking and why?
    - Is it real-time or not?
    - If yes, to what system and how is RTLS/Asset tracking integrated?
    - If yes, which departments are using this data?
    - If no, has RTLS/Asset tracking been discussed in your company?
- What do you need to start investing in RTLS/Asset tracking?
- How can your company utilize RTLS (more) in the future?
- Which (other) departments can utilize RTLS in the future?
- Are there any negative aspects to RTLS?

- What is your view/opinion on ERP RTLS/Asset tracking integration?

Questions for industry expert 2

- Which are the core modules of your ERP?
- Does your ERP provide any CRM module?
    - If no, why not?
- Does your ERP provide any MES?
    - If no, why not?
- Is it easy to integrate with 3rd party MES?
- Have you identified a need for asset tracking integration from your customers?
    - If yes, for which modules?
- Is it possible to construct connections between asset tracking in shop floor environment to ERP modules which are not operating towards manufacturing?
- Can all data collected to the MES and/or ERP manufacturing module be transferred to other modules?
- Do all modules have access to all data stored in the ERP?

Questions for industry expert 3

- What is your role?
- How many years have you been working at X?
- Is it possible to integrate RTLS/Asset tracking with the ERP system?
- What RTLS services are your customers using and what departments use the data?
- Have your asked for RTLS/Asset tracking and ERP integration?
- What are the enablers for integration of RTLS/Asset tracking with the ERP system?
- Do your competitors offer RTLS/Asset tracking integration with their ERP systems?
- What is your view/opinion on ERP RTLS/Asset tracking integration?

Questions for industry expert 4

- What is your role?
- How many years have you been working at X?
- What ERP system is your company using?
- What is your experience of RTLS/Asset tracking?
- Are you using RTLS/Asset tracking today?
    - If yes, which assets are you tracking and why?
    - Is it real-time or not?
    - If yes, to what system and how is RTLS/Asset tracking integrated?
    - If yes, which departments are using this data?
    - If no, has RTLS/Asset tracking been discussed in your company?
- What do you need to start investing in RTLS/Asset tracking?
- How can your company utilize RTLS (more) in the future?
- Which (other) departments can utilize RTLS in the future?
- Are there any negative aspects to RTLS?
- What is your view/opinion on ERP RTLS/Asset tracking integration?

8.2 Appendix 2 – Thematic narrative analysis of interviews

In this section, the narrative themes of the industry expert interviews resulted from the thematic narrative analysis is presented. This section follows each industry expert 1 to 4. First, a short introduction of the industry expert is provided followed by the associated narrative themes in each industry expert section.

Industry expert 1

Manufacturing company, Logistics consultant

The first person that was interviewed had worked as a logistics consultant for 9 years within internal logistics and warehousing projects at various companies within the manufacturing industry.

Cost

The logistics consultant explains that the use of barcodes and scanners is still a common method for asset tracking. The reason is that many manufacturing companies are managing large volumes and thus, the cost of attaching more advanced tags to the WIP´s and/or pallets would be too expensive. In many cases, it is simply not profitable to apply more advanced tracking techniques than barcodes. Applying tags to pallets, for example, would require a manual activity of attaching the tags to the pallets and you would rather not have any manual interaction in a sophisticated logistics system since it will reduce the efficiency. Consequently, an RTLS system must be profitable enough to overcome the cost of both buying and applying the hardware and this is not the case in companies that are managing large volumes at the moment. The prices would need to drop to match the cost of simple barcodes and scanners.

IT system deficiency

According to the logistics consultant, ERP systems often lacks the ability to handle RTLS data. For example, there are ERP systems that has no functionality to manage carriers. Therefore, applying even the simplest tracking techniques to the carriers and pushing the tracking data to the ERP would not have any impact since the ERP has no object or function to attach the data to. To overcome this, you need to have a more complex ERP system or a sophisticated WMS that is more adapted to manage logistical processes. Having a specialized ERP or a dedicated WMS can be considered an enabler for a successful RTLS implementation within logistics.

He continues to explain that traditional ERP systems can have issues interpreting the data provided by an RTLS. An RTLS will provide positioning data in terms of coordinates, x, y, and z and this information is rather difficult to utilize unless it is put in a relevant context. Finding the right context can be complex and difficult.

Return on Investment (ROI) / Business case

The logistics consultant continues elaborating on the location data. Knowing how to manage and utilize the data is the key. The data should be used differently in different warehouses and thus, it is difficult to perform a Return on Investment (ROI) calculation. It is evident that RTLS has a high implementation cost, but it is difficult to calculate the profit since it is dependent on for example the layout of the warehouse.

A key enabler for decision makers is to find good business cases and currently it is difficult. No manager or other decision maker would invest in an RTLS system without having a solid business case. Building a solid business case would require a known cost and a known profit and the profit is difficult to calculate unless you have a clear understanding of how the RTLS will benefit your unique business. Finding the business case is especially difficult in SME´s.

Operational process maturity

The logistics consultant explains that RTLS generally is a major investment for a small improvement. If the operational processes are mature and well developed, RTLS might help to optimize and finetune the processes. However, if the operational processes are less mature, simpler, and cheaper methods, such as visual management, can have a much larger impact to a much lower cost. An adoption of RTLS is to extract the last percentages of effectiveness. In short, RTLS is a system for adjusting and optimizing already well developed and mature processes.

Potential usage areas

As potential usage areas for RTLS, the logistics consultant mentions industries with large and few batches, for example within the brewing industry. At a brewery, there are not always firm storage areas so tracking of the forklifts can help brewing companies finding the exact location of batches by knowing where the forklift stopped and dropped the batch. In this case, RTLS would be applied to the forklifts.

Second, he mentions industries that manages products sold in bulks, for example gravel and bricks. In this kind of businesses, the forklift drivers operate mainly on experience and personal preferences. For example, if driver A places bulks of gravel at certain location, he known where to pick it up the next day. However, if driver A is replaced with driver B the other day, he would not know where to find the bulks of gravel. In this case, an RTLS system would be ideal.

This is however all hypothetical as the logistics consultant states that he has never been part of an RTLS implementation himself.

Improvements for other ERP modules

The logistics consultant brings up stocktaking as a potential improvement area regarding the accounting module. The Accounting department always has an interest in knowing where all things are and if the right asset is at the right place.

Further, he mentions that tracking resources (workers) could be interesting for the accounting department as well. However, this could be problematic in a Human Resource perspective since tracking of humans can provide overly sensitive data. It could, for example, be possible to measure the time spent on smoking breaks and toilet visits, but that would probably not be allowed by human resource principles and worker unions.

For the Sales & Distribution module, the logistics consultant reckons a lot of improvement potential. Knowing where the products are all the time, and thus being able to calculate accurate lead times, would be valuable for both Sales Managers and customers. For example, if a customer is waiting on a component delivery that is currently causing a delay in the production, it would be valuable to know when and where this component will arrive. This would be extra interesting if customers and suppliers within the same supply chain could share IT structure and thus have a transparent, real-time status of products and deliveries.

Lack of standardization

Regarding sharing real-time information within the supply chain, the logistics consultant mentions lack of standardization as a barrier since suppliers and customers often are using different, incompatible systems. Especially if the supply chain stretches between different continents, for example Europe and China. Globally standardized interfaces would simplify the RTLS implementation in supply chains.

Industry expert 2

ERP supplier, Managing Director Southeast Asia

The second interviewee has worked as Managing Director of Southeast Asia for 9 years. He has worked for the ERP supplier for 16 years and now he is managing implementation projects and support for customers in the Southeast Asia region.

Usage areas

The Managing Director states that he sees several areas of applicability for RTLS and ERP integration. For example, automatic production order timestamping which is automatic start and finish of production tasks. This will enable measurement of precise assembly time and non-productive time. Allow visibility of how much time is wasted on activities other than the production order. The Managing Director propose the automatic production order timestamping to operate by dividing the production layout into zones, where each zone represent different production tasks. The operator would be tracked, to differentiate which production task are executed by localizing which zone the operator is located in. This due to avoiding the in and out timestamping for the different work tasks.

The integration will facilitate extraction of interesting statistics according to the Managing Director. For example, how much time is spent at each workstation, how much time is spent on collecting materials for assembly, collecting the right tools, workstation cleaning and waiting time for new orders. The Managing Director said that this can illustrate percentages how much is spent on the production order and time spent on other activities.

Moreover, automatic stock transfers are tasks that could be achieved by the integration according to the Managing Director. Stock transfers are mostly done manually, where an operator must inform the system manually that material have been moved from stock position A to stock position B. If the informing to the system can be automated, he explains that this would make the work tasks more effortless.

The automatic system informing for both production order timestamping and stock transfers would be beneficial especially for companies in Southeast Asia. This is because there is a lack of knowledge and experience of interacting with systems and working by computer in the workforce in this region. Furthermore, the work culture is stricter hierarchical in Southeast Asia which mean that the management does not trust their operators to operate the systems. Therefore, is not much responsibility put on the operators to do timestamping or stock transfers in the system.

The Managing Director mentions that tracking tools should be able to work by the same principle as production order timestamping and stock transfers. Tools are registered towards production orders and tools are shared between workstations, therefore would it be beneficial to receive automatic tool registration and location of where a tool is located at the work floor.

According to the Managing Director will the automatic system informing result in timesaving, however more important is a constant updated ERP system. Currently, the systems are updated manually, and it is causing issues when not updated timely. For example, if stock transfers or inventory is not updated accordingly it inhibits correct picking lists, showing false material availability and risks production rescheduling.

The cost for an operator in Southeast Asia is a tenth of the cost for a Swedish operator. Because of the low cost, manufacturing companies in Southeast Asia are able hire employees that solely update the system manually. By contrast, if the utilization rate on an operator in Sweden can be increased by automatic system informing it will add up to great cost savings.

Safety is much more considered in Sweden compared to here in Southeast Asia says the Managing Director. In Sweden it may be particularly important to track forklifts, to determine how the drivers operate the forklift and drive in places where they should and should not.

Company maturity

The Managing Director explain that Swedish manufacturing companies have reached much longer in the journey of automatization and effectivization compared to companies in Southeast Asia. Therefore, companies in Southeast Asia are not on that level of optimizing material handling by analyzing picking times.

According to the Managing Director have the governments in Southeast Asian pushed manufacturing companies to become more modern and keep up in the technology development. The manufacturing managers are attending seminars discussing Industry 4.0, but they are still in Industry 2.0 or Industry 3.0. Also, an ERP in Southeast Asia is considered Industry 4.0 even if an ERP have been available for 20 years.

Manufacturers in Southeast Asia are asking for tracking solutions, but do not know why they should implement the solution. For example, it does not matter how much material the manufacturers track if they do not have a system that keeps track of stock availability explains the Managing Director. There are several tracking technologies available on the market, then again, the Southeast Asian manufacturers do not have the basics established. They cannot achieve much improvement because they do not have a system to integrate the tracking solution into. The Managing Director said that he has not enough insight into the Swedish market to answer what are the barriers for companies that have come longer in their journey of automatization and effectivization, such as lean development.

Integrating ERP and RTLS

There should not be any issues with integrating a tracking system and the ERP. Communicating through the open Application Programming Interface (API) between a tracking system and the ERP would be remarkably simple according to the Managing Director. He exemplifies, that it does not matter if the information about a stock transaction came from a keyboard or the tracking system. If the tracking system can communicate the stock transfer through open API with for example, "item number A, move from A to B", it will use the same functions and codes as this would be communicated manually to the system, explains the Managing Director.

Further, he explains that the ERP that his company are supplying have built in functionality that is similar to a MES. In other words, this ERP is specialized for manufacturing companies and does not need a separate MES system to handle shop floor data. Otherwise, this would probably have to be integrated with the RTLS as well, as the MES normally is the system that operates closest to the shop floor.

Modules

Their ERP offers six modules. Manufacturing, Purchasing, Sales, Accounting, Stock, and Time recording module. They do not offer any Human resource (HR) module due to differences in social laws, not simply between continents but between countries. The HR functions are provided by a separate system by suppliers specialized for those functions. The CRM functions are provided in the Sales module.

Usage per module

The Managing Director states that the Sales and Distribution module would benefit from tracking the trucks with loaded goods. The Manufacturing module would benefit from mentioned earlier, tracking humans, forklifts, material, and tools. The warehouse management module would benefit from tracking material. The HR module would benefit from tracking the employees to see how effective they are and determine if the employees are inside the intended manufacturing zones. There may be a problem regarding if it is allowed to track people especially in Sweden, for example it may not be legal to track how many minutes are spent on WC visits. But it would be interesting for safety reasons, employees walking, climbing, and driving forklifts in dangerous zones or dangerously close to other employees, states the Managing Director. All tracked data ends up in the accounting module in some way, but he does not see any direct connection to that module.

Industry expert 3

RTLS supplier in Italy, COO

The third interviewee has worked as COO for Operations and Supply chain division for the RTLS supplier for 13 years.

Customer Requests

The COO of the RTLS supplier started off by discussing some of the most common requests that they receive from current and potential customers.

First, he explains that the customers often request some sort of analysis tools and visualization in line with the RTLS, for example heat maps and spaghetti diagrams. These are both analyses that can be performed offline, after real-time data has been gathered. These tools are often requested by logistics managers and can for example be used for bottleneck identification.

Second, mission scheduling is mentioned as a common request. Knowing the real-time location of all forklifts in the fleet will enable optimization of scheduling of missions. With RTLS, one can calculate how long a mission will take to complete and then balance the mission scheduling accordingly.

A third thing that he mentions is Forklift Guidance System (FGS). The FGS is a system designed to assisting forklifts drivers by using a digital 3D-model which is visualized on a tablet in front of the driver. The FGS can show the missions to the driver, showing which pallet to collect and where to place the pallet and so on. Also, it can remove manual activities completely, for example scanning of new location.

System Integration

The COO continues by explaining that both mission scheduling and FGS often relies on integration between RTLS and the company´s WMS. If the company does not have a WMS, direct integration with the ERP could be possible but there is a risk that the ERP lacks functionality to utilize the RTLS data.

The WMS contains the basic information on which materials and products to be sold first and other kinds of strategic plans regarding warehouse management. The RTLS can retrieve the data and optimize the scheduling. Further, by integrating a 3D-model (or a digital twin), an FGS can be applied to guide the forklift drivers to ensure full efficiency in the execution of the optimized mission scheduling. Consequently, the COO suggests an IT structure including RTLS, WMS and a digital twin for best leveraging from RTLS within a warehouse context.

Barriers

The COO mentions three main barriers for RTLS.

First, the cost and difficulties in making a profitable business case. This is the traditional barrier regarding RTLS.

Second, technology inaccuracy is mentioned. It is not until relatively recently the accuracy of RTLS technique has become accurate enough. GPS has been a valid tracking technique for outdoor environment for a long time, but that only apply for outdoor tracking, not indoor.

In SME´s, there are still difficulties in creating interfaces between IT systems and thus integrating RTLS with existing IT structure. The reason is that many SME´s operates on old, primitive ERP systems and/or lacks specialized systems (for example WMS). Integration can also be expensive, especially when the systems are outdated, which refers to the first main barrier: cost.

The COO predicts that when the prices of hardware and integration decreases, it will be much easier to apply RTLS among SME´s. Then there will be a larger RTLS boom.

Competitors

When discussing competitors, the COO states that the main competitors are the ones using different techniques. The company of the COO has a focus on vision based RTLS while their largest competitors focus on UWB.

He also states that the market is under development and relatively small the moment. There are many suppliers of IT systems that can leverage RTLS (for example WMS suppliers), but regarding RTLS techniques, the market is much smaller.

Industry expert 4

Manufacturing company, CEO

The fourth interviewee has worked as CEO for 7 years and worked in industry automation for 15-year prior. The term RTLS was new to the CEO before receiving the interview guide document.

Usage per module

The CEO believes that most applications can be found in the Manufacturing and Warehouse management modules. Tracking objects through the production facility and supply chain to be able to determine how far the object have come through the facility or supply chain. Also, Sales are interested of how far until production orders are finished, but this information is collected from the Manufacturing module. For the HR module, it would be beneficial for automatic timestamping of employees to track attendance at work and automatic production order timestamping to reduce manual timestamping. Currently, all timestamping is accomplished manually, and it is time extensive. Thereby, the automatic timestamping could help to provide precise timestamping, reduce errors, and misses in timestamping for attendance and production orders caused by manual timestamping according to the CEO. He could not see an application to benefit the accounting module.

Potential usage

Today, current state analyses are executed separately between stations and each data collection occasion. Thereby, does the analysis simply provide a snapshot of the current state. In that way, it would be interesting to receive continuous current state analyses through the integration, says the CEO.

Barriers

A hinder to this integration would be that such solution is undeveloped yet. It would require extensive effort to make the systems work in an appropriate way. Both effort from the ERP supplier to get the ERP ready and make the integration operate in sensibly. In general, it is expensive to be the first to do such integration. If similar integrations have been assessed, then we do not need to start off a clean paper, explains the CEO. The company that the CEO is managing is not considering tracking solutions due to having more important developments that need to be made. They are not ready for such solutions yet according to the CEO.

According to the CEO, in general do not employees like to be watched or tracked. If the employees shall be tracked, union negotiations are required, and it can be difficult to get the tracking of the employees accepted. He has some insights of how other companies have applied tracking into their processes. To get the tracking of employees accepted, they were required to prove that the purpose was not to track the employees' activities, rather check that the employees pick right items. Thus, when customers complain about quality issues, with the tracking of employees can back-track to see if the right items were picked or not.