Tracking for future internal logistics

How to commercialise RTLS technology at Virtual Manufacturing

Master's thesis in Production development

ALICE HALLÉN, MARTYNA KRAJEWSKI

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE

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ALICE HALLÉN
MARTYNA KRAJEWSKI

Supervisor: Pontus Rosengren, Virtual Manufacturing
Examiner: Roland Örtengren, Department of Industrial and Materials Science

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Department of Industrial and Materials Science
Division of Production Systems
Chalmers University of Technology
SE-412 96 Gothenburg
Telephone +46 31 772 1000

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MARTYNA KRAJEWSKI
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Abstract

As new technology emerges, the need to innovate to remain competitive increases. Stemming from industry 4.0, the smart factory concept is the heart of the Industrial Internet of Things (IIoT), where real-time tracking is an important part of intelligent manufacturing. Real-time tracking of various objects in production and warehouses are an essential control element that supports the organisation's decision-making. When deviations and unplanned changes appear, it can supply the necessary information in the right format and at the right time. In collaboration with the consulting company Virtual Manufacturing Sweden AB (VM), this thesis project explores how tracking equipment can be commercialised to improve internal logistics. The result was a case study proving that the computer vision-based tracking system Dragonfly was fitted for indoor localisation of moving vehicles. Functions for visualisation of tracking data such as spaghetti diagrams were developed along with an early-stage standardised work method. Furthermore, the master thesis handles limitations, development areas, and opportunities within the subject of Real-Time Location Systems (RTLS) in manufacturing.

Keywords: internal logistics, tracking, RTLS, manufacturing, computer vision, Industry 4.0, digitalisation, VSLAM

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Alice Hallén & Martyna Krajewski, Gothenburg, May 2022

List of Acronyms

Below is the list of acronyms that have been used throughout this thesis listed in alphabetical order:

AGV	Automated Guided Vehicle
BLE	Bluetooth Low Energy
FPS	Frames Per Second
IIoT	Industrial Internet of Things
IPS	Indoor Positioning System
IR	Infrared Radiation
ISM band	Industrial, Scientific, and Medical radio band
LAN	Local Area Network
LoS	Line-of-Sight
MPS system	Master Production Scheduling system
MRP system	Master Requirement Planning system
NLoS	Non-Line-of-Sight
P2P	Peer-to-Peer
RFID	Radio Frequency Identification
RTLS	Real-Time Location System
SME	Small- and Medium sized Enterprises
SOP	Standard Operating Procedure
SSLP	Simplified Systematic Layout Planning
US	Ultrasonic
UWB	Ultra Wide Band
VM	Virtual Manufacturing
VSLAM	Visual Simultaneous Localization and Mapping
WPAN	Wireless Personal Area Networks

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1
Introduction

Internal logistics support all the internal processes of a company with the purpose to ensure control and alignment. It covers many areas such as planning, execution, and control of the physical flow and internal information of the company, seeking to optimise the resources, processes, and services with the highest possible efficiency. However, in several management ideologies, internal logistics is regarded as waste as it isn't creating any value for the customer. According to the principles of Lean, management should focus on streamlining the internal logistic processes to minimise waste.

All companies working with material handling are working with internal logistics, purposely or not. The range of improvement within this area varies depending on the level of maturity, where factors such as decision making strategies and degree of implemented automation technology matters. A key factor to be successful within internal logistics is understanding the material flow. By monitoring the movement of logistic equipment and material you can improve the routs and reduce waste.

1.1 Background

Virtual Manufacturing Sweden AB (VM) is a company working with Industry 4.0. Their vision is to create a process flow where everything is connected and communicating to help customers who implement the new technologies understand the manufacturing process and draw benefits from it. They have a standardised phase-gate driven process where they gather data from the current "As Is" scenario to be able to use it when creating the future "To Be" scenario. One way of gathering more data during the "As Is" state is by using tracking methods. Virtual Manufacturing has the equipment to perform assets tracking of moving vehicles but lacks a standardised method on how to use the tools to generate value-adding results for the customers. Thus, one part of this project will be to propose a standardised method aligning with Virtual Manufacturing's ideology and current services. However, it is not only limited as an improvement tool, but is rather intended to be used as a continuous tool in daily monitoring. Tracking equipment is a central concept within Industry 4.0 and the smart factory. Real-time tracking of various objects is an important control feature within intelligent manufacturing which supports the organisation during decision making.

1.2 Aim

This project is a case study with the purpose to identify which factors affect internal logistics and how it can be improved with the help of tracking technology used on moving vehicles. The aim should support two use-cases with tracking equipment, first one being as a one time improvement tool and the second as a full-time solution.

For the first case, the result should be an application useful during the "As Is"-state of a project to map the current material flow of forklifts, and support decision making during the "To Be"-state. The application will be derived from data collected from Virtual Manufacturing's customers.

For the second case, the result should verify if it is possible for an organisation to use tracking equipment as a control tool monitoring forklifts, AGVs, etc., in real-time to streamline the internal logistics.

1.3 Problem formulation

The manufacturing world rushes for the fourth industrial revolution, and organisations calculate the risk-reward ratio of becoming early IIoT adopters. As new technology arises, industrial companies have little to no choice in the matter of digitising if they want to maintain competitiveness.

Virtual Manufacturing support companies who want to improve their industrial processes by combining new technology, virtual aid, and classic production technology. As a consultant firm within manufacturing, it is important to be at the forefront of new manufacturing-related technology. Therefore, resources are allocated to investigate future solutions entering the market. This thesis will focus on vetting tracking equipment for internal logistic usage.
To guide the project three main questions, with corresponding sub-questions, have been formulated:

RQ1 What tracking equipment exists on the market?
- 1.1 How does it work? E.g., what technology does it use? What are the differences?
- 1.2 Which markets does the equipment target? E.g., what is the use area?
- 1.3 How mature is the technology?

RQ2 What user cases exist?
- 2.1 In what ways can the tracking equipment be used?
- 2.2 Does the usage area differ depending on the tracking technology?
- 2.3 How does VM plan to use the tracking equipment?
- 2.4 How do VM's customers plan to use the equipment?

RQ3 How can the technology be commercialised?
- 3.1 What type of solution does VM offer today?
- 3.2 What product could VM offer their customers in the future?
- 3.3 How should the best practice/standardized work method be designed?
- 3.4 How does VM want to present the generated data to add value?

1.4 Limitations

The project has a time frame of 20 weeks, limiting the scope of the project. Thus, the assets tracking will be delimited to moving vehicles like forklifts and AGVs. The time frame also affects the choice of company visits, as extensive tracking, e.g., monitoring more than two forklifts at the same time for more than 2 days, on-site would not be manageable. As this project is in collaboration with Virtual Manufacturing, work studies will be carried out with their partners and/or customers, used equipment will be accepted by VM, and the result should be fitted for implementation in their software. Furthermore, the project only aims to provide guidelines to commercialise tracking equipment based on testing, and will not handle a potential final solution ramp-up.

2
Literature review

In this chapter, the literature supporting the project framework is presented. The information is gathered from publications, product specifications, and industry interviews. The chapter covers project management principles, tracking equipment, and internal management theories.

2.1 Internal logistics

There are many different strategies when it comes to production and logistics. Some of the most common ones are the pull- and push-based models. In a push-based system, the demand is planned on estimations, where products and parts are pushed through the value stream to meet future demand. This way, companies are prepared when orders are arriving. In a pull-system, the real-time demand is controlling the material flow. Parts are being pulled upstream when they are needed. This method is often associated with just-in-time concepts and lean supply chain planning.

Depending on what type of products companies offer, a pull- or push-method are better fitted. For example, when a high degree of customisation is offered a pull-system could be beneficial. In the same way, when standardisation and volumes are high, a push system might be preferred. Today plenty of supply chains are operating as a combination of both, but with a primarily push-based system. However, we are seeing that as tools have become more sophisticated it has become easier to predict future demand with a higher degree of accuracy. The development of master production scheduling (MPS)- and material requirement planning (MRP)-systems are supporting internal logistics today, helping to forecast the customer demand and pull parts through the internal value streams when needed. This way, operations can be streamlined and waste avoided.

Another way to improve performance is to reduce waste. The point of Lean is to eliminate waste and non-value-adding operations in all business aspects. The ideology lists eight types of waste: defects, overproduction, waiting, non-utilised talent, transportation, inventory, motion, and extra processing. Thus, internal transportation of parts and components from A to B is not adding any value for customers and is a time and cost-wasting element of your business that should be reduced to a bare minimum.

To do so, the first step is to look at each process and evaluate material flows to identify and cut waste. When it comes to internal transportation, as many businesses are spending a lot of time and money on transporting material and finished products with trucks, there is a lot to win by reducing these types of transports. Overlooking the floor layout to optimise all flows is always important and should always be considered as a first step. At this stage, layout planning methods, e.g., simplified systematic layout planning (SSLP), could be used to chart relationships, and spaghetti diagrams to map the flows. At this stage, it is important to gain an accurate view of how the material moves, i.e., you have to see for yourself what movement occurs. Depending on the frequency of movement, the sampling rate might differ from just watching the vehicles for 10 minutes to a whole shift, to a couple of days. A common method to map movement has been to strap cameras to the objects and analyse the footage afterward. This way the driving route, driving time, down time, collisions, and near misses could be determined. However, this way of working is quite time-consuming, and thus new technology to lessen the workload has emerged. Using tracking equipment as a tool to generate spaghetti diagrams has gained popularity as it removes a lot of added work [1].

Furthermore, the next technological revolution within manufacturing, industry 4.0, brings forward new ways to improve internal logistics. As a part of the smart factory concept, control and monitoring approaches of objects are developed, helping shed light on complex overhead costs. One aspect is the real-time monitoring of objects where the usage of tracking equipment can help the organization make decisions based on current data to respond to unplanned changes and deviations. It would also support the internal processes by assigning and directing vehicles, autonomous or not, towards their next picking goal. Integrated with material handling tools, like bar-code scanning, it would be possible to have full control of where material and assets are located in the facility [1], [2].

Today, we see the biggest manufacturing organisations in the world are calculating the risk-reward ratio of being early adopters of industry 4.0 technology. At the same time, we also see a lot of companies making emotion-driven decisions, where for example best practice stems from old working ways rather than data. In these instances, the structure of the organisation plays a big part in how operations strategies are run. However, what we can see is that small- and medium-sized (SME) enterprises tend to fall behind when it comes to standardisation, digitisation, and knowing their internal flows. Opinions about why this is varies, but the easiest explanation, and most common, is the perception that smaller enterprises simply don't need to. The companies are in a position where they are still profitable even though they haven't streamlined all their processes. On the other hand, this is also one of the reasons as to why we can see that SMEs in development phases need support to handle their expansion. [3]

2.2 Project management framework

When working with project management many principles that can be applied to steer the job. Some of the most traditional ones are derived from lean, like the PDCA-cycle or the six sigma- and 5S roadmaps [4]. Other frameworks that could be used are ISO 21500:2012 and agile project management. The latter has over the years gained popularity as it allows for quick responses to changes. At Virtual Manufacturing, they have developed their own standardised phase gate-driven process as a best practice for project management.

2.2.1 Virtual Manufacturing phase-gate driven process

Virtual Manufacturing has their own project management framework consisting of six gates divided into four phases, see figure 2.1.

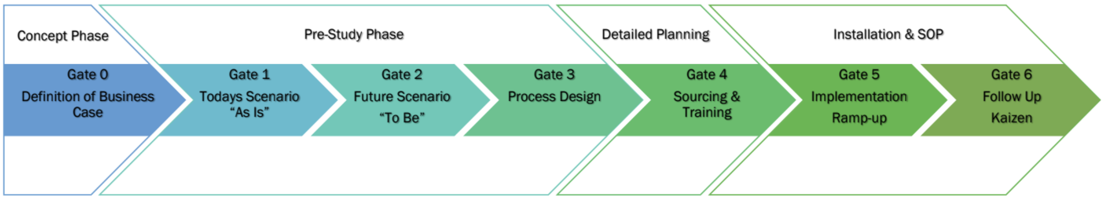

Figure 2.1: Phase-gate driven process used by Virtual Manufacturing.

Concept Phase
The first step of the process in the concept phase where the business case is defined and the scope and aim of the project is determined, along with any underlying issues that indicate the need for the project. The stakeholders of the project are identified, as there can be many, so that the envisioned outcome then can be clarified together with the stakeholders. The expectations for different stakeholders might differ hence it is important to interpret what goals are to be met so that the project might benefit all. During the concept phase it is also vital to estimate factors such as time and cost.

Pre-Study Phase
The next step is the Pre-Study Phase. This period is labour intensive as it includes defining today's scenario, the "As Is" state, and concretise the future scenario, the "To Be" scenario. The "As Is" analysis can be done on an entire business organisation or for specific processes or departments. The goal is to gather data to get an overview of how all the current processes are implemented presently which can then be used to identify issues in the current state and analyze potential improvement possibilities. When mapping the "As Is state it can become apparent which processes are not well documented or streamlined. The "As Is" state lays the groundwork for creating the future "To Be" scenario as the changes that are made are put in place to solve the issues found in the "As Is" state. The "To Be" state is usually developed in deliberation with the stakeholders to make sure that the solution meets the expectations. When the start and the end goal is specified, it is

possible to design the work process enabling the transformation. During the process design, it is also vital to estimate the resources e.g., time, cost, and skill, that are needed for the project to be successful and estimate if the resources available are enough to meet the goals.

Detailed Planning
After finalizing the process design the project enters the detailed planning phase. During the detailed planning phase a project plan is made for all activities that need to be carried during project on a more elaborate level than was done during the pre-study phase and how the tasks and activities will be carried out to reach the desired "To Be" state. Here necessary equipment and competence is sourced out. In order to be certain that the implementation will work, training is of vital importance. If any team member lacks the needed skill set for the project action has to be taken to ensure the competence need is met, either by training of employees so they acquire the necessary skills or by hiring personnel with the right competences.

Installation & SOP
During this phase the implementation of the "To Be" state are carried out according to the detailed plan. Here all the activities and tasks are put into action and managed to deliver results that met the goals and expectations decided upon. As activities are specific for each project the implementation phase is always tailored to the goals of the project, generally by making use of equipment and resources acquired for the project and by developing and implementing new routines. The proposed changes are implemented and standard operating procedures (SOP) are developed for all processes to ensure systematic best practices in all areas of the project.

2.2.2 Agile management with Scrum

Scrum is a part of the agile management manifesto. The methodology was developed during the 90:s and was mainly used by system developers. Today, however, it is well established and used around the world by different practitioners. The methodology was developed as a response to the rapidly changing climate that system developers were working in, to maintain flexibility and keep the business capabilities aligned. There is a strong product-oriented focus where the main goals are broken down into smaller ones, reducing complexity and supporting visibility. Scrum consists of different elements which the product development process goes through. During a shorter amount of time, a sprint cycle is carried out where a specific set of features or capabilities are worked on. The sprint is a way of breaking down the project into smaller parts, wherein each stage what is worked on next is based on feedback and features prioritised in the backlogs. The main parts of the scrum process can be divided into: product backlog, sprint backlog, planning, implementation, review, and retrospective, see figure 2.2. To uphold the structure, there are three distinct roles: a product owner, a scrum master, and a development team.

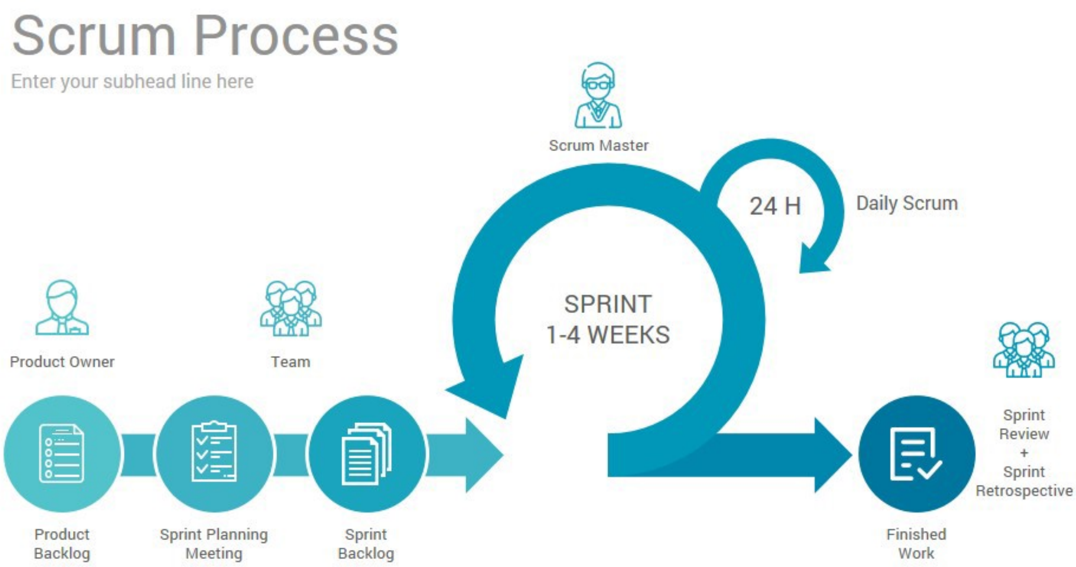

Figure 2.2: The scrum process.

Scrum roles
An agile scrum team consists of a product owner, a scrum master, and a development team, where the shared goal is to create a value-adding product for the end-user [5].

The product owner's responsibility is to maximise the return of investment by ensuring that the customers' and stakeholders' interests are represented in the product backlog. The product owner continuously prioritise and refine the backlog so the most value-adding features are being handled first. By doing so, the alignment between the project- and business objectives are intact [5].

The development team is a high-performing, self-organising group of people that carries out the actual work on the product. No assigned roles nor titles exist within the development team. However, individual members may have specialised skills and focus areas, but the accountability still lies with the team as a whole. The team is supported by the organisation to manage and structure their own work, where no one tells them how to turn product backlog into increments of functionality [5].

The scrum master's role is to serve the development team so they can perform their tasks. As the agile work method advocates for autonomy, where the development team is self-organising, the role doesn't necessarily hold any authority. Instead, the scrum master is thought to be an expert at Scrum and can therefore coach the team forward when needed. The person is responsible for creating an environment where the development team can be effective, which includes arranging daily scrum meetings, removing any obstacles and distractions, addressing team dynamics, and handling the relationship between the development team and product owner or other outside parties [5].

Product backlog

The first part of the scrum process is to define the product backlog. The backlog is a list including all features and functionalities that are needed from the product. The list items can come from external- and internal- stakeholders, and are usually of the characteristic: features, change requests, defects, technical improvements, or proof of concept. Often they are identified via user stories which later have to be broken down into smaller building blocks to be able to work with during the sprint [6].

Each item on the product log list has to be prioritised and have an estimated size. The size could be described in different scales, in figure 2.3 as small, medium, and large (S/M/L), to show how much time it will take to complete the functionality. It is the product owner that is in charge of managing the product backlog, and should therefore continuously overlook the priority of the list items to ensure that they are align with the stakeholders requirements. The most prioritised items are usually placed at the top of the product backlog list [6].

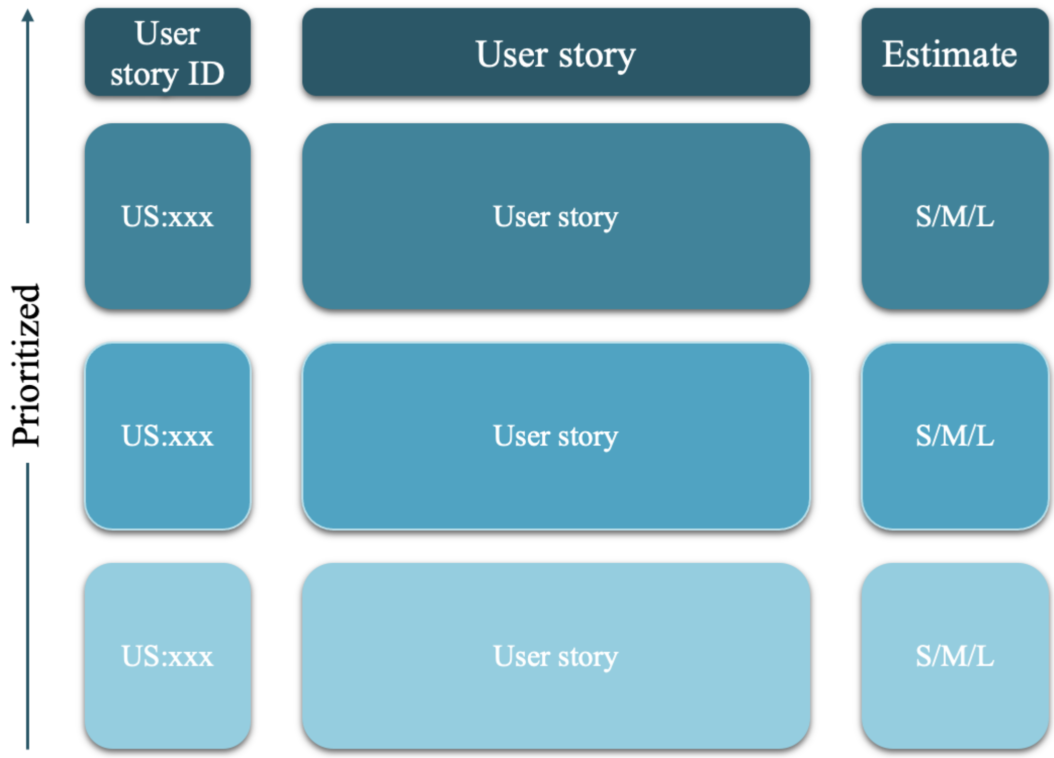

Figure 2.3: Product backlog from scrum methodology.

The product backlog should be detailed enough for the development team to pick up tasks to perform in the sprint. However, as the product backlog includes all features for a project that could go on for months, there will always be some high level functionalities that are not yet broken down into smaller pieces. The procedure to go from high-level functionalities to clearly defined sub-tasks is the product backlog refinement process. During a product refinement session the aim is to generate items that are ready to be picked for an upcoming sprint cycle, see figure 2.4. The session is lead by the product owner where the scrum team are in attendance [6].

Except for help monitoring the project, the refinement process helps ensure that there is consensus between everyone in the project. As the development team will help the product owner estimate the time of the different tasks, and the product owner will break significant functionalities into smaller pieces, the participants get a shared understanding of the product requirements and why they are important [6].

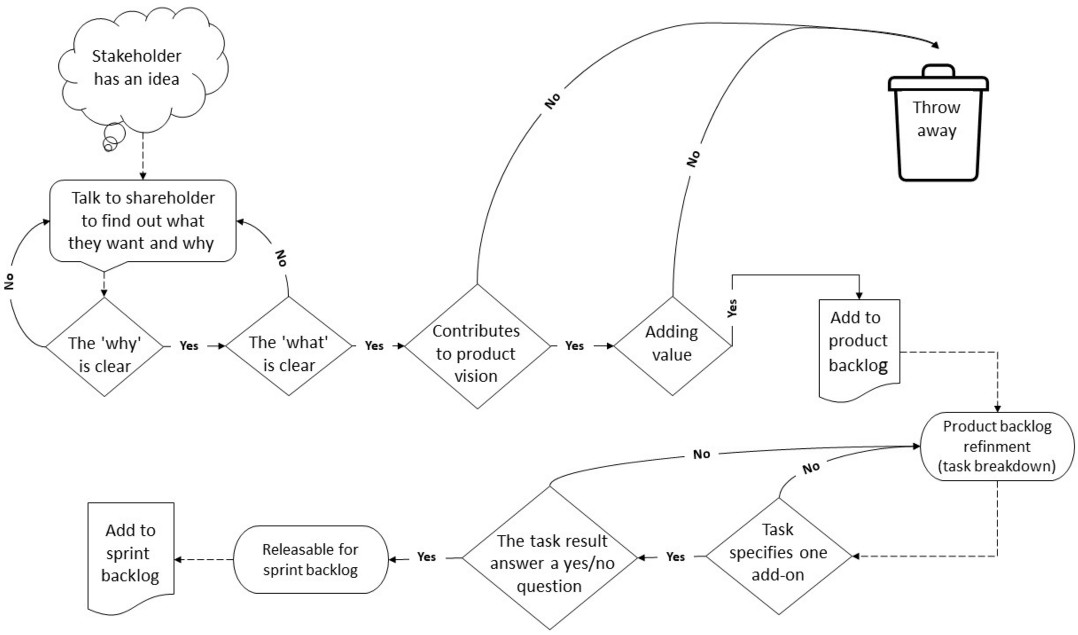

Figure 2.4: Task refinement process for sprint backlog

Sprint backlog

During a sprint planning meeting the aim is to generate a sprint backlog by covering three main topics: define sprint goal, story selection, and capacity planning. A sprint cycle usually takes between 1-3 weeks and the items that can be chosen to work on in the upcoming sprint need to be released as ready. During the meeting, the development team and the product owner goes through what is expected of the upcoming sprint, with the aim to create coherency between the functions. Together they define the scope and communicate a sprint goal that is valuable for the stakeholders [7], [8].

When the team have aligned with the sprint goal, they start look through which user stories in the product backlog that correspond to the aimed outcome. Here it is important that enough items from the product backlog have ready status, otherwise there is a risk that the development team doesn't have enough tasks to work on. The product owner is supporting the team by clarifying any questions regarding the user stories and the prioritisation of the list items [7], [8].

The last part is to control the sprint capacity. The goal is defined and the user stories are chosen, but is it possible to do in one sprint? With capacity both man power related to hours and existing competence are considered. As the development team is a self-organising group, they know weather or not they are able to perform the chosen objectives at the given time frame while producing value adding results. However, the product owner and team are often discussing the effort put in versus outcome to determine if it is worth working on the items in the sprint backlog [7], [8].

If the sprint capacity is enough, then the sprint backlog can be completed. In the backlog, it should be clear from which user story each task is derived. The total estimation of the user story item should be shown, in figure 2.5 as small, medium, and large (S/M/L), as well as the time-box of each task, in figure 2.5 as remaining work in hours. Furthermore, the task status should be visible together with the task owner. The sprint backlog is a visualisation tool for the current sprint cycle helping the development team to stay on track when working towards their sub-goals, as well as a verification tool when the sprint is over [7], [8].

Sprint	Product backlog item	Task	Task status				Owner	Remaining work in hours
			To do	Development	Verify	Done		
1	User story #1 ID: xxx Estimate: M	Task 1	Task 1					35
		Task 2		Task 2				15
		Task 3				Task 3		0
1	User story #2 ID: xxx Estimate: S	Task 4			Task 1			8
1	User story #3 ID: xxx Estimate: M	Task 5		Task 5				25
		Task 6		Task 6				40
1	User story #4 ID: xxx Estimate: L	Task 7	Task 7					50
		Task 8				Task 8		0
		Task 9				Task 9		0
		Task 10			Task 10			15

Figure 2.5: Sprint backlog

Sprint cycle

The sprint planning and creation of the sprint backlog is the first part of the sprint cycle. The following step is the sprint execution. The team works continuously and manage their own time and structure internally. To maintain the given time-frame, daily scrum meetings are held at the start of every day at the same time and location. The meeting is time boxed to 15 minutes to avoid unnecessary discussions, and instead keep the discussions pointed and focused. The daily scrum meeting is lead by the scrum master who's main task is to support the team. As the name implies, the scrum master is a specialist of scrum, and not necessary a master within the area the development team is working with. Thus the role is to support the team in how to be efficient when working with the agile method. The scrum master is facilitating the team by removing obstacles and/or distractions and ensures that best practice is followed [9].

At the end of the sprint, a sprint review takes place. During this meeting the increment is inspected and the product backlog is adapted. The stakeholders are able to inspect the current state of the product and adapt to it. This provides a transparent relationship between the development team and the customers where they can ask questions, give feedback, and be a part of the discussion on how to move forward. The goal of a sprint review is not to "demo a product" but rather present the current state and together with stakeholders decide on a way forward.

The last scrum event of the sprint cycle is the sprint retrospective meeting. This activity is held to ensure continuous improvement and evaluation of best practices. The scrum master, development team, and product owner all attend to reflect on the previous work. While the development team is self-inspecting, the findings might affect the rest of the scrum team which is why they are present. Together they map improvement areas and highlight what worked well and should be continued. To support this work its usual to use a visualisation board with the categories start, stop, and continue. Start means start improving the process, stop means stop doing this entirely, and continue doesn't need any rework.

2.3 Tracking equipment

A key factor of improving and streamlining logistics is ensuring that assets are available at the right place at the right time, and that the assets are moved in the most effective way. A key enabler of this is sharing and collecting data real time by tracking and tracing [10]. The recent development of efficient services based on IIoT has been supported by the ability to produce low-cost and low-energy hardware for a variety of sensors and communication technologies, not least in the field of indoor localization and tracking systems [11].

2.3.1 Real-Time Location Systems

Real-time location systems (RTLS) provide a way of tracking assets in a facility and combined with Industrial internet of things (IIoT) it provides technology to manage assets and detect underlying issues. Tracking assets in real-time can provide many benefits when managing equipment utilisation, inventory levels, and material flow in a manufacturing setting. The data retrieved from RTLS can be used for monitoring processes and in turn provide valuable information for improvement work. [10]

RTLS are commonly used for tracking and tracing within contained areas such as buildings [12]. Most tracking systems that are used indoors use three components: a tag, reference nodes, and a positioning engine. The tag is attached to the asset that is being tracked and sends signals to the reference nodes which usually have fixed positions in the studied environment [10], [13]. The positioning engine then uses a positioning algorithm to estimate the position of the tag [10].

There are several RTLSs available on the market using different wireless techniques. The majority of the RTLSs that are used today use radio frequency communication, but optical and ultrasound technologies are also available. The different techniques vary in terms of accuracy and sensitivity to the surroundings. There are limitations to using RTLS in industrial settings though as industrial settings often consist of large machinery, many metallic parts, wireless equipment, and are noisy which can all disrupt the signals of the RTLS and result in wrong estimation of position [10]. Table 2.1 provides a quick overview of the different RTLS technologies, and in the coming sub-chapters they are explained in more detail.

Table 2.1: Comparison of RTLS technologies.

	RFID passive	RFID active	Wi-Fi	BLE	UWB	US	VSLAM	IR
Typicall range [m]	<100 m	<10 m	<100	<10	<30	<30	<10	<5
Accuracy [m]	Depends on configuration	Depends on configuration	2-5	3-5	0.15–0.30	0.3	0.1	0.5
Power consumption	Low	Low	High	Low	Low	Low	High	Low
Cost	Low	Low	Low	Low	High	High	High	High

Based on information from [14]–[16].

2.3.1.1 Radio frequency technologies

Radio Frequency Identification (RFID) refers to identification systems attached to objects which use radio frequency or magnetic fields to communicate. The main components of RFIDs are the tag, reader, and middleware. The tag is the device attached to the object that is tracked and the reader is the device that is able to detect tags and read the information stored on them. The reader usually communicates using software with the middleware system which transmits the data further to applications. RFID does not require line of sight to read the information stored on them which means the objects being tracked do not need any supplementary handling or aligning [17]. Although, RFID does not have a built-in tracking capability as its intended use is identification and the movement of the assets unknown except for the places they are scanned, meaning it does not allow for real-time tracking anywhere on the premises but only in the places where the scanners are placed [10].

RFID tags can be either active, passive, or semi-passive. Active RFID tags are powered using internal power source, usually a battery with the life expectancy of roughly 5 years. Passive RFID tags do not have any kind of power source, instead they reflect back a signal from the reader which gives them a life expectancy of a lifetime. The semi-passive tags have a built in power source but unlike the active tags it is only used to perform certain functions and does not facilitate communication with readers, for which it uses the radio signals of the reader like the passive tags. Depending on which way the tag and reader communicate, it affects the strength and range of the signal, size, and price. Active tags have a longer transmission range of up to 100 meters compared to passive tags that have a transmission range of up to 10 meters, although typically around 1-2 meters. Although having the tags battery powered require larger tags and is more costly, while also shortening the life expectancy of the tags [17], [18].

Wi-Fi / Wireless Local Area Networks (WLAN) is often used interchangeably and refers to networks of computers that share the same wireless communications line within a small area, usually a room or a building [19]. It can be used to estimate the position of other mobile devices connected to the same network [16]. Since Wi-Fi is already commonly used in both industrial and non-industrial settings, the implementation of Wi-Fi-based RTLS is relatively easy as the existing infrastructure can be used. Routers can be utilized as access points and specialized tags or standard hardware devices like mobile phones can be used as tags for tracking. Wi-Fi is able to operate in Non-line-of-sight (NLoS) conditions without experiencing disturbances and has a range of up to 100 meters [10], [16].

Bluetooth Low Energy (BLE) is a standard for wireless communication technology that uses short-range radio waves for communication between devices [10]. It operates on the license free 2.4 GHz ISM band for its radio signals. Compared to conventional Bluetooth it consumes even less power which allows the devices to operate for a long time, up to five years, before needing to charge them or replacing the batteries [20]. BLE is a low cost solution since a lot of existing devices such as mobile phones can be used. Generally BLE does not require Line-of-sight (LoS), meaning the signal can travel directly from the emitter to the receiver, and the communication is not affected by obstacles like walls [20], [21], but to ensure good accuracy it is vital that the beacons are closely set in the premises [10]. Bluetooth can support a transmission range of roughly 100 meters at most, but is typically it is used for much shorter distances of roughly 5-10 meters [20]. BLE can track with an accuracy of roughly 3-5 meters [22].

Ultra Wideband (UWB) is a short-range wireless communication technology that can transmit information over short distances. It operates on frequencies over 0.5 GHz, but when used in RTLS it usually operates at a higher frequency of 3 GHz. Generally UWB is able to penetrate materials that obstruct the signal, but at the high frequencies used for RTLS applications it loses the ability to penetrate materials and as such it requires LoS between the tags and the reference nodes in order to operate with an positioning accuracy of a few centimeters. Depending on the accuracy level required for the positioning, the infrastructure has to be built out to overcome the issue with NLoS which increases the cost and maintenance of the system. [10]

2.3.1.2 Sound-based technologies

Ultrasonic (US) technologies are based on the transmission of ultrasound waves and operates in the low frequency band [16]. Unlike the radio frequency technologies the ultrasonic equipment is not referred to as tags and trackers, instead the ultrasound receivers are called listeners and the nodes broadcasting the signals are called beacons. The beacons are generally placed in fixed positions at a high height in the area where the tracking is done, and the listeners are placed on the object that is being tracked. The beacons transmit ultrasonic pulses to the listeners which in turn calculate the distances to the beacons to estimate their position. The architecture of ultrasonic systems can also be reversed, where the listeners are placed in fixed positions and the beacons are placed on the objects that are tracked [23]. US equipment is more suitable for room-level applications as ultrasound waves are unable to penetrate walls. The accuracy is also affected by interference from ultrasound signals that reflect off surfaces (e.g., metals.) [16].

2.3.1.3 Optical technologies

Visual Simultaneous Localisation and Mapping (VSLAM) uses computer vision for mapping and positioning. Generally VSLAM systems operate by identifying reference points in the environment by analyzing camera frames continuously to triangulate the location of its own position. Unlike the ultrasonic and radio frequency technologies the VSLAM technologies do not require tags for the positioning, instead it uses a camera and computer. It does require LoS to be able to identify reference points in the environment, and might be affected by light conditions in the environment. [10]

Infrared radiation (IR) technologies use electromagnetic waves in the spectral region of infrared to detect and track objects. Direct LoS is required between the transmitter and receiver for the equipment to work correctly, and it is best suited for room-level applications as it is unable to penetrate through walls [16], [24]. IR technology overcomes many of the interference issues that radio frequency technologies experience, but are in turn sensitive to interference of objects that block the LoS and strong light sources such as fluorescent light and sunlight. There are different types of system architectures for IR positioning, some being able to provide mm precise accuracy while others only provide a rough accuracy of a couple meters [16].

2.3.2 Tracking equipment used at Virtual Manufacturing

Virtual Manufacturing are using different types of equipment when tracking e.g., the Marvelmind Indoor Navigation System from Marvelmind robotics [25], the Dragonfly from Onit [26], MotionLab from Nexonar [27], and Industrial indoor positioning system from Navigine [28], and TMT250 Mini Trackers from Teltonika [29]. Therefore, the project is not limited to using only one certain type of tracking equipment system.

The Marvelmind System uses ISM band technology and ultrasonic beacons with different frequencies available. The beacons are available in different models and the architecture of the beacons and listeners is alterable so it can be applicable for different types of environments and use cases. Regardless of which architecture is used, the systems require setting up multiple beacons/listeners on the walls/ceiling of the premises. The equipment is also usable outdoors. [25]

The Dragonfly system is adapted to use when tracking forklifts, AGV, AMR robots, and drones. It uses a computer vision-based positioning system that provides the indoor location of the object. Cameras are mounted on the object and connected to a small computing unit that analyzes the real-time video stream to deliver the location. Dragonfly is well suited for tracking forklifts in busier environments as it doesn't use radio frequencies to transmit the signals, making it less sensitive to disturbances like noise, pillars, and shelves blocking the transmission. [26]

The MotionLab from Nexonar uses IR camera technology for measurement and analysis of dynamic processes and measurement of static coordinates. It is applicable in rooms of over 100 m^3 and measures motion with an accuracy of up to 0.3 mm. It is developed for motion measurement in assembly processes, robot workplaces, and tool-setting procedures, thus making it unsuitable for tracking of vehicles over large areas. [27]

Both the Industrial indoor positioning system from Navigine and the Mini Trackers from Teltonika are based on BLE technology and are easily integrated with existing infrastructure such as Wi-Fi, which makes it a low cost solution. Although, the systems require require up multiple receivers in the premises while only providing accuracy of a few meters. [28], [29]

3
Method

To guide the master thesis project Virtual Manufacturing's phase gate drive process was used as the backbone, chapter 2.2.1, with elements of the agile methodology, chapter 2.2.2, incorporated. This resulted in a two-phased gate drive process were certain elements were looped over in sprints, see figure 3.1. Virtual Manufacturing had communicated an area of interest, "How can tracking equipment improve internal logistics and bring value to our customers", which was considered the true north of the project while moving forward.

During the first phase the framework for the project was defined, including company interviews, literature studies, problem formulation, and execution planning. The second phase was more result focused and included execution, evaluation, implementation, and feedback.

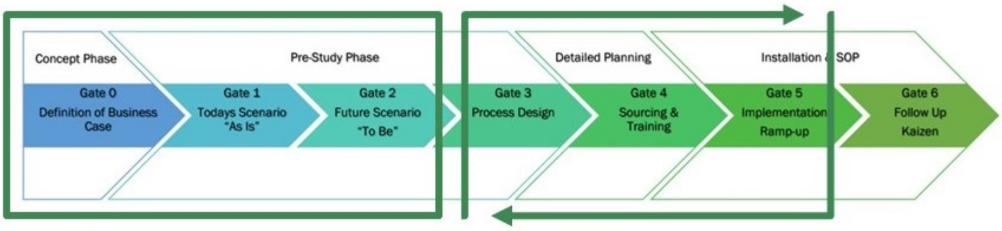

Figure 3.1: Derived two-phase gate drive process.

3.1 Phase 1

The purpose of the three first gates in phase one, see figure 3.2, was to define the problem formulation and corresponding research questions so they aligned with the interest of all stakeholders. The first step, gate 0, was to define the business case, which was the area of interest Virtual Manufacturing had expressed at the beginning. Then, to define As-Is state, interviews with employees at Virtual Manufacturing was held to understand what RTLS-equipment they had today and how they used it. In addition to the interviews, literature studies about RTLS technology was carried out obtain a holistic view of the use areas and a deeper understanding of how the technology worked.

The final gate was then to define how the future scenario should look like. Again, interviews with Virtual Manufacturing was held to understand how they would like to work with tracking equipment, what limitations and possibilities they saw, and what support functions had to be developed in order to obtain the envisioned outcome. To add value to VM's customers there had to be an alignment between the stakeholders wishes. Therefore, interviews was conducted with selected companies to understand their current usage of tracking equipment and investigate how the usage could bring value in the future.

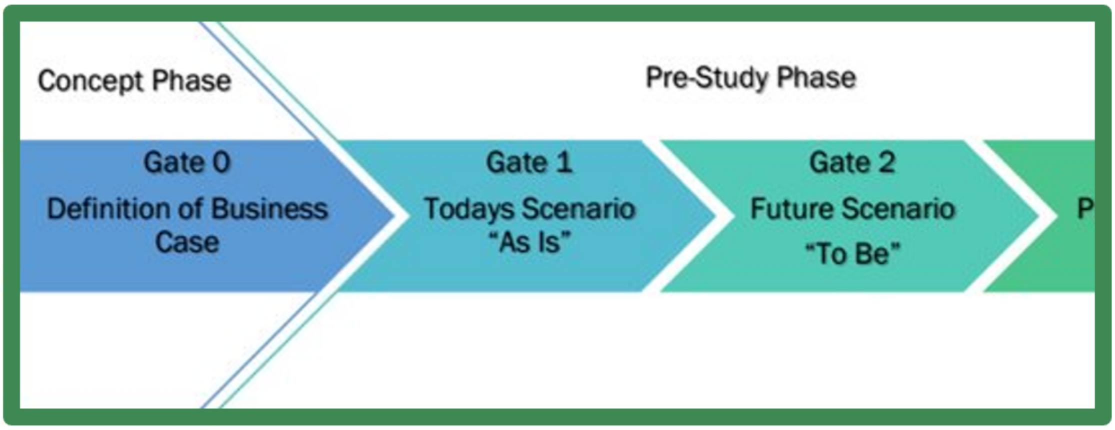

Figure 3.2: First phase: Definition of the business case.

Based on the results from the three gates, the scope, limitation, and research questions with corresponding sub-questions could be established. Furthermore, three partner companies was decided to visit with specified objectives for each place. Hence, the characteristics of the project resembled the one of a case study: where the current thesis was tested by real life implementation with the result then evaluated in order to decide how to proceed, shaping the the steps and the course of the project. For this reason, it was decided to use the scrum framework where you break down the overall goal into smaller activities to produce value adding results continuously and stay on-track throughout the thesis work.

3.2 Phase 2

During the second phase, the focus was to generate results from conducting test at company site. Each user story was picked up, went through the three gates in phase two, figure 3.3, in one sprint cycle, figure 3.4.

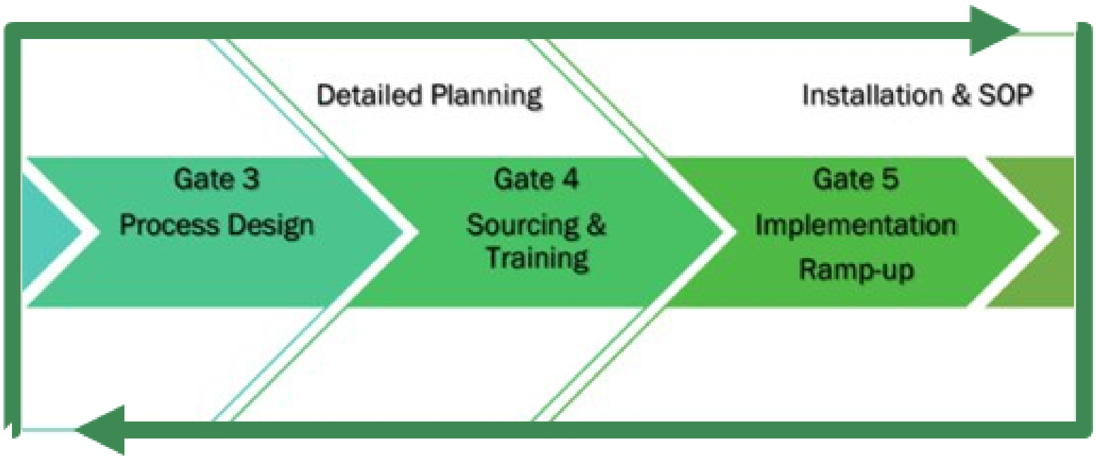

Figure 3.3: Second phase: Execution.

Figure 3.4: Sprintloop from the Scrum methodology.

3.2.1 Gate 3

The third gate was the process design. Before any sprint cycles could be planned, a product backlog had to be provided. From the interviews conducted with VM, Scania, Haglund's Industries, and Dana user stories about how a RTLS product should work was derived. Internal user stories were also added as they were important for the progression of the project. The user stories were estimated and collected in a first rough product backlog.

To be used in a sprint backlog, the user stories were refined, according to the schematics in figure 2.4, and prioritised, where the items with higher priority were most critical to break down. The items with lower priority could remain as high-level functions partly because they were not urgent but also due to the early stage of the project there was not enough knowledge to refine them further. The aim of product backlog is to have items that were in ready-status and could be picked up for any upcoming sprint cycles.

As each sprint would be based on previous experience, the sprint backlogs was created in the beginning of each sprint cycle and not on before hand. Based on ready-status and priority a user story was picked up and planned as a sprint, the first step being to create a sprint backlog.

3.2.2 Gate 4

In the fourth gate, the sourcing and training was conducted. Using the sprint backlog, preparations for the company visit was done. Specific equipment and methods to solve pre-determined tasks was sourced, together with training to be handle the equipment as well as the upcoming environment.

3.2.3 Gate 5

The final gate was implementation and ramp-up. This step consisted of the actual company visit where the tasks were carried out, supporting the ramp up towards final goal of creating an RTLS-service suited for Virtual Manufacturing. In extension the ramp up included parts like documenting value adding results, improve support functions for the RTLS-system, find limitations for the tracking equipment, and troubleshoot arising problems. At the end of each loop, a review- and retrospective-meeting was held. The first one included relevant stakeholders where the results was discussed to show transparency and ensure continued alignment. The retrospective meeting was held mainly internally, but occasionally attending supervisors from VM or Chalmers, to discuss the work procedure rather than the result. Here it was decided if the current way of working was suited, needed to be improved or just stopped all along.

4

Work procedure

In this chapter the work procedure and results of the master thesis are presented in chronological order. It includes detailed descriptions of each sprint cycle and the findings along the way.

4.1 Phase 1

The aim of the first phase was to outline the scope of the master thesis by defining the problem formulation and research questions. Therefore, the first step was to have an initial discussion with the supervisor from Virtual Manufacturing to elaborate more on the communicated area of interest. The problem formulation was focused on what is driving internal logistics forward and if tracking equipment could be an enabler. Virtual Manufacturing had bought different types of tracking devices, e.g., VSLAM-, BLE-, and ultra sonic equipment, to use during the as-is state when gathering information about the logistic flow at customer site. However, they had not managed to implement any of the tracking equipment successfully as an offered service yet. Therefore, their wish was for the master thesis to investigate how this could be done using preferable the existing equipment or source other solutions on the market.

Afterwards, literature studies on tracking equipment, in general and in regards of internal logistics, was studied to obtain a holistic view of RTLS-technology. The findings showed that control and monitoring approaches within industry 4.0 is dedicated towards real time tracking systems, where investments for big-scale implementations are made. The literature supported the usage of various tracking equipment continuously in daily operations to improve the internal logistics. For example, RTLS-systems integrated with ERP-, MES-, and MRP-systems can help keep inventory levels low, trigger action only when needed, prioritise which operator getting the picking order depending on moving distance, improve vehicle safety, and avoid misplacing or losing material.

Together with the literature studies and after observing how the employees at Virtual Manufacturing worked with tracking equipment it was concluded that it existed more than one stakeholder to consider when trying to capture the scope of the project. Except for Virtual Manufacturing's user stories their customers demands had to be considered to make sure the objectives aligned. Thus, interviews with Virtual Manufacturing's customers was held to understand their current and future scenario. Scania, Dana Inc., and Haglunds was interviewed on the subject. Scania and Dana Inc., both large enterprises, said that they researched tracking equipment for the purpose of daily monitoring and control, and saw that the technology could add value when used together with their existing enterprise control systems. As for Haglunds, a SME, they wanted to use tracking equipment to get a better understanding of their current material flow. Using spaghetti diagrams and heat maps for the movement of pallet lifters they could look into future layout improvements based on routing, distance, empty runs, and down time. From the interviews and literature, there was consensus that the biggest RTLS anchor-dragger is to make it work seamlessly in an industrial setting which offers challenges in the environment. For one instance, then demand on the infrastructure to support technology that needs to send a lot of data over a stable internet connection or communicate unhindered via radio frequencies are very high. Another aspect is the risk of being a "too early adapter", where you invest in a technology that proves to be not competitive in the near future. As the RTLS-technology is improving rapidly and new solutions are occurring on the market constantly there is a risk of investing to early and thus acquire a solution that is not robust nor mature enough.

With this knowledge, the problem formulation focused on how tracking could be commercialised by vetting the current technologies in order to see how it could be more widely implemented in manufacturing and warehouse logistics. It accounted for Virtual Manufacturing's interests as well as their customers and potential customers. Research questions could than be decided which helped guide the project from the As Is state to the To Be state, see figure 4.1.

Figure 4.1: Research- and sub-questions.

4.2 Phase 2

In the second phase, the process design, sourcing and training, and implementation and ramp-up was carried out based on the findings from the first phase. Because of the characteristics of the thesis, including company visits, use cases, and stakeholders, case studies would be the best approach forward. Viewing each company visit as a separate case study, the scrum framework allowed for a iterative work process where knowledge from earlier trials was utilised. The result was a structured framework which allowed for flexibility to rapidly change when needed and continuous learning along the way. Each case study would go over all gates in phase two during, the planned company visits were at Haglund Industri AB, Scania Smart Factory Lab, Dana Inc., and Virtual Manufacturing's production site in Linköping. Each user story was picked up and worked through in a sprint, and the results from the sprints are presented below in the following sub-chapters.

4.2.1 Project backlog

From the previous phase, the interviews, literature studies and observations were translated into user stories collected in a first rough product backlog, see figure 4.2.

User story ID	User story	Stakeholder	Estimate
ID: 1001	How can we commersilise the tracking equipment we have at VM?	External VM	L
ID: 1002	We want to use Marvelmind to track manual forklifts to understand AsIs state	External VM	M
ID: 1003	We want to test another tracking technology different from the ones we tried to use as a RTLS in our daily	External Scania	M
ID: 1004	We want to see if there is any tracking equipment that would be fitting to implement as an RTLS in our	External Dana Inc	S
ID: 1005	We want to verify if any tracking equipment at virtual manufacturing works to answer our reserch questions	Internal	M

Figure 4.2: Product backlog with user stories.

Afterwards, the user stories was refined to be in a ready-status to be picked for sprint cycles. Items had to be prioritised, where the ones with the highest priority got broken down into smaller tasks. Some items was not refined completely due to priority or because of the lack of knowledge during the early stage of the project. Figure 4.3 is the refined product backlog, where the user story ID:s marked in green are in ready-status and could be picked for an upcoming sprint cycle.

User story ID	Stakeholder	User story	Estimate	Tasks
ID: 1005	Internal	We want to verify if any tracking equipment at virtual manufacturing works to answer our reserch questions	M	Second testing of equipment at site
				Inital testing of equipment at office
				Research how the current equipment work
ID: 1002	External VM	We want to use MarvelMind to track manual forklifts to understand AsIs state	S	Get educated on how MarvelMind work
				Prepare how MarvelMind should be installed at site
				Perform tracking at customer
				Decide how many forkliftsshould be tracked and for how long
ID: 1003	External Scania	We want to test another tracking technology different from the ones we tried to use as a RTLS in our daily organisation	M	Research alternatives
ID: 1004	External Dana Inc	We want to see if there is any tracking equipment that would be fitting to implement as an RTLS in our daily organisation	M	Research alternatives
ID: 1001	External VM	How can we commersilise the tracking equipment we have at VM?	L	Investigate how tracking data can be visiulised in Gaspazho
				Investigate if there are any other solutions on the market better suited
				Investigate what tracking equiment is best suited for different use cases by testing on site at partners/customers

Figure 4.3: Refined product backlog.

The refinement work of the product backlog was an ongoing process during the course of the thesis. However, together with VM a preliminary schedule of the case studies was made, see figure 4.4.

Figure 4.4: The six sprints of the project.

4.2.2 Sprint 1: Haglund Industri AB

For the first sprint cycle the user story ID: 1002 was picked, see figure 4.5. At Virtual Manufacturing's request the US tracking equipment from Marvelmind was to be used at their customer Haglund Industri AB's site. Haglund Industri AB is a manufacturing company that produces industrial refrigerators, freezers, and refrigerated counters. Virtual Manufacturing wished to use tracking equipment to map their processes of the "As Is"-state and gain information for future improvement work. The goal was collecting data of how pallet lifters were moving inside the premises, focusing on the products that were moved in the final assembly area.

Sprint	Product backlog item	Task	Task status				Owner	Remaining work in hours
			To do	Development	Verify	Done		
1	We want to use Marvelmind to track manual forklifts to understand "As Is"-state ID: 1002 Estimate: S Time box: 32	T1 Get educated on how Marvelmind work					MK	18
		T2 Prepare how Marvelmind should be installed at site					AH	5
		T3 Perform tracking at customer					MK	8
		T4 Decide how many forklifts should be tracked and for how long					AH	1

Figure 4.5: Sprint 1 backlog: Tracking "As Is" state at Haglund Industri AB.

Before going to the customer site some preparations had to be done. For Task 1 and Task 2, research was done about how the Marvelmind equipment works and it was tested in the Virtual Manufacturing office to gain some experience in how to set up and use the equipment and how to interpret the data it generated. For Task 4 it was decided to gather tracking data from one pallet lifter.

The test runs of the Marvelmind equipment at the office were successful why it was considered to be able to be used for tracking manual forklifts at Haglund Industri AB. The key takeaway from the test runs was best practice when setting up the equipment to ensure the beacons could communicate with each other.

When trying out the equipment on site there was an issue with the setup of the equipment since the beacons had to be aligned to be able to communicate with each other, which showed to be a challenge in industrial settings as there are typically open space areas that do not always have walls or other fixed surfaces on which the beacons could be attached. This limited the area that the beacons were able to track the pallet lifters during this company visit.

When the beacons were set up in the final assembly area the listener was placed on the pallet lifter to gather tracking data (Task 3). During the tracking there was also an issue of interference of the signal as the metal in the refrigerators and freezers would block the signal of the beacons. When the signal was disturbed the position would bounce and give inconsistent data of the location of the tracked item. Using the ultrasonic equipment in this case was considered to not be able to generate reliable data as the final assembly area mostly consisted of large refrigerators that would cause a lot of signal disturbances.

After the visit it was concluded that the Marvelmind equipment was not ideal for this project as the pallet lifers travel over large distances which would require a large infrastructure of beacons to provide data of their movements. Hence the plan was to evaluate how tracking equipment could be used at different companies it became apparent that setting up the beacons for each company visit would be time consuming and thus more fitting for an fixed installation or tracking in a smaller area. It would also not be applicable in all cases as many industrial settings have a lot of metal machinery that would disturb the signal.

4.2.3 Sprint 2: Sourcing of tracking equipment

The aim of the second sprint was to investigate all tracking equipment possibilities at VM, see sprint backlog figure 4.6.

Sprint	Product backlog item	Task	Task status				Owner	Remaining work in hours
			To do	Development	Verify	Done		
2	We want to verify if any tracking equipment at virtual manufacturing works to answer our reserch questions ID: 1005 Estimate: M Time box: 56	T1 Second testing of equipment at site					AH	16
		T2 Inital testing of equipment at office					AH	16
		T3 Research how the current equipment work					MK	24

Figure 4.6: Sprint backlog for sprint 2: Verification of tracking equipment at VM.

After failing to track using Marvelmind at Haglund Industri AB, the focus was to find other tracking techniques that was better suited. Antoher aspect we realised was that the setup time must be low if the tracking equipment is going to be used for data collection during AsIs-state. Preferably it should involve as little adjustments to the infrastructure as possible. To reach the sub-goals of the sprint, research questions from the project was used to guide the RTLS research and the evaluation of technology, see table 4.1.

Table 4.1: Research questions

RQ1 What tracking equipment exists on the market?
- 1.1 How does it work? E.g., what technology does it use? What are the differences?
- 1.2 Which markets does the equipment target? E.g., what is the use area?
- 1.3 How mature is the technology?

RQ2 What user cases exist?
- 2.1 In what ways can the tracking equipment be used?
- 2.2 Does the usage area differ depending on the tracking

With the second sprint backlog and the research questions, the implementation phase of the cycle began. By studying literature and product specifications a comparison of the different RTLS could be conducted, see table 4.2.

Table 4.2: Comparison of RTLS technologies.

	RFID passive	RFID active	Wi-Fi	BLE	UWB	US	VSLAM	IR
Typicall range [m]	<100 m	<10 m	<100	<10	<30	<30	<10	<5
Accuracy [m]	Depends on configuration	Depends on configuration	2-5	3-5	0.15–0.30	0.3	0.1	0.5
Power consumption	Low	Low	High	Low	Low	Low	High	Low
Cost	Low	Low	Low	Low	High	High	High	High

Based on information from [14]–[16].

All RTLS technologies are represented at Virtual Manufacturing providing different benefits and disadvantages. The Marvelmind Indoor Navigation System (US) is usable outdoors and the Dragonfly system (VSLAM) is not. However, Dragonfly is better suited for forklifts in busier environments as it doesn't use radio frequencies to transmit the signals, making it less sensitive towards disturbances like noise, pillars and shelves blocking the transmission. The MotionLab system (IR) is developed for SMED applications making it unsuitable for tracking of vehicles over large areas. The Industrial indoor positioning system from Navigine (BLE) and the Mini Trackers from Teltonika (BLE) provide less accuracy than the other technologies. Both Marvelmind and the BLE technologies require installation of receivers in the premises which might be time consuming for one-off applications.

Based on the literature studies and the result from tracking at Haglunds, Marvelmind was not considered a valid alternative to proceed with for the tracking. After comparing the characteristics of the different RTLS, the VSLAM system was considered most likely to provide results when tracking vehicles. The VSLAM tracking system available at Virtual Manufacturing was the Dragonfly fron Onit.

To get a better understanding of how Dragonfly worked and if it was any idea to go through with testing at site, trail runs at the office were conducted. When tracking, a wide angled web camera was connected to a computer, in this case a laptop, and records the ceiling to find features to recognize and navigate by. The device was mounted on a cart and moved around the around the office area. The aim of this session was to get a basic knowledge of how to operate the equipment and what information you could derive from it. The first test at the office showed that the equipment had managed to navigate the office correctly and provided analytic information like spaghetti diagrams, heat maps, driving speed, down time, and driving distances. As Dragonfly have a cloud service where you can monitor your movements in real time, and visualise old data afterwards it is easy to use and doesn't require any manual data handling. As the office testing showed positive results, it was decided to go out to Virtual Manufacturing's production facility in Linköping to obtain more knowledge about the characteristics of the software and how it preforms in an industrial setting.

The testing in an industrial setting was also successful where the Dragonfly equipment was mounted on a pallet lifter, for which it worked well enough to generate data of how the pallet lifter had moved in the premises. By stacking the lifter with pallets that measured just over two meter was the LoS was tested. It showed that the equipment was still able to perform the tracking without problems as it provided accurate results, could be used over large areas, could be used for both one-off improvements projects and as a fixed installation, and was not disturbed by materials in the surrounding, see figure 4.7.

Figure 4.7: Spaghetti diagram from tracking at Virtual Manufacturing Linköping visualised in the Dragonfly Dashboard.

The generated tracking data was exported to Virtual Manufacturing's own application Gazpacho which they have developed for processing and visualizing data from different types of tracking equipment. Since VSLAM technologies had not been frequently used by Virtual Manufacturing in the past, the application did not read the csv file correctly, see comparison from Gazpacho and the Dragonfly dashboard in figure 4.8 and 4.9. Therefore, a Matlab script handling the same csv file by reading latitude and longitude instead of relative x- and y- positions, which was figured out Gazpacho did. This way, spaghetti diagrams and correct moving distances could be calculated. Later in the review meeting, the findings from the implementation phase was presented. The Matlab code solution was applied in Gazpacho by VM's lead IT-developer.

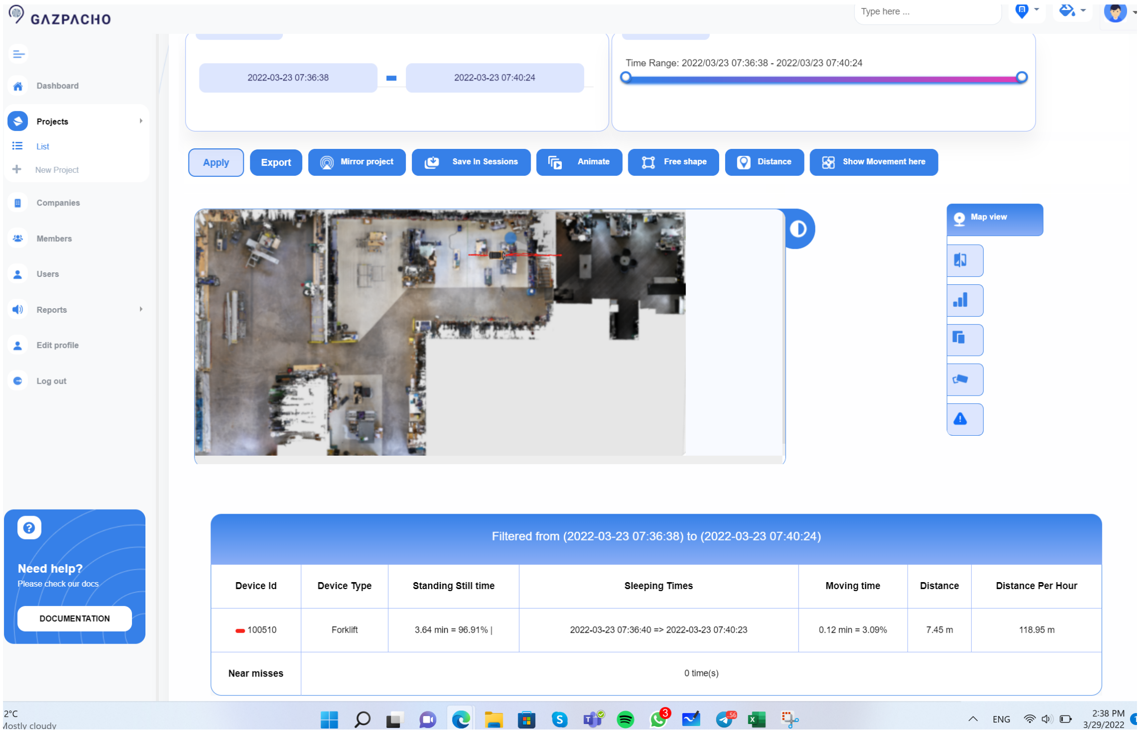

Figure 4.8: Spaghetti diagram from tracking at Virtual Manufacturing Linköping visualised in the Gazpacho Dashboard.

Figure 4.9: Spaghetti diagram from tracking at Virtual Manufacturing Linköping visualised in the Dragonfly Dashboard.

When the implementation phase of the sprint cycle was done, a review meeting with stakeholders from VM, master thesis supervisor and lead IT-developer, was held. During this session the successful result of the tracking was shared, as well as the detected error in Gazpacho and corresponding Matlab solution. The next step forward was decided, where the Matlab solution was going to be implemented in Gazpacho.

A retrospect meeting was held afterwards without any external parties participating. At the retrospect meeting, improvements and best work procedure when tracking at site was noted. Using a laptop when mapping is easier and quicker to set up and use as you can follow the process directly on said laptop. While as for the mini PC recommended by Onit, you need a remote screen, a remote control program, and Wi-Fi to hook it up. Also, if the mini PC would to start up without automatically connecting to Wi-Fi then you cannot use remote control and instead HDMI wires are needed, increasing the room for error. Moreover, the mini PC needs to be connected to a power source as it doesn't contain a battery. Taking a laptop will therefore require less devices, making it easier to use not only when mapping but when tracking as well. The advantages of the mini PC was that it is smaller in size compared to a laptop, and it came configured directly from purchase.

To be able to use the tracking equipment on all types of vehicles used in internal logistics, consideration also had to be taken to how the tracking equipment could be attached to the vehicles during the tracking. For this purpose a box was built to fit the laptop as well as a rod with a box on top to fit the camera. The box for the laptop could be mounted on the rod in which case only the rod would have to be attached to the vehicle, but it could also be attached separately from the rod if needed. The rod was made to be used when tracking forklifts, as the developer on the Dragonfly equipment recommend mounting the camera during mapping on the same height as the tracking will be carried out. During the visit at Virtual Manufacturing's production site the attachments were tested on a pallet lifter in order to ensure that the attachments would not get in the way or obstruct the handling of the pallet lifter when loaded with pallets, see figure 4.10.

Figure 4.10: Mounting equipment created at Virtual Manufacturing Linköping including: Camera box, mounting pipe, computor box.

4.2.4 Sprint 3: Scania AB Smart Factory Lab

The next case study was at Scania's Smart Factory Lab, where the scope was to show them a new tracking solution they had not tried yet. After a planning meeting with Lennart Lundgren at Scania Smart Factory, the deliveries became clear and a task refinement could be done and a sprint backlog could be created, see figure 4.11 and 4.12.

User story ID	Stakeholder	User story	Estimate	Tasks
ID: 1003	External Scania	We want to test a tracking technology different from the ones we tried to use for RTLS so far	M	Prepare necessary equipment to track at
				Show how choosen tracking method works at Scania Smart Factory Lab
				Show how adaptable to changing envrionment
				Perform position accuracy testing
				Test tracking in different ceiling heights
				Research and present alternatives Show real time monitoring performance
ID: 1004	External Dana Inc.	We want to see if there is any tracking equipment that would be fitting to implement as an RTLS solution in our daily organisation	M	Research tracking alterntatievs to find best alternative
				Do proof of concept
				Show real time monitoring performance
ID: 1001	External VM	How can we commersilise the tracking equipment at VM	L	Investigate how tracking data can be visiulised in Gazpacho
				Investigate if there are any other solutions on the market better suited
				Investigate what tracking equipment is best suited for different use cacases by testing on site at partners/customers

Figure 4.11: Refined product backlog for sprint 3: Tracking at Scania smart factory

Sprint	Product backlog item	Task	Task status: To do	Development	Verify	Done	Owner	Remaining work in hours
3	We want to test another tracking technology different from the ones we tried to use as a RTLS in our daily organisation ID: 1003 Estimate: M Time box: 32	T1 Showcase how adaptable to changing environments the equipment is					MK	3
		T2 Perform position accuracy test					AH	3
		T3 Test tracking equipment at different ceiling heights					MK	3
		T4 Show real time monitoring performace					AH	3
		T5 Research and present alternatives					MK	6
		T6 Prepare necessary equipmnent to track at customer site					AH	6
		T7 Showcase how choosen tracking method works at Scania Smart Factory Lab					AH	8

Figure 4.12: Sprint backlog for sprint 3: Tracking at Scania smart factory

At the smart factory they had a variety of tracking equipment installed on the premises such as UWB, US, and BLE which they tested. However, they had not tried VSLAM equipment and as Dragonfly just had been verified to provide valid tracking data in an industrial setting it was chosen as the standard method to use for tracking and to showcase for Scania. Given that the system worked as a real time monitoring system in a big scale setting, the company was only interested in a demonstration of how the equipment worked, how it performed during various scenarios, and what it would cost to implement, see sprint backlog of the third cycle in figure 4.12.

Except for technology research, the preparations included equipment building. After tracking at VM's site in Linköping, and extensive testing at the office, it became obvious that a cart for the mapping phase had to be built, see figure 4.13.

Figure 4.13: Cart created to facilitate the Dragonfly mapping process

On site at Scania Smart Factory Lab, the sprint implementation started with showing how to set up the Dragonfly system. After a brief explanation of how the Dragonfly equipment worked, the mapping process started. Creating a good map is the most important aspect as the condition of the created map affects the performance of the navigation later on. Thus it was important to be successful in this stage, using the best practice set from previous sprint cycle. There occurred some issues during the mapping, as the frames per second (FPS) would drop significantly enough for the Dragonfly equipment to not be able to pick up enough reference points in the ceiling to be able to localize its position and the camera would eventually lag completely. When contacting Onit support about this issue, a suggestion was made that the hardware used for tracking did not fulfill the requirements for Dragonfly to work properly. This issues resulted in the mapping process taking considerably longer than expected.

When the mapping was done, tracking at the area was conducted. Initially the tracking equipment was tested on two AGVs driving simultaneously to see how the real time monitoring of two devices worked. The test also showed that the map created for the tracking could be used to track by another device, meaning Scania could benefit not only from historical data of how vehicles and assets move but also get a quick overview of them real time and where they were located in the premises.

Next, the performance of the equipment for different ceiling heights was tested. When mapping, the camera should be located at the same height as it will operate on once attached to the vehicle. Thus, using the same map for vehicles at different heights like AGV:s and forklifts might affect the performance. Therefore, this was tested by tracking on three different heights, 60-, 100-, and 170 cm. When starting the tracking at a different ceiling height than the one used during mapping the equipment would sometimes take longer before being able to locate itself in the environment, but was eventually able to navigate as usual. When tracking in the Smart Factory Lab and then continuing the tracking in the final assembly area, where the ceiling height between the two areas differed by a few meters, the tracking equipment performed well.

Then, the performance in different environments was tested in two ways. The first test was mapping a part of their production facility, which had a higher ceiling and features that usually only occur at manufacturing sites, to see how the equipment performed. It showed that the equipment had no issues mapping and positioning itself in this area. The second performance test examined how the equipment performed in an area where the ceiling height would vary. When tracking in the Smart Factory Lab and then continuing the tracking in the final assembly area, where the ceiling height between the two areas differed by a few meters, the tracking equipment performed well. Important to see was if the navigation sometime went in a lost state, how quickly would it start navigate again. During the visit, demonstrations for several business units was conducted.

Lastly, the accuracy of the equipment was tested by tracking while moving between two markers that were placed on the ground and stopping at the marked spots. The coordinate data was then analyzed and compared for each stop, showing a deviation of maximum 10 cm. However, it is important to keep in mind that the human factor affects the outcome for this test as the equipment might not have been placed in the exact same spot, adding to the accuracy deviation.

At the review meeting in the end of the sprint cycle the master thesis supervisor, lead IT-developer from VM, and a representative from Scania was present to take part of the results. The results form the various tests were presented and showed to perform under various conditions which was a key aspect form Scania. All the tasks in the sprint were fulfilled and Scania expressed an interest in trying out and implementing the equipment on a more extensive scale. The issues that occurred during the mapping were brought to light for full transparency between all stakeholders. While at Scania the tracking data was presented in Onits own application. However, a request from both Scania and VM was to be able to use the data in VM's own software Gazpacho. This required further development of Gazpacho as it didn't generate the right size nor position of the spaghetti diagram. Instead it had to be resized and rotated manually. A suggestion was laid out to the master thesis supervisor and the lead IT-developer for how to visualise the spaghetti diagrams in Gazpacho the best way without having to adjust the diagrams manually, which was cleared from implementation.

During the retrospect meeting the handling of faulty equipment was mainly discussed. As problems occurred during the visit, a standardised procedure was developed for how to handle these issues. New hardware was ordered with increased capacity to use for future case studies to rule out that the issues stemmed from this. Onit also made suggestions of how the low FPS value could be handled by restarting the software and making sure no other programs were overloading the central processing unit (CPU) of the computer, which was noted for future work.

4.2.5 Sprint 4: Dana Inc.

During the fourth sprint the Dragonfly equipment was tested in an industrial setting at Dana Inc. After discussing with Magnus Hanson Fallenius it became clear that they saw value within RTLS and wanted to see a proof of concept for a recommended solution. Thus, a product backlog and a sprint backlog could be provided, see figure 4.14 and 4.15.

User story ID	Stakeholder	User story	Estimate	Tasks
ID: 1004	External Dana Inc.	We want to see if there is any tracking equipment that would be fitting to implement as an RTLS solution in our daily organisation	M	Research and present alternatives
				Show proof of concept
				Prepare necessary equipment to track at customer site
				Show real time monitoring performance
ID: 1001	External VM	How can we commersilise the tracking equipment at VM	L	Investigate how tracking data can be visiulised in Gazpacho
				Investigate if there are any other solutions on the market better suited
				Investigate what tracking equipment is best suited for different use cacases by testing on site at partners/customers

Figure 4.14: Refined product backlog for sprint 4: Tracking at Dana

Sprint	Product backlog item	Task	Task status				Owner	Remaining work in hours
			To do	Development	Verify	Done		
4	We want to see if there is any tracking equipment that would be fitting to implement as an RTLS in our daily organisation ID: 1004 Estimate: M Time box: 24	T1 Show proof of concept					AH	8
		T2 Show real time monitoring performace					AH	8
		T3 Prepare necessary equipmnent to track at customer site					AH	6
		T4 Research and present alternatives					AH	2

Figure 4.15: Sprint backlog for sprint 4: Tracking at Dana

The first part of the sprint cycle was an online meeting with Dana to present the tracking equipment that was intended to be used. Despite encountering errors when using Dragonfly at Scania it was still considered the most reliable and best suited equipment for the user story scope. As problems had occurred with the hardware previously, additional devices was brought along as backup. Furthermore, the support team from Onit was ready on standby to help troubleshoot the equipment.

On site at Dana, the mapping was carried out after lunch. From the previous sprint experience at Scania the awareness that the mapping session could be troublesome prolonged the process significantly. During the test session it became clear that navigation did not work properly and instead Dragonfly was lost the majority of the time. Similar to the situation at Scania the navigation system had a hard time finding any features and struggled with low FPS. When the map was finally done it was tested and evaluated doing test runs with the tracking equipment on the cart instead of directly mount it on a forklift. To maximize the performance of the tracking session another map was created after the trial run. When the second map was created Onits team joining digitally to support when needed. The low performance of the tracking system complicated the mapping and delayed the process significantly. However, the focus from Onits side was to gather data for them to troubleshoot when recreating the environment. In the end, a map that performed slightly better than the fist one was obtained, and during the following day the Dragonfly equipment was mounted on a forklift to gather driving data, see figure 4.16. Again, the performance was very strained and thus it was not good enough data to gain a proper proof of concept. A positive result was that it was possible to show the real time monitoring performance in the Onit cloud dashboard during the limited time when the equipment was navigating. During the second day at Dana the tracking device was strapped onto the roof of a forklift to track a moving object in an uncontrolled environment. The equipment used was the web camera, a laptop, and a power bank. During three hours the equipment was out trying to navigate with varying results.

Figure 4.16: Equipment mounted on the roof of forklift.

At the review meeting in the end of the sprint cycle the master thesis supervisor together with a representative from Dana Inc. was present to take part of the results. To provide full transparency towards the stakeholders, the current state of the tracking product was discussed. The issues with performance of the hardware and potentially the software was brought to light. But also, some proof of concept was possible to show from the sequences where navigation worked. But as the result did not reach the sub-goals set for the sprint, it was decided to come back. During the review meeting in the end of the sprint cycle the current state of the tracking product was told to the people at Dana. As it was not certain that the low performance stemmed from poorly performing computers, software problems, faulty best practice, or a combination of the aspects it was decided to come back with new laptops in an attempt to rule out one factor. For the retrospect meeting, the main focus was to go over the work method to see if it was something there that contributed to the low performance.

At the second visit mapping followed by tracking of a forklift the same ways as previously was conducted. The result was better compared to the first sprint cycle at Dana, where the forklift was tracked for 50 minutes before the battery of the computer died. In the review meeting it both the representatives from Dana and Virtual Manufacturing agreed that the technology had potential and that a proper proof of concept had to be generated to show for the Dana board. The second loop also highlighted problems when fitting your generated spaghetti diagram in Gazpacho manually. Often management doesn't know exactly where the forklifts have driven, and especially not if we are considering driving paths over some hours. Therefore, having to scale and rotate the spaghetti diagram so it will look correct on the floor plan in Gazpacho could be impossible. It also defeats the purpose of having monitoring system if you need to know on beforehand where the forklifts have gone to visualise the data. Therefore, a solution in Matlab that is intuitive for any user to manage was presented for the IT-developer and supervisor at VM. At the retrospect meeting it was decided to stop go out and track at stakeholders until the a standardised work method to handle deviations was in place.

4.2.6 Sprint 5: Best practice

Towards the end of the product backlog a new user story was added by Virtual Manufacturing. As the product backlog is a dynamic working tool it is common to add user stories, re-prioritise items, and remove finished product backlog items. After breaking down the new user story to smaller building blocks and updating the existing list, a new refined product backlog was ready for sprint release, see figure 4.17

User story ID	Stakeholder	User story	Estimate	Tasks
ID: 1006	External VM	We want you to establish best practice for tracking with Dragonfly so we can use it at customer to decide AsIs state	S	How much time is needed
				How do you get the best result from tracking
				What is the best way to set up the tracking equipment
				What equipment do you need
ID: 1001	External VM	How can we commersilise the tracking equipment we have at VM?	L	Investigate how tracking data can be visiulised in Gaspazho
				Investigate if there are any other solutions on the market better suited
				Investigate what tracking equiment is best suited for different use cases by testing on site at partners/customers

Figure 4.17: Updated product backlog for sprint 5: Tracking at Dana

The aim of the new user story was to establish a best practice when tracking with Dragonfly. Virtual Manufacturing were going to use the equipment at a customer to define their "As Is"-state, and wanted a description of how to use it before going out there. Hence, a new sprint backlog was created, see figure 4.18.

Sprint	Product backlog item	Task	Task status				Owner	Remaining work in hours
			To do	Development	Verify	Done		
5	We want you to establish best practice for tracking with Dragonfly so we can use it at customer to decide AsIs state ID: 1006 Estimate: S Time box: 16	T1 How much time is needed					AH	0,5
		T2 How do you get the best result from tracking					MK	12
		T3 What is the best way to set up the tracking equipment					AH	2
		T4 What equipment do you need					MK	1,5

Figure 4.18: Sprint backlog Best practice VM

When establishing the best practice, the knowledge from all previous sprints was compiled into one instruction manual, see Appendix A. Important was that the manual answered the tasks in the sprint backlog. As there is a instruction manual on how to get started with Dragonfly posted on Onits web page this was not covered in the checklist provided to the employees. Instead, the list was focused on what should be prepared on beforehand, what support equipment to bring, tips to think of during mapping and tracking, and mounting solutions. Except from writing down a manual, education at the office was conducted where the employees could ask questions.

4.2.7 Sprint 6: Virtual Manufacturing

The last item in the product backlog was the biggest user story. The scope was to answer how tracking equipment can be commercialised at Virtual Manufacturing. The created sprint backlog, see figure 4.19, has three tasks to resolve. However, not a lot of new research or testing had to be carried out as all of them have consciously been worked on during the course of the master thesis as the results from previous sprint cycles has provided a good basis.

Sprint	Product backlog item	Task	Task status				Owner	Remaining work in hours
			To do	Development	Verify	Done		
6	How can we commersilise the tracking equipment we have at VM? ID: 1001 Estimate: L Time box: 80	T1 Investigate how tracking data can be visiulised in Gaspazho					AH	21
		T2 Investigate if there are any other solutions on the market better suited					MK	8
		T3 Investigate what tracking equiment is best suited for different use cases by testing on site at partners/customers					MK	51

Figure 4.19: Sprint backlog Best practice VM

During this sprint cycle, the learning's from previous sprints along further development ensured that each sub goal could be reached. Considering task 1, the investigation of how tracking data can be visualised in Gazpacho was conducted by revising all earlier sprint cycles. Visualisation in Gazpacho had been solved from a technical point of view during earlier sprint cycles. However, to refine the usage of Gazpacho it had to become more intuitive and user friendly. When using the application there are steps when you do not know if you need to enter values in order to get the correct outcome or if you could leave it blank. Moreover, during the sprint the interface was evaluated more closely to improve the user experience. What features should be available, how it looks, and how easy is it to handle was aspects considered. when wanting to use the different features in Gazpacho there are a lot of reloading and reentering of decisions which feels unnecessary and annoying. Lastly the visual design of the application should be considered to improve if it is going to be used with customers. Mainly since Onits own application is easier to handle and better looking at the moment. This was then summarised and discussed with the supervisor and IT-developer at VM to reach consensus in what to implement.

To answer the second and third task in the sprint backlog, the results and experiences from earlier sprint cycles was used. In today's climate, the emerge of new RTLS is constant. However, not all systems are suitable for tracking vehicles in an industrial setting for one or two days. The way Virtual Manufacturing wants to use tracking in their own organisation is to use it as a tool to establish the As-Is state. Therefore, tracking equipment putting demands on the infrastructure in order to function is not a plausible solution. Furthermore, in large areas tracking systems requiring plenty of transmitters and receivers would be to time consuming to install. Thus is the VSLAM solution that Dragonfly uses considered the best solution for the way Virtual Manufacturing is intending to use tracking equipment of vehicles. Research on other computer vision navigation systems on the market was carried out. However, no findings of any commercial products was made. When using Dragonfly during company visits, knowledge about the product was gained which contributed when evaluating if this is a tracking solution worthy to move forward with. As the testing on site involved different clients with different user cases, the width of how the tracking equipment was desirable to be used was obtained. Also, as some customers already had used tracking equipment information why they was deemed unsuitable could be obtained.

The results of the sixth sprint cycle was presented at the review meeting where employees from Virtual Manufacturing was attending. Describing the state of the product and getting feedback from the stakeholders about their perception and experience of RTLS in general and Dragonfly in particular. The retrospect was held without any external parties and discussed documentation as an improvement aspect.

During the sprints the aim of the company visit was very different. The takeaway from Scania was that they are very far ahead when it comes to sourcing RTLS to implement in their daily operations and are looking to add value by not only using the monitoring aspect but the added features you can generate like picking missions. Thus, when coming there they were already very clear with how tracking was going to add value in their organisation, they just needed to ensure that the chosen equipment can deliver what they are looking for in terms of accuracy, implementation, and flexibility. At Dana they were also in understanding how tracking of forklifts could help improve their daily operations, but they had not come as far as Scania who were vetting different technologies. From them, the focus was to have a proof of concept of any tracking equipment that would be fitting which they could show to the board of directors. It was therefore vital show that the Dragonfly did work in their environment and how it worked rather than accuracy testing and future build-on:s.

In any regard, the results from Scania and Dana provided the insights that the concept of Dragonfly is well suited when wanting to use it continuously in your organisation. However, as the tracking equipment did not work seamlessly at their sites it is impossible to say that Dragonfly would be a working alternative based on the visits. Although, after meetings with Onit who developed Dragonfly it is clear that the equipment is meant to be used continuously at customer site and they have plenty of success stories to share of how they have installed it in big warehouses and in production.

Taking into account the other use cases were tracking was used as to map the movement of forklifts to understand the "As-Is"-state, the results show that there is a need for this type of solution. Using Marvelmind is not an alternative, but with the Dragonfly, which doesn't require any mounting on walls or any support from the infrastructure more than features in the ceiling, it would be possible to efficiently track vehicles over a large area. However, as the master thesis have not conducted any test of this at a customer on its own, feedback from the employees using it at BorgWarner was obtained. Unfortunately, as they used the equipment directly after Dana and it did not work properly their outcome was not successful, and thus it is impossible to say that the system would be a working solution based on experience. In theory though, if the tracking equipment works to track continuously in an organisation it should be possible to do it during shorter periods of time. After discussing this use case with Onit, the opinion from them is that it would work, but that the mapping session needs to be prioritised and time has to be allocated to do it properly even if the tracking is only going to be for a couple of hours. This aspect means that tracking might not be fitting to use during the "As Is"-state when only one or two vehicles needs to be tracked for an hour or two, as the setup time would be longer than the actual tracking time when doing it by mounting a go-pro. But for cases where 3 or more vehicles should be tracked for a longer period of time than 1 hour it would be a fitting solution, given that it works, as you don't need to sit and analyse the video material and draw a spaghetti diagram manually.

5

Discussion

As mentioned in the literature review, many tracking technologies exist on the market and have shown to be successfully implemented in manufacturing settings. For the different types of cases that were examined during this study, VSLAM technology was seen as best fitted. However, for other cases other types of tracking equipment could be better fitted.

The first question in this study sought to determine what tracking equipment exist on the market, how the technologies differ from one another, and how mature the technologies are for implementation. Different types of tracking equipment was researched and their advantages and disadvantages were weighed against each other to decide on what tracking equipment should be used for the case studies. If desired, other types of tracking equipment could have been purchased, but the attributes of the Dragonfly seemed fitting for the case studies. As to how mature the technology is, it is hard to determine. Although being able to produce accurate data of tracked vehicles, some issues were experienced during the tracking process. That is not to say that the technology is not mature enough, as lack of training and insufficient hardware were most certainly adding to the problems experienced.

The second question in this study sought to determine what types of user cases that exist in manufacturing settings and how tracking equipment can be used for different user cases, considering both VM and their customers. Virtual Manufacturing expressed that they want to offer tracking as a standard method when managing projects. When interviewing the companies in the case studies about how they plan to use tracking equipment it became apparent that the intentions were both for one-off improvement projects and as a continual implementation. Thus, it was important to consider that Virtual Manufacturing need to find a solution for both to satisfy the needs of future customers as the extension of the projects they take on vary widely along with the customers intended use for tracking.

The third question in this study sought to determine how the tracking technology could be commercialised at VM. As of today, VM does not offer tracking as a standard solution. Trials had been made in the past with different types of equipment that provided insufficient results, why the need for a standardised work method was needed. A manual for best practice during tracking with Dragonfly was developed, but further tests should be conducted to make it more extensive and to find solutions to some of the issues that weren't resolved. As to how the data is to be visualised in Gazpacho, a first draft of concept has been developed to make sure the spaghetti diagrams are visualised accurately in the software. However, the functions were implemented in the last stages of the project and will likely need to be tested more extensively to find bugs and improve the usability.

6 Conclusion

The main goal of the current study was to determine how tracking equipment could be commercialised at Virtual Manufacturing Sweden AB. This was investigated in several sprints where the requirements and expectations of both Virtual Manufacturing and their customers, some of who want to make use of Virtual Manufacturing's services when preforming tracking in the near future, were considered. Different tracking technology was sourced and two types of tracking equipment was used in industrial settings. The results of this study show that VSLAM technology could be an effective tracking tool that is fitted for both for single use in shorter improvement projects but also as a solution used in the daily use of companies. The VSLAM equipment was able to generate tracking data in several industrial settings, but issues were also experienced during use. For some of the issues a standardized work procedure has been developed, while some of the issues need further investigation as the reasons are still not known fully.

It was not possible to assess the usability of all types of tracking technologies; therefore, it is unknown if any other technology would be better fitted to use. Although, research was made about existing tracking technologies and their advantages and disadvantages and considered before deciding on using Dragonfly. In spite of the limited technologies tried out, this work offers valuable insights of what needs to be considered in order to commercialise tracking equipment at Virtual Manufacturing Sweden AB and companies alike.

A main factor to consider is to develop a standardized work method to be able to commercialise tracking as a service. Some insights were made on how to streamline the work when visiting a customer to preform tracking, but continued efforts are needed to be made to make the tracking more usable by all employees. A manual of best practice when conducting tracking was developed, as the manuals from the developer did not cover all the problems that arose when out tracking at customer sites. A part of the best practice manual considered what type of equipment had to be brought on site to be able to set up the equipment properly. Some equipment was also built to facilitate the tracking. A trolley was built to use during the mapping to be able to move around the equipment smoothly, to which a rod could be attached to bring the camera at the desired height. Attachments for the computers and cameras was built, although only on a prototype level. For future cases it is suggested that the attachments are developed to fit all types of vehicles that are to be tracked, and brought out to customer sites as a standard.

Another important factor that was considered was how to present the generated data so that it would be possible to add value. If visualised correctly, spaghetti diagrams are able to show which paths the tracked vehicles have taken and show where there is waste in the internal logistics such as improper trip routing, utilised equipment, and badly planned process flows. To ensure that the tracking is value adding, a lot of effort was placed on how to visualise it in Virtual Manufacturing's software Gazpacho in a user friendly way for both VM employees and customers. The software was developed to be able to handle the output data from Dragonfly and functions were developed for ensuring that the diagrams would visualise the correct paths on the layout when data was uploaded.

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A
Appendix 1

Devices needed to track
- Laptop - Laptop charger - Camera, bring both 170 and 180 degree wide angle - Camera extension cord (USB extension cord) - Powerbank - Powerbank charger - Cable connecting the powerbank to laptop with correct adapter - Wireless Wi-Fi - Wireless Wi-Fi charger
Preparations
- How many square meters are the tracking area, will affect the time needed to map - What is the ceiling height, might affect choice of camera - How are the ceiling conditions? Will feature enhancers be needed? - Prepare picture of the layout - How is the passability? Is it possible to do smaller loops or are the space restricted? - Verify what vehicle that is being tracked so equipment needed to mount the devices can be prepared - Make sure the customer talked with the union about tracking. The tracking equipment is using video feed looking up to the ceiling, thus camera recordings are involved. - Make sure that the laptops used have the camera calibration files for each camera - Make sure the laptops used have teamviewer with easy remote access so you can control it when it is strapped on the vehicle.
Best practice when mapping
Equipment to bring - Trolley - Camera mounting pipe - Camera tripod mount - Screw driver and kit with bits

Best practice
- When mapping use the trolley to push around instead of fasten equipment on tracking vehicle.
- Use a laptop instead of the computer Nuc sent by Onit. It is easier to look on the computer screen to see what you are doing.
- Make sure that the camera is mounted without any line of sight disruptions, e.g., laptop lid parts of the trolley, or yourself.
- Enable show 3D points in the dashboard
- After closing one loop, press stop and save the map. After the map is saved, press play again. Do not worry when the red line disappears, you can still continue mapping
- If the red line looks askew in the shape, then it might indicate low performance when mapping usually related to finding few or not exclusive features. Than it is recommended to start over as it might be hard to navigate on this map in the future.
- Depending on the shape of the facility it might be better to map small rectangular sections one at a time to build your map rather than mapping the outer boundary of the whole facility first and than doing inner loops. For example, if you have an L-shaped area, splitting it up into two rectangles in the beginning might give better map performance.
- Do not over constrain the system when setting markers. The first three markers are the ones used to triangle the area which are the most important ones. Additional markers can be added but only if necessary. You will not get better performance by adding markers.

Best practice when tracking

Equipment to bring
- Laptop case
- Powerbank case
- Camera mounting head
- Mounting material, e.g., strong magnets or duct tape

Best practice - Use laptops when tracking at customer as it is easier to handle in terms of setup. However, if you are at a customer who wants to implement Dragonfly in their daily operations be clear to explain that laptops are the solution when tracking for a day or two. When buying a solution product it will be a small Nuc mounted on the vehicle.

DEPARTMENT OF INDUSTRIAL AND MATERIALS SCIENCE
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden
www.chalmers.se

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