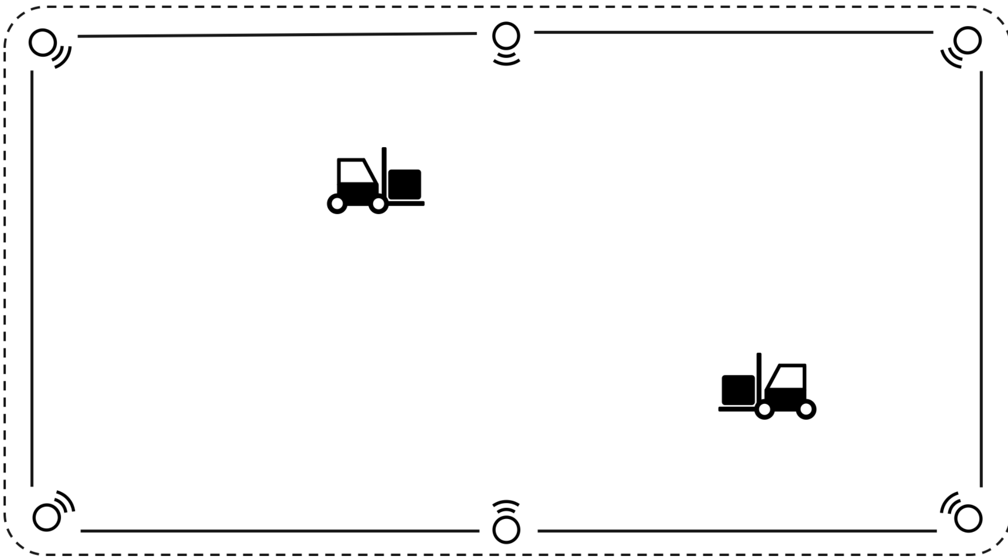
Indoor positioning in manufacturing environments

An investigation of system usage for Industry 4.0 applications



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Master's Thesis 2020
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Abstract

This study investigates how radio-based indoor positioning systems should be used to generate user value. To do this, problems that indoor-positioning can solve and potential system users must be found. The general approach is the design method *design thinking*. This means that iterations are used to continuously increase understanding of the user and the problems. To gather qualitative data 27 interviews (14 unstructured & 13 semi-structured) were conducted. This data was then analyzed using the Affinity Interralationship method do identify problems that indoor positioning could solve in the manufacturing industry. Quantitative data gathered from a positioning system at a manufacturing site was used for investigating possible system usages. Solution ideas were evaluated with the identified main user and a focus group. Our analysis shows that a radio-based indoor-positioning system can be used to solve problems with *lack of data* and *low-qualitative data*. It also identifies the production engineer as the main-user of such a system. User value is generated to this user by using the system to increase safety and productivity; Supply data for manufacturing KPI calculations; and enable manufacturing process analysis. The study concludes that indoor-positioning has many relevant areas of usage in manufacturing environments. However, solution ideas with the biggest impact are today limited to monitoring applications. We would, therefore, suggest further research regarding integration between systems used in the manufacturing environment and radio-based indoor positioning systems. This would enable controlling activities as well.

Keywords: Indoor positioning, Design thinking, KPI, Smart factories, Industry 4.0, Manufacturing

List of Abbreviation

AGV |Automated guided vehicle
GDPR | General data protection regulation
RTLS | Real-time location system
UX | User experience
ROI | Return on investment
GUI | Graphical user interface
TCP | Transmition control protocol - Protocol for internet communication
KPI | Key performance indicator

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Contents

1

Introduction

This introduction chapter aims to give an understanding of why this research is conducted. Initially a background is presented to problematize the lack of indoor positioning in the manufacturing industry. This is followed by a description of the purpose and limitations of the research. Finally, the research questions that this thesis will answer are presented.

1.1 Background

Manufacturing industries are constantly trying to optimize production processes by analyzing data from the production (Amrina, Firdaus, et al., 2018). This is often done by identifying and reducing activities that do not add value to the product. (Liker & Meier, 2006). Operations that occur in the production cells can be measured very accurately. But mobile activities over greater distances, such transportation of material or human activities on assembly lines, are harder to analyze. In outdoor environments analysis of moving objects can be done using GPS. But because devices and satellites requires free sight, positioning using GPS is not possible in indoor environments.

There are many different technologies making indoor positioning possible today. But no complete solution have been created to function as an indoor counterpart to GPS. Samama (2019) explains that this is not a technical problem but instead derives from the inability to meet required customer constraints, such as ease of use, cost, and performance. The inability to satisfy these parameters simultaneously is described as the *indoor positioning problem* and have caused many positional projects to deliver unsatisfying result. Because of this, investors are becoming increasingly reluctant to provide funding for indoor positioning projects.

The solution of the *indoor position problem* must be based on the actual needs of the industry (Samama, 2019). This requires an understanding of how industries operate when implementing new technology, as well as the potential user of those systems. Industries measures its operation using KPI's (Key Performance Indicators) and relates to parameters such as production output and overall equipment effectiveness (Amrina et al., 2018). Because of this, it is important to show how investments in new systems or technology can improve KPIs, especially when it comes to larger investments. Understanding this is key to present improvement suggestions that will be approved by upper management. Commonly these suggestions are backed up with a business case that explains how an investment will benefit the organization.

Successful implementation, however, does not only rely on correct business priorities. Loranger (2014) describes that these priorities often lack the reality of the user. With close user involvement, products are more likely to meet the user's expectations and requirements. This also increases the workforce's acceptability of new systems, which makes changes and new technology easier to establish (Benyon, 2014). Understanding the user is because of this essential, especially when a product is a result of technological advancement rather than market demand.

This study aims to find problems in the manufacturing industry that can be solved with indoor positioning. Identified problems will be analyzed to find solutions that generate value for system users in their work. The research is made possible by a previews venture project between Ericsson - Private Networks and multiple other industrial stakeholders. This project resulted in an indoor positioning system that can position material handling equipment and will be used to gather position data. The next section will give a brief overview of the system's functionality and purpose.

Ericsson Private Networks

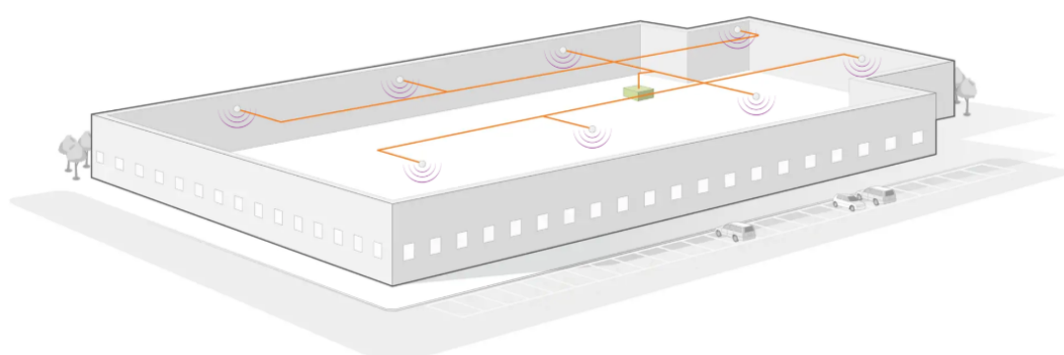

Figure 1.1: Ericsson Private Network setup

Ericsson offers cellular network Service Solutions, aiming to be a leader in 5G deployment. Ericsson radio technology makes it possible to set-up and manages small private cellular networks, see figure 1.1. This means installing radio antennas on a closed-off area. Cellular devices can then connect to this network. One of Ericsson's goals is to offer manufacturing industries this network solution. Ericsson is currently testing such a system at the SKF manufacturing plant in Gothenburg.

Positioning with cellular networks

Figure 1.2 shows a setup at an industrial facility. The cellular network is distributed via radio-dots (antennas) mounted in the facility. When several radio-dots covers an area, you can use the response time from a device to each radio-dot to position the device.

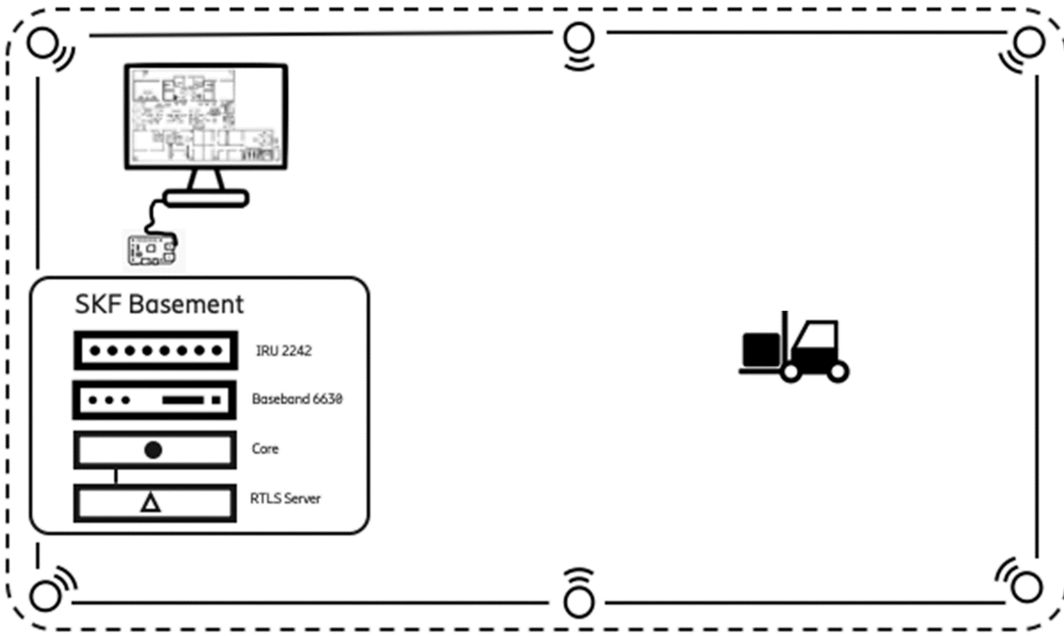

Figure 1.2: Overview of system setup with radio-based technology

1.2 Purpose

The purpose of this study is to investigate usages of radio-based indoor positioning systems for Ericsson. The potential benefits of position data generated by the test system installed at SKF will also be evaluated. The result of this evaluation will support usage prioritizing. It will also be used to investigate the return of investment (ROI) for radio-based indoor positioning systems. To do this manufacturing problems and system users must be identified.

1.3 Limitations

This thesis is limited to investigating problems, system users and system usages in manufacturing environments from January to June 2020. Because of this, variation on an annual basis will not be shown in the qualitative or quantitative data. Positioning data is gathered from a test system that is monitoring material handling equipment at a manufacturing site. This means that no comparison between similar positioning systems will be made. Finally, there will be no implementations of the findings. The ending phase of the design process will instead focus on the evaluation of the content and its value for the users.

1.4 Research Questions

To enable the best understanding of how an indoor positioning should be used in a manufacturing environment problems must be identified. This will be done by answering the question:

- What problems can radio based positioning systems solve in the manufacturing industry?

Identified problems must then be linked to potential users of the indoor positioning system. In particular a main user should be identified to enable the development of problem solutions that are likely to be value adding for the manufacturing industry. The second research question is, therefore, phrased as follows:

- Who are the main users of indoor positioning data in the manufacturing industry?

When problems and main users have been identified the best system usages will be investigated. The result should be able to answer the third research question:

- For what should indoor positioning systems be used?

2

Theory

The purpose of this chapter is to give the reader a short introduction to how manufacturing industries measures and improves production processes. This is done by explaining lean production philosophies and manufacturing KPIs. This is followed by a brief explanation of *Industry 4.0*. The chapter also describes a number of methodologies used for user centered design. These methods will later be used to analyze the processes and system usages in manufacturing environments.

2.1 The indoor positioning problem

Indoor positioning is a technology that makes it possible to find the location of an object in indoor environments. In the industrial section, indoor positioning could be used to improve safety systems, such as collision avoidance; or automated monitoring and quality control (Mautz, 2012). The main type of location that is discussed in this thesis is physical locations and is expressed in the form of 2-D coordinates. Location can also be expressed in symbolically with names like *office* or *warehouse* (Gu, Lo, & Niemegeers, 2009). Samama (2019) discusses the potential of positioning in industrial indoor environments and says that even though the economic outlook has been described as exceptional there still does not exist an indoor positioning standard. The reason for this is that the needs of the market are poorly formalized. Mautz (2012) agrees that user requirements must be redefined to enable the development of indoor positioning applications, but also emphasize in benchmarking of implemented systems.

2.2 The Manufacturing Industry and how it is measured

The manufacturing industry is sometimes described as the corner stone of the modern economy. Continuous improvements of industrial processes have led to increasingly better living standards. This chapter aims to give a brief overview of the manufacturing industry to better understand the challenges of creating change that improves production processes.

2.2.1 Industrial evolution

Even though the rapid growth of the industry during the mid 19th century often is refered to as *the industrial revolution*, many historians argues that the industrial expansion instead should be viewed as evolutionary (Basalla, 1988). Small improvements of the coalmine steam engines made it efficient enough to be used in other contexts, like the textile industry. This increased both the profit and complexity at the factory sites which called for a better understanding of the working processes. By breaking down longer working processes into small pieces and limiting variation, the work of a professional could be assigned to less experienced worker. This enabled lower production costs that made more products available to the common people e.g. the standardized T-Ford.

2.2.2 Lean Prodcution

Lean production or simply Lean is a production philosophy that grew from the American research program International Motor Vehicle Programme, conducted during 1985-1990. The research aimed to compare the effectiveness of different automotive manufacturing industries. The findings suggested that Toyota Production Systems (TPS), developed in Japan after World War II, had the most effective production methods (Womack, Jones, & Roos, 1990). Because of this many of the Lean production principles can be traced to the structure of TPS during the 80's (Börnfelt, 2009). Today Lean is widely used in industries that focus on increasing quality, shorten lead time and decrease variation in production (Liker & Meier, 2006). This is done by applying Lean principles and eliminating waste in the production.

Lean principles

The foundation of Lean stems from applying its methods to create maximal value for the customer and reach target organizational goals. Methodologies from Lean production aims to, as the name suggests, slim down operations leaving only value-adding activates to increase effectiveness (Börnfelt, 2009). Other fundamental concepts within Lean are flow and resource efficiency. Flow efficiency is defined as the sum of value-adding activities in relation to the throughput time. Resource efficiency instead focuses on the maximal usage of assets and people (Modig & Åhlström, 2012). Manufacturing industries traditionally have opted for resource instead of flow efficiency, even though Lean generally is regarded as a method the prioritize flow (ibid.).

Waste within Lean

Lean production defines seven different types of waste that all can be placed into the categories Muda, Muri and Mura. Liker and Choi (2004) describes that eliminating waste is key to reduce the number of activities that not is value-adding. Muda represents waste that stems from activities that does not increase value for the customer and is the main focus within Lean production. Muri instead focuses on the waste that stems from overloading employees or assets, resulting in injuries and mechanical wear. Finally, Mura represents waste from fluctuation which can create uneven material flows and overproduction (Womack et al., 1990; Liker & Choi, 2004). The seven types of waste consists of transport, inventory, motion, waiting, overproduction, defects and unused creativity.

2.2.3 Gemba

Gemba, a Japanese word for "the actual place" meaning the place where value is created, for example, in a manufacturing process (Richardson & Richardson, 2017). Going to Gemba, the place where value is created, is essential in many Lean tools. Toyota, the source of several lean principals, has a bias for low-tech visual management (ibid.). The company does not want its engineers and managers to sit at the office and monitor the production via updated visuals on computer screens (Richardson & Richardson, 2017). Instead, they prefer the low-tech visualizations based on data provided by people working in the process. More advanced monitoring systems can be implemented after low-tech visualizations have proven to be sufficient. Otherwise, one is likely to be trapped in a digital solution that does not fulfill the needs and is not able to change due to investments already have been made.

2.2.4 KPI - Key Performance Indicators in the manufacturing industry

The manufacturing industry measures different Key Performance Indicators to monitor the production processes. These indicators rely on data provided by the factory systems and employees and aims to describe the process current and historical state. By looking at this data, production personnel tries to minimize the production losses and maximize the utilization (Richardson & Richardson, 2017).

Stakeholders in the manufacturing industry need to prioritize which KPIs to monitor (Amrina et al., 2018). There are variations in how many, and which, KPIs a manufacturing site chooses to monitor. Some manufacturing KPIs are not possible to calculate with positioning data. The KPIs listed in table 2.1 are only manufacturing KPIs which can be calculated with positioning data. The KPIs contains both human aspects as well as technical matters.

Table 2.1: Manufacturing KPIs possible to calculate with positioning data

Acronym	Name	Formula of calculation
-	Loading Time	$total\ available\ time$ - $planned\ downtime$
OEE	Overall Equipment Effectiveness	$Availability\ rate * Performance\ rate * FPY$
AR	Availability Rate	$\frac{Operating\ time}{Loading\ time} * 100\%$
PR	Performance Rate	$\frac{Parts\ Produced * Ideal\ Cycle\ Time}{Operating\ time}$
FTY	First Time Yield	$\frac{\Sigma\ Units\ Leaving\ the\ Process}{\Sigma\ Units\ put\ into\ the\ Process}$
FPY	First Pass Yield	$FTY\ 1 * FTY\ 2 * ...\ FTY\ n$
VA	Value adding time	$\frac{Value\ adding\ operations}{All\ operations} * 100\%$
DT	Down time	$\frac{Total\ Downtime}{Loading\ Time}$
-	Idle	$\frac{non\ productive\ time}{Loading\ Time}$
ELR	Employee Late Ratio	$\frac{\Sigma\ Employee\ Late}{\Sigma\ Total\ Employee}$
-	On Time Delivery	$\frac{No.\ of\ products\ delivered\ on\ time}{No.\ of\ total\ produced\ products} * 100\%$

2.3 Organizational structures according to Mintzberg

The organizational structure can be divided into five parts (Mintzberg, 1979). Depending on the organization, these parts can vary in size and scoop. The five parts consists of *Operative core*, *Middle management*, *Strategic Apex*, *Support staff*, and *Techno structure*. Figure 2.1 shows an overview of these parts.

The foundation of an organizations is the operative core. People working in the operative core are responsible for the actual work that creates the product or services. This also includes direct support, such as planning of production. Mintzberg (1979) means that there exist a limited range of control that a manager is able to handle. Because of this, larger organizations needs a middle management to oversee day-to-day activities in the operative core. The middle management have also responsibilities to manage external relationships and branches of the company. At the top of the organizational structure the strategic apex resides. The strategic apex is responsible for setting up and reaching organizational goals. This does not only include economical goals but also goals regarding how the organization is perceived by media and customers.

Besides the core structure that has been presented, Mintzberg (1979) also identifies the technostructure and support staff as key parts of organizations. The technocstrucure consists of analysts, such as engineers, accountants and researchers. These roles are not responsible for operational tasks, instead they evaluate the processes and try to optimize them by using tools like work studies. The last key part is the support staff

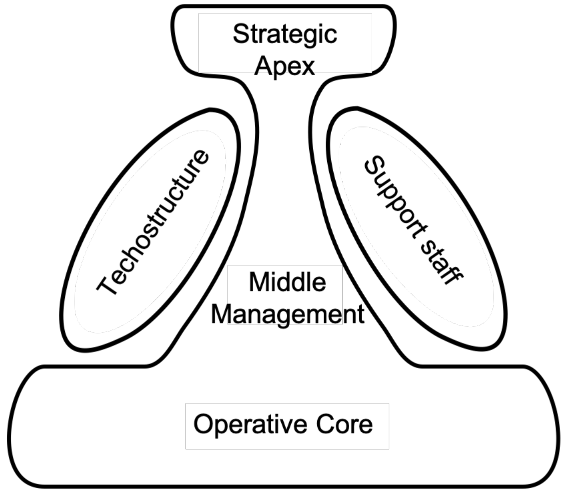

Figure 2.1: The organizational key parts

that provide indirect services e.g. salary administrators and cleaning services.

2.4 Industry 4.0

In order to recapture manufacturing to Germany the German government formed a strategy which is today is refereed to as *Industry 4.0*. The strategy rapidly spread to other European countries, as well as US and Japan (Reinhard, 2016)

Herman, Pentek (2016) describes the following design principals of Industry 4.0:

- **Interconnection** is about using the possibilities of connected devices. Once products, machinery, and other devices are connected to a network, ways of wireless data communication between them are possible. For the people controlling and working with these systems the Interconnection blaze a trail for increased efficiency and effectiveness.

- **Information transparency.** A fusion of the physical world and the virtual world makes room for new ways of controlling processes. Drawings, electronic documents, and simulation models are examples of the virtual world (Herman, Pentek, 2016). An example of information from the physical world would be the position of a tool. Sensor data from the real world must be transmitted to central databases, accessible for all connected devices (Herman, Pentek, 2016). Also, analyses of collected data must be accessible for both humans and devices in the system.

- **Decentralized decisions.** A combination of interconnection and information transparency enables decentralized decision making. Devices in an industry 4.0

manufacturing site will be as autonomous as possible, only when conflicts between devices occur the decision should be escalated to a higher level (Herman, Pentek, 2016).

- **Technical assistance.** The human's role in an industry 4.0 environment will be strategic decision-makers. Decisions close in time are taken by the devices. This puts requirements on visualization techniques (Herman, Pentek, 2016). Screens and wearables will be more important since the collaboration between the humans and the factory will be increased.

2.5 Design methods

User experience, *UX*, is the totality of a users experiences from a product (software, hardware etc). According to ISO 9241-210 UX is defined as *"a person's perceptions and responses that result from the use or anticipated use of a product, system or service"*. The UX field consists of studying, designing and evaluating user experience. UX methods can be used as tools for evaluating existing systems, but also for designing new ones. ISO 9241-210 clusters the following areas as the roots for user centered design:

- Positioning the user as a central concern in the design process
- Identifying the aspects of the design that are important to the target user group
- Developing the design iteratively and inviting users' participation
- Collecting evidence of user-specific factors to assess a design

Poorly designed software costs millions of dollars (Hartson & Pyla, 2012) because the product is difficult to use. This fact enhances the economic drivers for why good UX is preferable. This chapter will describe the theory behind *design thinking* as well as giving an introduction to methods that often is used in the designing process.

2.5.1 Design Thinking

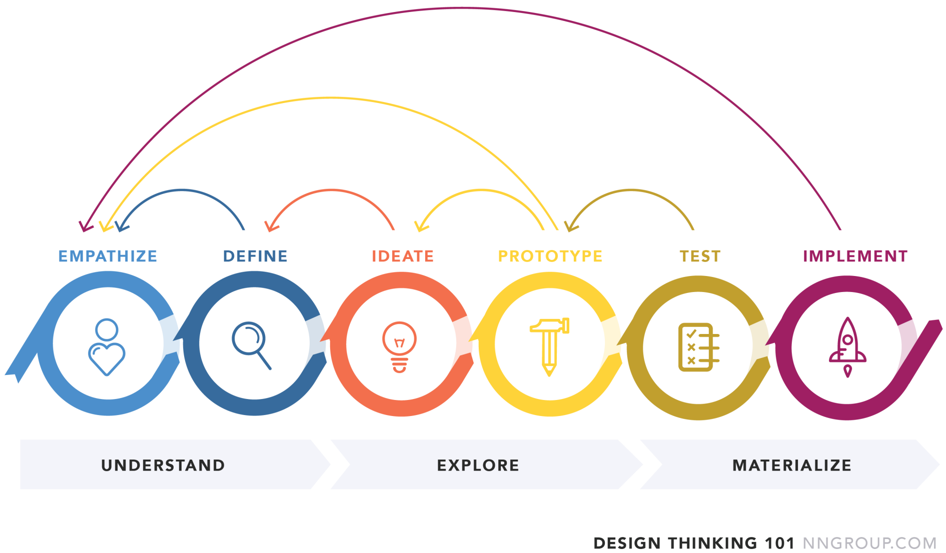

Figure 2.2: Design thinking process by Nilesen & Norman Group (Gibbons, 2016)

In order to achieve user satisfaction, for each and every user or sub-user of the system, the design thinking approach puts focus on the user perspective of the product. By using this method, created by Don Norman, the chance for a successful delivery that meets user expectation increases.

Design thinking means to intentionally focus the design around the concerns, interests, and values of the users (Denning, 2013, s.31). The steps in the iterative design thinking process (figure 2.1) starts with an understanding section, which contains a empathize and a design phase. The **empathize** phase is about what the user says, feels, does and talks about the product. You must know what motivates or discourages users to be able to empathize with the user an in that way see things from their perspective. Observations and unstructured interviews are suitable data collection methods for this type of information gathering. While empathizing with the users, the developing team should pay attention to what the user:

- **Says** What is actually said during the interview? Try to direct quote the interviewee.
- **Feels** How does the user feel about the experience? What worries the user?
- **Does** What the user does during the observation/interview?
- **Thinks** What is on the users mind during the interview? What matters to the user?

From a deeper knowledge of the user, opportunities for innovations is made possible. The gathered data is used to find the user needs and problems. This process is in design thinking referred to as **define** and together with **emphasize** it builds an understanding of both the user and the problems. Curedale (2019) also means that during defining it is important to identify the stakeholders.

Once you gain knowledge about the users you can enter the explore phase. The goal is to generate ideas that solves the problems based on the user. This often requires iterating back to previous phases to reinforce user knowledge and problem definitions (Gibbons, 2016). There are many tools available for **ideation**, such as brain drawing or brain storming. By aiming at quantity and range the target is to capture a wide variation of ideas (Wikberg Nilsson, 2015). Based on the ideas, still in the explore phase, you now create a **prototype**. The prototype shall, based on your ideas, solve the defined problem. If you feel that you lack information in this phase you must go back to the user and problems to expand your understanding of them.

Finally, materialize the prototype and expose it to the users. **Test** it, and use the feedback to improve the prototype, but also redefine the problem and if necessary go back and improve your prototype. When the prototype tests yield the desired result the last and most important step start - **Implementation**. This requires integration in current system or work processes and is often time consuming. Denning (2013) means that the there is a difference between design and innovation. An innovation is concerned with getting a community of people to adopt the concept rather than the design process behind it. Often this constitutes 90% of the work, and the actually design the other 10%.

2.5.2 Affinity Interrelationship Method -AIM

Affinity Interrelationship Method, AIM, is a 10 step method for analysing qualitative data sets (Alänge, 2009). It is a systematic approach to problem-solving and has been used at companies and universities for over 30 years (Alänge, 2009). Yet the AIM process is flexible. Depending on the specific purpose of the analysis the setup, can be changed to fit the problem being solved. Group size, problem scope, and the amount of data being analyzed are such circumstances that call for modification of the original process setup. The AIM requires:

- Post-its
- A White-board
- Pencils
- An appointed leader

The AIM is performed in 10 chronological steps:

1. **Formulate the question:** The study question should not be to narrow neither

to broad. Therefore, the question must fit the research projects scope and have a suitable detail level to support the project progress.

2. **Warm-up:** Each participant gets time to explain his/ her take on the formulated question. Time available for the warm-up is 5 min, so in a group of 5 participants every participant gets 1 min each. Criticizing is not allowed during warm-up.

3. **Collect data:** The target is to write 19-24 post-its in total.

   - The answers should be "full sentence answers"
   - Facts instead of opinions, use the interview data to formulate the sentence
   - Ladder of abstraction - choose formulations which is actually said/done by the interviees
   - Use multi valued information
   - Write a full sentence

4. **Clarify the Meaning:** All the answers on post-its must be clarified if needed. Each and every post-it is clarified by the team, in order to reach consensus about the meaning. The team is allowed to ask questions to the author, but it is not allowed to argue with the author of the post-it weather the statement is correct or not. The clarification of an answer will be written down on the original post-it. After the clarification process the post-it is moved to a separate part of the white board.

5. **Grouping - affinity steps:** The post-it's are now corrected. The team must now group post-it's with a similar meaning closer together. This task is based on grouping by searching for "affinities" between the post-its. The grouping is preformed during silence, and the members are allowed to split an rearrange groups. The grouping in this step is a consensus driven process, which ends when there is a shared view of the grouping.

6. **Higher level grouping:**

   - First level titles. The groups are summarized and the team put headings on each group. The headings explains the meaning of the group. Singular post-its can be leaved without headings.
   - Second level grouping. Continue grouping the headings and the singular post-its. This is the second level grouping. Some post-its, with no heading, also known as "lone wolfs", are accepted.
   - Third level grouping. After the second grouping, the team must put labels on the new groups. By applying the same procedure as in the second level grouping, new 3d level groups are constructed at the board.

Show connection interrelationships. In order to show if there is a connection between the groups the team points arrows between such groups. The aim is to go through the possible dependencies between all groups.

7. **Final Layout** When all the interrelations between the groups were pointed out the final AIM analysis was concluded. The data has now been analyzed and clarified and shows the answer to the question stated in the beginning of the process. It is important to find:
    - Outlines in first level groups
    - Outlines in 2nd/3rd level groups
    - and to draw final arrows
8. **Evaluation** With all the concluded answers the group ranked the answers depending on the impact on the original question. The most important issue which influenced the question analyzed was pointed out by each group member. Where there was a different between the individual rankings done by the group members voting was applied. The finalized rankings were stated on the AIM board when finished.
9. **Concluding** The AIM session ended after the main problems were put in a full sentence where the importance from the rankings decides in which order the problems being listed.

2.5.3 Braindrawing

Braindrawing is a creative ideation technique that utilizes sketching as a way for the participants to express their ideas (Wikberg Nilsson, 2015). There are four roles to follow when braindrawing:

- Don't criticize, neither yourself or others.
- Aim for wild and crazy ideas.
- Combine ideas and seek improvements.
- Quantity before quality.

By using sketches instead of talking and writing when expressing the ideas the participants might find new perspectives. A collaborative approach will contribute to common ownership of the ideas, which prevents a strong personal connection to specific ideas (Wikberg Nilsson, 2015). Brandrawing is executed as follows:

1. Place papers and pencils on a table
2. Define the theme
3. Prepare the team and explain the theme

4. Sketch ideas for 5 minutes
5. Rotate the sketches within the team members
6. Continue drawing on the newly provided sketch
7. Stop when all participants have sketched on all papers

After the idea sketching round the team discuss and categorize the ideas. The most important findings and ideas will be noted and presented as the result of the brain-drawing.

2.6 Persona

When developing solutions for users, it is suitable to have a specific, fictive but yet realistic, user to elaborate around. The persona will act as a real user for the development team, and the team can use the persona when describing suggested solutions in order to enhance the benefits of, or reject ideas (Hartson & Pyla, 2012). The number of personas must vary depending on the size of the user group (Hartson & Pyla, 2012). Since it is an bottom up process the exact number of personas is not possible to tell until the creation process is executed. In figure 3.6 the constructed persona template is shown.

2.7 Knowledge gaining and transfer

Double-loop learning is the meta-process of changing the main process based on feedback (Argyris, 2002). It is about questioning why you solved a problem in a specific way. To explain double-loop learning you must first be familiar with single-loop learning. Single-loop learning is where the learner performs an action based on an action strategy and then corrects its action strategy based on the consequences.

Double-loop learning occurs when the learner reflects over why he/she picks the specific action strategy. The learner reflects over "why we do what we do", compared to single-loop learning, where the learner corrects "what we do".

Knowledge gained during research projects is essentisal for the result. The majority of organizations have some sort of knowledge management system (Werr, 1998). The gained knowledge will be accessible for the organization first when the learner has shared with others. There are two established methods for an organization to treat knowledge, either knowledge is regarded as something that can be objectified and organized or its regarded as something that is socially embedded (Werr, 1998). Depending on how knowledge is treated in the organization one can construct different knowledge sharing methods.

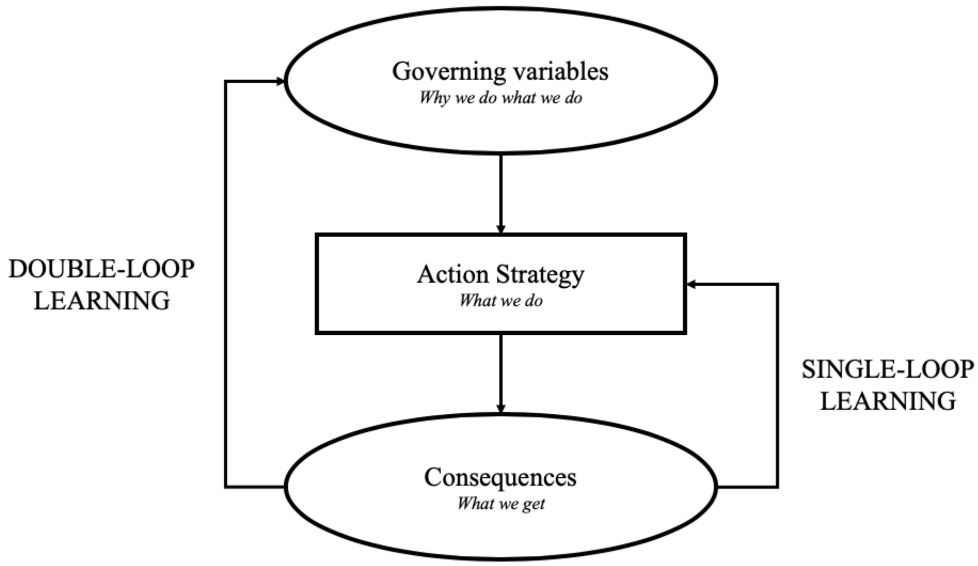

Figure 2.3: Visualization of the stages in single and double loop learning

3

Method

This chapter will describe the methodology that was followed during this Master Thesis. Initially the overall research design will be presented, followed by descriptions of the literature study and the collection of quantitative and qualitative data. This also includes a short summary of methods used for both data gathering and analysis. The remaining part of the methods describes the design thinking process which focus on identifying user and what users value about a positioning system.

3.1 Research design

When writing a scientific report, the choice of research design will greatly impact the study's results. Therefore, it is important to evaluate and choose a method approach suitable for the scope of the study. The first question that needs to be addressed is what type of data that is most likely to answer the research question. In this case the problem revolves around the supposed needs of positioning in the manufacturing industry. Since the study will be conducted at only a few factory sites, the sample size will be much too small to make any quantitative conclusions. The positioning data that is available is however extensive enough to enable analysis of the factory processes. Because of this quantitative data will still influence the end result, even though the study is considered qualitative.

The report takes a bottom-up approach in its attempts to answer the research questions. This goes very well together with the Design Thinking methodology that emphasize in understanding the actual users. Defining problems from this perspective gives a better chance of solutions that aligns with current needs and increases success rate of implementations. The iterative process described in Gibbons (2016) have because of this served as the main influencer of the research design.

3.1.1 Case Study

Case studies are an approach that through in-depth examinations of a particular case can bring understanding regarding a complex issue (Lichtman, 2014; Dooley, 2002). Most commonly it is used in qualitative research projects but has found uses in the quantitative field as well. The purpose of case studies is described by Dooley (2002) as a way of answering questions of how and why. Clardy (1997) expands this further by including questions of *who, what, where* and *when* targeted at a specific situation.

When conducting case studies of groups or organizations one of the main goals is to find key informants giving access to the needed knowledge. In research these individuals are also named Gatekeepers because of their ability to give access to information that otherwise would be unavailable (Given, 2008). This is also the biggest weakness with case studies, since the research results heavily depends on finding theses informants (Lichtman, 2014). Case studies are also criticised by Yin (2014) that claims that they are unable to tell something about general matters. Dubois and Gadde (2002) replies by stating that this should not be the aim of a case study. Instead case studies should be used to connect phenomenons to their context. This can be done by using what Dubois and Gadde (2002) refers to as *systematic combination*.

3.1.2 Systematic combination

Dubois and Gadde (2002) describes systematic combination as a nonlinear process that matches reality with theory by evolving theoretical framework, empirical fieldwork, and case analysis simultaneously. This process aims to strengthen case studies by increasing the reliance on theory. By doing this the data can provide better support for theory building or expansion. Systematic combination bears resemblance to the abductive research approach, which aims to investigate the reletionship of everyday language and concepts (Kirkeby, 1990). The main focus is to allow for the study to make a "best prediction" by acknowledging that observations always will be incomplete. This makes it different from the inductive reasoning that uses specific observations to draw general conclusions (Dudovskiy, 2016). Abduction and induction also differs in its theoretical objective. The inductive approach is described as a method for theory generation, whereas systematic combining builds on the refinement of existing theories (Dubois & Gadde, 2002, p.559).

Theory building by case studies generally requires an overlap of data analysis and data collection. The juxtaposition between these two activities can create creative insights that force the reframing of case perceptions (Eisenhardt, 1989). Systematic combinations uses these learnings to reconsider and change the framework. This allows for a more stringent relationship between framework and research results, making it easier for the reader to follow the process (Dubois & Gadde, 2002). The learnings taking place in the interplay between search discovery are, however, interesting at a meta-level. Dubois and Gadde (2002) means that understanding the researchers learning process would benefit learning in the research society. In this report the learnings will, therefore, be discussed as a parallel result to the research answers.

3.2 Litterature study

As a first step in finding an answer to the given research question, a literature study were conducted. The aim was to get a better understanding of the field both regarding the technical aspects but also look in to what indoor positioning system usages that already existed. To limit the amount of search results different key words were used and sources that were considered relevant were stored in an excel sheet. Sources were sorted by title and theme followed by a short explanation and a ranking of its perceived usefulness. The reason for this was to make it easier to review the sources at later stages of the writing process. Example of key words were *RFID*, *UWB*, *Visualization* and *User Interfaces*. The databases used for conducting the searches was mainly Scopus because of the Field-Weighted Citation Impact parameter linked to each source. Values higher than 1 suggests that the report or article have been citations than similar sources. The approach limited the searches and increased the over-all quality of the consumed literature.

3.3 Data collection

This section describes the different data collections that will be used in this research. The qualitative data will mainly consist of interviews. There will also be quantitative data collection, that will be used to enable visualization of the positioning system.

3.3.1 Quantitative data

Positioning data from the test site will be gathered over via a API communication with the system server (RTLS). The data contains information of:

- Position (X,Y,Z)
- Device ID
- Time
- Confidence interval

Positioning data was gathered from the test site using a built-in API that could communicate with the positioning system server. The data was received in a continuous flow of text strings containing the position (x, y, z-coordinates) linked to a specific Tag-ID and a timestamp. In *Table* 3.1 an example of the data-string is shown.

Table 3.1: Structure of positioning data

Tag-ID	x	y	z	Timestamp
0x001337	16.09	13.85	1.76	1575936000.05

The data could either be used to show real-time positions of forklifts in the production or be saved to enable analysis. Data-storage was done with the help of a Linux service set up to run a Python program. The service acted as a safeguard for potential problems like power failure that would cause the computer to restart. To increase usability the data was sorted in timestamp intervals spanning 24 hours and saved in files named after the corresponding date. As a first step a heat-map, see Figure 3.1, over the test facility was created. The heat-map showed how the data were distributed, and if the collected data was reliable. When the reliability of the data had been confirmed a database was constructed to allow searches in the extensive data. Using SQL quarries could isolate this information from the 3218828 lines of data to visualize routes of specific forklifts. In figure 3.2 a query and the result is shown.

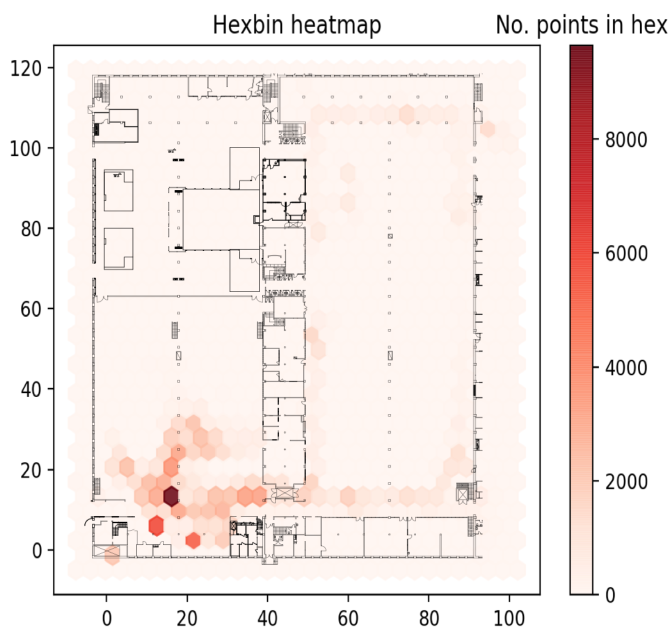

Figure 3.1: Heatmap over data ploted on the map

```
[sqlite> SELECT x,y,truck_id,timestamp FROM positions
[   ...> WHERE truck_id = '0x00029B' AND
[   ...> timestamp BETWEEN 1575763200 AND 1576281600;
x           y           truck_id    timestamp
----------  ----------  ----------  -------------
16.2        18.04       0x00029B    1575936003.06
16.2        18.04       0x00029B    1575936017.55
16.21       18.03       0x00029B    1575936032.61
16.21       18.02       0x00029B    1575936047.24
16.21       18.01       0x00029B    1575936062.28
16.22       18.01       0x00029B    1575936077.04
16.22       18.02       0x00029B    1575936092.04
16.23       18.02       0x00029B    1575936106.61
```

Figure 3.2: Example of Query search in database

To further push how quantitative data could be used to better understand it a web-based GUI was created. Real-time data from the RTLS-API was visualized on a local host. This required a server setup that connected with the RTLS through a TCP-socket, and a client connected to this server. The client could then use the data to visualize forklifts icons in real time on a custom map built using the JavaScript library Leaflet. Figure 3.3 shows a screen capture of the running browser GUI.

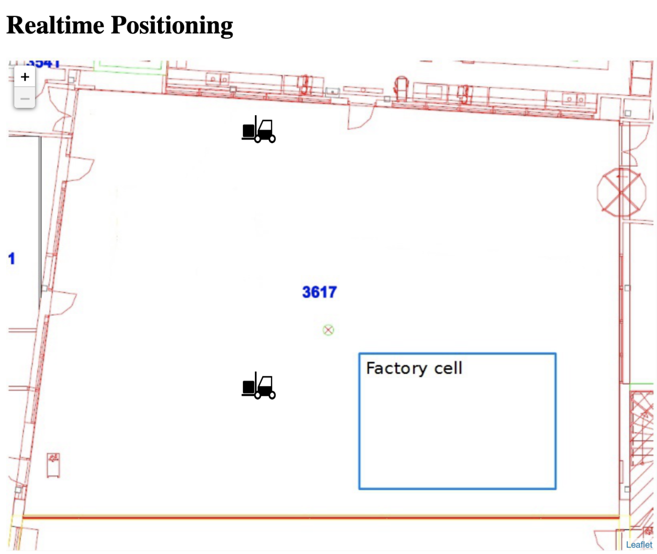

Figure 3.3: Real-time applications running on a JavaScript tcp-socket

3.3.2 Qualitative data

The qualitative data mainly consisted of interviews but focus groups and testing sessions were also used to gather data. Information was also gathered using unplanned conversations with manufacturing employees.

Interviews

Both semi-structed and unstructured interviews were conducted. Semi-structed interviews uses pre-structed questions that are more formal than questions in a normal conversation. Unlike structured interviews questions can be added or removed during the sessions. It is also allowed to change the order in which the questions are asked. This requires that the interviewer have a good understanding of the subject, so that the added questions does not confuse the interviewee (Phillips & Stawarski, 2008). Unstructured interviews is freer and allows the interviewee to interpret the asked questions. The focus is instead to use follow-up questions to gain a deeper knowledge of a the subject (Trost, 2007).

Since the reserach aimed to have a bottom-up structure, the target of the interviews mainly consisted of people that would use a positioning system in their work. This was also a way to build a network of people to contact for future testing of system usages. A few interviews was also conducted with professions responsible of investments in factory settings to better understand the path of decisions. The interviews started with a brief description of the study and its aims to generate a better understanding of what information that was sought. The interviewees were encouraged to speak as freely as possible to lower the risk of forced answers. Because manufacturing industries are very protective when it comes to information regarding production cycles and processes, a choice to not use recording equipment was made. This allowed the interviewees to talk more freely without feeling monitored. In table 3.2 the full list of interviews is presented.

Table 3.2: List of interviews

Interviewees	**Unstructured interviews**	**Semi-structured interviews**
Logistic engineer	0	2
Plant manager	1	0
Production engineers	1	3
Production planner	0	1
I4.0 Transformation manager	1	1
Logistic and digitization manager	1	1
Logistic Strategist	0	1
Digital and solutions officer	1	1
Math Scientists	0	1
Production Engineering Phd.	0	1
Production System Phd.	0	1
Fork lift operator	1	0
Production staff	7	0
Sum	**14**	**13**

Focus groups

As part of the qualitative data gathering focus group sessions was conducted. Focus groups in early stages of the research gives a better understanding of the subject and helps with defining the research question. At later stages focus groups can be used as a tool for interpretation (Esaiasson, Gilljam, Oscarsson, Towns, & Wängnerud, 2017). The preferred size and setting of focus groups is 6-8 people from similar social and cultural environments. (Liamputtong, 2011). But smaller focus groups can also be used.

A successful focus group relies heavily on a non-threatening and open environment to enable the participants to speak their minds (ibid.). Because of this focus groups have a moderator that monitors the discussions, which also make sure that the group does not stray too far from the subject. To enhance the data that is gathered from focus group studies, two moderators can be used instead of just one. The advantage of this is that one of the moderators can focus on the questions while the other can attend to the answers. It is also easier to make sure that the session stays on track and hold up to the time plan.

3.4 Identification of valuable system usage

The design process is not linear, it is iterative. Therefore when reading this section it should not be interpreted as chronological. To increase the readability of the report the process although is explained as chronological. The design process consisted of three main phases, **Understand**, **Explore** and **Evaluate**. Iteration occurred mostly within a phase, but also between the phases when the project team lacked knowledge.

3.4.1 Understand

According to the user centered design approach the data must be gathered from all kinds of users which might interact with the system. The following stakeholders were identified and interviewed during the understanding phase:

- Logistic engineer
- Plant manager
- Production engineer - medium size company
- Production engineer - global company
- Production planner
- Industry 4.0 Transformation manager
- Logistic and digitization manager
- Logistic Strategist
- Digital and solutions officer
- Math Scientists
- Production Engineering Phd.
- Production System Phd.
- Fork lift operator
- Production staff

At the test facility automation of the material handling fleet was recently preformed. This system had similarities with the radio positioning system regarding data visualization. The project responsible for the new material handling system, a production engineer, had interesting takes on positioning systems and data usage from such systems. The team interviewed him and by combining his experiences with interview data from interviews with the responsible person for the installation of the test system the team concluded potential work roles at companies that generally had a stake in positioning data usage. This approach led to interviews with the corporate functions listed above. By searching for companies within the research project scope at a reachable distance from our location we manage to get in touch with both medium sized and global production responsible.

Defining problems with AIM

Interview data were analyzed via the Affinity Interrelationship Method, AIM. Since the research group consisted of fewer participants than suggested by the AIM method the appointed task leader also took part in the analysing process. In order to analyze the outcome from the qualitative data collection a study question were chosen. Each member of the AIM session had 5 minutes to summarize the interview session with their own words. The other member of the session were not allowed to criticize nor comment while listening to the summary. Each participant formulated answers to the problem. The answers were written on post-its, one answer per post-it. The team then followed the AIM process and concluded the analysis. Figure 3.5 shows the board during the AIM process and figure 3.4 shows a summarized result.

Figure 3.4: AIM outcome and its levels

Figure 3.5: One AIM board during analyze

Persona development

In figure 3.6 the constructed persona template is shown. This template is based on the collected qualitative data the interviewees goals, pain points, motivators and backgrounds were sorted out. The process was of bottom up character, where the many interviewees attributes was sift in to a few distinct different personas.

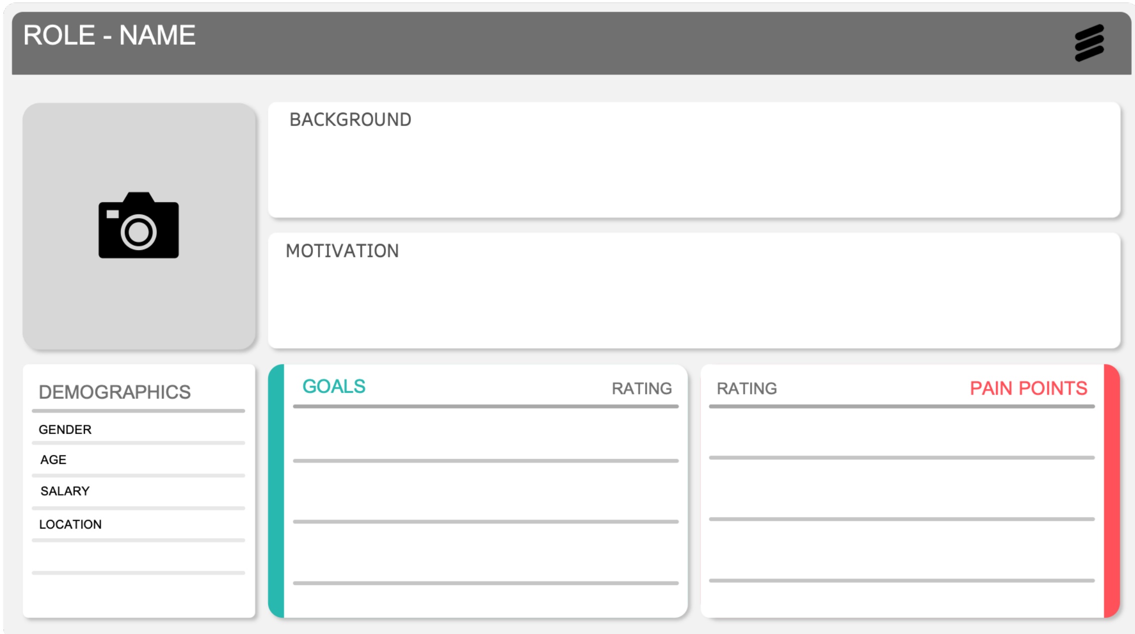

Figure 3.6: Persona Template

Using this template, three unique personas was identified. Their roles consisted of *Plant Manager*, *Production Engineer* and *Production planner*. The personas can be found in Appendix A.

3.4.2 Explore

Based on the findings from the understanding activities ideas and concepts were to be made. Problem descriptions from the AIM process second grouping session were used as themes for the braindrawing activities. Even though the themes were based on the AIM outcome, they were discussed and reworked. Since the purpose of the research was to investigate potential usages for radio-based positioning systems in Industry 4.0 environments future applications needed to be considered. The AIM, however, only focused on current problems. Because of this, a "future applications" theme was added to enable discussion of industry 4.0 solutions. By stating the problem descriptions from the AIM session on board including the future theme, the team combined and or split the statements until six themes were brought up. The themes were the following:

- Driver support
- Safety
- Historical visualization
- Material carrier
- Work Studies

- Future applications

The selected themes were used in braindrawing sessions, where the team members based on the themes draw ideas of how to use radio-based positioning data to solve the found problems from the Understanding phase. Figure 3.7 shows an example of how the ideas were presented. The braindrawing process suggests the drawn ideas were formed by all team members. This makes it easier to scrap ideas.

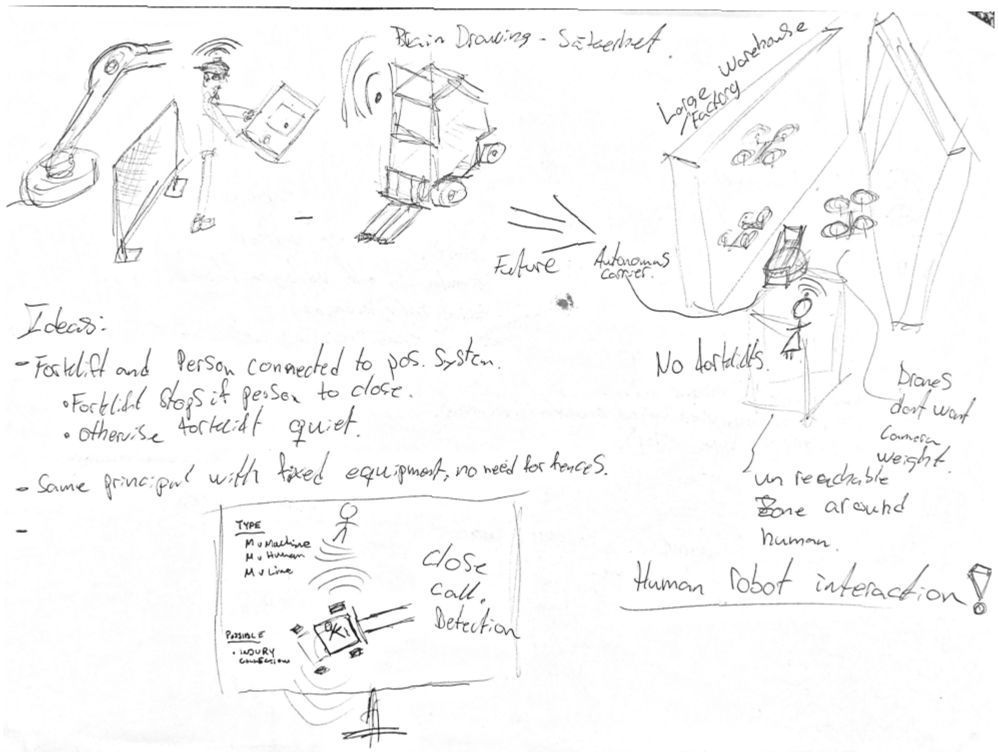

Figure 3.7: The result of one braindrawing session

A total number of 60 ideas were produced during the braindrawing sessions. The ideas were listed in a spreadsheet. Each idea was explained in words by the team. The solution ideas were listed as described in table 3.3. To get a better understanding of who would use the a specific solution three more columns were added, representing the three personas. If it was likely that a persona would use the idea the box was checked. This made analysis of a potential main-user possible by counting how many of the ideas that had a fit with a specific persona. The idea-list was also used to build idea-clusters. The clusters were ideas that had similar user and area of usage. From the 60 ideas 10 usage clusters was built:

1. A system usage based on zones, such as geo-fencing in manufacturing environments.

2. A system usage focusing on safety-features and possibilities of using radio positioning to increase safety in manufacturing environments.
3. A system usage that would visualize position data for material handling operators.
4. A route planning tool with live updated driver information (like indoor GPS).
5. A system usage focusing on object tracking.
6. A system usage facilitating FIFO operations.
7. A system usage which visualize Manufacturing KPI's whith position data.
8. A system usage based on adaptive production setups.
9. A system usage focusing on large heavy industries like airplane manufacturing.
10. A system usage towards digital twin and data ponds.

Table 3.3: Organized Ideas with description

Idea name	**Description**
Speed zones	Divide the factory into speed zones that restrict the speeds for material carriers. It could also establish temporary zones because of maintenance and similar activities.
Production equipment tracker	Shows how much mobile production equipment has moved on, for example, a shift, a day, or around a certain product.

Table 3.4: Ideas linked to personas

Idea name	**Description**	**Production planner**	**Production engineer**	**Plant manager**
Speed zones	...		X	X
Production equipment tracker	...	X	X	
...	...	...	...	...

3.4.3 Evaluate

When moving from the explore phase in the Design Thinking process normally a materializing phase starts where concepts are tested and implemented. In this researched this step was swapped with an evaluation phase where the system usages only were tested. To evaluate problem areas that was found in the understand phase new meetings with previous interviewees were set-up. This made it possible to not only evaluate the findings but also ask additional questions regarding the production. A focus group was also conducted. The result from the evaluation allowed for prioritization of the systems usages. This was then used to build the use-cases discussed in 1.2. The use-cases can be found in Appendix B Examples of what was shown at these sessions is presented in 3.8.

Evaluation with production engineer
Many of the concepts from the ideation-phase was linked to the production engineering

persona. Because of this additional interviews with individuals working in these roles was considered necessary to evaluate the best system. Since interviews already had been conducted with these individuals the understanding of the subject was good and less explanations was needed. The system usage drafts was at this session presented as they were intended to be shown to a potential customer. A semi-structured interview format was used to ask questions when showing the content. Example questions were:

- Explaining a use-case
- Ask for a first opinion
- Ask for feedback of specific parts
- Ask for overall usefulness of use-case

Focus group
A focus group was conducted to test both the problem findings from the understand-phase and the system usages. Unlike the other evaluation sessions the participants in this focus group had not been part of the study earlier. This required a briefing that explained the subject and the research aims. The group consisted of people experienced in production and production planing. Discussions could because of this start at a relatively advanced level. As a first topic the group discussed how positioning was used today and what benefits came from using that data. This discussions was bridged to productions problems and uncertainties originating from lack of positional knowledge. By listening to the groups argumentation's the defined problems from the exploration-phase could be evaluated. The group was reminded that no answers were wrong and encourage to speak freely.

To evaluate the early versions of the usage drafts the group was asked to describe how they would use a positing system if it was given to them for free. The reason for stating this scenario was that it removed economical aspects which would make it easier to discuss usage more freely. It also allowed for the individuals to imagine a system that was tailored to their own needs instead of the entire organization. By asking what they would like to be able to measure, monitor or visualize data regarding industrial needs of different roles were gathered. Finally the focus group was shown the system usage drafts and was asked to asses their usefulness. The group was encouraged to be critical of the content and reminded that the data quality depended upon their honesty. Answers aligning with previous data was used to reinforce earlier observations while critique acted as a tuner to create better usages.

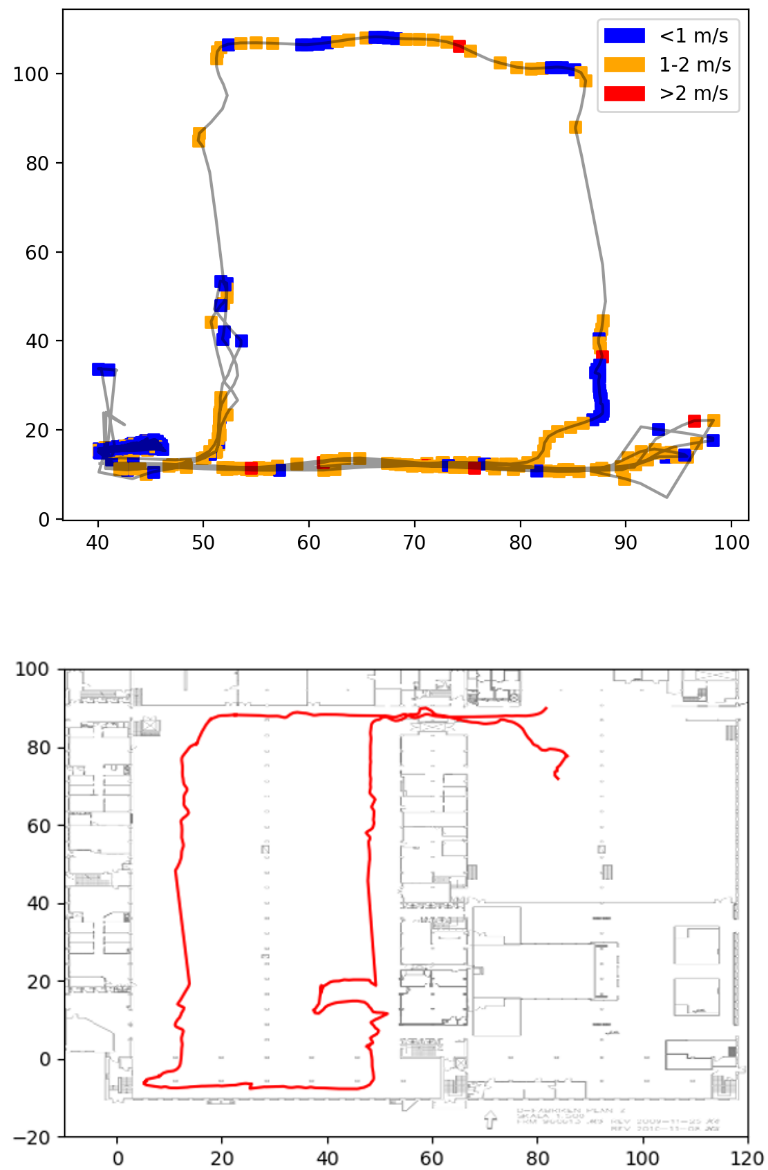

Figure 3.8: Visualization of different velocities and a path at the test site

4

Results

This chapter will present identified problems that indoor positioning can solve, identified users of an indoor positioning system and how the system can generate value for the identified users.

4.1 Identified problems that indoor positioning can solve

The interview data suggested that one of the biggest problems on the production sites was the lack of high-quality data, easily accessible data regarding the production. Further, the analysis allowed for this problem to be divided into two themes of data-related problems. These themes were: *missing data* and *misused data*. Missing data refers to unavailable data that users thought would benefit decision-making and improvement suggestions. Misused data refer to low-qualitative data that still is used for calculations of KPI-values.

4.1.1 Missing data

A majority of the interviewees reported that they lacked data to support the use of data-driven decisions. Typical things they wished they had more information about was the localization of equipment and vehicles, variation in the production, and throughput times of products. The uncertainty of these parameters caused decisions to rely on employees' production experience, rather than actual production data. Not being able to localize equipment was also described as a source of frustration when it caused disruption and delays in the production.

The tested system shows promise when it comes to tracking bigger objects in an industrial setting. Especially vehicles since they can supply a positioning tag with electricity. By analyzing the historical data, graphs could be drawn to show up-time and route variations of the material carriers and other objects. This can increase feedback on daily activities and makes comparison between different production cycles possible. The interviews also revealed that information regarding the specific tool operations like which tool that performed a certain task, was very valuable. By using positioning data to track the location of the tools and linking it to activity this could be achieved.

4.1.2 Misused data

When asking interviewees to describe the process of data usage in their work, problems regarding misused data emerged. Misused data in this instance refers to data of low-quality that still is used. Low-quality data was stated by our interviewees to frequently yield odd-looking KPI's, such as OEE-values exceeding 100%, which is impossible. This was often caused by human errors during data collection that resulted in faulty measurements. The problem is so common that the production staff has learned to simply ignore KPI outliers.

4.2 Identified users of an indoor positioning system

Data from the interviews and observations was also used to identify three personas that would use the system output. However, from the ideation process it became clear that most ideas were in some way connected to the production engineer, see figure 4.1. Because of this, this persona is highlighted in the result to emphasize the importance of having this role in mind when developing indoor positioning. Apart from being the main user of such a system, the production engineer also was perceived as the role with best knowledge regarding system requirements.

In one of the interviews the production engineer stated that *The biggest problem is not that we don't have data, it is that data that is gathered finds no later usage* and *We have a lot of routing problems that stems from the low quality of the factory floor.* As stand alone comments they would still have been interesting but it is the combination that shows the width of the production engineers scope. Both physical problems and data gathering projects concerns this role. This means that the production engineer needs systems that can give increased visibility of the production e.g. position data.

Another example of how data pointed towards the production engineer as the main user came from the evaluation sessions of the ideas. A quote from this sessions was *I want all of this, but first I must know that it is economically defensible.* The interest of the possibilities of indoor positioning were unmatched by other roles that was encountered. Production engineers also had a better understanding of the relation between system integration from an economical point of view than other factory workers.

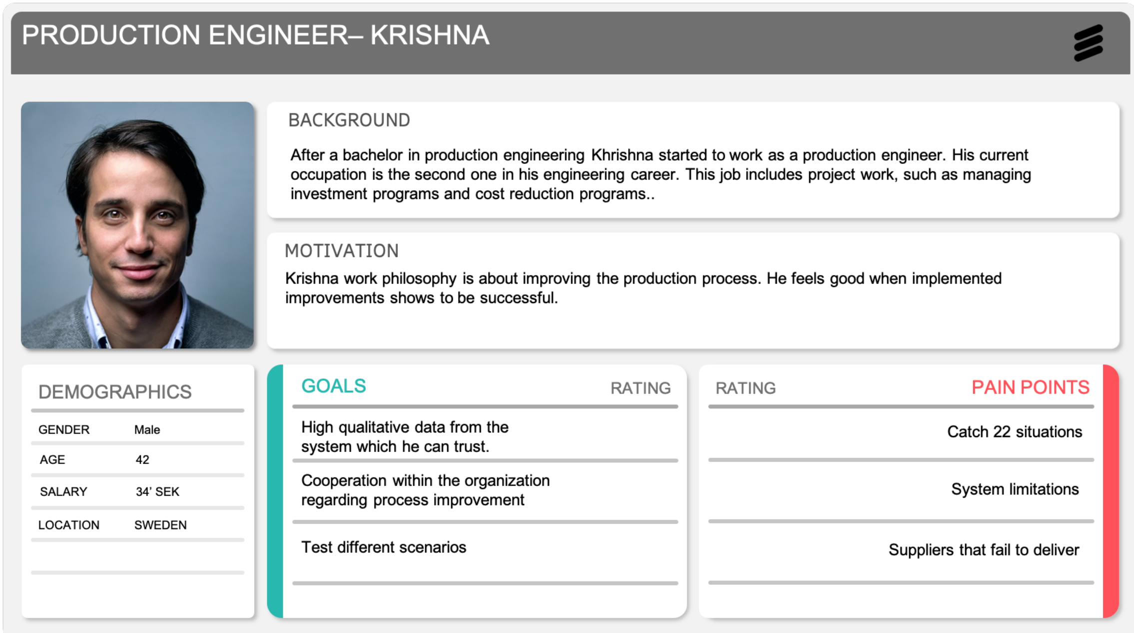

Figure 4.1: The production engineer persona

An additional way to visualize this is to show how the different personas related to the organizations structure described by Mintzberg (1979). The *production engineer* mainly work with optimizing the manufacturing processes unlike the *plant manager* and *production planner* that works much closer to the core structure, see figure 4.2.

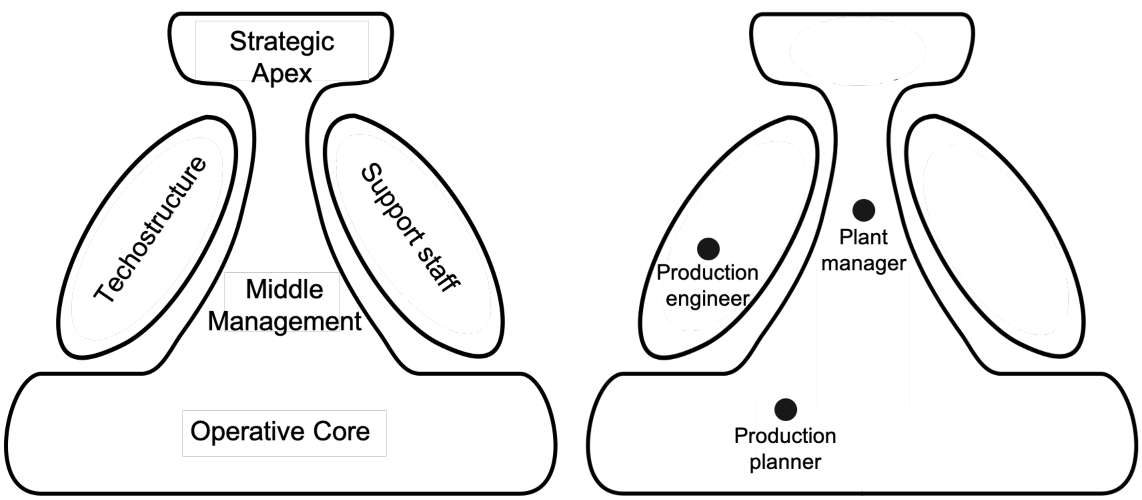

Figure 4.2: Mintzbergs organizations structure related to personas

4.3 Identified value adding system usages for main users

The qualitative data suggests that indoor positioning have potential to improve employee safety, increase productivity and gain insight in production flow. However, the interview data showed ambiguous results regarding how the potential best is realized. Individuals working in the manufacturing industry tended to highlight that indoor positioning solutions must be able to communicate with other systems. When analysing the possible solutions for positioning systems it was clear that some solutions required more data than just positioning data, especially when the data would be used for production controlling.

Industrial researchers also showed a positive attitude towards indoor positioning but said that many of the terms regarding the subject needed clarification. The lack of definitions regarding technical terms, such as digital twin, was described as a friction for communicating between stakeholders in the manufacturing industry.

This study suggests that positioning systems in manufacturing industries should initially be used for:

- Increasing safety and productivity at the manufacturing site
- Supplying data for manufacturing KPI calculation
- Manufacturing process analysis

4.3.1 Increase safety and productivity at the manufacturing site

Using data from the test system at SKF enables calculation of near misses of the material handling equipment. A near miss happens when two vehicles, or one human and a vehicle, are closer than a certain "near miss"-threshold. By counting the number of near misses in different areas heat-maps can be drawn. This information can be used to visualize areas where accidents are more likely to occur.

Integration is required to enable control over material handling equipment. However, if this limit is removed geo-fencing in the manufacturing is made possible. Geo-fencing is a digital geographic zone where connected vehicles can be controlled (Trafikverket, 2020). Controlling actions in these zones would enable equipment to dynamically change the speed to fit the surrounding. If no humans are close by higher velocities can be allowed. This will provide solutions that can increase flow, which generate a higher ratio of value added activities according to Modig and Åhlström (2012).

4.3.2 Supply data for manufacturing KPI calculations

Positioning data can be used to calculate several common manufacturing KPIs. Examples of such KPIs are Idle time, Availability Rate, Down time and On Time Delivery. Data from the SKF test site can be used to visualize Idle vs Operating time for three different forklifts, see figure 4.3.

KPIs are used to monitor the production process (Amrina et al., 2018) and manufacturing responsible acts upon these indicators. Alongside the Industry 4.0 principal decentralization decisions should move closer to the devices (Herman, Pentek, 2016). KPI calculations from positioning data can be used for controlling the process directly without human interference. An example of this inherits from the On Time Delivery KPI (See 2.1). By letting the production process control systems prioritize orders the process could automatically prioritize urgent orders.

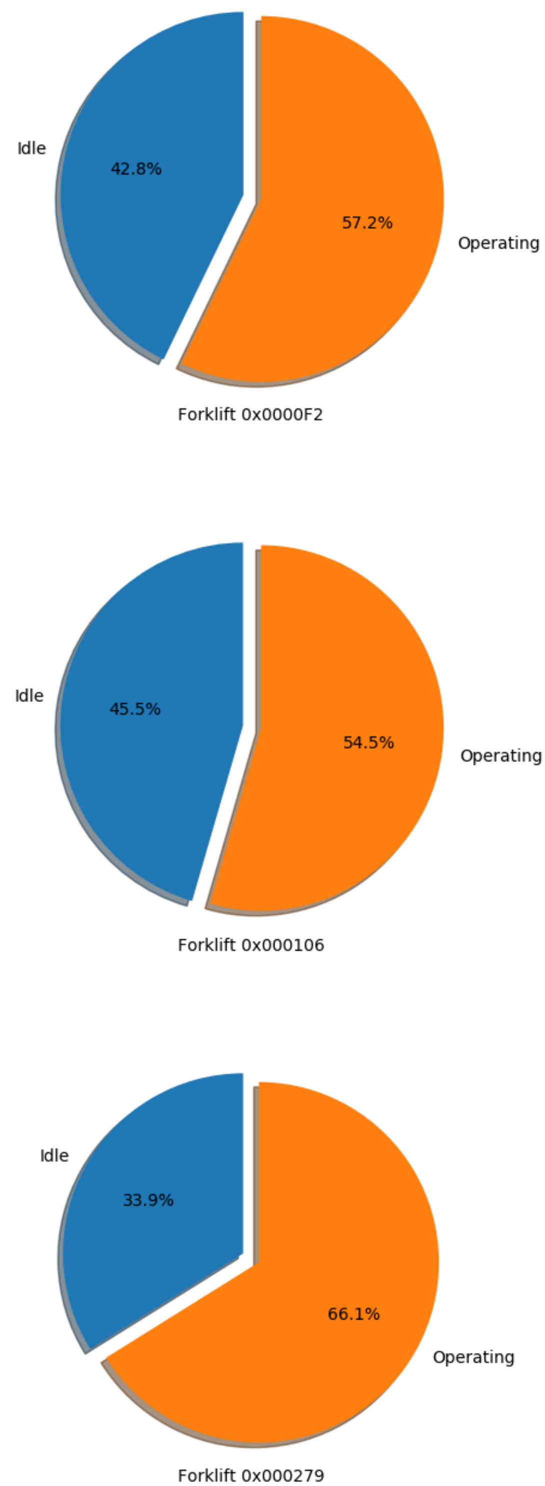

Figure 4.3: Utilization of three different forklifts at the test site

4.3.3 Manufacturing process analysis

Lean principals, as bottleneck tracking (Liker & Meier, 2006) are common approaches to production problems. Analyzed positioning data can support production engineers to detect bottlenecks. Figure 4.4 shows two different rounds on the same route performed by the same forklift, but at different times. Analyzing historical data will also enable better understanding of AGV behaviours. Today this data is only available during a limited time after error raises. Using an indoor positional system would remove this limit and allow for comparison of problem scenarios.

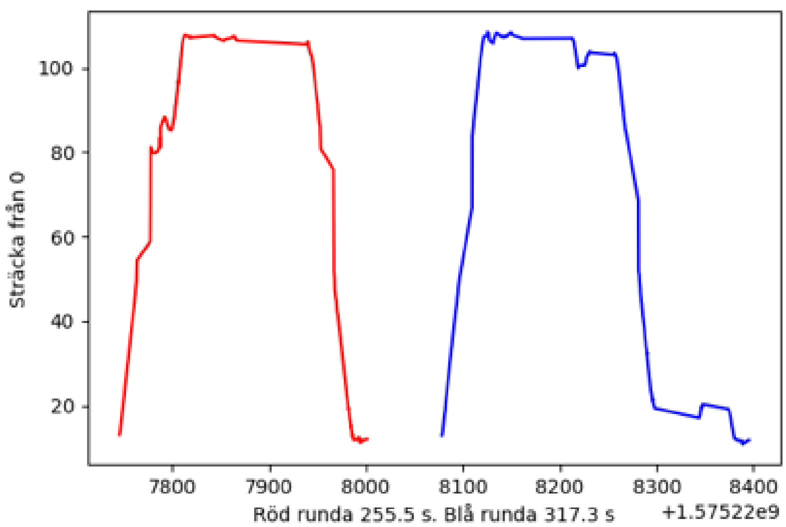

Figure 4.4: Comparison between two forklifts at the SKF test site

5
Discussion

This thesis has investigated what problems that can be solved with radio-based positioning in the manufacturing industry. Identified problem areas were then linked to the potential users of such a positioning system. By applying design thinking methodologies, solutions were developed to generate the most value for identified users. This chapter will discuss the thesis results, but also the learning process that took place during it. The aim is to increase the understanding of the result by explaining the learning in an iterative process.

5.1 Result interpretation and implications

The result support the claims of Samama (2019) that addresses the need for clear constraints of an indoor positioning system. By specifying the technical requirement downsizing of the number of potential solutions is made possible, allowing for comparison and priorition. This will likely benefit both user and developer because it forces communication in a more narrow field. However, the results also transcend the need for technical constraints and shows that better understanding of the end users first must be satisfied to develop meaningful solutions. This is done by highlighting the production engineer persona to emphasize the need for system functionalities that deals with production optimization.

Cooper (1984) describes that strategies that finds a balance between technological prowess and a strong market orientations are those who sees the best results (s.156). A strong market orientations should in this statement be interpreted as product development deriving from market demands (ibid.). Indoor positioning does not see any commercial use as of now (Samama, 2019), because of this identifications of system users and definitions of their needs must first be established to locate the market demand. This makes the result of identified system users particularly interesting because they are rarely in charge of system purchases, which mean that they often have little influence of what system will be accuired.

Case studies limits generalization and analyze through statistical inference (Dubois & Gadde, 2002). The strength of the case approach instead comes from its ability to in-depth insight in empirical phenomenons. This is especially true if the framework and theory is allowed to evolve through iteration during the research (ibid.). The design thinking method relies on the same back-and-forth mechanism to continuously add to problem and user understanding. Because of this the result should not be used to make broad statements about the manufacturing industry, but instead used as insight into what problems that indoor positioning can solve. The validity of this result will, therefore, rest on the iterative process rather then its ability to give general answers to the research questions.

Combining positioning data from the test-site with interview findings from industry stakeholders yielded results that showed that there is an interest in the usage of data generated by a positioning system. Waste elimination is crucial to approach a lean manufacturing process (Liker & Meier, 2006) and there is a need for tools that can support data-driven decision making (Amrina et al., 2018). Position data collected over time will give the engineers working in manufacturing environment high-resolution data to base their analyses and KPIs on. Compared to manually collected data, data from a continuously operating positioning system will generate more cost effective data. Manufacturing engineers are a limited resource. Systems enabling more time for analyzing data and less time spent on data collection will make it possible to utilize the capacity of the manufacturing engineers more economically.

This study also shows the upsides of a Gemba approach where interesting findings come from close contact with the manufacturing environment (Richardson & Richardson, 2017). If all data collection for KPI measurement in a future manufacturing scenario will be atomized the manufacturing engineers might miss potential interesting findings in the manufacturing process during data collection. Close observation in manufacturing environments was an important part of understanding how indoor positioning could be used. Because of this, it is hard to recommend the production engineer to solely rely on a positioning system to analyze processes. Our findings instead suggests that using data to complement observations during Gemba is a more suitable system usage.

One main problem found in this study is the misuse of data by the manufacturing industry. Accepting that positioning data likely will be misused as well one must find ways for proper data usage. However, interpreting the analyses from positioning data with real know-how of the process setup decreases the risks of data misuse. Independent of the data quality, the interpretation of the analyzes will be easier if the engineers have solid process know-how, gathered from Gemba.

The result also showed that many of the ideas required further investigation of system boundaries to enable viable solutions. This study shows that material handling control systems can not be accessed by a superior system. This limits Ericssons test system to only monitoring functions, since controlling actions such as giving a material carrier allowance to a certain area requires permission from the carrier manufacturer. Future studies is therefore encourage to analyze possible joint system development with other manufacturing equipment companies. In collaboration; system boundaries could become more clear, which would enable a more focused market strategy.

Learning in iterative processes

As mentioned in the method; answering the research question was not a linear process. Instead iterations were used to continuously update the framework, theory and overall understanding of the subject. This 'back and forth' motion over different research activities is in this study portrait as a unique trait of the design thinking process. In reality, however, this movement is the underlying mechanism of learning that allows new knowledge to influence the end result. Dubois and Gadde (2002) describes learning as the essence of all research projects. Despite this, the readers seldom are allowed to follow the actual learning process of the writers, even though it is the most important part of the research process(ibid.). Just like in any subject the transformation from tacit to explicit (Werr, 1998) knowledge could aid other researchers by giving insight into how ideas take form during a project.

In the early stages of the research time was spent reading up on the subject to understand both technical and organizational aspects of indoor positioning. Understanding the vocabulary used in a certain field is of-course a must when trying to understand a subject. It was especially important since lack of subject knowledge would make it difficult to construct relevant interview questions.When interacting with users in the early stages of design projects, it is important to try different approaches and constantly iterate a set of questions and topics to find the most suitable way for accessing the users knowledge.

The research project was performed with Ericsson as a project sponsor. When the project started, the stakeholders had interpretations of how the system output might be used. Although the research team was free to choose the research method. Going to the users for answers as done in design thinking (the chosen method) includes defining the problem. But what if the defined problem can not be solved with the project sponsors offered product or service? The research team understood that the stakeholders and the users had some different thoughts on how to use positioning data.

Questioning "why" when performing a design project enables double-loop learning (Argyris, 2002) but the research team can easily step outside the project scope when questioning the purpose of the project. The user needs might not be compatible with how the system is designed. Using iterative design methods like design thinking enables many learning opportunities for the research team, but it can also create conflicts with the sponsor's goals. Therefore, it is important to set up and maintain concrete limitations for the project in order to get clear results. In this project, we have tried to identify user needs and define the ones that fit within the project scope. But one could also have investigated the user needs without the limitations, and questioning "why" even further. Such double-loop approaches in an iterative manner open up for answers far away from clear answers and thus are of little use for project sponsors.

Some knowledge gained during this project is the result of such double-loop learning processes. When describing the research methods and results one tries to transfer the gained knowledge to the reader. We as researchers want to give the reader the best possible chance to learn from our study. But adding all findings from the research project to the report will blur the message. Therefore only the most important findings and the process steps taken to reach them are added to the report for the highest possible readability.

5.2 Ethical aspects

Information about where objects are located can be sensitive, both for the employees and the company where they work. Manufacturing companies suffer from competition from other actors on the market. Manufacturing setups and value chains can be the difference between a successful company and an unsuccessful company. Therefore keeping positioning data secret is crucial for the company. A positioning system must not share information to unauthorized users. Even though the positioning data might be classified, data about dead objects don't interfere with GDPR laws.

But positioning data, and visualized positioning data where *humans* are involved require consideration about integrity. The GDPR laws must not be violated when doing research. Our research methods in this project involve interviewing people and observing work procedures. To ensure that no integrity violations against GDPR laws occur we must keep the data about people anonymous. One must not be able to identify the interviewees by reading this report.

Keeping data anonymous is also important when visualizing positioning data via a positioning system. Among colleagues, visualized positioning data might be used in a way that is not intended by us who developed it. For example, workplace bullying is experienced by many employees every day [1], and positioning services might be used by staff for bullying. By visualizing poor performance together with user data the positioning system could be used for matters that the unions would reject.

Protest against positioning systems has previously been held by the unions [2]. The surveillance possibilities for corporate organizations increase with positioning systems. For Ericsson company, as a provider of positioning services, integrity must be considered before the system is launched.

Lastly, positioning data provides information that can be used to control the connected equipment. Inefficient use of the equipment can be spotted, and the fleet can be managed and used in better ways with positioning services. Higher throughput of the installed equipment will in an extent put less environmental footprint since the consequence of investing in un-utilized due to lack of information can be prevented.

[1] https://www.bbc.com/news/business-51182651

[2] https://www.svt.se/nyheter/inrikes/kritik-mot-gps-overvakning-av-personal

6

Conclusion

This thesis aimed to investigate if there is a potential to solve problems in the manufacturing industry with radio-based indoor positioning. To do this, problems regarding data usage were identified and how a positioning system can be used to increase productivity, gain insight into the production flow, and improve employee safety. Based on qualitative analysis it could be concluded that indoor positioning is perceived as a promising technology with the potential to improve production processes. However, this requires the solutions to have a strong connection to the system users and the manufacturing industry KPI's.

The data also identified three personas that would work with a positioning system, and the production engineer as the main user. Further more, analysis using the AIM method reveled that problems in the manufacturing industry could be grouped into - *Data is missing* and *Data is misused*. From this, value adding usages for the production engineer were identified by using design methodologies described in section 2.5. The best system usages were found to be:

- Increase safety and productivity at the manufacturing site
- Supply data for manufacturing KPI calculation
- Production process analysis

This study has confirmed the potential of radio based indoor positioning both in theory and with system user evaluations. The literature emphasized the focus on technical constraints. By applying design thinking methodologies this research have aimed to expand this by also involve the user perspective and Lean principles regarding waste eliminations. Denning (2013) describes design as the creation of artifacts and innovation as the process of making people adopt the artifact into the organization. We are convinced that understanding of the manufacturing system users and the environment where they operate is key to develop ideas that can go from designed applications to used innovations.

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A

Personas

PLANT MANAGER– SVEN-ERIK

BACKGROUND

With a Msc in economy Sven-Erik started to work as a accountant at the firm after completed studies. With a successful career-path Sven-Erik managed to reach the high level management.

MOTIVATION

Sven-Erik is motivated by the thought of a lean process with minimal losses and a well functioning organization. He likes when the staff is doing what told and works according to the agreed process.

DEMOGRAPHICS

GENDER	Male
AGE	57
SALARY	42' SEK
LOCATION	SWEDEN

GOALS	RATING
Well functioning business	
No accidents in the company	
KPI fulfillment	

RATING	PAIN POINTS
	Suspects that information is suger coated
	Always expected to have the answear
	Making important decisions on limited data

PRODUCTION PLANER– TUFVA

BACKGROUND

Tufva has a long career at the company, starting when she was a teenager. She has become "inventory" and plans to stay at the company until she retires. Apart from her planning responsibilities she also monitores the automated processes and oversees the production flow.

MOTIVATION

Data must be in place at all levels for her to feel that works is done. Correct and up to date data is the main inputs to her administrative work. When all data is set, and the production schedule is completed she feels satisfied. The work done by Tufva no other at the company manage to do, which makes her a key asset.

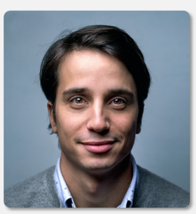
DEMOGRAPHICS

GENDER	Female
AGE	57
SALARY	42' SEK
LOCATION	SWEDEN

GOALS	RATING
Productions planning = Production outcome	
Continous improvment of planning skill	
Utalization of master data	

RATING	PAIN POINTS
	Feels undervalued
	Different prioritizations from different departments
	Communication outside the systems

PRODUCTION ENGINEER– KRISHNA



BACKGROUND

After a bachelor in production engineering Khrishna started to work as a production engineer. His current occupation is the second one in his engineering career. This job includes project work, such as managing investment programs and cost reduction programs..

MOTIVATION

Krishna work philosophy is about improving the production process. He feels good when implemented improvements shows to be successful.

DEMOGRAPHICS

GENDER	Male
AGE	42
SALARY	34' SEK
LOCATION	SWEDEN

GOALS	RATING
High qualitative data from the system which he can trust.	
Cooperation within the organization regarding process improvement	
Test different scenarios	

RATING	PAIN POINTS
	Catch 22 situations
	System limitations
	Suppliers that fail to deliver

B

Use-case

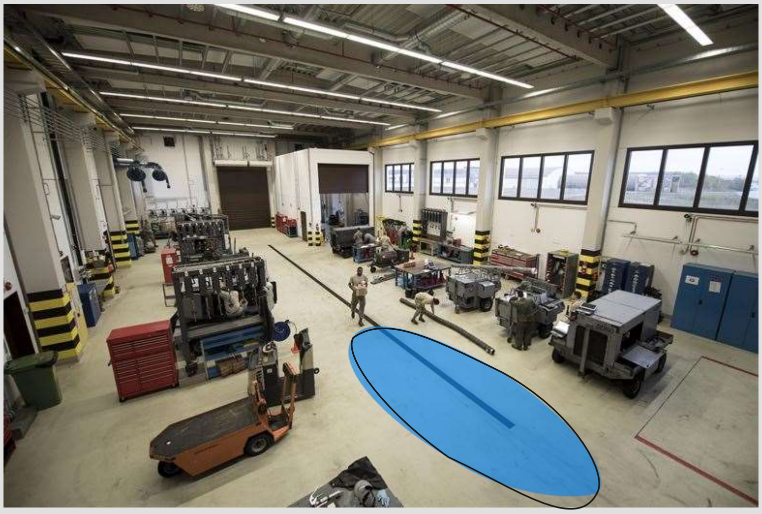
Digital Zones

Positioning use-cases for manufacturing industries

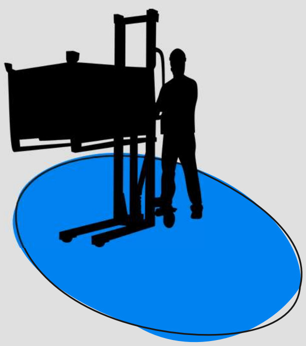
What is Digital Zones?

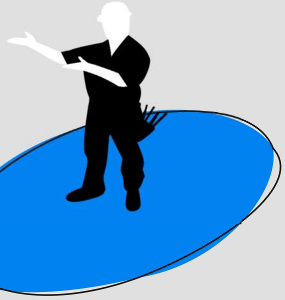
Digital Zones are a defined area where one can measure different parameters and declare local rules.

Digital zones are based on a positioning technology, that enables real time location updates from connected objects.



Different zone-types



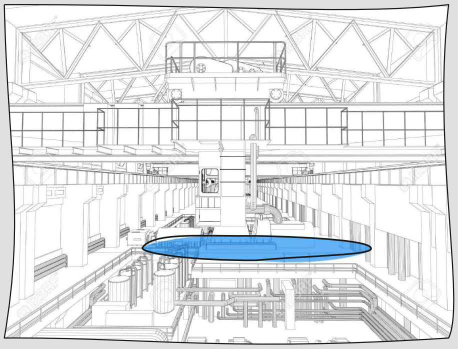


Around objects:

Zones can be defined around objects. All objects connected to the positioning system can be surrounded by a zone. Peopling carrying connected gadgets can also be positioned.

In the factory:

At the shop flor, areas can be divided in zones. These zones are not connected to a mobile object, but to virtual geometrical boundaries.



Benifits for the manufacturing industry

The manufacturing industry constantly working towards lower costs, increased productivity, and safer work environments. Digital zones can:

- Ensure safer work environments
- Increase productivity
- Lower the costs

Use-case: Geofencing

Rules in digital zones can be declared in order to control objects connected to the positioning system. Suitable rules for a manufacturing industry are:

- Speed limitation
- Allowed operating areas
- Allowed operations (see quality assurance use-case)

With connected people the advantages are even bigger. For example, when the system recognizes a person and a vehicle in the same area vehicle slows down until there is no risk for collision.

Operators and machines can share the same space with out risk of injured staff. The need of physical fences and obstacles will be unnecessary

Use-case: ISO Quality assurance

Quality assurance according to ISO standards (e.g. ISO 9001) requires supervision of production parameters. Connected equipment delivers data to databases. It's important to know which product which values refer to.

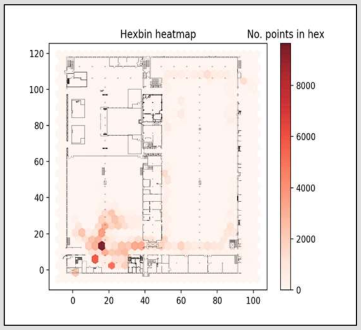
At assembly lines, this can be done by knowing the product's position and the tool position. Common in the automotive industry is to use wired tools, with a certain cable length. The tool thereby is only allowed operate on one product at the time. A radio positioning system will allow you to use wireless production equipment instead of wired.

Use case example – Screwdriver

- 3 classes
  - Class 3:
    - No supervision
  - Class 2:
    - Torque supervision
    - No data storage
  - Class 1: (CC / SC)
    - Torque supervision
    - Rotation angel supervision
    - Data storage
- Class 1,2 is Positioning critical (You must know which product you're working on)

Use-case: Heatmaps

Based on position data heatmaps shows the most intensive zones. All tracked objects can be monetarized this way.

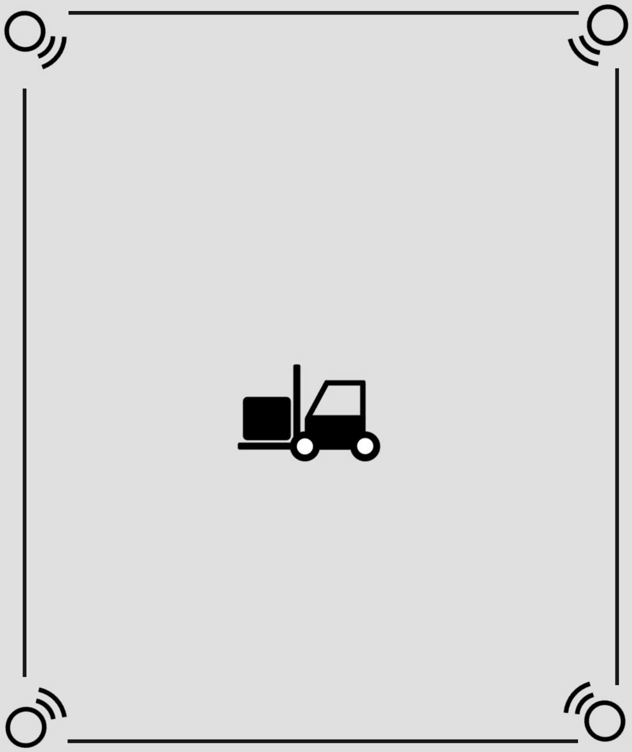


One can set up zones around objects and in the facility. Then it is possible to track if, when, and which objects that might conflict. The number of near misses, or collisions can be calculated based on positioning data.

Technical requirements

Monitoring:

- For monitoring activities the system requires coverage where you want to monitor.
- All objects that being monitored must be connected to the positioning system.
- For monitoring activities at least 2 anchors must be within reach.

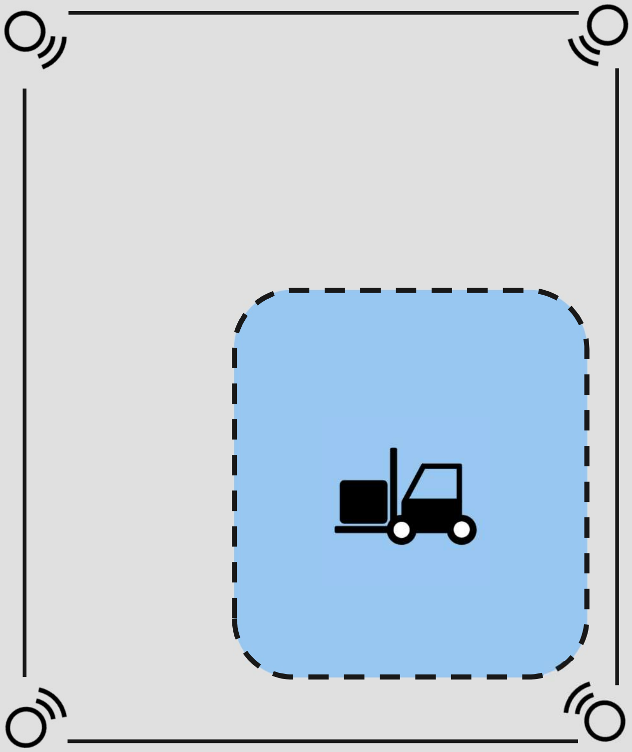


Technical requirements

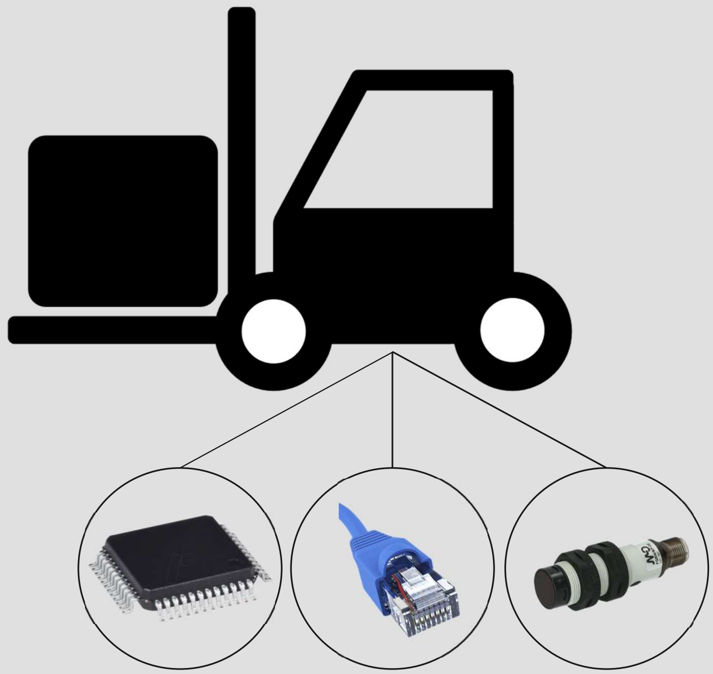
Controlling:

Besides the requirements for monitoring controlling activities has further technical requirements:

- Connected objects (eg. forklifts). The controlled object must be connected to a network (LAN).
- The controlling system must connect to the vehicles CAN* bus.
- A defined decision hierarchy between the system and the vehicle.



CAN bus Communication in vehicles



Description:

A Controller Area Network (CAN bus) is a robust vehicle bus standard designed to allow microcontrollers and devices to communicate with each other's applications without a host computer. It is a message-based protocol, designed originally for multiplex electrical wiring within automobiles to save on copper, but can also be used in many other contexts. Definition from Wikipedia.

There is no standard for communication between superior systems and material handling equipment in the manufacturing industry according to our interviewees.

It is complicated to get sensor data from the vehicle CAN bus. Therefore the vehicle might ask the positioning system for permission rather than being order by the positioning system.

Vehicle data possible to successfully combine with positioning data

The manufacturing engineering analyzes can be enhanced by combining positioning data with other data formats.

- Data from a connected vehicles (e.g. forklift) CAN bus system:
    - Speed
    - Steering angle
    - Telescope position
    - Actuator information
    - Break information
    - Accelerometer information

Cost example geofencing

The use-case includes geofencing where one can set-up and manage speed zones. This will enhance safety but in larger facilities it can also increase productivity. Here is an Example: Increase of vehicle speed in safe zones.

Investing in a system like this, at a facility with 100 manual non automated vehicles an increased maximum vehicle speed at safe areas from 6 to 12 Km/h might improve the productivity with up to 17,5 %. Since 1 driver + forklift costs 680 000 per year, a decrease from 100 to just 98 drivers will ret.

INVESTMENT COST: 1 000 000

RUNNINGCOST: 250 000 / year

SAVINGS: up to 11Msek

PAY OFF: 1 year

Cost example wireless screw driver

At a large automotive manufacturing sites visited during the research project **changes in the production** setup occurs on **daily basis**. Screw bandage is one of the most used fastenings at automotive sites. For CC classes 2 and 1 positioning of the tool is required. Average time to move a stationary screwdriver (mounted via cable) is **16h**. This operation can not be done during running production, it needs to be scheduled to a production free period (e.g. weekend).

Moving a CC class 2 or 1 screwdriver will cost approximately:

$$16 \times 900 \ = 14{,}400 \ sek$$

This is excluding the soft costs regarding changes in the system setup. The un-flexible stationary screwdrivers also makes the production engineers limited to areas where these are installed for certain operations. Therefore some minor improvements are not possible and the production process is not as flexible as it could be.

Potential Customers

- Large Manufacturing sites
- Intensive Logistic Operation Companies
- Workforce intensive manufacturing
- Companies with a mix of automatic and manual activities

Manufacturing process analysis

Positioning use-cases for manufacturing industries

What is Manufacturing process analysis?

The manufacturing industry constantly improves its production processes. The improvement process vary from site to site, but common approaches divers from the LEAN philosophy and or the SIX SIGMA methodology.

The improvement process often starts with an identified production problem, for example production capacity issues. Manufacturing process analysis refers to the analyses performed to solve the issue.

Manufacturing engineering analyses and work studies:

When performing a manufacturing analyze you can use position data to compare different work setups. Traditionally these analyzes are done manually on paper, but with a positioning system, you can perform multiple analyses simultaneously. Continues data collection can also assure good data quality over time, and for different shifts/workforces.

Work studies can be performed on equipment and workforce. Compared to manual work studies you'll get a better resolution on the collected data.

Types of manufacturing engineering analyses and tools where positioning data can be used:

<u>**Examples of work studie activites where positiondata can be improving the quality:**</u>

- **WBB – Work Balance Board.**
- **VSM – Value Stream Mapping.**
- **Frequency studies.**
- **Bottle neck tracking**

<u>**Examples of what position data can show:**</u>

- Process Deviations
- Wait time
- Utilization
- Best practice / Path

Manufacturing engineering software (potentilal analyzing software) :

- MVV (Casat)
- AXXOS
- NOVOTEK

KPIs compatible with position data:

The manufacturing industry constantly measures different Key Performance Indicators to monitor the production processes.

These indicators rely on data provided by the supervision systems (SCADA) and aims to describe the process current and historical state.

KPIs possible to calculate with positioning data:

- **OEE – Overall Equipment Effectiveness**
- **AR –Availability Rate**
- **PR – Performance Rate**
- **FTY – First Time Yield**
- **FPY – First Pass Yield**
- **VA – Value Adding time**
- **DT – Down Time**
- **Idle**
- **ELR – Employee Late Ratio**
- **On Time Delivery**

Advantages with positioning data for manufacturing analyzes

Processes with large operation sites or with high equipment density has complex flows of booth material and equipment. All production system has bottlenecks, processes where the production capacity is limited. At complex operation sites with many tools and equipment carriers, these bottlenecks can be hard to find, since they are caused by dependencies between the product and the equipment. By tracking the equipment you provide the engineers with reliable information.

Positioning data can be used for visualizing:

- Reduce variation between shifts
- Reduce the distance equipment is moved
- Reduce the number of equipment movements
- Plan when to move equipment
- Calculate the right number of equipment
- Fast reliable data when abnormalities occurs.