Exploring an open-loop RFID implementation in the automotive industry

Packaging Logistics

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Mathias Wiberg

ABSTRACT

This master thesis has been conducted to investigate why and how Plastal in Arendal (PAGO), Sweden have implemented RFID technology.

RFID technology has become very popular in recent years (1). It is said to have potential to increase the level of automation (2), reduce the labor levels and to improve the supply chain in areas such as inventory, visibility etc. (3) (see chapter 1.2.1 for more examples). PAGO is one of the first major companies in Sweden that have implemented an open-loop RFID system (see chapter 1.2.3.2) that tag on item level. They are also a supplier of injection-molded and surface-treated plastic to the automotive industry; an industry that is characterized by high level of automation and fierce competition. It is thus very interesting to investigate why and how PAGO implemented RFID technology; did any problem arise? How did they solve them? What where their underlying reasons?

To minimize the errors caused by manual updating – resulting in incorrect storage levels – PAGO have implemented a RFID system. The system has 24 RFID gates, divided into seven places: injection molding, entry and exit point of high storage 1, paint shop, entry and exit point of high storage 2 and after the sequencing process. The RFID system will help reduce the effects of entering the wrong quantity at the entry and exit point for high storage 1 and 2. It will also reduce the effects of specifying the wrong color or product. Furthermore, it will also help them verifying that each product is correctly assembled.

During the implementation, PAGO encountered some problems with ESD, reading too much or too little, tags becoming partially or completely detached and a long installation time. Most of these problems have been fixed but some of them remain.

There exist several reasons why PAGO implemented a RFID system, other than verifying the assembly and minimizing the effect caused by manual updating. One of those is believed to be because of the nature of the company – They only have 8h to sequence deliver the order, high turnover rates with expensive products and highly automated processes. Another reason is that RFID was a solution that solved both of their specified problems, but also supplying them with more features. Other reasons are that it will probably become a demand from Volvo in the future and that the technology is more future proof than any other technology that would have solved their problem; it is for example believed to be the successor of barcode. Major advantages, both visible and hidden, can be achieved with this RFID implementation. More reliable inventory levels could for example reduce the safety stock level, increase the level of automation and reduce the number of incorrectly assembled products sent to Volvo and thus increase their relationship.

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1 INTRODUCTION

In this chapter an introduction to the master thesis will be given along with the purpose of the thesis, the focus, the target group and a disposition.

1.1 LOGISTICS

Logistics is considered by many researchers to be a fragmented discipline that is very difficult to overview (4) and thus also have many different definitions. The Council of Supply Chain management Professionals (CSCMP) gives in (5) the definition of logistic management as follows:

> "*Logistics Management is that part of Supply Chain Management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services and related information between the point of origin and the point of consumption in order to meet customers' requirements…*"

Stock (6) states that "*logistics research is primarily an outgrowth from the business disciplines of marketing and management, with some input coming from engineering*", while Mentzer and Kahn (7) say that "*Logistics research has been influenced by the economic and, to a lesser degree, the behavioral approaches to scientific study*". Moreover Stock (8) also claim that having a limited view of logistics can cause serious problems and that "*many of the business and non-business disciplines have much to offer logistics in terms of concepts, principles, methodologies and approaches that could be applied to various logistics issues, problems and opportunities*". In (6), Stock gives an extensive list of application of theories from other disciplines, for example: accounting, business/management, computing, economics, marketing, mathematics, philosophy, political science, psychology and sociology, where the economic discipline focuses on cost minimization and profit maximization whereas the behavioral disciplines focuses on questionnaires, interview and case studies (7). In (6) Stock gives three benefits from applying borrowed theories to logistics:

- Learning from the experiences of others.
- Advances in knowledge and understanding, which might not have occurred otherwise, or perhaps taken longer, could occur more quickly.
- The inclusion of theories from other disciplines further enhances the linkages between logistics and those disciplines.

Furthermore, Gammelgaard and Larson states in (9), that logistic managers need a broad cross-functional awareness and that the top ten most important skills are: teamwork, problem solving, supply chain awareness, ability to see the "BIG Picture", listening, speaking/oral communication, prioritizing, motivation, cross-functional awareness and leadership; while Giunipero and Pearcy (10) claim them to be: interpersonal communication, customer focus, ability to make decisions, negotiation, analytical, managing change, conflict resolution, problem solving, influencing and persuasion, computer literacy. Nevertheless, "*For the study of logistics to advance, new perspectives need to be combined with the traditional concepts.*" as said by Stock in (8).

There are three paradigms that logistics research can be divided into: traditional science paradigm (analytical approach – seeks general, time and value free explanations (11)); a system theoretical paradigm (systems approach – shows the system as maps and models because logistics is regarded as too complex for deriving casual-effect relations (11)) and social constructivist paradigm (actor's approach – The view that supply chain management must be implemented differently in different organizations (11)) (4), where the analytical paradigm is according to Mentzer and Kahn in (7) the dominating when an economic approach is used. Gammelgaard states in (11) that "*The preferred research method is quantitative*…" and that systems thinking "…*is a major advantage in the analysis of logistics research*", while Arlbjørn and Halldorsson in (12) mentions that the systems approach may have been over emphasized.

1.2 SUPPLY CHAIN

The supply chain is today global, enabling products and services from all over the world, which also have made it to be more vulnerable to, for example: natural disasters and wars. The focus has moved not only from physical processes to managing information but also on competition between firms to competitions between supply chains. (13)

The final users/customers actual demand is in a traditional supply chain often distorted and the further upstream in the supply chain the greater the aberration of the demand becomes, because every member in the supply chain makes its own decision based on the information it got from the subsequent member. This causes the orders from the upstream members to have a greater variance than the actual demand of the final customer – This phenomenon is called the bullwhip effect (14) or the Forrester effect (15), which can lead to excessive inventory, out-of-stock, unreliable deliveries, inefficient production schedules and larger expedition costs ((15), (16), (17)). The historical solution of reducing uncertainty was by buffering resources through inventory or capacity, while today the solution is visibility – to make the real demand known in the entire supply chain with minimal delay and distortion – and therefore information sharing and close collaboration across the supply chains are vital to the supply chain. IT doesn't just reduce the unnecessary inventory, but it also enables processes to be automated and for manager to make more informed decisions in new areas where information previously have been lacking (13). However, automation has its limits and can, if improperly implemented, cause supply chains to go out of control or even havoc (18).

The supply chain is both a network and a system – specified by its interactions. A network, a process, and sets of relationships are the central parts of the supply chain, where the network's function is to transform resources into finished products and/or services delivered to the final stage of consumption. The system is viewed as being both dynamic – The system is affected by both managed decisions and by external forces – but also non-linear – The effort to adapt to these forces reflect feedback loops. (13)

1.2.1 RFID TECHNOLOGY

Automatic Identification (Auto-ID) has in recent years become very popular in many industries such as: service, purchasing, distribution logistics, manufacturing (19). For RFID, being an Auto-ID technology, only 18 % have no plans for RFID implementation (see Figure 1), according to a survey of 496 companies assessing the RFID market from 2005-2007. Over 1/3 of the companies had plans to evaluate RFID during 2005-2006, while another 1/3 either where in pilot use or full deployment. Schmitt, Michahelles, and Fleisch (1) identified during the same years, the most important adoption factors of RFID technology:

- Perceived benefits – The advantages companies think can be generated by adopting RFID technology.
- Costs – The initial investment in the technology (including infrastructure and transponders).
- Complexity – Evaluating the challenges of adopting RFID into existing systems and processes.
- Organizational size – Bigger organizations typically have bigger budgets when investing in new technology and are usually able to generate return on investment faster them smaller organizations.
- External pressure – Includes competitive pressure, mandates to implement RFID and legal restraints.
- Performance – The RFID project will only proceed if promised performance is accomplished.
- Compatibility – How well the technology fits the adopting company.

- Top management support – The RFID project affects numerous departments and functions in the company.
- Standards.

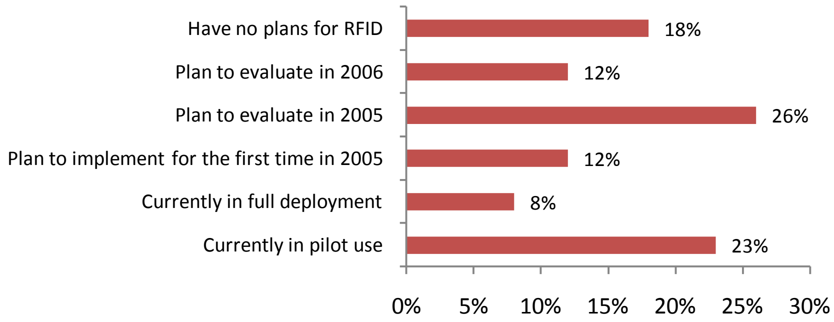

FIGURE 1 – STATE OF RFID TECHNOLOGY DEPLOYMENT. SOURCE: (20)

According to Google, the search trend for both RFID and barcode have declined since 2004, while the number of news (in Google News) have increased for RFID while it has been unchanged for barcode during the period 2004 – 2009 (see Figure 2). What this can mean, is that the "hype" of RFID is over, but it is still a popular subject, which coincides with Schmitt, Michahelles and Fleisch (1).

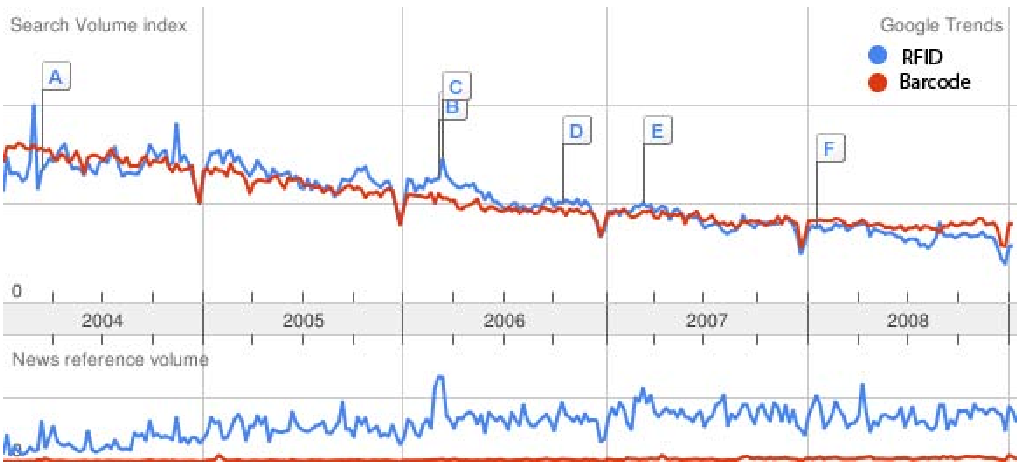

FIGURE 2 – RFID AND BARCODE TRENDS. SOURCE: (21)

There are a lot of literatures indicating that RFID have the potential to improve the supply chain in areas such as: visibility, labor reduction, tracking of various sorts, inventory and return management, security, sales, customer service etc ((22), (23), (17), (24), (25), (26), (3)). Increased degree automation is also often mention, which can increase productivity and decrease errors (2). Chappell et al. stated in (2) that "*Case-level tagging will bring the greatest number of benefits in* *the retail supply chain*" and that there will be a 5 – 40% reduction of direct labor within distribution centers. Furthermore Park, Park and Lee in (19) claim that RFID is to "*become the bedrock of most supply chains over the next twenty years*".

Bhattacharya, Chu and Mullen concludes in (27) that the benefits obtained from implementing RFID technology is the dominant – with a frequency of 91% for manufacturing companies – driving force when adopting RFID. They also conclude that "*Improved operational efficiency*" stands for 1/3 of the obtained benefits, followed by "*increased visibility*" at 32% and "*Better management of inventory*" at 10%, while "*tracking and tracing*", "*inventory management*" and *"automated shipping/receiving*" are the most significant RFID applicable tasks.

1.2.2 RFID INDUSTRY DRIVERS

Wal-Mart is the largest retail firm in the world (28) and operates 894 discount stores, 2.610 Supercenters, 146 Neighborhood Markets, 599 Sam's Club locations and 40 distribution centers, employing more than 2 million associates (29).

Wal-Mart announced in June 2003 that they had intentions of adopting RFID technology. The intent was to improve the supply chain efficiency by using the RFID data generated with automated electronic interchange technologies. One year later, in April 2004, Wal-Mart began a RFID pilot project consisting of 21 products out of the more than 100.000 products that can be found in a typical super center. These 21 products came from Wal-Mart's top eight suppliers: Gillette, Procter and Gamble, Johnson and Johnson, Kimberly Clark, Kraft Foods, Nestle Purina Pet Care, Hewlett-Packard and Unilever. The project was limited to tagging on pallet or case level and for shipment going to Wal-Mart's regional distribution center in Sanger, Texas and from there to eight stores in Dallas-Fort Worth-Arlington metropolitan area. (30)

Wal-Mart estimated that 10% of the total sales where cost in the form of lost sales from manual processing. By implementing RFID technology, Wal-Mart projected that they could reduce these cost by 6-7%. For example, the restocking of shelves were carried out by employees in two manners:

- Physically inspecting the shelves.
- In the backroom, scan the products to determine if there was space on the shelves for it or for products that may not be on the shelves yet.

Both these methods are labor intensive and inaccurate, and by utilizing RFID technology these tasks could be automated. RFID technology could automatically determine which products that needed to be replenished with data generated as the products move from distribution center, backroom, store shelves to a customer and also restock those products automatically. Thus reducing stock-out and manual labor, but also improving and helping the employees minimizing situations where products are in the backroom but are missing on the shelves. Furthermore RFID technology could also help in providing alternative routes for shipments in case of delays because of the visibility, or by recovering misplaced cases in the backroom. (30)

In January 2005, Wal-Mart issued a mandate to its top 100 suppliers requiring that shipments of cases and pallets to its three distribution centers in Texas – It was chosen because of the high concentration of Wal-Mart's operations in the area – be fitted with RFID. The project started with 137 suppliers, 37 of which voluntarily become RFID compliant. One year later, in January 2006, the number of suppliers had increased to 200 and to 13 distributions centers. (30)

The impact of RFID technology on inventory accuracy was examined in a study from May to October 2007 where RFID enabled products in 16 Wal-Mart stores (including a mixture of Supercenters and Neighborhood Markets) where studied. The stores were divided into two sets; 8 RFID-enabled (test) stores for measuring RFID's impact, and 8 (control) stores as a reference chosen based on a set of criteria used to determine a comparable profile (including demographics, size of stores, annual sales, the absence of known impacts such as annual inventories, remodels / resets, markets trial and other known disruptions). The study showed a 13% reduction in perpetual inventory[1] inaccuracy for the RFID enabled stores compared to the reference stores and that the number of manual adjustments per week per store went from 3.4 to 2.0. (31)

In the beginning of January 2008, Greg Spragg, executive VP of merchandising for Wal-Mart's Sam's Club division, sent a letter to all Sam's suppliers for the distribution center in DeSoto, Texas asking them to start tagging pallets, and by the end of January also on case level (32) (33). It also stated that by the 31th of October four additional distribution centers required tagging on pallet level and for the Texas distribution center tagging should be on case and mixed pallet level. The letter also said that by 30th of January all remaining 17 distribution centers required tagging on pallet level and four additional distribution centers required tagging on case and mixed pallet level. (34)

[1] Perpetual inventory is also called continuous inventory. The information system is updated continuously with real inventory in stock, in contrast to periodic inventory where updates are made on a periodic basis (164).

Those failing on tagging on pallet level would be charged $2 per pallet, because Sam's Club would have to add the tag at its own distribution center. The letter explained that the fee would rise to $2.5 after the 30 of October and to $3 at end the January 2009. (35)

1.2.3 AUTOMOTIVE INDUSTRY

The automotive industry has since the last 15 to 20 years been undergoing extensive reorganization, for example: make-and-deliver-to-order, zero-error-production, lean management, just-in-sequence (JIS) and just-in-time (JIT) production. This is partly due the necessity of reducing costs and cycle times. Along with the fact that the vehicle manufactures began restructuring their supply chain, and outsourcing functions which weren't seen as core competencies and thus establishing closer and tighter cooperation between all companies in the supply chain, have made the automotive supply chain one of the world's most information-intensive management process. A shift have gone from classic tools of data transmission such as sheets of paper, faxes and phone calls towards Electronic Data Interchange (EDI) and Enterprise Resource Planning (ERP) systems, which with barcode technology have increase both the quality and the amount of information. (1)

The automotive industry has been evaluating the possibilities of RFID technology for a long time, but has in contrast to the retail sector been more reluctant to adopting it. On the other hand, the automotive industry has been using RFID technology for years in some specific implementations such as vehicle immobilizers, while when it comes to supply chain management and operations with many partners; it is still a process at the beginning (see Table 1 for an overview of existing and completed RFID technology pilot projects in the automotive industry). According to Schmitt, Michahelles and Fleisch (1) there are three reasons: Skepticism about the EPC concept and the EPCglobal; long-lasting standardization process – The lack of an agreement for a single RFID standard; and lack of mandate. (1)

TABLE 1 – EXISTING RFID SYSTEMS AND PILOT STUDIES IN THE AUTOMOTIVE INDUSTRY. SOURCE: (1)

Field of application	Application example	Open/closed loop
Asset utilization	• Container management • Loading equipment management • Truck control at loading stations	Mainly closed-loop
Asset monitoring and maintenance	• Torque key control	Closed-loop
Item flow control	• Tagging of car bodies in: o Body shell work o Painting o Assembly	Closed-loop
Inventory audit	• Tracking of finished cars • Warehouse management • Pallet tagging	Closed-loop
Authentication	• Assembly documentation for security-relevant items • Identification of car gears	Closed-loop Closed/open-loop
Theft control	• Car keys	Other

The automotive industry needs an open-loop standard that can be used in many different processes and diverse application in sophisticated supply chains all over the world and thereby enabling synergic effects in the supply chain network – From the parts or modules delivered by the supplier, to the assembly line and later on to the customer. This would make the automotive industry into a more service oriented industry compared to today's product industry. (1)

Until now the automotive industry aims on a completely different approach compared to the basic EPC (Electronic product code) principle where each tag stores a unique id which is linked to a database. The aim is for every tag to store process information such as shipping date, receiving date, sender and recipient information, part number, quantities and process step or sequence. This is because JIT and JIS require that the information should be accessible even when there is no connection to the database. The automotive industry is also more driven towards an ISO standard while the other industries have adopted the faster developing user-driven EPCglobal-standard. The difference can shortly be described as: ISO adopts a more application-independent cross industry perspective with a very generic approach focusing mainly on the air interface, while EPC-global adopts a more application-specific approach. (1)

The Automotive Industry Action Group (AIAG) – Founded by DaimlerChrysler, Ford Motor Company and General Motors in the 1980s – published a standard called "B-11: Tie and Wheel Label and RFID standard" in 2006. The standard solves the challenge of facilitating both the EPC and ISO standard with a single RFID tag. The solution can shortly be described as using inoperable bits as a flag to denote whether EPC or ISO is used. This solution is also adopted in the recommendation [VDA 5501] given by the Association of German Automotive Industry (VDA). The different standardization approaches all have in common that they operate in UHF and that they want to apply EPC conformed hardware and to use the free memory capacity in the tag for additional user data. (1)

1.2.3.1 RFID IN CLOSED-LOOP SYSTEMS

A closed-loop system refers to a system with "*RFID transponders that are attached to an object and permanently remained on it while it is shipper or move within a cycle and eventually returns to its point of origin*" (1). This was the first RFID system to be implemented in the automotive supply chain. Example of closed-loop systems are given by Schmitt, Michahelles, and Fleisch (1):

- Management of valuable assets, tools and returnable containers
- Inventory management where pallets or cases are equipped with a transponder for identification purposes

The reason why closed-loop systems were the first RFID system to be implemented was simply because of the cost of both the tags and the infrastructure and because the flow was easier to coordinate and there were no standardization issues. Vehicle manufacturers such as DaimlerChrysler, BMW and Volkswagen are today either already using or testing RFID systems in closed-loop. (1)

The goal of local closed-loop applications are basically to substitute the manual handling with automation, reduce the media breaks caused by manual barcode scanning and the typing of numbers into a computer.

1.2.3.2 RFID IN OPEN-LOOP SYSTEMS

According to Schmitt, Michahelles, and Fleisch (1) the main characteristics of an open-loop system is that "*the RFID transponder remains on the object and leaves the process or production site for a long period of time or without reuse for the same process*". As previously mentioned, open-loop systems are rare in the automotive industry but some examples are: tagging specific parts, modules or vehicle for distribution, recall management and maintenance history. The reason for the poor diffusion in today's automotive industry is said to be: the high failure and loss rate of the rather expensive tags, complex multidirectional relationships, need for a widespread infrastructure for most applications and the globally accepted standard. (1)

1.3 PURPOSE

The purpose of this master thesis is to explore and describe how and why PAGO[2] have implemented RFID technology. The reason for this is that the implementation is one of the few open loop systems that tag on item level.

1.4 FOCUS

This thesis has focused on the RFID implementation in PAGO and therefore no other plants will be studied. It focuses on the logistic processes, i.e. neither the production quality nor the production processes have been considered. The reason is that PAGO already have very good production processes. For example, every product Volvo receives that have some kind of error, i.e. damaged or wrongly assembled etc. gets returned to PAGO for further inspection. PAGO examines the type of error; how this kind of error could have happened and why, and what actions should be taken to counteract it in the future. Another reason is that Volvo reported that PAGO have an error rate of 12 ppm, compared to the allowed level of 100 ppm. Also, some monetary thoughts are given, but it is not the main focus in this thesis.

1.5 TARGET GROUP

The target group of this thesis is for students with logistic interest and to Plastal and PAGO. It can also be useful to industries where RFID have potential benefits, or to companies thinking about implementing RFID technology.

[2] Plastal in Gothenburg.

1.6 DISPOSITION

Chapter 1
Introduction
In this chapter a brief introduction is presented along with background, the purpose of the master thesis, the focus and the target group.

Chapter 2
Methodology
This chapter presents the author's view of knowledge and explains how the thesis was conducted. It also gives some arguments why certain methods were chosen over others, along with a deeper explanation of those. Furthermore expressions like validity, reliability, and objectivity are given a short clarification.

Chapter 3
RFID
In this chapter relevant theory on Radio Frequency Identification is introduced. The chapter is divided into seven parts: A brief background, tags, scanners and readers, antennas, host, RFID adoption phases and challenges to RFID adoption.

Chapter 4
Case description
The most important and relevant information is presented in this chapter; Gathered both from the interviews and the supplied data.

Chapter 5
Results and discussion
In this chapter the analysis of the data is presented. The chapter begins with a summary that describes how Plastal in Gothenburg have implemented the RFID technology, followed by an analysis on the topic "why". The chapter ends with a short mathematical model that shows the autocorrecting effects of the RFID implementation.

Chapter 6
Concluding remarks
This chapter discusses why some of the problems arose during the implementation, along with a short summary of my own conclusions.

Chapter 7
Appendix
This chapter includes a figure over Plastal at Gothenburg.

Chapter 8
References
Here all of the references are given in order of their appearance.

2 METHODOLOGY

In this chapter, different types of methods are described. The purpose is to give an explanation of my selection of methods and to present sources of criticism.

For some people, bothering about methods just seems like a waste of time and they maybe more interested in the analysis or discussion. Nevertheless, the methodology is the foundation of the research and its goal is to provide a clear and complete description of the specific steps to be followed, so that a naïve reader may replicate the study. According to Oxford English Dictionary (36) methodology is defined as "*a method or body of methods used in particular field of study or activity*", while a method is "*like a filter, it reveals some kinds of facts but obscures others*" (37). And as said by Simon (38) referred by Churchill and Iacobucci (39) "*There is never a single, standard, correct method for carrying out research*" or by Arbnor and Bjerke in (40) "*You can never empirically or logically determine the best approach. This can only be done reflectively by considering a situation and your own opinion of life*". According to Gammelgaard in (11), methodology ensures that no approach is taken for granted and it gives the reader a better understanding of previously conducted research but also how to proceed in the future.

To get a broad understanding of methodology, I began the master thesis by reading a couple of books and reports in the subject (see for example (41),(42),(43),(44)). Along with the books a great deal of research reports has been read, to get a deeper view in each subject as well as more up-to-date knowledge. The books have been a great help with not only the methodology but also with the process of completing the master thesis. I hope that by doing a comprehensive review in the subject of methodology I could eliminate or at least minimize the most general and common mistakes.

2.1 METHODS

There are four relevant methods for master thesis in applied science (43):

- Survey: A compilation and description of the present for the object or phenomena being studied. Survey often aims to describe a broad question.
- Case study: In-depth examination of one or many events (cases), where you try to minimize the influence on the object being studied.
- Experiment: Comparative analysis of two or more alternatives, where you try to isolate a small number of factors and manipulate one of them.
- Action research: A careful supervised and documented study of an activity that aims to solve a problem.

Instead of exploring a question from just one method, Höst, Regnell and Runeson (43) suggest that a combination of several methods is preferable.

2.1.1 QUALITATIVE VERSUS QUANTITATIVE RESEARCH

Choosing between qualitative and quantitative methods depends on the aim of the study, but a combination of them both in the same research is often an improvement, where they strengthen each other's failing. (44)

The qualitative research concentrates on investigating subjective and qualitative data – for example perceptions like; meanings, attitudes and beliefs – with help from qualitative analysis. (45)

The quantitative research focuses on what can be measured and mainly to test hypothesis and involves collecting and analyzing – with statistical methods – numerical data. (45)

This thesis will mostly be qualitative for the reason that it's more of an investigation of subjective data collected from interviews. However, the chapter "Propagation of error" has a more quantitative nature.

2.1.2 SURVEY

A survey is a research type "*in which a sample of individuals are asked to respond to questions*" (46) or as Coons (47) puts it: "*Survey research is a method of gathering data from a subset or sample of individuals intended to be representative of the population being studied*" and thus involves collection information from a large number of people – which is typically the most expensive aspect of a survey (48) – either by face-to-face (interviewing gives the best high-quality data (49)) or at distance (questionnaires the primary data collection tool (47) (46))(37), i.e. the main difference is the intensity of contact between the researcher and the respondent (48).

Survey research is said to have high generalizability, while being limited to provide information only to topics which respondents have answered and therefore the results are often questionable; For example questionnaires can be highly structured and thus may overlook vital information (see Brewer and Hunter (50) for more examples). Survey often includes doing a statistical sampling of the population (47), which permits the research with a known degree of confidence to describe how well a particular sample represents the population (50). The sampling selection should have equally disturbed probability for every member of the target population and it is the primary factor for representativeness or generalizability. (47)

A high response rate helps to ensure that the survey results are representative of the target population (51)[3], – which is the biggest concern when doing a survey (49) – while with a lower rate there is higher likelihood of response bias (47). According to Fowler (52) *"There is no agreed-upon standard for a minimum acceptable response rate"*, but according to the National Center of education Statistics, the item response rate for each key item should be at least 90% (51), while Coons (47) and Janes (49) suggest a response rate above 50% or else it could compromise the representativeness of the target population (see (47) for more examples of minimal acceptable response rates). But there are other factors that might bias the results as well, such as if only certain kinds of people have answered (49).

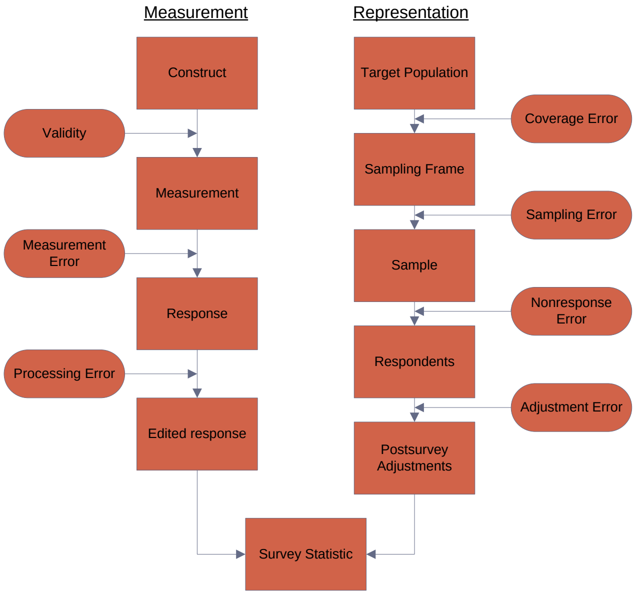

FIGURE 3 – SURVEY LIFECYCLE. SOURCE: (53)

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[3] Krosnick (166) claims by giving examples where surveys with low response rate can be more accurate then surveys with higher response rate. The representativeness doesn't always increase monotonically with increasing response rate, i.e. low response rate isn't directly correlated with the nonresponse error. To support this, Krosnick (166) states that:

- Using probability sampling, a lower response rate doesn't necessarily give lower representativeness.
- Conclusion often remained unaltered when improving the response rate.
- When the conclusions did change, there were no evidence that allowed researchers to assess whether finding were more accurate or not with a higher response rate.

In (53) Groves et al. divided the lifecycle of a survey into two processes: measurement process and representation process, also called sampling process (see Figure 3).

There are two general categories of error according to Groves (54) (see Umbach (55) for suggestions how to minimizing those):

- Observational – Created in the measurement processes (see Figure 3) and are deviations from the true value of a measure and that of the respondent's answer.
    - Measurement error – When respondent's answer to a survey question is inaccurate, imprecise, or is incomparable to any other respondents' answers and are often because poor constructed questionnaires, the selection of words etc.
    - Processing Error – The three most common sources of processing error are: coding, data entry and outliers.
- Non observational error – Created in the representation process (see Figure 3) and are errors when the researcher do not take measurements on part of a population.
    - Coverage – Arises when a person isn't included in list or frame used to identify the members of the population.
    - Sampling – Arises in every sample survey because the statistics is calculated on a subset of the population. Different subsets exhibit different statistical characteristics and thus, the every sample survey is dependent on which subset is being measured.
    - Nonresponse
        - Unit nonresponse – Arises when a member of the sample either refuses or isn't located.
        - Item nonresponse – Occurs when a respondent doesn't respond to one or more of the survey questions.
    - Adjustment – Arises when trying to reduce errors of nonobservation (coverage, sampling, nonrespons). The two most common adjustment methods are: weighting and the handling of missing data.

TABLE 2 – WAYS OF REDUCING ERROR IN SURVEY RESEARCH. SOURCE: (55)

Type of error	Suggestion for Reduction
Observational error	
Measurement error	• Have a defined objective. • Pay close attention to question wording. • Evaluate your survey questions by convening focus groups, consulting with experts, conducting cognitive interviews and pretesting your questionnaire.
Processing error	• Try to avoid open-ended questions. • Search for outliers.
Nonobservational error	
Coverage error	• Maintain good data. • Be careful in your selection of mode of collection.
Sampling error	• Determine the appropriate sample size. • Report confidence intervals. • Consider stratified sampling.
Nonresponse error	• Use multiple contacts. • Keep the questionnaire brief. • Draw a sample. • Know your population. • Check to make sure your respondents match your population.
Adjustment error	• Consider use of weights. • Be thoughtful in how you handle missing data.

This thesis will not conduct any surveys. The main reason is because the focus is within the plant at Arendal where only handful persons have qualitative knowledge about the RFID project and the aim of this thesis isn't to give a representative and general explanation of how and why a RFID implementation is done. On the other hand, there were some thoughts about conducting a survey on the employees' thought of the RFID project, but as time ran out this was unfortunately not done.

2.1.2.1 DESCRIPTIVE RESEARCH

Descriptive research is basically guided by an initial hypothesis and is involved with exploring either the frequency of a phenomena or the relationship among two or more variables (56). According to Churchill and Iacobucci in (39), descriptive research can be divided into two groups (56):

- Cross-sectional (often called sample survey) – Measuring at a certain point in time with several variables, i.e. a snapshot. If measured by its frequency of use, it is the most important type of descriptive research (39).
- Longitudinal – Repeatedly measures variables and thus providing a series of measurements.

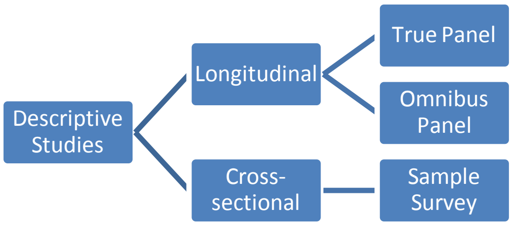


FIGURE 4 – CLASSIFICATION OF DESCRIPTIVE RESEARCH. SOURCE: (39)

Questions in descriptive research may sometime appear to seek a causal connection, but compared to experimental research it lacks the random assignment and manipulation of a treatment, thus the descriptive research can only uncover the correlation or association of factors – Correlation only indicates that two or more factors are associated with each other and not whether a factor causes another – while the experimental can uncover the actual causal relationship. (57)

The aim of this thesis is to describe and explore how and why PAGO have implemented RFID technology, and thus this suits the descriptive research well. The main descriptive research style chosen for this thesis has been the cross-sectional style because of the limited time and because of the nature of this thesis.

2.1.3 CASE STUDY

The case study is a research strategy that is all-encompassing – covering the logic of design, data collection techniques and data analysis – and relies on multiple sources of evidence and represent both single and multiple case studies. It is generally the preferred strategy when the natures of the questions are of “how” or “why”, the investigator has little control or when the focus of the research is on a phenomenon in a modern real-life situation. (58)

It is defined by Yin in (58) as:

1. A case study is an empirical inquiry that
    - Investigates a contemporary phenomenon within its real-life context, especially when
    - The boundaries between phenomenon and context are not clearly evident.

2. The case study inquiry
    - Copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result
    - Relies on multiple source of evidence, with data needing to converge in a triangulating fashion, and as another result
    - Benefits from the prior development of theoretical propositions to guide data collection and analysis.

Case studies are analytical generalizable – expanding and generalizing theories – and not statistical generalizable – enumerate frequencies – and are said to be "generalizing" in contrast to "particularizing". While bias can affect both experiment and case studies, it may in the latter be more frequently encountered and it is less frequently overcome. (58)

There have been some concerns about case studies. Yin (58) mentions four:

- The lack of rigor in case study research – Possible the greatest concern of them all. For example when the investigator has not followed systematic procedure, used vague evidence or has a biased view.
- Confusing case study teaching with case study research – Case study teaching may use altered material to effectively demonstrate something while in case study research such act is strictly prohibited.
- Case study research provide little basis for scientific generalization – Scientific facts are often based on multiple set of experiments, not on a single one and the same method can be used in case study, i.e. using multiple-case studies.
- Case study takes too long and result in massive, unreadable documents – This may be true for case studies that has been conducted in the past, but it doesn't automatically apply to the future.

Even though all of these concerns can be alloyed it is still difficult to conduct a "good" case study and some problems still exists, e.g. there isn't any good way of screening or testing an investigator's ability to conduct a "good" case study. (58)

This thesis is only concerned with PAGO and the results can't be generalized. A single case study method has thus been chosen for this thesis, and also because the purposes are of "how" and "why" which suits the method well.

2.1.4 EXPERIMENTAL RESEARCH

When determining whether there is a relationship between cause and effect the experimental research is very useful. It reveals the casual relationship by directly manipulating an independent variable – The variable that is manipulated, managed or administrated by the researcher – to measure its effect on a dependent variable – the variable that is measured in the study, often called predictor variables. (57)

Even though experimental research is said to have high internal validity and objectivity, it also has some disadvantage like: having a low external validity, which means that the methods isn't very generalizable to situations in the real world; or difficulty in isolating independent variables. (37)

The thesis also includes, to some extent, an experimental research. This is especially evident in chapter 0 where a mathematical model is used.

2.1.5 ACTION RESEARCH

Action research has not one widely accepted definition (see Altricher, Kemmis, McTaggart, and Zuber-Skerrit (59) for a more detailed and extensive explanation of action research) but according to McNiff (60), the perhaps most widely accepted working definition of action research is given by Carr and Kemmis (61) as:

> Action research is a form of self-reflective enquiry undertaken by participants (teachers, students or principals, for example) in social (including educational) situations in order to improve the rationality and justice of (a) their own social or educational practices, (b) their understanding of these practices, and (c) the situations (and institutions) in which these practices are carried out.

Action research can because of that be said to be a problem solving systematic and reflective process that is based on knowledge through reflection and observation. Kurt Lewin, who coined the term "action research" in 1944, described action research as a spiral of steps (see Figure 5) – planning, acting, observing and reflecting (60), which is defined by Kemmis and McTaggart (62) as; problem identification, systematic data collection, reflection, analysis, data-driven action taken, and finally, problem redefinition – and thus the person develops a form of "adaptive" expertise that will result in a understanding how forces interact with each other. (63)

Ortrun Zuber-Skerrit – the founding member of ALARPM (Action learning, action research and process management) – have in (64) given a summary of Kurt Levin's concepts, where he describes the four steps in action research as:

- Planning critically informed action to improve what is already happening.
- Acting to implement the plan.
- Observing the effects to critically informed action in the context in which it occurs.
- Reflecting on these effects as the basis for further planning, critically informed action and so on, through a succession of cycles.

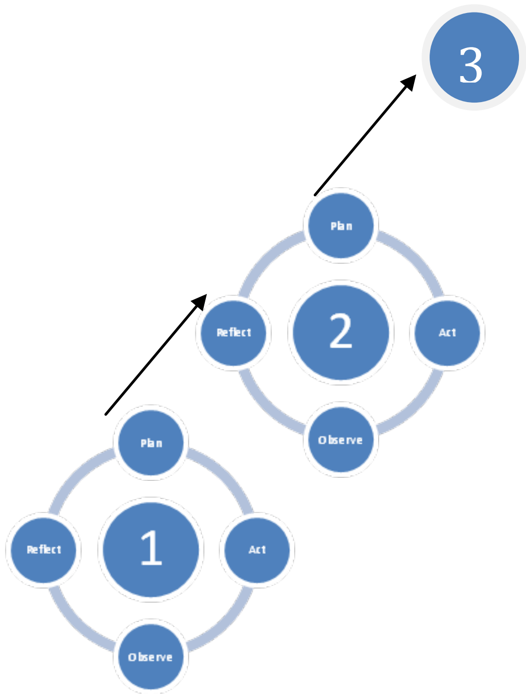


FIGURE 5 – THE SPIRAL OF ACTION RESEARCH CYCLE. SOURCE: (65)

No action research is conducted in this thesis because action research is more suited for social situations and the aim of this thesis is of more explanatory and descriptive nature.

2.1.6 TRIANGULATION

Triangulation is crucial in research and it is defined as: "*the application of different methods, theories, investigators, samples, conditions of occurrences and levels of analysis to the study of the phenomena*" by Marshall (37) and thus it is a strategy that, in contrast to using a single research strategy, provides for more valid results (66). Triangulation is also a way of ruling out alternative hypothesis or preventing the development of theories that lack alternative explanation and it can also give some degree of confidence in that the assumptions are neither theory bounded – "*any relationship concluded would not disappear if conditions were different*" – nor assumption bounded – "*that different observers would not perceive the same phenomena differently*". (66)

Triangulation comes in various forms, for example given by Marshall (37) and Jensen and Jankowski (66) as follows:

- Triangulation of method – both within (replication) and between (using various methods to study the same object).
- Triangulation of theory – using of different theories and disciplines for allowing for different interpretations.
- Triangulation of investigator – using several analysts or coders, which will increase confidence that the investigator bias has not distorted the conclusions.
- Triangulation of data – dimensions of time – testing hypotheses at different points in time, space – e.g. testing hypotheses in different geographical regions.
- Triangulation of analysis level – e.g. if aggregated data supports a finding produced by non-aggregated data as for an example interview transcripts.

There are not only advantages in combining several methods that all have different but complementary strengths but also because all research strategies are neither not completely perfect even in their area of greatest strength and thus they can benefit from corroboration by other methods' results, nor are they completely imperfect in their areas of relative weakness and thus they can probably provide some degree of corroboration.(50)

Therefore a multimethod approach adds to the strength of the evidence and increases the feasibility of verifying or validating theories, but one should also take into consideration that even strongly agreeing multiple measurements may lead to wrong conclusions, if for example undetected source of error affect each method equally. (50)

Questionnaires are constructed of closed-ended questions which force the respondent to choose among a limited number of answers and therefore also making the data highly comparable but also prone to errors such as the respondent being forced to choose an option not truly appropriate and thus obscuring some facts. Interviews on the other hand can provide finer detail at expense of comparability and by triangulating the interview data, such error may be revealed. (37)

I've chosen to do a multiple triangulation, i.e. a combination of the described triangulation forms. As you – the reader – may have already notice I've have selected to do both a descriptive and a case study research along with a small chapter that uses experimental research. I've also tried to do a triangulation of theory, not only in the frame of reference chapter but through the whole thesis. To some extent, I have also tried to do a triangulation of data. For example, comparing the data given in the interview with the company's homepage, but also through reading previously made master thesis at Plastal or by interviewing different persons etc.

2.2 SCIENTIFIC REASONING

There are three different forms of reasoning: abduction, deduction and induction (see Figure 6).

The first stage, where the hypothesis is created to explain the observations, is called abduction; the second stage, where the analysis and testing of the hypothesis and deducing consequences from the hypothesis, is called deduction and the third stage, where establishing to what level the consequences are satisfied with the experience (67)(68).

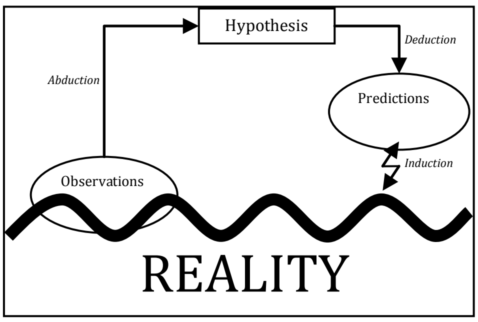


FIGURE 6 – THE THREE STAGES OF SCIENTIFIC INQUIRY. SOURCE: (67)

2.2.1 DEDUCTION

Deduction is a technique by which conclusions are drawn from given premises, general rules or theories (69) and is truth-preserving (70), i.e. "*deductive arguments can have formal justification*" (69). Its strength is that it is necessary while its weakness is that it isn't ampliative, i.e. it only rearranges the representations contained in the premises (70), and thus for creating new theory either abduction or induction have to be used, while deductive reasoning works well for testing existing theories(12).

An example of deduction, given by Niiniluoto (71) and Downard (70) follows:

Deduction proceeds from the rule and the case to the result (70):

- Rule – All the beans from this bag are white.
- Case – The beans are from this bag.
- Result – These beans are white.

2.2.2 INDUCTION

Induction, which has been called the "*scandal of philosophy*"(72), is a process of reasoning where a limited sample of a class is generalized to a conclusion about the class as a whole (70), i.e. induction generalizes from observations (69) or as said by Downard (70):

> (i)nduction is where we generalize from a number of cases of something is true, and infer that the same thing is true of the whole class. Or, where we find a certain thing to be true of a certain proportion of cases and infer that it is true of the same proportion of the whole class.

Induction has been attacked (see (73)(74)) for its necessity and validity – false conclusion can only by proven by deductive reasoning and thus pure inductive reasoning does not exist (75), but still scientists rely on it. The strength of inductive reasoning is that it is ampliative – extending what is already known and introducing new content into the reasoning – while its weakness is that it is prone to error (70) and as previously mentioned its necessity and validity.

According to Meheus (76), an important difference between deductive and inductive reasoning is that inductive logic is non-monotonic – increasing the size of knowledge base doesn't increase, but it can shrink, the set of conclusions (77), which means that inductive inferences are conditional while deductive interferences can never be "undone" by new information and the acceptance of the conclusions is only dependent on the acceptance of the premises (76) (77).

An example of induction, given by Niiniluoto (71) and Downard (70), tells that induction proceeds from the case and the result to the rule:

> Induction proceeds from the case and the results to the rule (70):
>
> - Case – The beans are from this bag.
> - Result – These beans are white.
> - Rule – All the beans from this bag are white.

2.2.3 ABDUCTION

Abductive reasoning is one of the most important forms of reasoning (78), and is like induction ampliative (70) with the difference that abduction "*tries to overcome the kind of incompleteness of a theory that regards describing, explaining, observations, whereas induction tries to overcome incompleteness in the sense of applicability of available descriptions to more phenomena*" (79). It is also said to be less formal than induction (69) and to be a weak mode of inference (80). It can be traced back to the scientist and philosopher Robert Grosseteste, or by the more later G.W. Leibniz, who was the first to notice the insufficiency of traditional modes of reasoning – either purely deductive (analytic) or purely inductive (synthetic) – while Charles Sanders Peirce probably is more well-known on the subject. (81)

Peirce argued that there is a third mode of inference, beside deduction and induction, which he called "hypothesis", "abduction", "presumption" and sometimes also "reduction"[4] (71) (82) (83). There exist several variations and definitions of abduction, mainly because Peirce's writings typically are fragmented (69) (84). Some of them are:

- *Abduction is an inference from a body of data to an explaining hypothesis.* (84)
- *Abduction is the process of finding the most likely explanations of a given set of manifestations, given some rules relating explanations and manifestations*. (78)

[4] Phyllis Chiasson questions this in (82) and suggest that the term "abduction" should be used "*for the reasoning method by which conditional purposes (hypotheses) are constructed*" and the term "retroduction" as the "*overarching method by which theories are engendered (by the interplay of abduction, deduction, and induction)*".

- Abduction is characterized as reasoning "*"from effect to cause", and as "the operation of adopting an explanatory hypothesis"*". (71)
- Abduction is "*the process of forming an explanatory hypothesis form an observation requiring explanation*". (67)
- Abduction is described as "*a capacity for 'guessing right', a, 'mysterious guessing power' underlying all scientific research*". (67)

While Michael Hoffmann in (85) discusses some of the problems with the definition of abduction – That abduction "*appears as the path from fact towards ideas and theories*" – Harry Frankfurt tries in (86), to clarify what Peirce really meant with abduction. According to Frankfurt "abductive interference *cannot* be the method by which we arrive at new ideas", instead abduction "leads us to adopt hypotheses as *working hypotheses*, as worthy of investigation and verification". In (87), Fox and Josephson states that the hypotheses given by the abductive process should not *only* be a hypothesis, but hopefully the "best" possible hypothesis, i.e. the most plausible and simplest hypothesis obtainable. This also concurs with the definition given by Liberatore and Schaerf in (78) where they state that abduction is the "*process of finding the most likely explanations of a given set of manifestations*…".

Abduction occurs in various domains: diagnosis, discovery, interpretation, every day problem solving, semiotics, linguistics, artificial intelligence, Logic Programming (87) (81).

An example of abduction, given by Niiniluoto (71) and Downard (70) follows:

Abduction is the inference of the case from the rule and result (70):

- Rule – All the beans from this bag are white.
- Result – These beans are white.
- Case – The beans are from this bag.

This tells us that, with the abductive reasoning, the hypothesis is that the beans are from the bag, which could be said to be a good guess and thus worth further investigation (70).

2.2.4 FALSIFIABILITY

Falsifiability is according to Popper "*[A] statement (a theory, a conjecture) has the status of belonging to the empirical sciences if and only if it is falsifiable*" and is the criterion for distinguishing science from non-science (88) – Falsifying our theories and beliefs is the only way knowledge can grow (89) – and also the foremost task of natural science (90).

Popper criticized verifiability as the criterion of demarcation and noted that a certain type of statement could be verified but not falsified, for example(88):

> "Unicorns exist" – This statement could be verified by finding a unicorn, but it could not be falsified and thus the failing of not finding a unicorn does not establish that none exists. Using verifiability as the criterion would have lead to the conclusion that "unicorn exists" as a part of science. (88)

Or the opposite; certain type of statement can be falsified but not verified, for example (88):

> "All swans are white" – Finding one black swan would falsify the statement, but it is not verifiable because even if all observed swans are white, one can't know whether an unobserved black swan exists somewhere (88). This is also given by Hume's challenge, which postulates that: "*We cannot exclude that, form tomorrow on, everything is entirely different from today's world*" (90). But this is not taken too seriously, because then all arguments about whether theories where true or false, would be idle.

Hansson however claims in (91) that most modern high-status research are either explorative – and thus no hypothesis could have been postulated – or that the hypotheses do not have the logical form "All x are y". In (92), Ruse argues that if something went wrong, there is no need for a scientist to throw out his (or her) theory, but on the contrary to continue the work and to try to invent an alternative hypothesis that would explain the falsifying data. In (93), Hines claims that "*There are no scientific theories from which all anomalies or falsifying observations have been eliminated*" and gives examples of work done by scientist like Galileo, Copernicus, Newton and Bohr.

Some even state that "*conception of the role of falsification in the use and development of theories is an oversimplication that is close to being a caricature of scientific procedure*" or that falsificationism is of very limited value (91), while

Ruse in (92), argues that falsifiability is one of a number of important factors for making genuine science.

This thesis has not included any falsification, mainly because the level of research is on a master thesis level and the statements I've made are neither general nor are they to be taken as the truth. Furthermore, the thesis is descriptive and explorative without any postulated hypothesis. The chapter has been included nevertheless, essentially to enlighten the reader into this important subject.

2.3 SYSTEMS THEORY

Systems theory is a widely known theory and has its roots from Paul Weiss, Ludwig von Bertalanffy and Rupert Riedl in the 1920s and was meant to be an integrative tool for all sciences (94) or put differently "*unification of science*" (95). Bertalanffy's most cited definition of system (95) is given in (96) as "*sets of elements standing interrelation among themselves and with [the] environment*" while Checkland (97), describes the concept of system as "*The central concept of 'system' embodies the idea of a set of elements connected together which form a whole, this showing properties which are properties of the whole, rather than properties of its component parts*".

According to Bertalanffy, systems theory is a "*worldview of holism and attacks over-specialization; it is not one of many specialized disciplines of science; its methodologies and methods are supposed to support holism*" (96), which means that systems theory uses holism to avoid reductionism on the assumption that the system does not have to equal the sum of its parts (96) (98) but rather that the 'whole is greater than the sum of its parts' – referred to as the system principle or holism (99) – or with a slightly different view said by Arbnor and Bjerke (40) "*The whole is more (or is less) than the sum of its parts*" along with "*not only the parts but also their relations are essential, as the latter will lead to plus or minus effects (synergy)*" (see Figure 7). The systems theory is supported by Mulej in (100) where he says that "*humankind is in crisis due to lack of holism and due to too much reductionism*", which is also shared by Mulej et al. in (101) where they state that "*holism is essential for humankind*" and that there is a bigger chance of success in complex areas with a more holistic view.

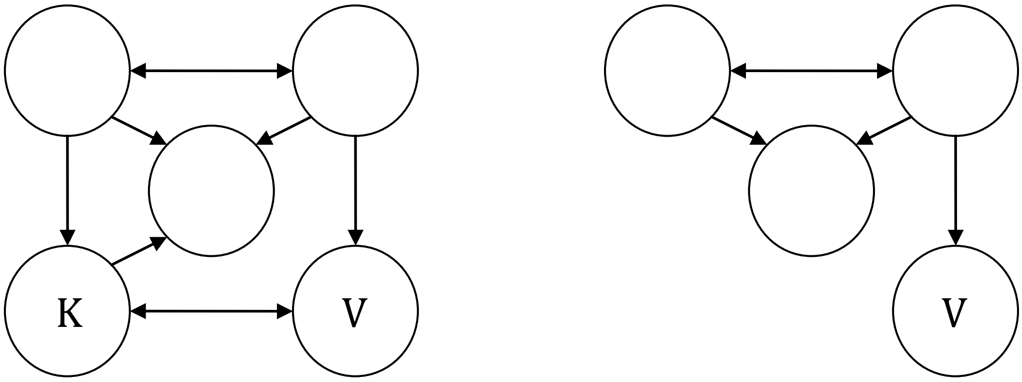


FIGURE 7 – SYNERGISTIC EFFECTS. SOURCE: (40)

2.3.1 SYSTEMS THEORY IN LOGISTICS

Systems approach is a big advantage in the analysis of logistics research and is often used as an approach to solve logistics problems (11) and thus it has a necessary role in logistics (12). Supply chain models have evolved over the years with more dimensions in the form of multiple facilities, multiple products, multiple transportation options or multiple echelons distribution network not only because of the need to improve the models' but also to take advantage of the benefits of utilizing supply chain holistically (102). Yildirim, Barut and Kemal (103) shares this view and argues that most companies are now searching for better ways to improve their supply chain based on the fact that "*strength of the chain depends on the weakest link*" and therefore "*the new trend in organizations is system approach*". According to Gomes and Mentzer(104) "*The importance of the total system approach to JIT research cannot be overstated" and "the total system approach is basic to logistics research*". They also present a list of observations given by Heskett, Glaskowsky and Ivie in (105) about logistics systems:

1. *A logistics system possesses multiple interrelated parts.*
2. *The performance of one part affects and is affected by that of others; consequently, to analyze any subcomponent in isolation constitutes a serious methodological error.*
3. *The alteration of certain subcomponents generates more change in system behavior than others.*
4. *Overall system performance is dependent upon "balance" achieved among the subcomponents.*
5. *The weakest member often dictates the upper bond of system performance.*
6. *Optimum system performance is often not dependent upon the optimal performance of each subcomponent, but requires balance and coordination among them.*

De Hayes and Taylor (106) claims that "*systems theory ...permits logistics considerations to extend across the artificial barriers of organized functions*" and that "*unfamiliarity with the general systems theory is no doubt a major reason why the logistics concept is often misapplied by business when it attempts to organize for it*". Moreover, Boykin and Martz (107) assert that "*General systems theory creates a powerful linkage between classical concepts of information systems and today's enterprise-wide perspective*" while authors such as Lambert, Stock and Ellram (108) claims that "*The systems approach is a critical concept in logistics*", which coincides with Lumsden (109) who claims that "*logistics it built upon a holistic view*" but also with Skjøtt-Larsen et al. (13) who says that "*The essential characteristics of the supply chain is its inter-organizational relationships*".

In 2004, Gammelgaard (11) stated that "*Today…the systems approach is still prevalent in logistics research*". Yildirim, Barut, and Kilic (103) claims that all cost reduction have come to a limit, customer service level and cost efficiency depend heavily on other companies' performance within the supply chain, and that competition is not between companies but between supply chains, and therefore "*the new trend in organizations is system approach*".

2.3.2 SYSTEM DESIGN

A system consists of three constituents (see Figure 8): unity, parts and relationship where the unity is illustrated as a large circle drawn around both parts and relationships – connections between the parts. Because the unity coexists as a separate constituent, the system is more than the sum of its parts and relationships (95). Each element's behavior has an effect on the behavior of the system and is interdependent to each other, meaning that a change in one element can have either positive or negative effects on other elements (99). This results in what is described by Skyttner in (99) "*A system cannot be understood by analysis of the parts because of their complex interactions*" hence the main concern is to studying the relationship and interaction between the elements and the system.

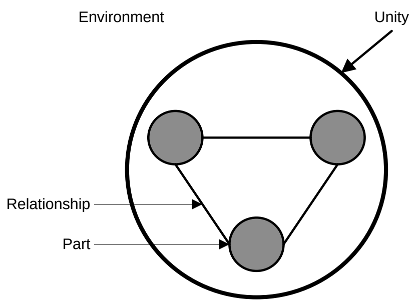


FIGURE 8 – PICTURE OF SYSTEM IN SYSTEM THEORY. SOURCE: (95)

2.3.3 DIFFERENT SYSTEM APPROACHES

There exists a broad variety of different systems approaches, for example: hard- and soft systems thinking; critical systems theory; world system theory; functionalism; autopoietic theory; sociocybernetics; complexity and chaos theory; living systems theory, and others (110).

The hard systems thinking is interested in 'how' (111) and use more mathematical models and simulation (97) and its view is described by Rychetnik (112) as "*systems are absolute*" and "*there is no difference between appearance and substance, and every rational observer has no doubt about it*" and thus is more appropriate in well-defined technical problems(113)(114). The soft systems thinking emphasizes the 'what' (111), involves interaction with people(97) and is less quantitative (110), is more concerned with defining "better" ways of doing things (115) and its view is described as "*systems are relative*" and it "*admits the possibility of a difference between appearance and substance*" while "*an observer may see and interpret reality…as one system, different from the system seen by other observer*" (112) making it more appropriate in messy, ill-structured problems (114) or as described by Checkland (113) "*fuzzy ill-defined situations involving human beings and cultural considerations*". Thus, the hard systems thinking have a more objective reality view where researcher can distinguish the whole system, while the reality view of soft systems thinking is more subjective (98)(96).

Furthermore, there is a distinction made between open and closed systems. An open system is always dependent on its environment because of the interaction and relationship to it, while a closed system is self-contained and has no interaction or relationship with its environment (99)(101). But to dichotomize all system as either opened or closed can create difficulties, because "*most social organizations and their subsystems are "partially open" and "partially closed"*", and thus one should view the distinction as a matter of degree (116).

The view throughout this thesis will be on system theory, especially the soft systems thinking because it the data gathered are mostly from interviews and it is thus subjective and qualitative. As just described the systems theory is very suitable in the analysis of logistics research and to solve logistics problems. Therefore the holistic view is especially evident through the analysis chapter, where an explanation on how the RFID system is implemented and what the autocorrecting effects are.

2.4 DATA COLLECTION

Collected data can either be quantitative or qualitative. Quantitative data exists in a range of magnitude and can therefore be measured for example: number, weight, color etc, hence it can be processed by statistical methods. Qualitative data are described in terms of quality and constitutes of words and description with informal or relative characteristics such as warmth and flavor and require analytical methods that are built on sorting and categorization.(43)(117)

2.4.1 PRIMARY DATA

Primary data is defined by Rabianski (118) as "*Information that researchers gather first hand*" and thus it is facts and information that is collected specifically for the immediate study.

2.4.1.1 INTERVIEW

There are three types of interviews: structured, semi-structured and open-ended. An interview is when an interviewer systematically questions an interviewee about a specific topic, while a questionnaire is more self-administrated by the respondent. (43)

In an open-ended interview, the questions can be asked in different order and formulations between different interviews and it permits the interviewee to provide additional and unexpected information spontaneously. The questions are typically broad without a fixed set of answers. There is a chance that the topic being discussed is caused by what the interviewee is most willing to talk about, e.g. astray, and therefore one should reserve time for every subject. It is an explorative method and therefore it is often used for pre-understanding. (43)

In the semi-structured interview, the questions are both structured and open-ended. For the structured questions, it is important that they are asked in the same order and in the same formulation for every interview, or else they could affect the interviewee in different ways, e.g. context effects. (43)

A structured interview is more or less an oral questionnaire, where the interviewer reads the pre-defined questions exactly as they appear. An advantage with a structured interview compared to a questionnaire is that the interviewee doesn't have to fill in the answers and thus reducing the chance of drop-offs and also that the interviewer have the opportunity to explain unclear or ambiguous questions. A disadvantage is that it takes a lot of time and may overlook vital information as questions are pre-defined in advance. It is often used when the interviewer wants to give a descriptive or explaining relationship between concepts, theory and relations or when objective and generalized results are needed. (43)

It is also important how you formulate the questions, e.g. it's easier to agree and answer yes, than doing the opposite – for example leading questions. The answers also depend on how the respondent interprets the questions, which may depend on sociodemographic factors such as class, sex and ethnicity. (119)

Another aspect is that different interviewers have different personalities, biases and perspectives, which may to some degree, influence – as described above or even by non-verbal signs – the data they collect, thus by using more than one interviewer these errors will hopefully compensate for each other resulting in a more accurate result. (37)

2.4.1.2 THE IMPLEMENTATION OF THE INTERVIEWS

The interviewees were chosen based on knowledge and engagement in the RFID project. Therefore Mikael Erlandsson became an obvious selection as well as Olle Hydbom from RFID Constructors.

Mikael Erlandsson started at PAGO within the process engineering, and later moved to project management. He is today the manager of injection molding but and is also the person responsible for the RFID project.

Olle Hydbom has been working at RFID Constructors for 1.5 years and is responsible for the technical aspects. He has been working with RFID since 2004 in different forms e.g. been involved with standardization. He has thus a good understanding about the technology and has been involved with the RFID project at Plastal since autumn 2008.

Three interviews were conducted, two with Erlandsson and one with Hydbom. They were all of semi-structured type, because to get a structured interview that isn't as limited as a closed interview. To improve the reliability of the results from the interviews, every interview were recorded and transcribed.

Furthermore mail contact was established since the start of the project. There more specific questions that didn't need as much explanation were asked and it was also used for requests of data and material.

2.4.2 SECONDARY DATA

Secondary data is defined by Rabianski (118) as "*Information from secondary sources, i.e., not directly compiled by the analyst; may include published or unpublished work based on research that relies on primary sources of any material other than primary sources used to prepare a written work*" and thus it is gathered facts and information that are not for the immediate study but for some other purpose but can on the other hand be useful in the analysis. Secondary data can be divided in to two different groups: primary sources – the original source in which the data was collected and organized; secondary sources – any other source that made some modification to the data, for example summarized it. (118)

According to Rabianski (118), there exist four categories of potential errors in secondary data (some also apply to primary data):

- Sampling error – Sample does not reflect the population.
  Non-sampling error
    - Frame error – Sample omits certain groups.
    - Measurement error (response error) – False or misinterpret data.
    - Sequence bias – The order of the questions in an interview or questionnaire induces an idea or opinion to the interviewee.
    - Interview bias – The influence an interviewer have on the respondent.
    - Non-response bias – Some respondents are unwilling to participate or answer some questions.
- Errors that invalidate the data
    - Manipulation – The data could have been manipulated or reorganized to meet a certain goal.
    - Contamination by ineptness, confusion or carelessness – The process of the data collection, organizing, distribution was not specified or that the collectors' didn't care about quality and validity.
    - Concept error – The difference between the concept to be measured and the indicator.
- Errors that require data reformulation
    - Changing circumstances – A non evident change that affects the data.
    - Inappropriate transformations – The data have been transformed to fit a certain purpose that may not suit the current research.
    - Inappropriate temporal extrapolations – Data that have been either interpolated or extrapolated.

    - Inappropriate temporal recognition – The time lag between the primary data is collected and published.
- Errors that reduce reliability
    - Clerical errors – Common typing mistakes like misplaced decimal, added zero.
    - Error due to changes in collection procedures – A change in the collection method or the conditions may generate different data.
    - Error due to corrected data – Errors (often clerical) that may appear in previous versions, may be corrected in the latest version.

2.4.2.1 ARCHIVAL ANALYSIS

Archival analysis refers to the use of documents that have been made for a different purpose then for the research, e.g. when you use a company's financial reports to study its growth (43). Even though many prefer collecting their own data, there are some advantages with using archival data, for instance savings in: time, money and effort along with methodological advantages such as that "*the information is generally non-reactive to the specific purpose of the present evaluation"* or that archival data often are available for a variety of populations or for an long time period. (120)

But there are also some concerns with using archival data (120), such as:

- Appropriateness
    - Purpose of Data Collection – When the underlying principle for the collection of data is different to the current evaluation.
    - Quantity Oriented Data Bases – A common problem where data collected, often by government agencies, emphasizes document of quantity of effort, e.g. number and kinds of persons served.
    - Data Format – The form of the data collected or stored may be aggregated and thus not suitable for the evaluation.
- Accuracy
    - Reliability – The user has no control over the reliability of the archival data
    - Validity – Differing perception of the meaning of the data along with the lack of control the user has over the system.
    - Time Span – Reliability and validity of archival data is affected by time – the sooner the better.
    - Significance – Attaching more significance to the data than is justified.
    - Understanding the program.

- Accessibility
    - Political Barriers – Confidentiality of data.
    - Hardware and Software Barriers – Incompatibility and incapability of varying systems used to collect and analyze the data.

All information gathered from reading previously made master thesis conducted at Plastal was first sent to PAGO for verification before using it in this thesis. The verification process was proven to be very necessary and a proof of this is that one of the thesis stated that PAGO had been discussing implementing a new technology, e.g. Bluetooth senders infused into the cases to enable traceability and real time reporting of the production. But according to PAGO they have only been focusing on RFID technology.

2.5 METHOD EVALUATION AND SOURCES OF ERROR

Reliability and validity is said by Gabrenya (121) to "*comprise the dual "holy grail" of research*" and can greatly improve the scientific rigor and quality of a research. They are thus crucial for meaningful research, and without them, the research becomes nonsense.

2.5.1 VALIDITY

Validity means you measure what you intend to measure and it is concerned with the relationship between the object you aim to measure and the object you really are measuring (43), i.e. "*validity is the degree to which what we are recording or measuring is what we set out to record or measure*" (37). Validity can be divided into two subgroups (for more classifications see (7), (9)):

Internal validity – The degree to which methods have been measuring what was intended to be measured (37) or as Churchill and Iacobucci describes it in (39): "*Internal validity refers to our ability to attribute the effect that was observed to the experimental variable and not on other factors*". Mentzer and Kahn (7) name some threats to internal validity such as:

- History effects – External events happening over time.
- Maturation effects – Respondents becoming more experienced.
- Instrumentation effects – Method of measurement changes over time.
- Selection effects – How respondents are chosen.

External validity – The degree to which results from a sample can be generalized to the general population (37) or put differently: "*External validity focus on the problems of collecting data that demonstrate that the change in the criterion* *variable observed in the experiment as a result of changes in the predictor variables can be expected to occur in other situations*" (39) and can't according to Mentzer and Kahn (7) be established without replicated results in different settings.

A multi-method approach called methodological triangulation, i.e. different investigative methods are applied to one research object, can enhance the validity in a study (43). Another way to improve validity is by phenomenological validation which means that the researcher states all of the influences which may have affected their interpretation of the data, for example: the researcher's social class, gender, prior personal experiences etc. (37).

As described before, the purpose of this thesis isn't to make an external generalization of the results but to evaluate a specific case. In other words the external validity is not a big concern in this thesis.

2.5.2 RELIABILITY

Reliability is defined as "*measure's ability to repeatedly yield similar results across similar situations*" (7). According to Höst, Regnell, and Runeson (43) reliability can be improved by lengthening the analysis, conducting the measurements more thoroughly and exact or for an interview: to present the data in a written form for the interviewee and thus hopefully minimizing the likelihood of misinterpretation. Mentzer and Kahn gives in (7) three approaches for evaluating reliability:

- Test-retest – *A correlation coefficient is calculated on the data obtained from the same measure given at different times.*
- Equivalent forms method – *Correlation coefficient is calculated on the data obtained from two comparable forms of the same measure.*
- Method of internal consistency – *Includes the split-half method and/or the calculation of coefficient alpha.*

2.5.3 REPRESENTATIVENESS

"Representativeness means your conclusions are general" (43) and strongly depends on the selection. While a survey or an experiment can only, in strict sense, be generalized to the population where the selection was made, a case study or an action research can't be generalized. But if the circumstances are similar to that of the study, there is a higher probability that the observed object will behave in similar way in the new situation. Representativeness can be improved by either minimizing the number of drop-offs or ensuring that it doesn't affect one type of subjects, or by giving a good and detailed description of the examined situation. (43)

2.6 SUMMARY

To summarize it all, I've chosen to conduct a case study and an experimental research along with a descriptive research (see Figure 9). The systems theory has been used as a framework for analyzing and describing the data. All of these methods have then been used together for triangulation.

The most common type of reasoning made in this thesis is from induction, but deduction and abduction are still used.

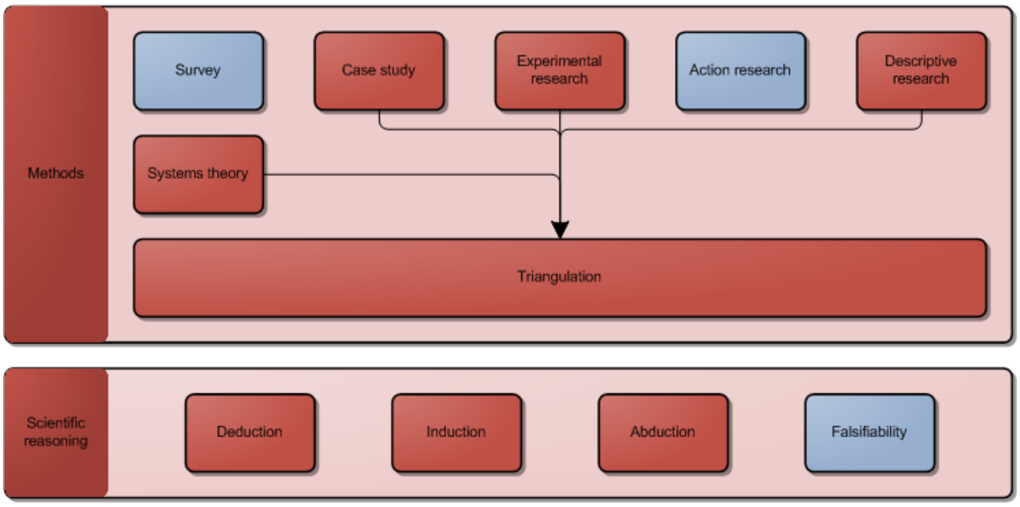


FIGURE 9 – SELECTION OF METHODOLOGY.

3 RFID

In this chapter, the RFID frame of reference will be presented. The chapter is divided into eight parts: introduction, technical history, tags, scanners and readers, antennas, host, RFID adoption phases and challenges to RFID adoption. It should also be noted that RFID technology has previously been discussed in the introduction (see chapter 1.2).

The world today is dominated by global forces as we live in a new globalized world economy (122). Global competition, rapid response to customer needs at low costs and rapid technology deployments are just a few of those forces(13). As markets grew and became more diverse, a need emerged for a mechanized system that would simplify the process of managing complex inventories (123). Barcodes – which were created to solve the problem of managing large complex inventories (123) – didn't suffice, but it is still the most common type of Auto-id technology used today (124).

The successor of barcodes is said to be RFID, Radio Frequency Identifier (125)(126). RFID system contains, as with many other types of automatic identification systems, a set of interrelated components (124). Such components are tags (passive, active, semi-active or semi-passive), antennas and readers forming an RFID system (124). More detailed explanation will be given later in this thesis.

Problems with barcode systems today are: dirt, intense sunlight, scratches in the barcode (123), temperature and hazardous contamination (24). The main differences between barcode and RFID technology is that RFID technology offers extended data capacity (identification on item-level) and extended data capture possibilities such as collected data without line of sight (127). The technical differences between barcode and RFID are given in Table 3.

TABLE 3 – TECHNICAL DIFFERENCES BETWEEN BARCODE AND RFID. SOURCE:(128)

System	Barcode	RFID
Data Transmission	Optical	Electromagnetic
Typical Data Volume	1 – 100 Bytes	128 – 8K Bytes
Data Modification	Not possible	Possible
Position of Data Carrier for Read/Write	Visual contact	Non line of sight possible
Reading Distance	Several meters (line of sight)	From centimeters to meters (depending on the frequency and tags)
Access Security	Little	High
Environmental Susceptibility	Dirt	Very small
Anticollision	Not possible	Possible

3.1 TECHNICAL HISTORY

RFID is based on an array of technological innovations from the early 1940s and has its roots in the early military identification system (123). It was first used in the World War II for an application called "Identify Friend or Foe" (IFF) and was the first active RFID system (125) (124) and is said to be the technological successor of RADAR (123) (124). One of the first papers written about the potentials of RFID is Harry Stockman's "*Communication by Means of Reflected Power*", where he discusses the use of reflected radio signals as a way to identify a remote object. During the 1960s a couple of companies (Knogo, Sensormatic and Checkpoint) were founded with the intent of creating an electronic article surveillance (EAS) product for preventing shoplifting (129) (123). They initially created a 1-bit tag which made it possible to identify the presence of shoplifters as they walked through a protected portal, sounding an alarm that would alert the store security (123). The EAS technology was the first widespread use of RFID technology and is still used in retail packaging today at retailers (124).

In the early 1970s Mario Cardullo and his team at ComServe began designing and building the first actual RFID tag, based on the Mario Cardullo's patent –The first RFID-like tag with dynamic memory, which got approved by the U.S. Patent Office in 1973. The first commercial application for electronic identification technology was vehicle tracking and was first used as an electronic automated toll collection application. Radio detection applications for livestock tracking, vehicle movement monitoring and supply chain management soon followed. During the 1980s and the early 1990s the main drivers for continued activity was the ability to track vehicles and containers (123), but it was also widely used for cattle identification in Europe (125). Seven highway agencies in the United

States formed the cooperative E-Z Pass Interagency Group in 1990, which now have 24 agencies across 13 states (130).

In the beginning of 2000s RFID became a "hype" technology, and were seen as a successor of optical barcodes. But a time of disillusion soon followed, because of the immaturity of the technology as it was not applicable for such wide-scale application. Today, RFID is a fast growing technology, but the "hype" seems to be over. (125).

3.2 TAGS

Tags, also called transponders (123) (127) are both utilized synonymously. But as tags emphasis on the use as a label and the application for item identification and transponder emphasis on the communication process (125), the term tag will be used in this thesis.

Tags are the devices affixed to the items or material that is to be tracked or identified within the supply chain by the RFID system (123) (124) and come in all sorts of shapes and sizes, where the most common construction format is the so-called disk (coin) – a tag in a round (ABS) injection molded housing (127).

The tag contains three basic parts (124) (see Figure 10): electronic integrated circuit – to store some digital ID information (131); a miniature antenna – to transmit the ID to the rest of the RFID system which is the primary function of the tag; a substrate – to hold the integrated circuit and the antenna together (124).

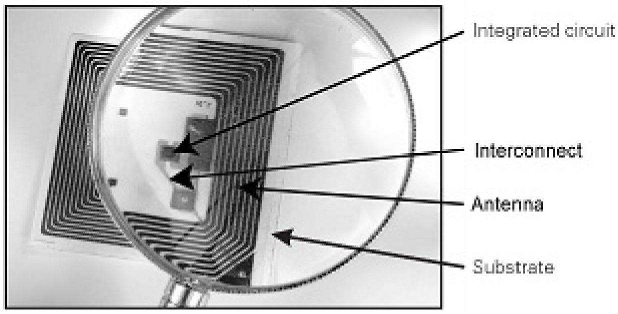


FIGURE 10 – COMPONENTS OF A RFID TAG. SOURCE: (132)

RFID can be mounted in a lot of different ways: as stickers – Also called adhesive labels and is the most common mounting form for RFID tags; card transponders; glass cylinders – Used in i.e. animal identification (127) (124); plastic packaged transponders – Developed for applications involving particularly high mechanical demands (127); robust industrial packaging (125).

Tags transmit over a spectrum of frequencies, from short range low frequency to long-range ultra high frequency and microwave frequencies (131) (see Table 4). According to Wu, Nystrom, Lin, and Yu the biggest potential for passive RFID tags lies within the ultra high frequency (133).

TABLE 4 – FREQUENCY BAND.

Frequency Band	Description	Range	Common Applications
135 KHz	Low frequency	< 0.33 m	• Vehicle identification • Animal ID
13.56 MHz	High frequency (HF)	Near contact ~ 1 m	• Electronic ticketing • Fare collection • Contactless payment • Access control • Sample tracking
860 – 960 MHz	Ultra high frequency (UHF)	1 – 3 m	• Compliance tagging and other case and pallet ID • Returnable container tracking • Work-in-process tracking • Asset management • Baggage tacking
2.45 GHz	Microwave	1 m	• Long-rage identification with active tags • Airline baggage

Tags can be: read-only – The stored data can be read but not changed; read/write – The stored data can be altered or rewritten; combination – Some of the stored data is read-only while the rest is read/write (24). The most accepted RFID protocol today is the EPC C1G2 [EPC class 1 generation 2](134)(135), which support read/write features (136).

3.2.1 ACTIVE

Active tags (see Figure 11), also called radio frequency beacons (131), are the size of a small coin but are both significantly larger and more expensive than their passive counterparts because they contain an onboard power source with an additional circuitry (124). The battery powers both the tag's internal circuitry and the onboard antenna, which results in that the range of active tags are generally far more superior to that of passive tags – The range of a transmission for an active tag[5] is tens (131)(137) to even hundreds (124) of meters whereas passive tags have a transmission range up to just a meter.

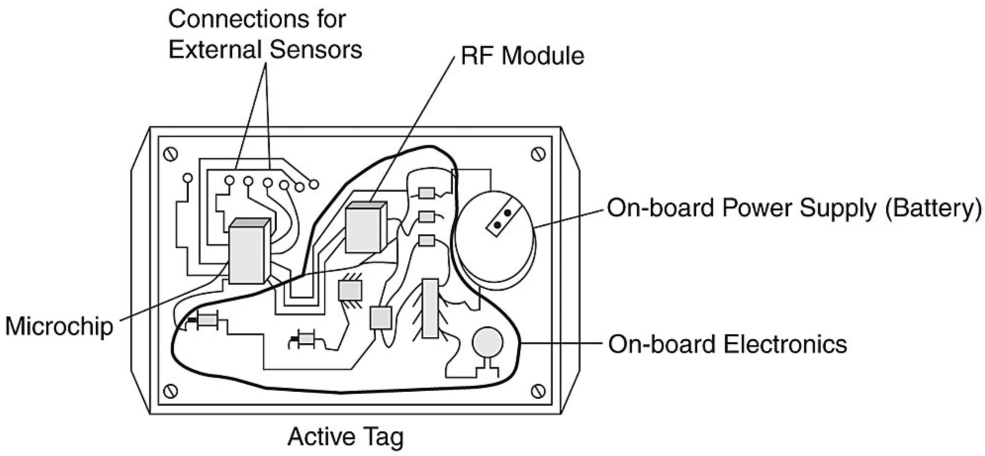


FIGURE 11 – COMPONENTS OF AN ACTIVE TAG. SOURCE: (138)

Many active tag batteries resemble normal commercial batteries, but they also come in many other different shapes and sizes and they are likely to function on a higher voltage – 3.6V and 1.5V for the smaller cells (used in many defense-related RFID tags). Because of the higher voltage the active tag batteries may also require different battery chemistry then usual commercial battery, which utilize alkaline, nickel-cadmium or nickel metal hydride whereas the RFID battery are likely to be based on a more costly advanced battery technologies such as lithium chemistry. (124)

A lot of active tags have plastic housing and thus cannot simply be adhered to high-volume inventory as with a film or Mylar-based passive tag, so specific consideration must be made when affixing the active tag to the inventory or pallet being tracked (124). Because of this and the fact that the active tags are

[5] According to Shepard in (123), the reading range can be as much as a dozen meters in some cases but that is just a fraction of what is claimed in (131) (137) (124). Without going too deep in this matter, we assume that the range is at least tens of meters.

larger and more expensive than the passive counterparts they are more suitable for a different set of application, often where they will be deployed in smaller numbers (123); It's very unlikely that active tags will ever be used at the individual consumer product level (124) – Shepard (123) states that the choice between an active vs. a passive tag is purely dependent upon the application for which it will be used. For example, active tags are often used when the tag must be at a great distance from the reader (automated toll-paying application, E-Z Pass, as previously mentioned), tracking large items (pallets, containers, etc.), trucking or shipping container identification application or certain supply chain implementations. (123)

3.2.2 PASSIVE

Passive tags' chips are about the size of a grain of rice (139) (131) (140) and the tags are much smaller in both size and memory (131) than active tags and are also more popular (24). They do not contain any power source, and are thus only active when they come within the range of a reader's signal – The RFID system antenna powers the tag through electromagnetic power. Since passive tags do not contain their own power source and have less memory the design can be simpler and it is cheaper to manufacture (131) (124), which makes them ideal in situations where large numbers of them are required, for example: in fuel-dispensing application, bookstore/library access-control application (123) – The passive tag have to be affixed in close proximity to the reader in order to work.

Passive tags consist of two main components: A microchip and an antenna (see Figure 12) and it is therefore, as mentioned before, very simple in its construction. Because it has no moving parts it is generally resistant to harsh environmental conditions. Some passive tags can even withstand corrosive chemicals (acid) or temperatures to over 200°C. (138)

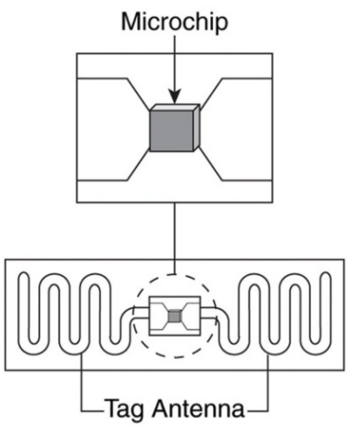


FIGURE 12 – COMPONENTS OF A PASSIVE TAG. SOURCE: (138)

While active tags are dependent on the number of times the tag is activated, passive tags are not and can therefore have an unlimited shelf life (124)(141). Passive tags have therefore been the focus of most government and commercial RFID mandates and many experts believe that passive tags are the future of RFID (124).

The price of the passive RFID tag have steadily gone down during the last years (see Figure 13 and Figure 14 or (142) for another prediction model) as a result of increased scales of production, reduced silicon prices, more economic production methods etc. When the price reaches five cent[6] the total demand will be explosively larger (143), significant acceptance will be achieved (124). According to Dinning and Schuster (137), the passive tags are feasible for widespread application, especially high volume consumer goods manufacturing with high selling prices like razor blades, batteries and perfume. When the passive tag reaches one cent the demand for passive RFID tags will be equal that for barcodes (143).

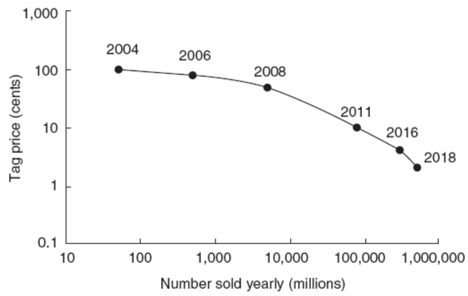


FIGURE 13 – TAG'S PRICE PREDICTION. SOURCE (144), REMADE BY (140)

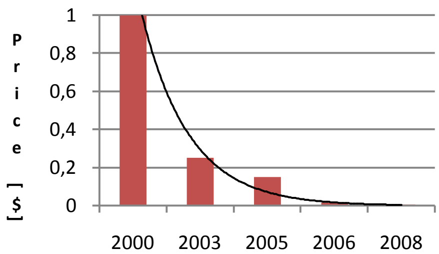


FIGURE 14 – THE RFID TAG PRICES CHANGE. SOURCE: (25), REMADE (ADDED AN EXPONENTIAL CURVE)

3.2.3 SEMI-ACTIVE / SEMI-PASSIVE

In contrast to passive tags, semi-active tags (see Figure 15) and semi-passive tags have an onboard power source, and may also have an onboard sensor. This makes these kinds of tags more expensive than passive tags, but they are on the other hand cheaper than active tags. They fall in the middle between passive and active tags compared to both price and capabilities. (124)

There seems to be some confusion in the industry about the difference between semi-active and semi-passive tags (and also active and passive)(145). The

[6] At that point Jones and Chung (124) believe that RFID tags may be placed on many consumables while Santana (167) claim that it has to be even lower than five cents for tagging products at item level.

definition that will be used in this thesis for semi-active and semi-passive tags are based on the definition of passive and active tags, whereas (148):

- An active tag uses a battery to power or boost the signal.
- A passive tag relies entirely on the energy from the signal.

Resulting in:

- A semi-active tag uses a battery to power or boost the signal, but respond only when they are within the range of a reader's signal.
- A semi-passive tag relies entirely on the energy from the signal, but may use the onboard power for sourcing onboard sensors etc.

The difference is thus on whether the power source powers the signal or not.

The onboard power source has two purposes (124):

- To provide continuous power for the sensors.
- To allow the intelligence contained in the chip to function without harvesting energy.

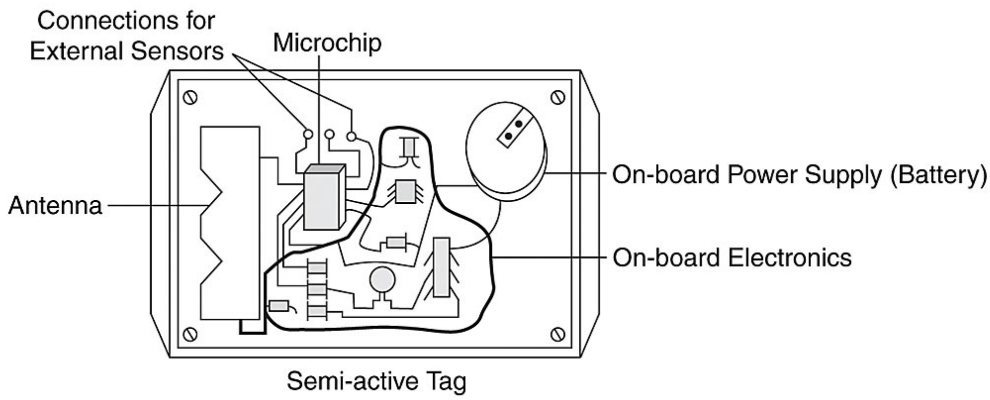


FIGURE 15 – COMPONENTS OF A SEMI-ACTIVE TAG. SOURCE: (138)

Normally semi-active tags exist in a sleep mode to conserve battery power – this ability greatly lengthens the operational life of a semi-active tag and enables the tag to be operational for several years – so the actual lifetime of the battery is dependent on the number of times the tag is activated. The tag is woken up or activated upon entering an RFID system interrogation zone where it provides data to the RFID system as requested. This means that the RFID engineer have to design the RFID system so the semi-active tags that are stored within an interrogation zone will not be continuously activated until their batteries are exhausted. (124)

Because the chip is powered by the onboard power source, semi-active tags are suitable when there is a need to take readings even in the absence of a reader, or in an unfriendly environment or if the read range needs to be increased. They are also suitable when a large number of items needs to be monitored (with sensors), or when the tags cannot be reused. Semi-active tags are currently being tried in the cold chain, where items such as frozen food or drugs must be kept below a given temperature. (140)

3.3 SCANNERS AND READERS

Readers are radio frequency transmitters and receivers that have two tasks (128):

- To communicate with the tags through an attached antenna.
- The pass the signal the reader captures to a computer for processing.

It can therefore be seen as a bridge between the host and the emitting antenna. The reader is controlled by a microprocessor, or digital signal processor that handles all the communication with the tags. In a passive tag system, the reader sends out a wake-up beacon and the necessary energy for the passive tag to operate, while in an active system, the onboard power supply on the tag is used to boost the signal strength and thus the reading distance. A reader can either be affixed in a stationary position, or integrated into a mobile computer such as a barcode scanner, or embedded into electronic equipment such as a label printer. (146)

3.4 ANTENNAS

The largest part of the tag is the antenna, which is connected to the tag interconnect (see Figure 10). The antenna is usually made of thin metal strips of either copper, aluminum or silver with the shape of either a spiral coil, a single dipole, dual dipoles (one perpendicular to other), or as a folded dipole. It is the geometry (both size and design) of the antenna that determines its operating frequency and thus the design of the antennas is based upon which frequency the tag is going to operate on (132). Large antennas operate on low frequencies, while small antennas operate on high frequencies (128). The actual size of the antenna can and is typically reduced with creative antenna design (132).

Depending on the tag, the antenna has slightly different functions when receiving a signal from the interrogator. For an active tag, it transmits the signal, while for both semi-passive and passive tag, it reflects it. And for passive tags, the antenna also supplies the tag with power collected from the radio waves.(132)

There are three kinds of methods for manufacturing antennas: copper etching, foil stamping and screen printing. The fastest and least expensive of them all is screen printing, but the down side is that antennas created using this method are also less efficient than those created by one of the other methods. (132)

3.5 HOST

Host, also called software system, are both hardware and software components that is separate from the RFID hardware (reader, tag, and antenna) and is composed of the following four components (138) (see Figure 15):

- Edge interface / system.
- Middleware.
- Enterprise back-end interface.
- Enterprise back-end.

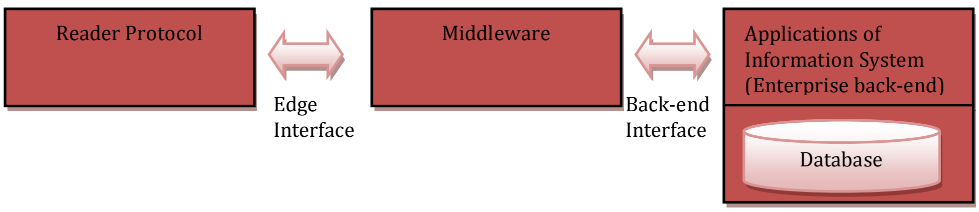


FIGURE 16 – LOGICAL COMPONENTS OF RFID. SOURCE: (147)

3.5.1 EDGE INTERFACE / SYSTEM

The main task of the edge interface is establish communication and retrieve data from the readers, but also to control the readers' behavior and to use the readers to activate the associated external actuators[7] and annunciators[8]. Furthermore it can also be used for example filtering out duplicate reads from different readers or providing settings for event-based triggers for activating an annuciator or actuator. (138)

3.5.2 MIDDLEWARE

The middleware component is the most complex and important component of the host and software system and is defined as "*everything that lies between the*

[7] "*An actuator is a mechanical device for controlling or moving objects. Examples of actuators include a programmable logical controller (PLC), robot arm, mechanical arm for an access gate, and so on.*" (138)
[8] "*An annunciator is an electronic signal or indicator. Examples of annunicators include audible alarms, strobes, light stacks, and so on.*" (138)

edge interface and the enterprise back-end interface" (138). Often, a more general description is given, for example: "*RFID middleware controls and manages the readers, and performs filtering, aggregation, counting of tag data between the edge interface and the enterprise back-end interface*" (147). The component provides for example (138):

- Data sharing both inside and outside of an enterprise.
- Data management for the RFID system.
- Compatibility to a wide range of other systems.

3.5.3 ENTERPRISE BACK-END INTERFACE

This interface is responsible for integrating the middleware component with the enterprise back-end component and thus this is the place where the implementation of the business process integration is located. Enterprise scale system such as Enterprise Resource Planning (ERP), or Warehouse Management Systems (WMS) usually have an enterprise-scale integration interface built in. (138)

3.5.4 ENTERPRISE BACK-END

The enterprise back-end component acts as the business process engine for the entire enterprise and as the data repository, and thus it includes the entire suite of applications and IT systems of the enterprise. (138)

3.6 RFID ADOPTION PHASES

The adoption phase for RFID can be divided into three phases according to Attaran (24):

- Elementary phase (or slap and ship) – This phase includes the learning about RFID technology and the startup process. In this phase the tags are normally only applied to a small number of products. The "slap and ship" refers to RFID tags that are applied to pallets or products right before the shipment to the customer without using the information in their own system.
- Intermediate phase – In this phase the company applies the RFID tag during production and uses the technology for data collection. RFID is also used for receiving goods and processing shipments. The collected information is then shared and used for improving the company's own supply chain processes.

- Final phase – In this phase, RFID is enabled in all facilities and the companies uses the information to better understand customer demand and to make better supply chain decisions and thus trying to optimize the profit across the supply chain.

Another implementation model for RFID technology is given by Hellström in (148), where he have made a modified version of Cooper and Zmud's model of the information technology implementation process (149). This model is divided into six stages. A brief description is given in Table 5 (see (148) for further details).

TABLE 5 – MODEL OF THE RFID IMPLEMENTATION PROCESS. SOURCE: (148)

Stage	Activity description
Initiation	• Problem identification – Identify the problem and define the objective. • Concept development and system design – Develop different solutions.
Adoption	• Cost-benefit analysis – Economically assess the system design and the different solutions made from the concept development. • RFID trial – Test the technology in its working environment.
Adaptation	• Choose system integrator – Choose system integrator based upon software, hardware and cost requirements. • Installation – Software, hardware are installed along with changing the affected business process and training the employees.
Acceptance	• Education and training – Inform, train and discuss the use and usefulness of the system to the employees and end-users. • Communication – Inform the involved organizations about the use and implication of the system.
Routinization	• Improvements – Improve the level of automation and make changes to accommodate employee's needs. • Process the collected data – Analyze and interpret the accumulated data.
Infusion	• Expand the implementation – Use the system for other applications. • Transfer the technology – Use the knowledge attained.

3.7 CHALLENGES TO RFID ADOPTION

While the above mention adoption of RFID may seem to be a straight forward and an easy task, it isn't. There are several challenges that may hinder the adoption. In (133) Wu et al. divides the major challenges for RFID adoption into seven different categories: technology challenges, standard challenges, patent challenges, cost challenges, infrastructure challenges, return on investment challenges and barcode to RFID migration challenges.

3.7.1 TECHNOLOGY CHALLENGES

Material effects on antenna power pattern

The material to which the RFID tag is attached to, have different effects on the radio waves. Some materials like liquid refract large portions of the radio energy sent by UHF radio waves; while materials like metal reflect large portions of the radio energy. For the receiving antenna both refraction and reflection will result in signal strength degradation and interference. Reflection from multiple sources may even cause multi-path interference to the antenna.

Tag antenna orientation affects radio wave reception

The relative position and orientation between the tag antenna and the reader antenna can affect the power pattern and thus the readability. An example of this is if the two antennas are perpendicular to each other, the tags antenna cannot receive the reader's radio signal. Another problem is if there is an obstacle between the two antennas, because it will attenuate the signal and therefore reduce the reading range. To solve this issue, several readers may be installed all with different orientations, along with the RFID tags that have random antenna orientation. Even if a tag's antenna is perpendicular to one of the reader's antenna, another antenna will not be.

Collision caused by simultaneous radio transmission

If the system is designed to read the tags one by one, the change of high readability is high. But this is a time-consuming matter, and in UHF RFID applications, hundreds of tags may respond simultaneously to a reader's signal causing collision interference. To be able to communicate with multiple tags at the same time, some collision-resolution protocols must be used. There are three major anti-collision procedures which all demands some additional communication sessions, and for that reason the reading speed will also be slower. Binary search is an alternative method that can prevent signal collisions.

3.7.2 STANDARD CHALLENGES

A standard will ensure interoperability among different vendors and across national boundaries, and the cost will be reduced because of higher demands due to compatibility and exchangeability. And the RFID market will grow when there is an accepted international RFID standard. For more examples see (128).

Lack of unified RFID standard
There are two organizations that are developing an international standard: EPCglobal and International Standard Organization (ISO). These two standards are not compatible with each other, and have thus caused many companies to hesitate in adopting RFID.

Lack of consistent UHF spectrum allocation for RFID
There is no unified international regulation on radio spectrum. Therefore, while USA and Canada allocate 902 – 928 MHz for UHF RFID, Europe uses 865.6 – 867.6 MHz, and Japan uses 953 – 954 MHz for RFID. This makes the usage of RFID in a global supply chain very complex, with the addition that power regulations and certification procedures are also incompatible between countries.

3.7.3 PATENT CHALLENGES

The purpose of developing international standards is to *"leverage existing IP (Intellectual Property) and technologies from all vendors in the industry*" (133). Under the EPCglobal's IP policy, there are two ways for vendors to make their IP available to others: royalty-free basis or on a reasonable and non-discriminatory royalty-bearing basis.

3.7.4 COST CHALLENGES

According to Bhattacharya, Chu and Mullen (27) the most dominate challenge for the manufacturing sector when implementing RFID is the high costs (45%) followed by technical issues (21%).

Manufacturing costs
A main reason that RFID haven't been explosively adopted is because of the high cost of the RFID tag. The two major cost elements of the tag are the chip cost, which is related to the die size and fabrication yield, and the assembly cost.

Customization costs
As previously stated, installing an RFID system is not a simple task. An RFID system must be customized for its specific working environment and application purpose, for example: The right spectrum must be chosen, the tag antenna design must be based on the material the tags are attached to and multiple readers must be installed at proper locations and orientations.

3.7.5 INFRASTRUCTURE CHALLENGES

Multiple companies can benefit from an adoption of a RFID system along an entire supply chain if an entire RFID infrastructure can be established. This will increase the management efficiency in the entire chain because the visibility at every stage in the flow.

3.7.6 RETURN ON INVESTMENT (ROI) CHALLENGES

The expected benefits of an RFID adoption can be divided into two parts:

- Cost reduction – labor cost reduction, inventory cost reduction, process automation, efficiency improvements etc.
- Value creation – increase in revenue, increase in customer satisfaction due to responsiveness, anti-counterfeiting etc.

But because no comprehensive RFID infrastructure exists, it is very difficult to calculate an accurate return on investment.

3.7.7 BARCODE TO RFID MIGRATION CHALLENGES

While RFID is still being developed and integrated into new markets, barcodes systems are deeply-rooted and will not be replaced any time soon. Therefore, both barcodes and RFID systems have to coexist for a long time. This increases the demands on system capabilities and compatibilities along with increased maintenance and operation costs.

4 CASE DESCRIPTION

In this chapter the empirical data collected during the thesis will be presented. The chapter is divided into seven parts: Plastal, production processes, implemented RFID system, implementation process, potential RFID improvements, implementation issues and fixes and RFID visions.

4.1 PLASTAL

Plastal is a supplier of injection-molded and surface-treated plastic to the automotive industry. It manufactures and surface-treat both interior and exterior plastic components, mainly bumper systems (see Figure 17).

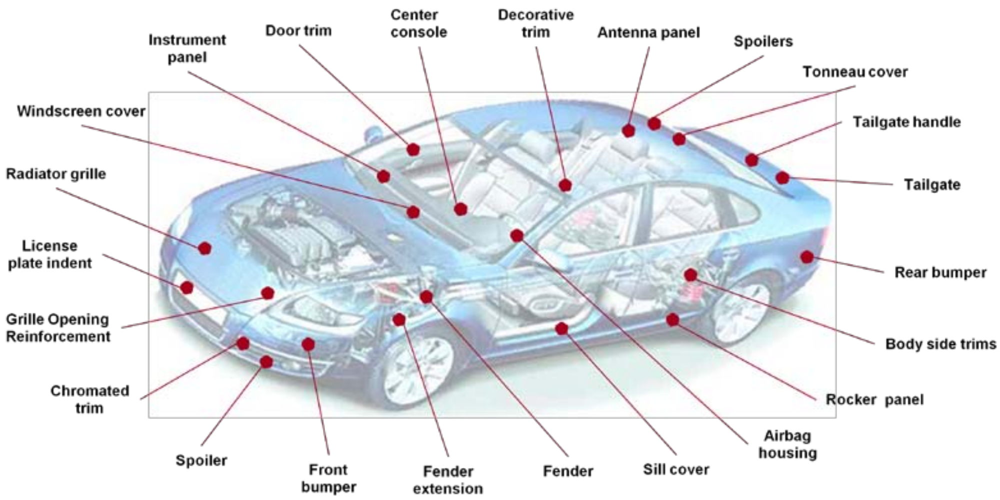


FIGURE 17 – PRODUCT EXAMPLES FOR PASSANGER CARS.

Plastal was founded in 1934 in Trelleborg, Sweden and has since then grown to be one of the 100 largest automotive suppliers in the world, and was in 2007 among the 50 largest in Europe with 30 plants spread over ten countries (see Figure 18). Plastal is mostly located in Europe where Spain – Valencia is one of the best running factories with the lowest scrap rate – and Germany have the largest plants. In the northern region, Plastal is located in: Gothenburg, which is biggest according to sales, and Uddevalla, Simrishamn, and also Raufors, who produce spare parts for the aftermarket.

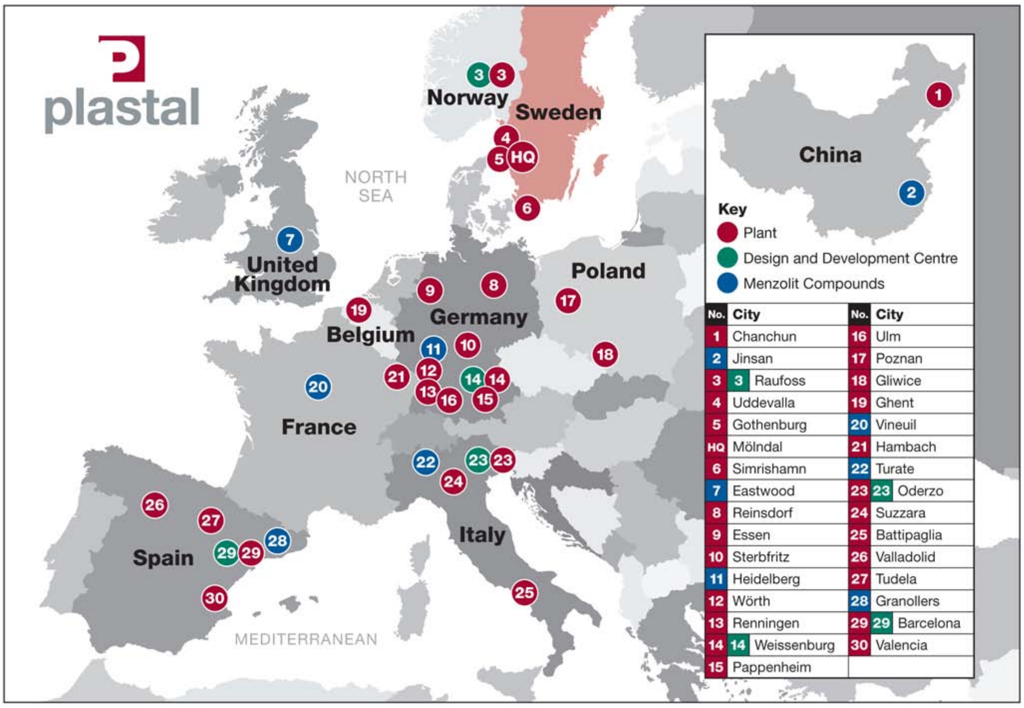


FIGURE 18 – MAP OVER PLASTAL'S ORGANIZATION.

The company produced its first product in thermoplastics in 1940 and had in 2007 sales of €1300M with over 6000 employees. But recently, due to the global financial crisis the automotive industry have been hit hard. This have resulted in a lot of problem for Volvo (see (150), (151), (152)) and thus have affected the situation for Plastal very badly (see (153), (154), (155), (156),(157), (158), (159)), so bad that Plastal have petitioned for bankruptcy.

Plastal have since its start both been acquired and itself acquired numerous companies and is today owned by Nordic Capital (a private equity firm). The company has a functional organization that is led by a board of directors and the Plastal Group Management (PGM) team (see Figure 19) where the board of directors is responsible for objective, strategy and core values for Plastal.

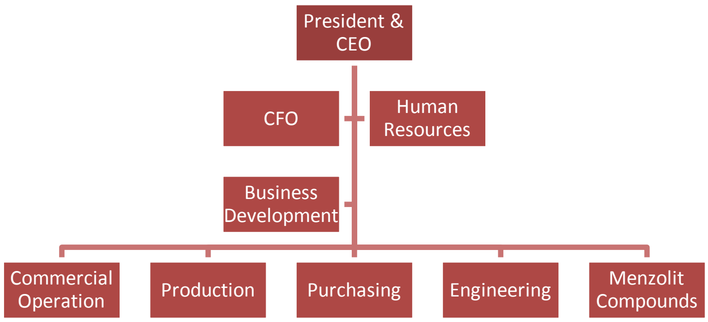


FIGURE 19 – ORGANIZATIONAL LAYOUT

Plastal has a great number of customers in the automotive industries such as: Audi, BWM, Ford, Mazda, Mercedes, Nissan, Opel, Porsche, Renault, SAAB, Scania, Skoda, Toyota, Volvo Cars and a lot more.

4.1.1 PLASTAL IN GOTHENBURG

Plastal in Gothenburg (PAGO) was founded in 1997 and is located in Arendal (see chapter 4.1.2), near Volvo in Torslanda, and have Volvo Cars as their main customer, while Plastal in Simrishamn and Uddevalla have SAAB as their main customer. PAGO produce parts for V70, XC70, S80, XC90, C70 but they also deliver some spare parts for the old SAAB 9000 and a couple of other old models, which totals to approximately 1600 different parts(160). They sequence deliver fully loaded trucks with bumpers, spoilers and complete bumper sets every half hour directly into Volvo's assembly line. They therefore have JIT (just-in-time) deliveries in JIS (Just-in-sequence). When PAGO receives an order from Volvo, they have only 8h to deliver it to Volvo. And as the throughput time is more than 8h, PAGO has to build to stock; the de-coupling point is located in high storage 1. If some articles would come in the wrong sequence, PAGO would get an administrational fee of about 200€.

As previously described, things have been looking bad for PAGO, but things can change as Volvo is investigating making more parts in plastic. This is because of the positive effects of using plastic, such as: lower weights, less costs and that plastic can't rust. This is what Tata Motors have done with their Nano model ("*the least expensive production car in the world*" (161)).

4.1.2 ARENDAL

Arendal is located in the west of Gothenburg and is also here where most of Volvo's suppliers are located (see Figure 20). Those who aren't located here have an inventory located nearby. It is thus a clustering of automobile corporations, obtaining benefits from being located near each other, i.e. economics of agglomeration.

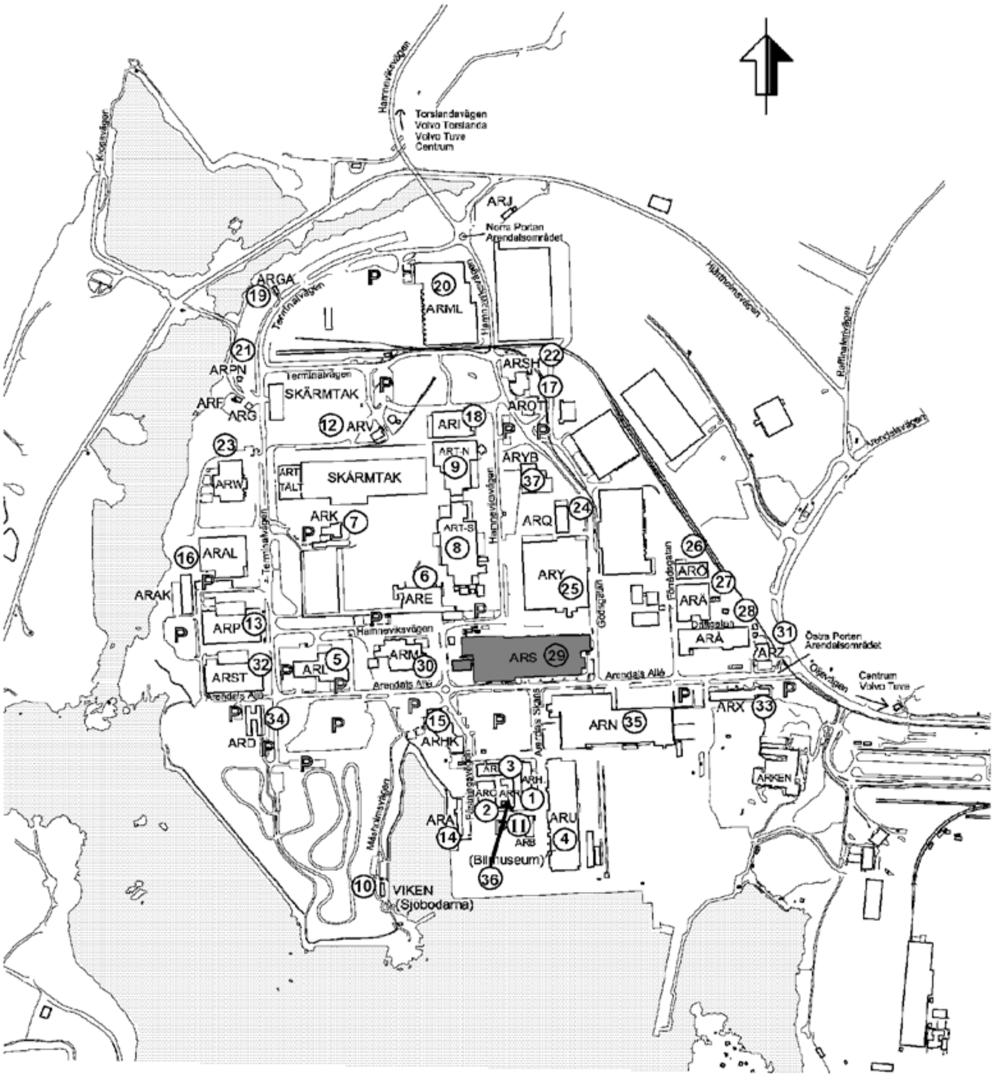


FIGURE 20 – MAP OVER ARENDAL. SOURCE: (162)

4.2 PRODUCTION PROCESSES

PAGO have nine processes: Injection molding, high storage 1, masking, paint shop, polishing and controlling, high storage 2 (and assembly station), assembly, sequencing and loading (see Appendix 7.1 and Figure 21). There is also a RFID system that is divided into 24 gates, located at: the injection molding, in and out of high storage 1, paint shop, in and out of high storage 2 and between sequencing and loading.

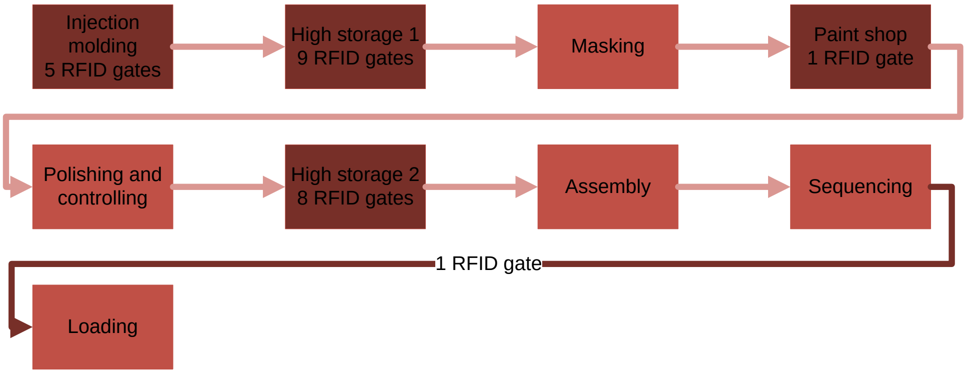


FIGURE 21 – PRODUCTION PROCESSES AT PAGO. PROCESSES MARKED WITH DARKER COLOR HAVE A RFID GATE.

PAGO uses three different kinds of load carriers: racks (see Figure 22), skids (see Figure 23) and cassettes (see Figure 24).

FIGURE 22 – RACK.

FIGURE 23 – SKID.

FIGURE 24 – CASSETTE.

4.2.1 INJECTION MOLDING

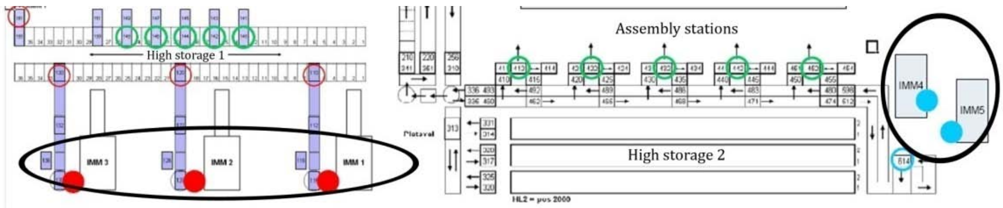


FIGURE 25 – INJECTION MOLDING WITH FIVE RFID GATES.

PAGO have five injection molding machines: one small weighting 2300 ton, two medium at 3200 ton and two big at 4000 ton with a total of 29 different molding tools (see Figure 26). They run each batch between 5 – 12 hours, which corresponds to approximately a batch size of 60 for low volume products and 600 for the rest. Changing to a different molding tool takes about 45min along with a scrape rate of one product per change. The production rate is 40-45 bumper / hour and 100 – 120 for spoilers. The higher rate for spoilers are mainly due to the fact that spoilers are produced two at a time (two cavity mode), while bumpers are produced one at a time. The raw material is distributed by Borealis[9] in the form of pellets, which is feed into one of the five injection molding machines.

[9] http://www.borealisgroup.com/

FIGURE 26 – INJECTION MOULDING TOOL.

The RFID tag is affixed after the molding is done (see Figure 27) by the robot. The tag is then checked (by trying to read the serial number) whether it's working or not – In that case, a new tag is affixed – and then the serial number is added into a database through a serial connection and Ethernet connection. After that the products gets loaded onto a rack. The number of products loaded on each rack is sent to the database to update the number of products available in high storage 1 (or high storage 2 for grained parts). The whole process of molding, affixing the tag and loading it on the rack is fully automated. Each rack has four levels and can store four to six products per level.

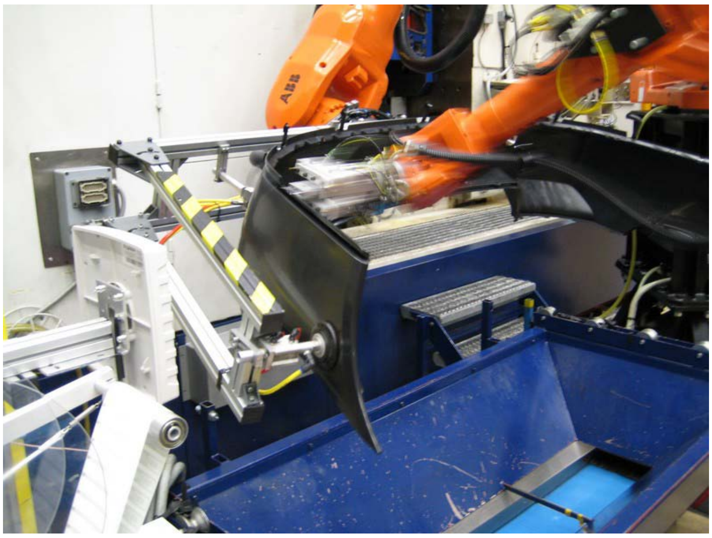


FIGURE 27 – ROBOT CELL.

4.2.2 HIGH STORAGE 1

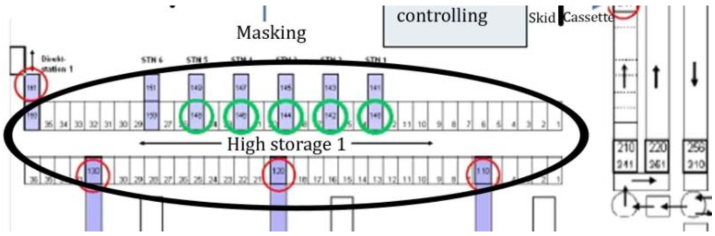


FIGURE 28 – HIGH STORAGE 1 WITH NINE RFID GATES.

Next in sequence is a buffer called high storage 1, which is fully automated. The entry point into high storage 1 has four RFID antennas – one for each level of the rack (see Figure 29) and the exit point also has four RFID antennas (see Figure 30). This way, PAGO can keep track of the current quantity and product on each rack to confirm the storage status. High storage 1 can store about 360 racks with approximately 20 – 25 products per rack for unpainted products, which adds to a total of 7200 – 9000 products. This yields a turnover rate of one to two days. The storage has three automated gates located at the entry points along with five automated and one manual gate located at the exit points.

At each entry point, there is a manual station where the operator can control whether the parts entering high storage 1 have some damage. If there is some kind of damage to a product, that product gets removed from the rack and the number of products on that rack is then manually updated.

At the exit points there is a manual process where the products gets removed from the racks, and loaded onto skids. The operator then updates (by typing the amount on to a computer) the number of products that are sent back on the racks into high storage 1. Each skid holds three to eight products or articles.

Today, the inventory isn't checked manually, i.e. no person counts the products to check whether the storage level is correct or not. Thus PAGO fully relies on the storage levels given by the system. It is neither physical possible to count every product in the storage nor would it be to any benefit, because the storage would have been refilled several times during the time it would take to count the products. This also holds for high storage 2.

FIGURE 29 – ENTRY POINT TO HIGH STORAGE 1.

FIGURE 30 – EXIT POINT TO HIGH STORAGE 1.

4.2.3 MASKING

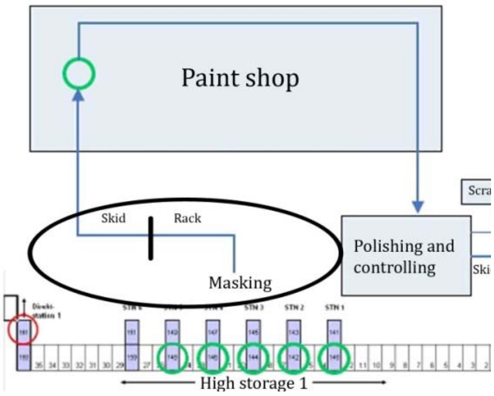


FIGURE 31 – MASKING.

Subsequent is masking an operation where the surface that isn't going to be painted is covered. This is an operation that isn't operational much these days because most products are either spoilers or bumpers and they don't need any masking. It is also in this process where the products gets manually checked, e.g. if there are any rough edges. After that, they get loaded onto skids. The operators working in this process also work at the exit points for high storage 1. This makes this one of the most labor intensive process in the factory.

4.2.4 PAINT SHOP

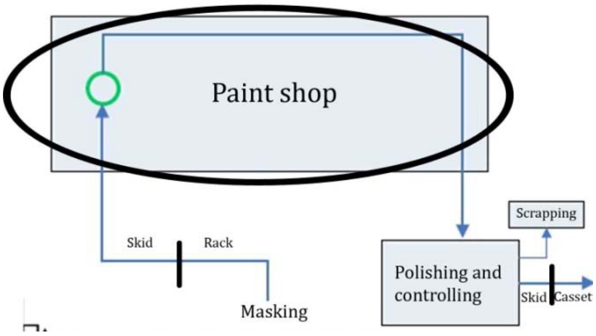


FIGURE 32 – PAINT SHOP WITH ONE RFID GATE.

Following is the fully automated paint shop, which also have a RFID gate (see Figure 33). The skids with the products are sent into the paint shop for painting. After the painting is done, the RFID tags are read so the specific color can be set on each of the products. The RFID gate is thus used for setting the color of the tag and consists of four antennas and a reader. It is after this procedure the product becomes an article.

FIGURE 33 – TWO RFID ANTENNAS IN THE PAINT SHOP.

4.2.5 POLISHING AND CONTROLLING

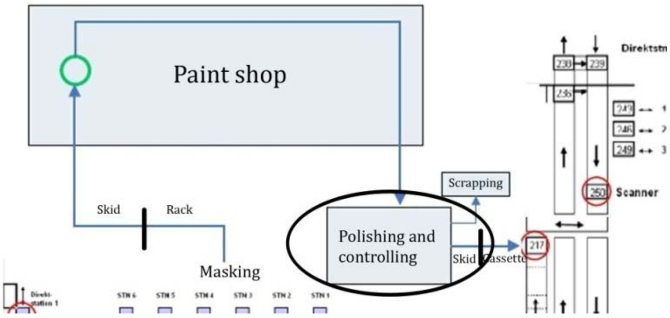


FIGURE 34 – POLISHING AND CONTROLLING.

Next in sequence is polishing and controlling. This is a manual station where the articles gets checked and polished if needed, and loaded onto cassettes. It is also in this station where the barcode gets attached onto the article. Polishing is only used if necessary and 88% of the articles are normally acceptable and can pass without any polishing, while the rest 12% require some form of polishing. Of these only 67% can be refurbished with polishing while the rest have to be discarded. Thus they have a scrap rate of about 4% of the total articles entering into polishing.

4.2.6 HIGH STORAGE 2 AND ASSEMBLY STATION

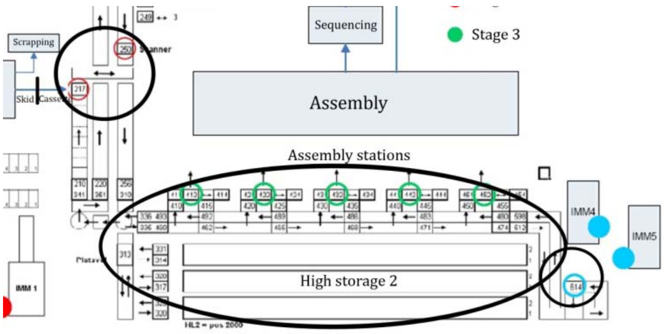


FIGURE 35 – HIGH STORAGE 2 WITH EIGHT RFID GATES.

Subsequent to polishing and controlling is another buffer called high storage 2. High storage 2 is used for the articles but also for grained[10] parts – The rear bumper for XC90 or XC70 both have a textured part. It has, like high storage 1, a RFID gate on both sides and with two antennas for each entry and exit point (see

[10] Painted, stamped or printed design that imitates the pattern found in wood, leather or stone (165).

Figure 36 and Figure 37). They are used for keeping track of current quantity of articles on each cassette to confirm the storage status. The entry point to the storage is called “Position 217” which you can see in Appendix 7.1, while the exit point is called the assembly station.

The entry point to high storage 2 is a manual station where articles come loaded on cassettes. Before the cassette enters high storage 2, the operator specifies the number of articles on the cassette along with the color of the articles. Each cassette has the same color on all the articles.

PAGO have a total of five assembly stations, all of them are manual. Each assembly station is automatically supplied cassettes from high storage 2. The operator then unloads the number of articles specified on a screen located at each station. When the article(s) has been removed the operator signals the system and the number remaining on that specific cassette is automatically updated – The amount of articles before the unloading is subtracted by the amount of articles specified on the screen.

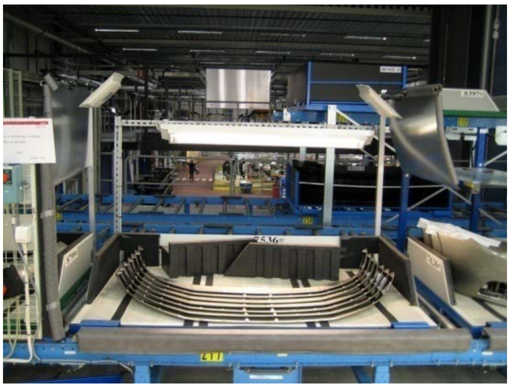


FIGURE 36 – ENTRY POINT TO HIGH STORAGE 2.

FIGURE 37 – EXIT POINT TO HIGH STORAGE 2.

4.2.7 ASSEMBLY

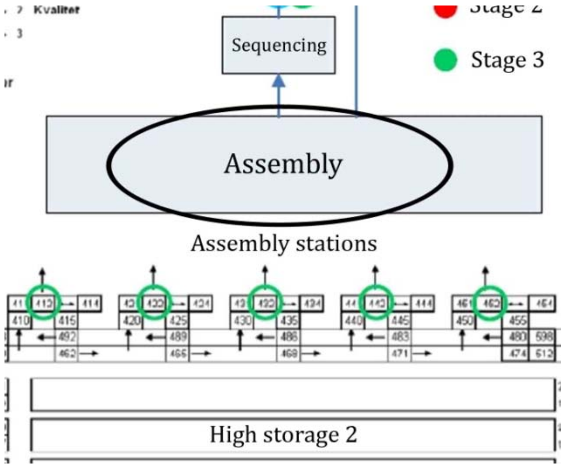


FIGURE 38 – ASSEMBLY.

Following is the assembly, which is divided into the front assembly and the back assembly for spoilers and bumpers. Here the assembly of a spoiler and its corresponding bumper gets assembled along with some additional equipment such as parking sensors, wipers, fog lamps etc. specific for each order. The assembly is one of the processes that need the most personnel.

4.2.8 SEQUENCING

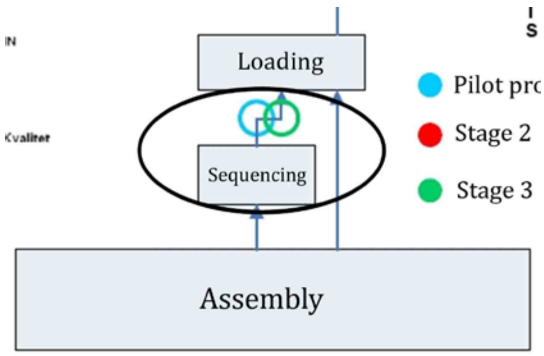


FIGURE 39 – SEQUENCING WITH ONE RFID GATE.

Next in order is sequencing. This is a fully automated process that can handle approximately 100 articles at a time. One of its features besides sequencing is that it can optimize the order you assemble parts. For example, if the operator assembles a bumper and spoiler for a XC90 and sees there are an exact same order for the XC90 only ten cars later. The operator can then assembly those both products in a row and send it into the sequencing process, which will automatically sort them, so they will end up in the right order. That means that the operator doesn't have to assemble in sequence.

Right after sequencing there is a RFID gate. This gate has two antennas and its purpose is to detect variations in color between a spoiler and bumper and if it's according to specification.

4.2.9 LOADING

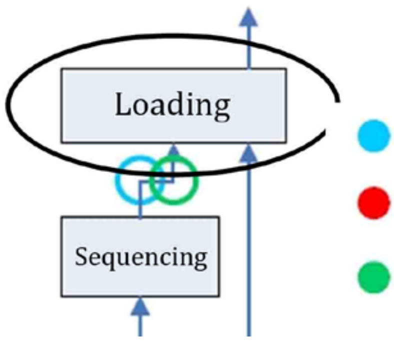


FIGURE 40 – LOADING.

Loading is done onto sequencing racks that are sent to Volvo. The racks are loaded into the trucks from the side which enables easier handling and easier preservation of the sequence.

4.3 IMPLEMENTED RFID SYSTEM

In the Plastal concern, PAGO is the only one that is currently implementing RFID technology. The plants at Gent and Valencia are looking into it, but they are waiting for the results from PAGO, i.e. the benefits and how PAGO solved the issues that arose, before they take any further step.

PAGO uses a dual system with both a RFID system and a barcode system, which is used for backup reasons in the future. They only tag products that travel through either high storage 1 or 2, i.e. only bumpers and spoilers are tagged. The reason why they chose to go with an Auto-id technology was mainly because they had a lot of manual reporting in different processes, all of which could result in an error. For example, the entry point for high storage 2 (position 217, see chapter 7.1) is a manual station where the operator specifies what color each article has. In addition, some of the colors are exceptionally hard to differ from each other. Other reasons why they chose an Auto-id technology were because they wanted to minimize the risk of having incorrect storage status, increase traceability in the processes and for the possibility to control the equipment in the processes based on the information stored on the RFID tag. RFID was chosen among the other competing Auto-id technologies for a number of reasons but essentially because PAGO couldn't find any other Auto-id technology that could read their parts when they were loaded on the load carriers (racks, skids and cassettes). Another reason was that they have to read the parts without having visual contact – The parts can't be moved around when they are loaded on the load carrier because of the risk of causing scratches. RFID technology satisfied these needs but also it gave the ability to read many tags simultaneously.

4.3.1 TAG TYPE

They use 96bit passive RFID tags that operate in the UHF area (860 - 960 MHz) with a reading distance of 2m, which is sufficient for PAGO. They chose UHF tags mainly because of the reading distance but also because there is no interference from consumer electronics and that it has good propagation characteristics. If they had chosen HF tags, then each tag would have been more expensive (roughly two – three times more expensive compared to UHF tags) because they are bigger in size and thus require more material. But also the reading distance is far less compared to that of UHF, so not only would they have been forced to use more and bigger antennas, but it would be a problem within the paint shop where the area is very limited. One solution to the problem in the paint shop could have been to install the antennas on a robot, but that would be both very expensive and time consuming.

Every car can have up to four tags each, two on the spoilers (front and back) and two on the bumpers (front and back). PAGO uses an open-loop system, thus the tags are not killed when it leaves the factory. This allows PAGO so identify when and where the product where produced if they get a bumper or spoiler in return[11].

PAGO uses a unique serial number on each tag. They constructed the serial number on their own, because they felt there was no standard way of doing it. The serial number is constituted of a country code, area code, a unique number and a factory code. As previously described, each tag's serial number is also stored in database, and they are thus connected with each other. The attributes stored in the database are for example what color the specific bumper has, what kind of article it is and what gate it has passed etc. The tag can be viewed in Figure 41.

[11] This was actually seen in the factory in Uddevalla where they started to notice tags with different serial number then their own on the C70 car. This was because the C70 car is also produced in Gothenburg. This means that the tags are still alive when it reaches the customer.

FIGURE 41 – THE TYPE OF TAG THAT PAGO USE.

The tags cost 0.12€ but is estimated to drop to 0.07 – 0.08€ in a not too distant future. The price of the tag wouldn't decrease even if the tags were changed to a simpler version, for example one that stores less than 96bits – It would probably even be more expensive. This is because the price of the tag is mainly driven by the volumes produced. And as for the next generation tags, the price will likely be the same but it will have better performance and a bigger memory size. Included in the price is delivery cost, preprogramming cost (the serial number is preprogrammed into the tags) and the cost of using a special coating or paper face. The coating helps encapsulate the small silicone levels that are in the adhesive, which otherwise could be a problem in the paint shop.

4.4 IMPLEMENTATION PROCESS

The RFID project began with a pilot that started in 2005 and was supposed last for a half year, but ran for 1.5 years. It was limited to the injection molding in the eastern part of the plant, the manual station for high storage 2 and for the gate between sequencing and loading (see Appendix 7.1). It was also mostly limited to grained products, and thus most of the products didn't pass through the paint shop. For the remaining products (not grained parts), the RFID tags were manually affixed properly. This is the reason why they didn't have any problems with tags detaching until after the pilot (see chapter 4.6.5). The purpose of the pilot was to test, control and evaluate a small limited installation of the RFID system; thereby enabling them to find and correct issues and problems before a full-scale installation.

The pilot's members were: Plastal, RFID Constructors[12] (see chapter 4.4.2) and Else[13], and on some part also Animex[14] who supplied a complete solution for the

[12] http://www.rfidconstructors.com/
[13] http://www.else.se/

gripper (see Figure 43 and Figure 44) and the dispenser unit (see Figure 42). RFID Constructor was the supplier of the RFID technology, including hardware, while Else supplied and designed the IT system. In January 2007 the order for the equipment was sent and the implementation process began for the entire plant.

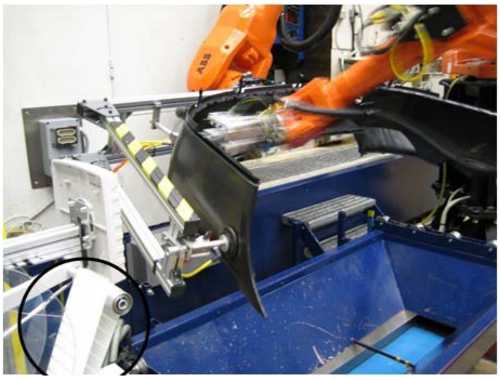


FIGURE 42 – ROBOT CELL WITH THE DISPENSER UNIT MARKED.

4.4.1 PROJECT PHASES

PAGO have divided the RFID project into four phases or modes:

- Inactive mode – When the system isn't in use at all.
- Passive mode – Only collecting and storing data. No information is passed to the personnel. The information isn't used to control the flow in any way but they use it to compare data reported by the operator and that of the automated system. This is the stage PAGO is in right now.
- Active mode – The information (color, amount etc.) is reported to the operator on a panel.
- Automatic mode – When they fully trust the RFID system. In this mode they only have to check each part for defects, no other manual reporting is done.

4.4.2 RFID CONSTRUCTORS

RFID Constructors where earlier a division of Nordvalls[15], but is today a separate company. They have two and a half full-time workers and their main focus is providing RFID system solutions that can be divided into four tasks:

[14] http://www.animex.se/
[15] http://www.nordvalls.se/

- Retailer and distributor of RFID tags and smart labels (label with RFID tags) through Nordvalls.
- Retailer of other RFID electronics, such as readers and antennas and printers etc. Mainly on the Finnish and American market.
- Training and educating customers in RFID technology.

Test and verify new ideas in the test facility located in Lund.

4.5 POTENTIAL RFID IMPROVEMENTS

There are a lot of manual reporting and updating in the system. All of these tasks are prone to errors. For example, there is manual reporting at the entry and exits points for high storage 1 and 2, and at the assembly.

4.5.1 ENTRY POINTS FOR HIGH STORAGE 1

A problem seems to be at the control station right before the entry point to high storage 1. This happens when the operator unloads a product that is damaged but forgets to update the correct number of products that are left on the rack. Without RFID, this causes a problem, because the incorrect number of products is reported entering high storage 1. With RFID these problem will be solved because right before the rack enters high storage 1, the RFID gate will automatically scan the rack and automatically update the correct number of products entering the storage.

4.5.2 EXIT POINTS FOR HIGH STORAGE 1

The same problem exists at the exit points of high storage 1. At the automatic stations, the most common problem is that the operator updates the wrong number of products going back into high storage 1. In the manual station another problem also occurs; this is when the wrong kind of product is specified. This can only happen in the manual station because there the operator has to specify not only the amount of products, but also the model, while in the automatic stations the model is automatically preselected. And it is not very likely that the operator accidentally changes a model that is already given. These kinds of errors will be fixed with RFID because each exit point has its own gate that automatically corrects the number and model for the rack going back into high storage 1.

4.5.3 ENTRY POINT FOR HIGH STORAGE 2

At position 217, the entry point for high storage 2, there are three kinds of error that can occur: wrong amount, wrong product and wrong color. Without the help of RFID, the operator has to manually input these values to the database. For example, some of the colors are very hard to distinguish from each other, which make it very hard to specify the right color for the articles. These errors will be corrected with RFID. If not all tags are read in the paint shop the system automatically suggests (in active mode) or corrects (in automatic mode) the correct number of items and its color. For example, say that three of four products are read in the paint shop. When the skid then reaches the entry point to high storage 2, and the RFID system notices three articles and one product (an article without color), it will suggest a correction of this, i.e. it will prompt the operator asking if the product has the same color as the articles on that skid. Even if this is a manual operation, it is easier to distinguish that the colors are the same then specifying the correct color.

4.5.4 EXIT POINTS FOR HIGH STORAGE 2

In the assembly station, the exit point for high storage 2, a problem that can occur is when the operator chooses to unload more articles then specified. This usually happens when they previously have had some scrapping and thus is one or more articles short. The system will then update the wrong number of articles going back into high storage 2. This is also something that will be corrected by RFID. Without RFID, these kind of problems results in incorrect storage levels which in return can result in an extra color swap in the paint shop. This will not only be time consuming, and more labor intensive but it will also be more costly because each color swap results in an increase in the total number of scrapped products.

4.5.5 ASSEMBLY

There are a lot of errors that can happen in the assembly. For example, a grained spoiler can be assembled with a colored bumper or a color spoiler can be assembled with the wrong colored bumper etc. Without RFID these kinds of problems are hard to find and can result in that a new part has to be build on demand. The RFID implementation enables the articles to be checked against each other, to verify that the colors and articles match specification. This is done after the sequencing and before the loading. The reason why this isn't done in connection with the assembly is because of technical limits in the assembly.

4.6 IMPLEMENTION ISSUES AND FIXES

PAGO have had some issues with the implementation. For example: electrostatic discharge, readability at high storage 1 and 2 and in the paint shop, detached tags and some other minor challenges.

4.6.1 ELECTROSTATIC DISCHARGE

One big issue that wasn't noticed during the pilot project was with ESD (electrostatic discharge). After the molding process, each product had a charge of about 20kV while each tag only could withstand a surge of about 1kV. This resulted in that about 30% of the tags were lost. To solve this, PAGO tried different antistatic equipment, like ionizing tools, but it didn't work fast enough. They finally came up with the idea of using a lightning rod on the gripper (the two metallic pins seen on Figure 43), which grounds the charged area. The reason why the problem didn't arise during the pilot project was because they weren't running the molding process at full speed, and thus each product had time for it to discharge itself.

4.6.2 READABILITY AT HIGH STORAGE 1

One other thing they had problems with was reading too much. An example of this was at the entry and exit point to high storage 1. There they had problems with reading tags that were behind the reader or when the crane was loaded with parts and moved past the antennas. PAGO first tried to fix this by tweaking the antennas, but that resulted in too low readings (70 – 80%). Instead, they solved the issue by using a filtering technique. By adding flags to the database for each product, each tag could be determined which gate it had passed, i.e. if it was recently created in the injection molding or if it has been moved into high storage 1. Another problem was with the fences surrounding the high storages facilities (see Figure 29, Figure 30, Figure 37). Even if the mesh gauges are 5cm, the fences acts like a solid metallic plate in ultrahigh frequency and thus causing reflection.

4.6.3 READABILITY AT HIGH STORAGE 2

The entry point for high storage 2 (position 217) have also caused some problems with readability. The main problem was that they read too much; they read adjacent tags and thus couldn't determine what article belonged to what cassette. The cause of this problem was that beneath the conveyor belt there was a metallic surface covered by a plastic carpet that hadn't been taken into consideration during the implementation. The problem was then that as most of the cassettes have non-metallic bottoms and the conveyor belts roller's have a big gap between them, the radio signal propagates through the cassette, gets reflected on the metallic surface resulting in that the antennas also reads tags from articles on adjacent cassettes. There exist several solutions to this problem, for example by using different kinds of shielding techniques.

Another problem was with the other types of cassettes, which have a metallic bottom. This was because the RFID antennas where placed perpendicular to the cassettes (see Figure 36), which creates a stationary wave phenomenon. This resulted in that the RFID tags that are in the nods of the wave can neither be read nor seen by the antenna. The solution is to adjust the antennas so they don't become perpendicular to the cassettes.

4.6.4 READABILITY IN THE PAINT SHOP

Furthermore, there have been problems with readability in the paint shop. This is because the paint shop is made of metal, and thus acts as a waveguide. This results in stationary waves, and as said before, there is no readability at the nodes. PAGO are currently thinking about moving the antennas to the entry point of the paint shop, which would eliminate the problem.

Another problem was low readability for front spoilers in the paint shop. This is caused by the fact that the skids have borders made of metal, and the spoilers are very thin, thus being covered by the metal border. To be able to read those products the signal strength has to be increased, which causes the waveguide phenomenon described above. This only affects spoilers because they are much smaller compared to bumpers.

4.6.5 DETACHED TAGS

They also had some problems with tags becoming partially or completely detached in the paint shop. This was due to the tags got lumpy when they were affixed improperly. In the injection molding a robot first verifies the tags identification number, and then affixes it onto the product. The problem was with the gripper. The old gripper (see Figure 43) only had four small sucking coups – Used for picking the tags. This resulted in lumpy tags, which made it possible for the tags to detach in the washing step in the paint shop. The solution to this problem was to install a new gripper (see Figure 44) when affixing the tags. The new gripper had many small sucking coups and thus the force was divided evenly over the tag so the tag could be properly affixed without becoming lumpy.

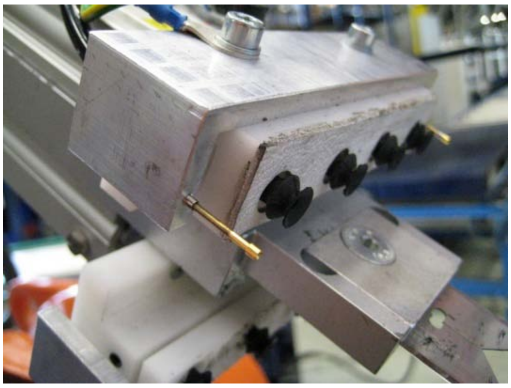


FIGURE 43 – THE OLD GRIPPER

FIGURE 44 – THE NEW GRIPPER

This improved the results but didn't completely solve the problem. The problem that remained was that the surfaces of the parts where the tags are affixed have an arched form, while the surface of the gripper is flat. This resulted in a gap between the tag and the part (see Figure 45).

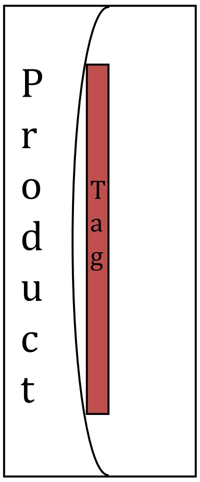


FIGURE 45 – AN SIMPLE ILLUSTRATION OF THE GAP BETWEEN THE TAG AND THE PART

The solution was to change the gripper to one with an arched surface, and to reprogram the robot to affix the tag with a rolling movement, i.e. from one side to the other instead of using a retractable movement.

What remains is if the standard adhesive they use today works with the oily surface covering the product. One option is to add a cleaning process before affixing the tag but that does not only generate cost but also adds to time and space. Another option is to change the adhesive to something that works better with the oily plastic surface. But changing adhesive can be very tricky because only a limited number of chemical substances are allowed. For example, the adhesive isn't allowed to contain any silicone as it contaminates the processes, especially in the paint shop.

4.6.6 OTHER CHALLANGES

Some other more minor challenges that PAGO encounter was:

- The project had a long installation time.
- The testing for the injection molding was way over due because it took a long time to find a process that worked.
- Communication between the robot and the warehouse management system – getting them to talk to each other in a safe way. This was caused by an unstable firmware in the robot and thus wasn't a RFID specific problem. But at that time, it was thought to be a problem with the RFID system.
- Insufficient cycle time for affixing two tags in two cavity molds – When two products are created in two cavity molds they are attached to each other. This is because there is only one entry point for the plastic into the mold. The robot thus only has 60s to apply the two tags, cut the plastic between the two spoilers and load them onto the racks.

4.7 RFID VISIONS

PAGO have several visions and aims with the RFID system. Their current goal is mostly to get it working and when it does they aim for 99.5 % readability. This could contribute to an increased profit, minimized uncertainty of the inventory levels and an improved quality to the customer.

They also have some vision about obtaining information about how long it takes for a product to pass through the gates, and what the inventory turnover rate is.

Another potential benefit is the ability to automate the prognosis. The prognosis is today made manually, and could probably be more accurate if it would be done automatically along with having the correct inventory levels. The safety stock in the inventory could maybe also be minimized and thus reducing costs.

Other visions are for example when PAGO gets an article in return. When the returned article is updated and specified as faulty in the system, every product or article in that corresponding batch could automatically get updated; adding a warning to each article so that the operator checks it more thoroughly.

5 RESULTS AND DISCUSSION

In this chapter an analysis of “how” and “why” Plastal implemented RFID technology will be presented.

5.1 “HOW”

PAGO implemented an Auto-id technology to minimize the risk of manual error, especially for high storage 1 and 2. RFID technology was chosen because it was the only technology that was sufficient for their needs, i.e. reading without visual contact and reading many tags at the same time. UHF was selected because it had sufficient reading distance, no interference with other electronics, it had good propagation characteristics and that it was thought to be the next standard and thus reducing costs.

The project began with a pilot project that ran for 1.5 years and was mostly limited to grained products, i.e. for injection molding in the eastern part of the plant, the manual station for high storage 2 and for the RFID gate between sequencing and loading.

After the pilot, PAGO chose to continue with the implementation. As of today, they have 24 RFID gates: five in the injection molding, three for the entry to and six for the exit points for high storage 1, one in the paint shop, three for the entry to and five for the exit points for high storage 2, and one between sequencing and loading. This equals to 63 RFID antennas: one for each injection molding unit, four for each gate in and out of high storage 1 and for the gate in the paint shop, and two antennas for every other gate.

PAGO are currently in the beginning of the intermediate phase in Attaran’s (24) RFID adoption phase model; they are thus applying the RFID tags during production and use the technology for data collection. There are still some things that need to be fixed before they can enter the “final phase”. According to Hellström’s RFID implementation model (148), PAGO would be in the routinization phase where they improve the level of automation and analyze and interpret the collected data.

There were some issues with the RFID implementation:

- ESD – After a product is molded it has a charge of 20kV, while the tag could withstand about 1kV.
- Reading too much
    - Reading products and articles in the high storages.

    - Metallic fences surrounding the high storages acts like a solid metallic plate.
    - Metallic floors at the entry point to high storage 2.
    - Some of the cassettes having metallic bottoms.
- Tags becoming partially or completely detached in the paint shop
    - Lumpy tags.
    - Affixing a tag with a flat gripper on an arched product.
- Readability in the paint shop
    - Paint shop acts like a waveguide.
    - Too low readability for front spoilers.
- Long installation time for the RFID project.

Most of these issues should have been solved during the elementary phase in Attaran's (24) RFID adoption phase model; or in adoption phase in Hellström's RFID implementation model (148); during the RFID trial, where the technology is tested in its working environment.

5.2 "WHY"

PAGO have five main sources of manual error: in and out of high storage 1 and 2, and for the assembly. The types of error that can occur are:

- Entry point to high storage 1 – Wrong quantity.
- Exit point for high storage 1 – Wrong quantity and for the manual station also specifying the wrong product.
- Entry point to high storage 2 – Wrong color, quantity and product.
- Exit point for high storage 2 – Wrong quantity.
- Assembly – Assembling the wrong articles together, not according to specifications.

The reasons why PAGO implemented a RFID technology, are not just because they wanted to get there inventory level more accurate or to know that every part they deliver are according to specifications. These issues could probably have been solved in different and cheaper ways, for example using some kind of optical recognition for the products, such a video camera to identify the colors of the articles. I therefore argue that there are some more underlying reasons why PAGO implemented a RFID technology.

First of all, PAGO isn't just a company that manufactures plastic parts. It is a highly technological and automated company that manufactures and sequence delivers injection-molded and surface-treated plastic to the automotive industry. The production has to be highly automated because when PAGO gets a synchro (a sequence order), they only have 8 hours to manufacture and sequence deliver it to Volvo. Without automation, such a thing wouldn't have been possible – Make-and-deliver-to-order, zero-error-production, lean management, just-in-sequence (JIS) and just-in-time (JIT) has evolved due to the necessity of reducing costs and cycle time (1). It is thus my belief that one of the underlying reasons why PAGO chose RFID technology was because of the automation process along with the fact that they have to sequence deliver the products 8 hours after order. RFID technology is a technology that is very fast at reading a lot of tags at the same time and can be fully automated into the processes. This also coincides with Chappell et al. (2) who say that RFID technology can increase the degree of automation, which can increase productivity and decrease errors. Another reason is that RFID technology is the solution to both their problems, i.e. it provides correct inventory levels and it also provides (in this case) the ability to check whether a product matches its specification. And furthermore, RFID technology also has the ability to increase tracking of various sorts, labor reduction and customer service.

The products stored in the inventory are fairly expensive, which means that a big cost reduction can be made in decreasing the safety stock levels. But in order to do that they need reliable data on the inventory levels. But as the inventory has a high turnover rate (one to two days) its level has to be calculated automatically without any human interaction, i.e. no manual updating of any kind. Another thing that is important to mention is that, there can't be any shortage in the inventory because the production process, from injection molding to delivery, takes more than the 8 hours they have to deliver the products. An order delivered to Volvo where a product is missing causes a big problem for Volvo. The reason why Volvo has sequence deliveries is because of the limited time they have to assemble a car, and thus every product is delivered into the production line. This doesn't only add to cost for both PAGO and Volvo but more importantly it has negative effects on their relationship, i.e. intangible costs. RFID technology provided the ability to keep more accurate inventory levels and in turn be able to reduce the levels without shortage.

Instead of investing in a couple of different technology, specific for solving each problem, RFID technology had the ability to solve them all. Furthermore, it also gave them the ability to do much more than just having correct inventory levels and match a product with its specification. And in the near future, RFID technology can also be a demand from Volvo, who already uses RFID in their assembly line. RFID technology has also gained usage in recent years, and as some believe, can be the successor of barcodes. So, an investment in RFID technology is probably more future proof than any other technology(ies) that would have solved their problems.

5.3 PROPAGATION OF ERROR

In order to get an understanding how RFID technology will benefit PAGO, a simple model has been constructed that shows how the errors caused by manual updating and reporting (see chapters 4.5 and 5.1) can be reduced by the autocorrecting effects of RFID technology.

This model uses the five most common tasks where manual errors occur (see Figure 46): prior to entry of high storage 1, exit point to high storage 1, entry point for high storage 2, exit point to high storage 2 and the assembly.

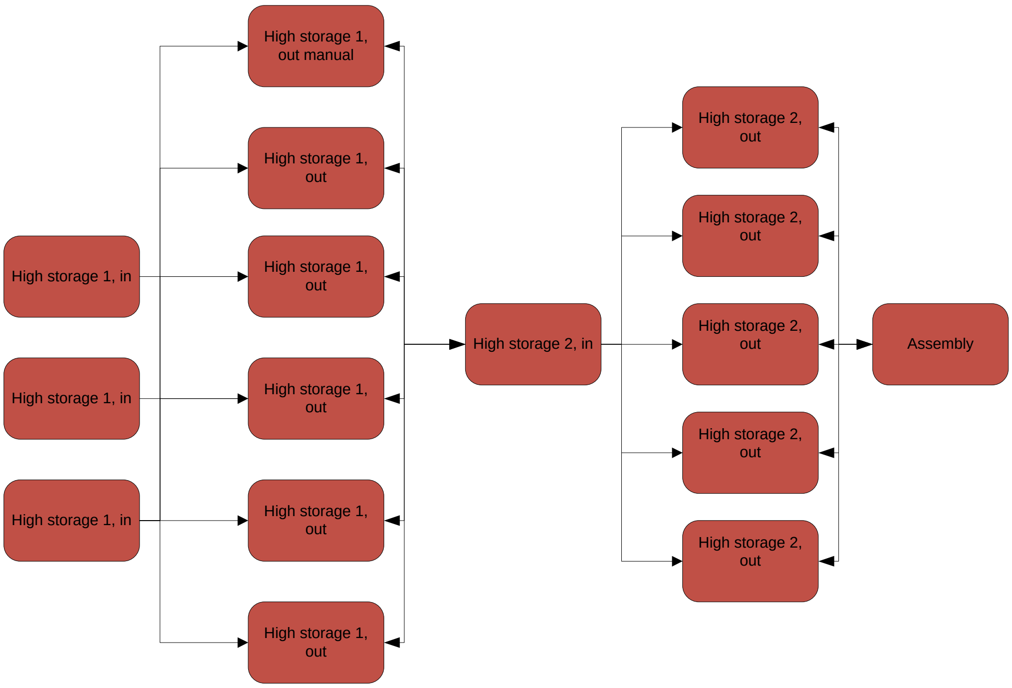


FIGURE 46 – TASKS WHERE MANUAL ERROR CAN OCCUR.

If a task has a mean error rate of ε_n, and Y_{n-1} denotes the number of non-faulty articles entering the task, then the mean number of non-faulty articles leaving the task is going to be: (number of non-faulty articles entering the task – number of faulty articles leaving the task) $Y_{n-1} - Y_{n-1} * \varepsilon_n$. This also holds for the next task and therefore, if the number of non-faulty articles entering the first task is denoted as Y_0 the following formula can be given:

$$\begin{cases} Y_n = Y_{n-1} - (Y_0 * \varepsilon_n)\left(\frac{Y_{n-1}}{Y_0}\right) = Y_{n-1} - (\varepsilon_n * Y_{n-1}) \\ Y_0 := \text{Number of articles entering the first task} \\ \varepsilon_n := \text{Error rate for task } n \end{cases}$$

FORMULA 1

The model from Figure 46 along with the formula given in Formula 1 was used for measuring the effect of RFID's autocorrecting effect. Each task was assumed to be uncorrelated with each other, i.e. an occurrence of a manual error in one task isn't correlated with another task. The values given for the mean error rates were chosen based on the assumptions that the error rate for human data entry is 1 in 300 (163). This value is also applied in the assembly process where a spoiler and a bumper are assembled, even though this process doesn't have any manual reporting. The results for the system without an RFID implementation can viewed in Table 6, based on 10.000 products entering the system.

TABLE 6 – THE SYSTEM WITHOUT A RFID IMPLEMENTATION.

	High storage 1, in		High storage 1, out		High storage 2, in		High storage 2, out		Assembly
Task error rate, ε_n	1%		2%		0%		2%		0%
Total error rate	1%		3%		3%		5%		5%
Difference		2%		0%		2%		0%	
Number of non-faulty articles leaving the process	9900		9702		9670		9508		9477
Number of articles, Y_0	10000								

The error rate for a RFID system is assumed to be the same as for scanning barcodes, i.e. between 1 error in 394.000 and 1 error in 5.400.000 (163). The results for the system with an RFID implementation can be viewed in Table 7.

TABLE 7 – THE SYSTEM WITH A RFID IMPLEMENTATION.

	High storage 1, in	High storage 1, out	High storage 2, in	High storage 2, out	Assembly
Task error rate, ε_n	0%	0%	0%	0%	0%
Total error rate	0%	0%	0%	0%	0%
Difference	0%	0%	0%	0%	
Number of non-faulty articles	10000	10000	10000	10000	10000
Number of articles, Y_0	10000				

A comparison between the two systems can be viewed in Figure 47. Note that the total error rate (the left axis) is in logarithmic scale. The difference between the two systems is obvious; RFID is superior to manual updating. Even if these figures are just hypothetical, it gives us a glimpse of where and how much a RFID implementation can offer compared to that of manual reporting. Even if the error rate for the assembly is 1 in 3000, i.e. 10 times less than the previous mentioned, the results would be the same. These are thus the effects that the autocorrecting RFID system contributes to.

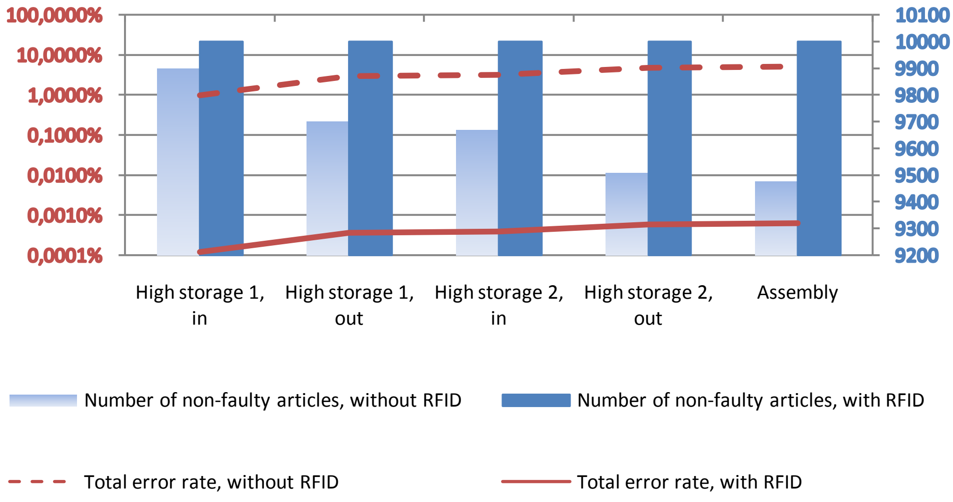


FIGURE 47 – A COMPARISON BETWEEN THE TWO SYSTEMS.

In PAGO's case, going from manual reporting to a fully automated RFID system will greatly reduce the number of errors for the logistic processes. It will help them improve the accuracy in the inventory levels, which can help them reduce the safety stock and thus also costs; this coincides with Skjøtt-Larsen et al. (13) who claims that IT doesn't just reduce the unnecessary inventory, but it also enables processes to be automated. It will also help them reduce the number of delivered articles that don't match specification, which will reduce costs and improve their customer relationship.

PAGO have themselves calculated that the number of errors for high storage 1 is roughly 1150 per year, each that yields 10min additional time for the injection molding process. The injection molding costs approximately 2400kr per hour, and thus the total cost per year for these kinds of errors are 414.000 kr (based on a 90% stop rate in the injection molding due to this errors). The costs associated with the RFID hardware implementation was in 2008 roughly 2.500.000 kr. This yields a payback period of six years without any interest. This is only based on the additional cost in the injection molding caused by incorrect storage levels in high storage 1. Thus, if all other errors where to be analyzed and added in these calculation, the payback period would decrease even more. It is thus safe to say, that it only takes a couple of year for this investment to be up and running for it to be profitable for PAGO. The additional cost for the tag hasn't been considered into the calculation because it only amounts to a couple of percent of the price for each product.

6 CONCLUDING REMARKS

In this chapter the conclusions of the RFID implementation will be given.

Even though UHF RFID technology was just a draft when PAGO decided to use it, it was a good choice. It turned out to be one of the most common and cheapest RFID technologies used. I also believe that choosing RFID technology instead of any other Auto-id was a good choice, not only because it can be a future demand from Volvo, but also because of the increased usage (see chapter 1.2.1) from different industries. Furthermore, it also has the ability to provide more just the solutions for their current problems; therefore maybe unknown needs or future demands will be satisfied with the technology.

All of the problems that PAGO encountered could not have been anticipated, but it is my belief that a lot of them could to some degree have been avoided or at least been minimized. For example, the problem with readability probably occurred because the installation was made the same way as you install a barcode reader and no consideration was taken on how radio waves propagate. Furthermore, the pilot project was concentrated on some parts of the plant only and did not include every gate. Nor were every gate checked one at a time, in isolation to every other part of the system during the installation.

Another thing is only to use antennas with circular polarization when needed. If you know how the tags are affixed, then you don't need circular polarized antennas, and you can use linear polarized ones instead. Using circular polarized antennas result in 50% less power efficiency (see Figure 48 and Figure 49). This is because only the components with the same orientation of their oscillation have any effects. This would enable a reduction of the signal strength for the antennas and thus also reducing interference and reflection phenomena.

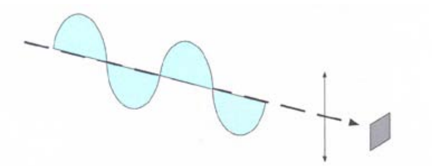


FIGURE 48 – LINEAR POLARIATION.

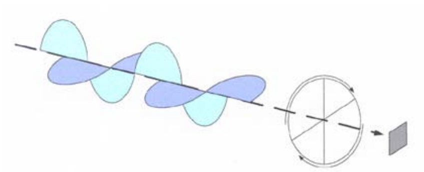


FIGURE 49 – CIRCULAR POLARIZATION.

A lot of the problems seem to relate to the technical understanding how RFID technology works. It is thus my belief that all of the involved parts neither had the technical expertise nor the knowledge that was required for the project and that they all underestimated both the size and the time for it. Furthermore, more time should have been given on clarifying the goals and roles and responsibilities of all participants in the projects. For example, PAGO have several times thought that they had completed 80% of the RFID project, but as new areas and problems were encountered, the finish line seemed to move further and further away.

It is also important to note that projects of this size are very limited in time when they can be started due to budget etc. And as the project was initiated by upper management, this could be one of the reasons why some of the problems arose. Maybe, the upper management felt that they had to launch the implementation, or else it would be too late, while the project group felt that they needed more time for testing and researching. Another thing one should have in mind is that, when the project was initiated, UHF RFID had just been release and there was little knowledge about it.

Nevertheless, one can safely say that all of the participants involved in the project have gained a lot of experience and knowledge with the technology. PAGO's interest of getting the project up and running has increased during 2008 and most of the problems were fixed during that time. I thus believe that before the end of 2009, the project will be up and running with just some minor issues.

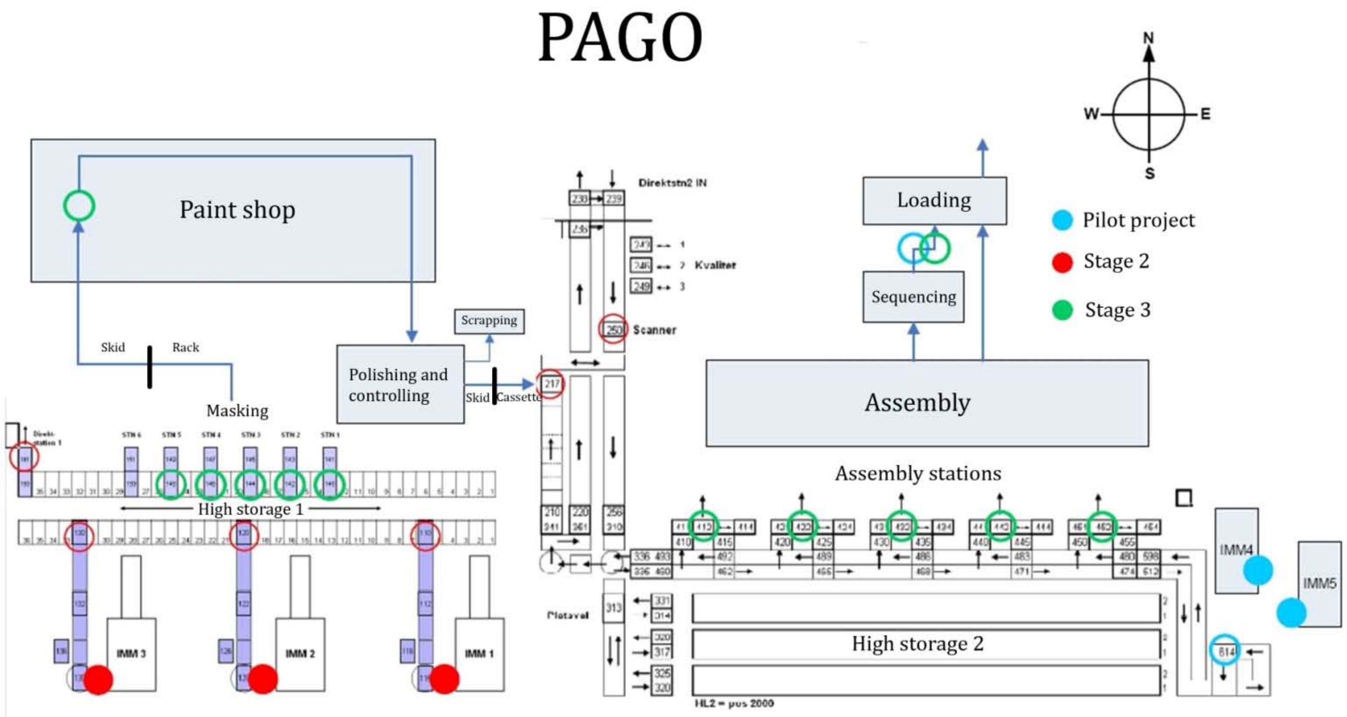
I hope that this thesis will bring value not only for PAGO but also for Plastal and for their future implementations of RFID technology in their other plants. I also hope that this thesis has clarified how and why PAGO implemented RFID, what the effects of the implementation are and what problem arose along with its corresponding solution.

To sum it up, my conclusions on the implementation are:

- Have better knowledge about the technology and its limitation.
- Test every gate in isolation before getting the system online.
- Clearer goals, roles and responsibilities for all participants.
- Don't begin implementing until all problems are solved.
- Solve each problem as soon as they arise.

7 APPENDIX

7.1 PAGO OVERVIEW



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