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Master Degree Project in Logistics and Transport Management

The Quest for Accurate Inventory Records

A case study of the scrap management process at a Swedish manufacturing company in the automotive industry

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Abstract

Inventory record inaccuracy (IRI) occurs when the inventory system records and the physical inventory level do not align which can result in reduced operational efficiency and increased operational cost. Every situation where inventory is transferred physically or in inventory records can be potential sources of IRI. The purpose of this study was to examine a manufacturing company's scrap management system and how it affects the company. With a mixed methodology, containing both quantitative and qualitative methods, three objectives were used to register the effects and cover the study's purpose. Firstly, to identify vulnerabilities of the current system employed. Secondly, to identify trade-offs and other operational effects that the current scrap management system causes. Thirdly, to compare the current method of counting scrap with an additional, more automated system at the company. The findings indicate that the vulnerabilities of current scrap management system originate from its high dependency of human interaction. To achieve more accurate inventory records the company were found to sacrifice production time as well as time used for value adding activities for employees, trade-offs identified to be caused by the current scrap management system. The comparison confirms the company's choice of scrap counting system, where the more automated method proved more unreliable than the currently used system. Of the previous research regarding IRI in manufacturing environments simulations where found to be the dominant method of use. However, simulations tend to neglect the complexity and dynamics of the real manufacturing environment. Case studies focusing on IRI are mainly present when examining retail companies. The contribution of this paper lies in the in-depth and detailed case study, examining the field of IRI at a manufacturing company through the assessment and exploration of their scrap management system.

Keywords: Inventory record inaccuracy, inventory management, operational trade-off, manufacturing strategy, mixed methodology

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1. Introduction

1.1 The inventory inaccuracy problem

To cope with the increasing market competition, companies need to perform more effective work with less resources. In strive for profitability, there are increasing efforts and principles adopted by companies that increases productivity and efficiency such as lean manufacturing. A core principle of modern age manufacturing is to increase the proportion of value-adding activities that customers are willing to pay for, compared to non-value adding activities being everything else that customers are not willing to pay for (Jeyaraj et al. 2013). A commonly mentioned non-value adding factor to get rid of is holding excessive amounts of inventory, which drives costs but is not in the end paid for by customers. A prerequisite for total elimination of excessive inventory is having accurate inventory records, i.e. the physical inventory matches the inventory records. Avoiding inaccurate inventory records become more important with decreasing inventory levels, meaning that the margin of error diminishes the more "lean" a firm becomes (Wild, 2004). Inventory Record Inaccuracies (IRI) occurs when the physical inventory does not align with what the inventory system (IS) records (Kumar & Evers, 2015).

1.2 Causes of IRI

Four primary causes of IRI is presented by Kang and Gershwin (2005): stock loss, transaction errors, inaccessible inventory and incorrect product identification. The stock loss can be categorised as known or unknown stock loss. The known stock loss are situations where inventory is removed from the IS and recorded, such as when products that are out of date. Such situations do not generally cause IRI since it is recorded in the IS. However, the unknown stock loss will inevitably cause IRI since inventory is removed physically, but not in the IS through a transaction. Situations like this may appear from illegal activities, such as theft, but also from failing to perform transactions because of it not being possible or due to forgetfulness (Kök and Shang, 2014). The transaction errors are primarily related to manual activities with human interaction within different functions at companies (Kang and Gershwin, 2005). For instance, IRI can occur when employees transfer physical stock and does not make the transfer in the IS correctly. Other situations are when components are incorrectly scanned. If three physically alike, but in the IS differentiated products are treated as the same, IRI will be present for all three products (Sethi and Shi, 2013). An example of this is the classic case of the supermarket cashier who enters three strawberry yogurts at the cash-out register, but the actual quantity should be one strawberry, one blueberry and one pineapple yoghurt. Hence, the strawberry yoghurt will be consumed threefold and have underestimated stock level, and the other yoghurts are not consumed at all and thereby have overestimated IS stock levels. Incorrect product identification can be another cause of IRI and is assumed to have two root causes. The first relates to wrong labels being placed on products which results in consumption of the wrong items in the IS if not noticed (DeHoratius and Raman, 2008). The second relates to products are not identified correctly when doing inventory audits, which leads to incorrect inventory levels not being adjusted (Kang and Gershwin, 2005).

Where transaction errors occur naturally depends on the line of business. Chan and Wang (2014) remarks that IRI is a common phenomenon in mass production environments where it is difficult to track raw materials and work-in-progress at all stages in the production processes. In production, components are generally consumed as the manufacturing process progresses and creates different inventory hierarchies. These hierarchies typically include raw-material, work-in-progress and finished products and are visualized in Figure 1. When this is performed automatically by the IS, it is commonly referred to as backflushing (Sheldon, 2004). Components are consumed as they pass onto the next hierarchical level and becomes products or sub-assemblies. Subsequent levels do not take components into consideration at all as they only consume the refined product or sub-assembly from the earlier stage. By using backflushing in the inventory system, manual transactions can be eliminated and thereby decrease the cost of manual labour. However, it requires transactions to be performed correctly so the right amount of inventory is consumed at each stage.

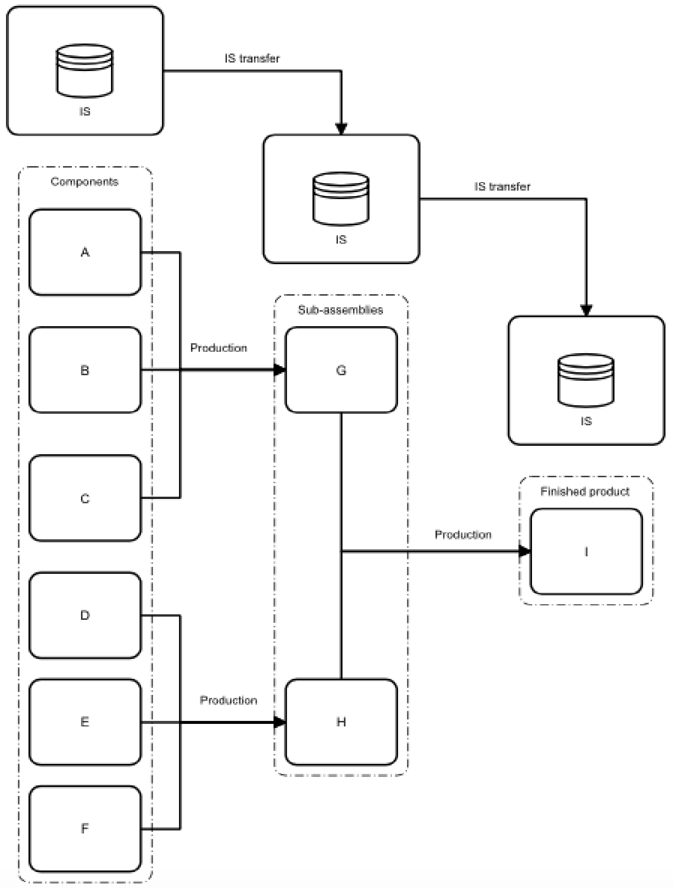

Figure 1: An example of the backflushing principle using components A-F, which are processed into sub-assemblies G, H and later to product I. When the components have been physically processed in various production steps, the hierarchy level changes in the IS.

1.3 Consequences of IRI

A well-functioning IS enables access to the right products, in the right time and in the right condition. When these conditions are not met, negative impacts may affect departments at different levels within a company, which constantly needs to adapt to poor conditions instead of focusing on their core activities (Wayman, 1995). Struggling with IRI at a manufacturing company generate consequences for the company's business performance, whereof Fleisch and Tellkamp (2005) mentions several; when material is not found re-scheduling of planned production might be necessary, getting more material from suppliers increases cost and customers that do not receive their orders might claim for compensation for default delivery. Moreover, since items not found cannot be sold, IS inventory still carries costs, but do not generate revenue from customers (Sethi and Shi, 2013). The IRI distorts the book value of inventory and thereby important business decisions. Discrepancies between the IS and the actual physical inventory can result in severe economic losses for companies (Chuang and

Olivia, 2015). IRI can be viewed as decreasing business productivity, since every input of raw material is not turned to output in terms of finished products as discussed by Rajeev (2008) and Ruankaew and Williams (2013). Additionally, most companies rely on data from their IS when purchasing. Efficient purchasing procedures becomes difficult due to IRI in terms of purchasing products in time and of sufficient quantity (DeHoratius and Raman, 2008). The reversed scenario where physical inventory exceed IS is also an issue, mainly due to excessive warehousing in short term, but also a long-term issue in terms of driving costs of excessive inventory. Therefore, this scenario also hampers the ability to reduce inventory levels and increase business efficiency (Arifin and Ismael, 2019)

1.4 Company and process description

The study object of this thesis is a Swedish manufacturing company operating in the automotive industry. In the manufacturing process employed at the company, two highly automated sub-processes, supervised by trained operators are producing sub-assemblies which are used as key parts in the finished products sold to customers. One of these sub-processes, hereon referred to as: “PRE-lines”, has been the primary focus of this study. At the PRE-lines, combinations of five different components (A, B, C, Dx and Ex) are assembled in several production processes into a finished sub-assembly which are used in subsequent manufacturing processes. By the time this study was performed, the company had six PRE-lines which produced different versions of the sub-assemblies depending on the finished product.

Table 1: Description of components

Component	**Variation**	**Description**
A	No	Metallic, cup-shaped detail. 40 x 25 mm.
B	No	Thin metallic disc. 35 mm.
C	No	Button-shaped metallic detail. 25 x 5 mm.
Dx	Yes, 5 versions	Thin, hole-punched metallic disc. Variation in number of holes (5-9). 20 mm
Ex	Yes, 6 versions	Metallic vessel, varied sizes. 40 x 50-75 mm

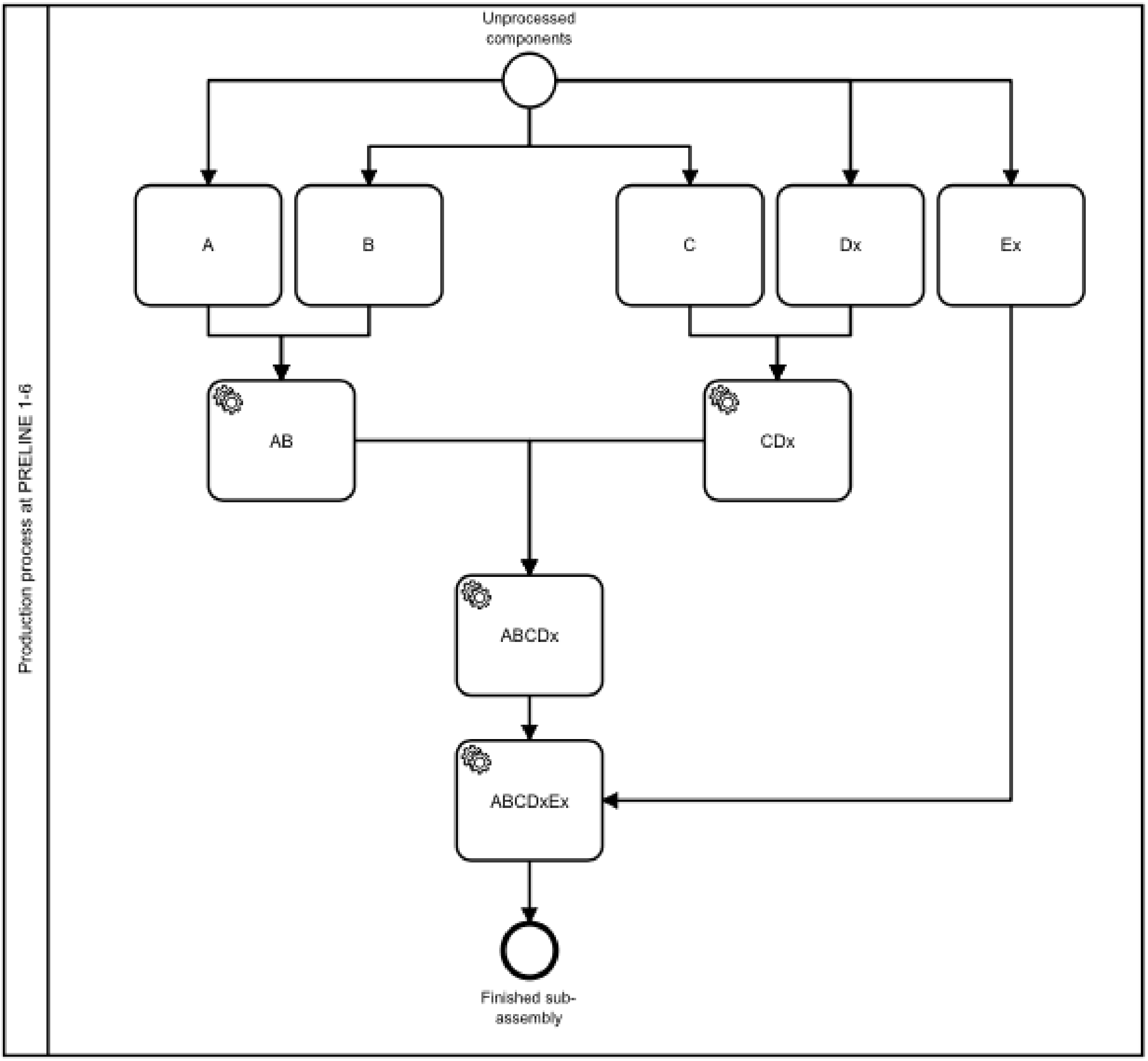

Figure 2: Overview of the PRE-line production process with using components A-E. The cogwheel symbol indicates a process where components are assembled and value-added.

1.5 Problem statement

There are several philosophies of how to cope with IRI, whereof three are mentioned by Sethi and Shi (2013). The first option is to prevent IRI from occurring in the first place by using tracing technologies such as RFID. However, studies that emphasize RFID have often been set in a retail environment and is usully not a feasible solution for mass-producing manufacturing companies (Ruankaew and Williams, 2013). For instance, Chan and Wang (2014) states that mass-producing manufacturing companies usually have far greater volumes and variety of inventory (raw material, work-in-process and finished products) compared to retail companies. For RFID-effectiveness in a mass-producing environment, RFID-tags would have to be placed on all inventory, encompassing several hierarchical levels which makes RFID unsuitable due to high implementation cost. The absence of RFID in this environment, without other suitable solutions for tracking inventory can generate missing links between the inventory on hand compared to the inventory records (Rajeev, 2008). This brings forth the second option, which is to correct the IRI by doing periodic inventory audits (Kang and Gershwin, 2005; Atali et al. 2009; Agrawal and Sharda, 2012). Periodic inventory audits can, however, be seen only as a temporary solution to get rid of IRI. If the real sources of IRI are not identified, IRI will eventually reoccur (Wild, 2004). Therefore, efforts must be directed at the source of the problem for sustainable improvements (Rossetti and Buyurgan, 2008). Also, periodic inventory audits can be hard to perform for manufacturing companies since it often requires complete shutdown of operations (Kang and Gershwin, 2005). The third option is to integrate the inaccuracy factor into the planning and decision-making of inventory management (Sethi and Shi, 2013). An integration of the inaccuracy does, however, require knowledge of the inventory inaccuracies extent, i.e. that the inaccuracies are stable with low variability in order to integrate IRI into decision-making (Hoerl and Snee, 2012).

The inherent complexities of mass production enterprises bring difficulties in tracking material and work-in-process at every stage in the manufacturing process (Chan & Wang, 2014). In general, inventory in a manufacturing process travel two possible paths. It either ends up as finished product and proceeds to be sold to customers, or it is discarded as a defect and will subsequently be dismantled, re-worked or thrown away. In either case, all transfers, either physically or digital inventory records are potential sources of IRI. Accordingly, there is a constant need of always enforcing the inventory records to keep them accurate (Wild, 2004). In particular, manual handling of inventory records together with informal practices are drivers of IRI, as discussed by Rajeev (2008) and Ruankaew and Williams (2013). Thus, in the strive for increasing inventory record accuracy, attention needs to be directed to all activities that handles inventory and inventory records, which includes the need of precise and accurate scrap processes, where discarded components are removed from the company’s IS. A vital goal for manufacturing companies is the total elimination of generating defects at all. Until this is achieved, however, discarded components must be acknowledged accurately and removed in a correct way from the IS.

Manufacturing organisations are commonly faced with decisions that require trade-offs between different business operations (Sarmiento, 2011; Adamides & Pomonis, 2009; Da

Silveira, 2005; Shahbazpour & Seidel, 2007). The company examined in this study faces a plethora of different business objectives that might conflict each other. Often discussed areas in the literature includes business objectives such as: cost, delivery lead-time, volume, or the quality conformance of the finished product. However, the objective of maintaining inventory record accuracy is often overlooked as it is seldom regarded as a dimension of manufacturing that brings value and competitive advantages to the company. Although, Adamides & Pomonis (2009) brings forth that whether narrower functional objectives are prioritized over company-wide objectives in a trade-off situation is dependent on the attitude of the manager. Gumrukcu et al. (2008) notes the cost-related to trade-offs that manufacturing companies may have to accept that can follow in the wake of IRI. Their simulation focuses on cycle counting as a primary mean to combat IRI and avoid higher holding costs. In the absence of a reliable automatic scrap counting system the examined company in the study utilizes a similar costly and resource-demanding solution to ensure correct inventory records. The manual scrap counting performed at the case company does not only demand significant time from operators and shift managers, but does also require the production lines to be stopped for unnecessarily long times, causing unnecessary production downtime and hence reduces productivity. The general view of trade-offs within a manufacturing context involves raising one aspect of performance at the expense of other aspects (Skinner, 1992). The company in focus has chosen to work with a manual, time-consuming scrap counting system that, inevitably, has negative repercussions on other activities.

1.6 Aim, purpose and objectives

The aim of this thesis is to investigate a manufacturing company's scrap management system with the purpose of evaluating if this is a source of IRI and how their current scrap management system affects the company. The objective of this research is threefold. The first objective is to investigate the manual scrap counting systems' vulnerabilities and propensity in terms of generating IRI. This has been performed through a mixed methodology using both qualitative and quantitative data. The qualitative data consisted of on-site observations together with interviewing key personnel involved in the scrap management process to understand how the process is performed, as well as its vulnerabilities that cause IRI. The quantitative data consisted of measurements of the generated scrap at the PRE-lines where the causes of error were identified. In the discussion chapter, both methodologies are coupled to analyse the current systems performance based on both quantitative data as well as the qualitative data for possible explanations of potential sources of IRI in the scrap counting system. The second objective examines what impact the current manual scrap management system has on the operations it affects. Due to that the automatic system not having been considered reliable enough, the company uses a manual scrap counting system. However, the manual system demands considerable resources which could be spent on other value-adding activities. The identified areas of operations that are affected by the current manual scrap management system are examined and analysed in the discussion chapter. The third objective comparatively measures the performance of the two scrap counting systems at the company in order to strengthen the validity of the study and gain knowledge and understanding regarding the company's decision to reject the automatic system. This objective serves to investigate the systems' reliability in providing accurate inventory records since the company to this day has limited knowledge about how the two systems actually are performing.

1.7 Research questions

1. What vulnerabilities that can cause inventory record inaccuracy has been identified in the company's current scrap management system?
2. What areas of operation are affected by the company's current scrap management system?
3. How do the company's two scrap counting methods perform in terms of generating inventory record inaccuracy?

2. Literature review

Previous literature within the field of inventory record inaccuracy has been examined as a baseline for this paper. From this literature review, it has been found that most studies has simulated IRI, such as Fleisch and Tellkamp (2005); Kang and Gershwin (2005); Sahin and Dallery (2009); Agrawal and Sharda (2012); Xu et al. (2012); Chan and Wang (2014) and Kumar and Everts (2015). The simulations do however suffer from inherent drawbacks, such as having to make assumptions of facts and that simulations are unable to portray the dynamic and complex reality that companies face (Oliveira et al., 2019). This inherent inability may reduce the validity of the conducted research (Brown, Inman and Calloway, 2001). Therefore, more attention has been directed at reviewing the case-study related works. Most of the case-studies have, however, been conducted in a retail- or store setting (Raman, DeHoratius and Tan, 2001; DeHoratius and Raman, 2008; Chuang and Olivia, 2015). Few studies have been conducted in a manufacturing environment which distinguishes from retail by using raw material, compared to mostly finished goods handled in retail companies (Ruankaew and Williams, 2013).

2.1 Previous literature - simulations

The simulation-related literature has mainly focused on the impact of IRI in supply chains. Fleisch and Tellkamp (2005)'s paper of inventory inaccuracy and its relationship with supply chain performance found that both technical (RFID) and non-technical strategies (benchmarking of non-IRI units, awareness-building of employees and process improvement) could solve IRI but with regards to different aspects. RFID was found to solve problems related to deficiencies of inventory audits and non-technical strategies for avoiding the occurrence of IRI-problems in the first place. However, in contrast to this conclusion, Xu et al.'s (2012) found that non-technical strategies are insufficient for solving IRI in a study of impact of inventory shrinkage and IRI. Instead, Xu et al. found that only RFID solves IRI efficiently, although with a substantial cost. Other simulation studies have chosen more internal and operational focus. Kang and Gershwin (2005) studied the impact of IRI and automatic inventory replenishment systems and found that even small rates undetected IRI can lead to severe stockouts, which is more costly for businesses than the actual cost for the lost material itself. Similar to the previous works mentioned, Kang and Gershwin emphasizes that RFID-solutions can solve IRI, but concludes that RFID require substantial investments not only of money, but also of the time needed for implementation, without any guarantees for actually solving the IRI. Agrawal and Sharda’s (2012) simulation investigated the impact of doing inventory audits with respect to the frequency of stockouts both with and without RFID-solutions and showed that a frequency of monthly audits seemed to be optimal for decreasing the risk of stockout. A higher frequency than this, would however not lead to further improvements. The impact of IRI on safety stocks with variation in both demand and lead time was studied by Kumar and Evers (2015) and showed that IRI can cause problems for management planning and using data for decisions related to inventory replenishment and safety stock levels. Most businesses use automatic replenishment systems for material, which result in efficiency drawbacks for firms suffering from IRI. Chan and Wang (2014) investigated the impact of IRI on production costs. In their paper, they presented two main options for firms that are experiencing IRI. The first option is to accept IRI and mitigate problems through higher inventory levels and increases holding costs, while the other option simply is to accept low service levels and face backlog costs from customers.

2.2 Previous literature - case studies

The previously performed case-studies presents several interesting findings regarding the impact of operational processes that, although most studies have been performed in the retail industry and not the manufacturing industry, still can provide relevant information. Raman, DeHoratius and Ton’s (2001) study regarding the impact of operational executions in a retail chain added several important findings to the IRI-related research field. Firstly, they found that an increasing variety of products cause more complexity in the operational execution. Similar, but systematically different products can be treated as the same. When two different products are treated as the same, it will cause an overestimation of one product in the IS, which eventually may lead to stockout. The same problem would also lead to an underestimation of the other product, since it is not consumed at all. This error was especially related to new employees, unfamiliar with products and the operations. Another factor that increases complexity is related to the framework and difference between the actual system and the reality of many businesses IS. In reality, inventory has several locations for logic reasons, such as that making it available for operations. But in the IS, inventory often only has one location. Therefore, when inventory physically runs out in one location, employees have to look at several locations, which often is further complicated by misplacement of products in stock-locations. To cope with these problems, Raman, DeHoratius and Ton (2001) suggested that businesses need to create awareness of the whole chain of activities, originating from the source of the problem, up until the point where the problem is experienced. Transaction errors leads to IRI, IRI leads to stockouts, and stockouts leads to lost sales and thereby lost revenues. If employees are unaware of this chain of events, the problem will most likely remain for the business. Awareness can be built and strengthened by operational processes that have reduced levels of complexity such as elimination of steps and sub-processes that do not bring any value to the system's output (DeHoratius, 2008). Furthermore, building well-functioning operational processes and procedures requires documentation of the processes from start to end. Additionally, to maintain the functionality of the processes, the actors within the system need to have an understanding of the different parts of the processes, and checklists and routines for the system must be robust (Ruankaew and Williams, 2013). Building awareness can also concern employee training. Employees need to be properly trained to execute their actions in a process in order not to make unintentional errors (Ruankaew and Williams, 2013; Chaung and Olivia, 2015). In order to spread sustainable improvement between processes, identifying crucial factors and their performance have been suggested by DeHoratius and Raman (2008). By doing this, well-performing processes can be benchmarked and later transferred to poor performing processes.

2.3 The cost of avoiding IRI

Enhancing the inventory management to avoid IRI is often an extensive task that needs to be anchored within the management of the company and their manufacturing strategy. Boyer and Lewis (2002) describes trade-offs in this context as the need for manufacturing plants to assess and prioritize their strategic objectives, and in a later stage allocate necessary resources to strengthen capabilities needed to reach the stated objectives. In most cases the broader company-wide objectives get prioritized, while more specific functional objectives often demand special attention from managers in trade-off situations (Adamides and Pomonis, 2009). However, as mentioned in earlier sections, there are several ways to combat IRI and strengthen the inventory management in the organization. Kang and Gershwin (2005); Agrawal and Sharda (2012) and Xu et al. (2012) discusses implementation of RFID as a plausible solution to avoid IRI. However, they all acknowledge the trade-off this amounts to as the solution comes with a significant cost attached. Agrawal and Sharda (2012) furthermore examined the trade-off between costly alignment of inventory through regular cycle counts and eventual stock-out as a result of IRI. Gumrukcu et al. (2008) examined operational trade-offs in mitigating IRI as well. The two major cost dimensions discussed constituted the trade-off between cost of performing regular cycle counting and the cost of holding additional inventory. While their favored solution, cycle counting, proved useful when handling slow-moving high-value goods, applying cycle counting in an environment characterized by low-value goods only result in trivial savings.

An improvement trajectory to manage trade-offs is suggested by Da Silveira (2005), who notes that companies need to acknowledge trade-offs and hold efficient tools to manage trade-offs within their organizations. These tools demand influence over the manufacturing strategy as well as the structure of the organization. Caution should be taken, however, to ensure that the individuals at the different levels of hierarchy in the manufacturing company have the same view of the priorities generating the trade-offs (Boyer and Lewis, 2002). In contrast to Da Silveira, Shahbazpour and Seidel (2007) argues that manufacturing companies should strive towards eliminating trade-offs, instead of improving trade-offs and deal with compromises, and propose management of manufacturing system and process innovation as the most suitable solution. Miltenburg (2008) notes how trade-offs often arise from technological boundaries, and as processes improve, the boundaries move further out, reducing the impact of the trade-off. Sarmiento (2011) further develops these thoughts and argues that trade-offs exist in every organization, but so does compatibilities. It is up to the companies to analyze and identify what objectives can be considered trade-offs and thereby will affect each other negatively when improving the counterpart, and what objectives can be considered compatibilities and will have a joint positive impact with improvement.

3. Methodology

3.1 The research approach

The research process of this study uses a mixed methodology approach. This specific approach typically includes the collection, analysis, and interpretation of both quantitative and qualitative data in a single study or in a series of studies (Leech & Onwuegbuzie, 2009). This study needed to encompass and rely heavily on quantitative measurements due to the subject's nature in order to find out the precision and performance of the company's scrap counting system. By adding a qualitative aspect with data collected through interviews and observations, a broader perspective could be reached. Traditionally, business-related studies within fields such as supply chain management, business operations or logistics have been void of studies using a mixed methodological approach (Golicic & Davis, 2011). The decisive reason for this is that research reports including quantitative techniques have had much greater chance of being published. There have naturally been occasions where researchers and scholars have used qualitative data, but they have tended to conceal or even quantify their qualitative data in order to please the publishers (Sutton, 1997). However, since the years following the millennia, the mixed methodology approaches have gained more recognition. In specifically complex phenomenon of interest the qualitative aspects serve to provide the researchers with a grounded understanding of the subject, mainly the context surrounding a problem and the variables affecting it (Golicic & Davis, 2011). A visualization of the interplay between the qualitative approach and the quantitative approach developed by Golicic et al. (2005) is presented in Figure 3. This study concerns IRI, a considerably complex area in itself, within a manufacturing plant with several different important variables in play. The usage of a mixed methodology was therefore judged to be the most suitable for the study.

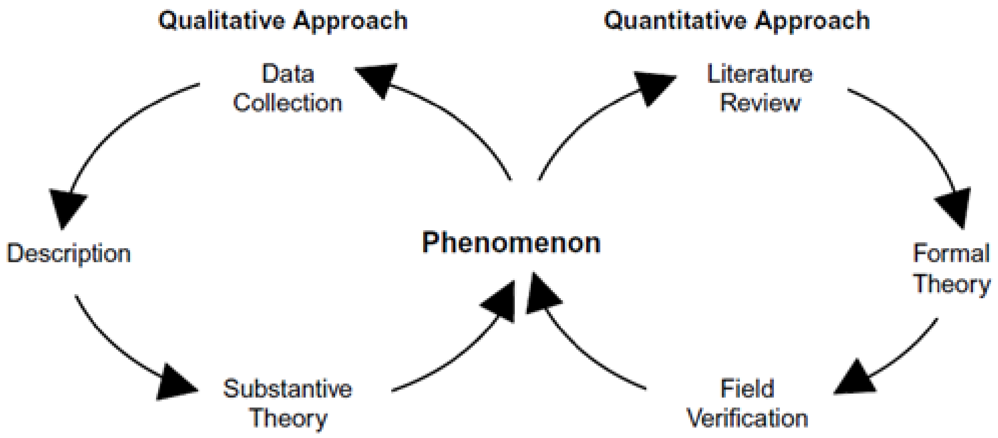

Figure 3. The balanced approach model developed by Golicic et al. (2005, p.20). The model shows the interplay between qualitative and quantitative approach to investigate the research problem i.e. the phenomenon.

3.2 Quantitative data collection

An exploratory quantitative data collection method was used to investigate the performance of the manual and the automatic scrap counting systems. This method was used primarily to provide the study with basic information of whether the manual scrap counting system and the automatic scrap counting system are sources of IRI, which connects to the purpose of exploratory investigations explained by Collis and Hussey (2014). The quantitative data collection was performed by initially, in consultation with the production department at the company, establish a temporary work instruction for collecting all discarded components at the PRE-lines 1-6. The instruction implemented differentiated from the current routine by introducing a subsequent step which enabled the authors to compare the actual scrapped material to the reported scrapped material, as visualized in Figure 4.

In the current system, scrap generated from the PRE-lines 1-6 are collected in “scrap-bins” which are manually counted and recorded on scrap lists for each line at the end of each shift. After being counted, the scrap is transported by operators to a location in the warehouse and subsequently thrown in a scrap container. All scrap lists are collected every Thursday where the shift manager summarizes the scrap generated on all PRE-lines during the previous week and performs the IS transaction from RF/PP to SCRAP, which will be further explained in the findings chapter. The scrap management system ends with the production manager authorizing the removal of the scrap volumes from the IS.

In the temporary work instruction implemented by the authors, the routine differentiated slightly for the authors to measure the scrap counting performance. Instead of throwing the components into the scrap container after being counted, they were put in cardboard boxes nearby the current scrap-bins. These boxes were collected by the authors who counted all components from each shift and each PRE-line, recorded the material in numerical form into a raw data file, and lastly threw the scrapped components into the scrap container. The boxes were returned to the respective place nearby the production line and the procedure was repeated daily during the measurement period. Concurrently to counting the scrap volumes the authors also collected data from the scrap lists as well as from the automatic scrap counting system for the PRE-lines where it was functioning at the time of the data collection (PRE-lines 1, 2 and 3), and subsequently added these figures to the raw data file as well. Prior to the measurement period, the authors documented specific material characteristics such as dimensions, markings and colour differences of each component in order to distinctly be able to separate the variations of each component when accounting for the scrap volumes and enable identification of potential transaction errors to strengthen the study’s validity.

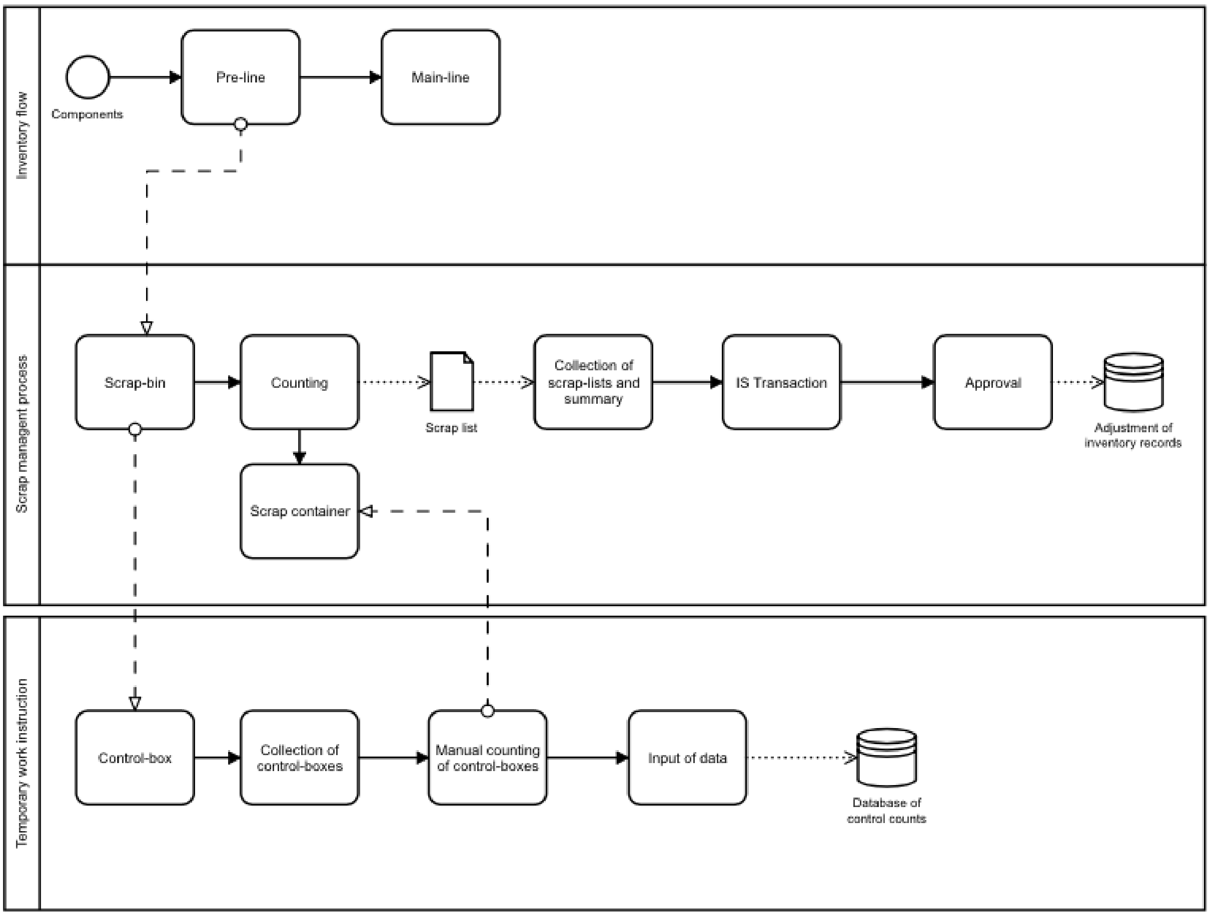

Figure 4: A simplified visualization of the current scrap management process together with the temporary work instruction implemented.

The temporary work instruction established by the authors was active during the period w.11-13 2020. In terms of the operational definition of what was measured and entered in the raw data working file, a decision was made to collect scrap data generated from the PRE-lines based on the parameters in Table 2. In order to ensure the study's reliability, it was decided that the operational definitions and purpose of measuring these factors was determined before starting the data collection, based on Hoerl and Snee (2012)'s discussion about ensuring reliability of studies and enable the study's repeatability. The variables in the raw data file provided the authors with useful and manageable data to work with during the course of the study following the data collection period.

Table 2: Parameters used in data collection and motives for inclusion.

What was included in the raw data file?	**Why was it included?**
Date	To structure the raw data set and analyze the scrap reporting data based on when it was generated.
Line	PRE-line 1-6. To analyze scrap reporting data from the different PRE-lines.
Shift	Early, late or night (three shifts in total) to analyze scrap reporting data based on the different shifts.
Component name	(A, B, C, D, E) To analyze scrap reporting data considering the component type, but not the component variations.
Component number	(A, B, C, Dx, Ex) To analyze scrap reporting data considering all component variations.
Manual scrap counting	To analyze scrap reporting data generated from the manual scrap counting system.
Automatic scrap counting	To analyze scrap reporting data generated from the manual scrap counting system.
Control count	To have a baseline with correct scrap data to compare with the two scrap counting systems.

The chosen collection method had several benefits compared to other considered methods. Firstly, the procedure minimized the impact on the current used method and thereby also the impact on the concerned parties (the production staff) since the implemented temporary work instruction minimized the change of their work process. The temporary work instruction was developed through several meetings and was perceived as crucial to this study's validity as well as reliability for both the authors and the company. The validity of the study is fortified by the authors' routinely data collection, in line with earlier methodological research of validity in data collection (Collis and Hussey, 2014; Yin, 2018). In terms of the measurement's reliability, the authors strove for transparency of explaining how the employed methods were used and the underlying purpose of the methods chosen. Related to this, other methods were considered but ultimately rejected. For example, a considered, but not used method was to not implement a temporary work instruction and measure the scrap that is thrown into the steel container. However, if this method was used, it would not be possible to measure the quantity of scrap on each line and in terms of components other than comparing the total quantity with the scrap lists. This type of measurement would also not enable an accurate comparison with how the manual and automatic scrap reporting system performs, to what is actually thrown in the scrap bins. Therefore, the method was considered inferior to the method employed for the study.

3.3 Qualitative data collection

An explanatory qualitative data collection method was chosen to identify vulnerabilities in the company's current scrap management system as well as how that system impacts other areas of operation. The explanatory method can be appropriate when research intends to provide with explanations and analyse why and how certain events occur (Collis and Hussey, 2014). Throughout the research process, direct observations and semi-structured interviews was used for collecting qualitative data, further explained in subsequent sections 3.3.1 and 3.3.2.

3.3.1 Direct observations

The foundation of this paper was constructed by direct on-site observations where key personnel (Respondents 7, 8 and 13) demonstrated and explained pre-production and scrap processes employed at the company. During three walkthroughs, notes were taken on paper which later served as a foundation for a process mapping, which is favored by Rother and Shook (2003). The process map served both as a supporting tool for the authors in the understanding of the process and for presenting the findings (Damelio, 2012; White and Cicmil, 2016). Throughout the research process, the process mapping was continuously expanded and strengthened by the semi-structured interviews, where missing links in the process mapping were clarified. In this study, Business Process Management Notation (BPMN) was employed for visualizing the company's scrap process. BPMN is according to Rodriguez, Fernandez-Media and Piattini (2007) one of the most commonly used process visualization tools and offers high level of understandability for both technical oriented and non-technical oriented readers (Owen, 2003). The final process maps presented has been produced with the software *CAWEMO*, which is a free-to-use software as service (Camunda, 2020).

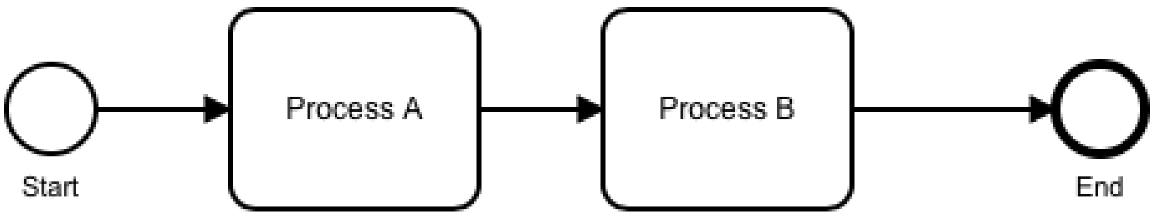

Figure 5: A two-step process illustrated with business process management notation (BPMN) "Business process diagram" based on Owen (2003, p.7)

3.3.2 Semi-structured interviews

To get deep-insight information of how and why functions at the company are affected by the current scrap management process, semi-structured interviews was performed with identified personnel which are affected by this process. The semi-structured method allowed the authors to gain insight regarding different views and opinions regarding the scrap management process based on the respondent’s line of work. Before conducting the interviews, an interview guide was constructed with determined topics, questions, and potential probes for questions. The final interview guide is presented in Appendix A. When constructing the interview guide, special attention was given to formulating good, relevant, and non-leading questions similar to the guidelines presented by Yin (2018) for constructing high quality interview guides. In total, ten telephone interviews and four face-to-face interviews were performed with respondents at the company (Appendix B). The interviews were conducted in Swedish and consecutively transcribed. In the final text, only quotes were translated to English in order to keep the respondent’s views as correct as the authors found possible. During the interviews, the interview guide was considered more of a supporting tool for the authors rather than followed strictly, a method which is favored by Kallio et al. (2016). This is beneficial since the interview can reveal issues which were not considered before the interview and the researcher can treat the interview more as a conversation and listen to what the respondent is saying, rather than taking notes and lose important information (Yin, 2018). Before the interviews were conducted, the respondents were informed of the study’s purpose, why they were being asked to participate, and if they would give their consent to the interview being recorded. In order to not cause any potential damage to the respondents, the authors decided to treat all respondents anonymous as a rule rather than exception, which is supported by Yin (2018) in order to get access to potential harmful and sensitive information. All interviews were transcribed to paper in order identify important information given by the respondents during the interviews.

3.3.3 Qualitative data analysis

The initial stage of qualitative data analysis was characterized by handling the transcribed interviews based on the content analysis methods presented by Bengtsson (2016) and Ergilsson & Brysiewicz (2017). The first step consisted of reading the transcribed interviews multiple times to understand the context and meaning of different respondents' statements. During this step, the authors took individual notes and codified the transcribed text. These notes and codes were subsequently compared and served as a base for categorizing coded statement. The codification process was characterized by what Bengtsson (2016, p.10) refers to as *"deductive reasoning"* since the codes were derived from the decided research questions. For example, the code *"Interpretation of scrap lists"* was used every time a respondent referred to the difficulties in reading the figures written on the manual scrap lists. In Table 3, examples are presented for how the process from raw interview data to final categorizations was performed, which can serve to strengthen the validity of studies (Ergilsson & Brysiewicz, 2017).

Table 3 Examples of how the content analysis was performed based on Ergilsson & Brysiewicz (2017)

Raw interview data	**Code**	**Category**
"When we receive goods, everything is firstly checked in at stock location RC and then transferred to stock location RF, PP or Other" - Respondent 8	Information about the inventory system	Background information about the inventory system
"In a mass-moving manufacturing environment, it is hard to measure and correct the inventory levels" - Respondent 3	Inventory management difficulties	Other, non-scrap related information about IRI
"You really to make an effort to see what is written on the scrap list" - Respondent 2	Scrap counting procedure by shift managers	Vulnerability
"It takes quite some time since there is a hefty bunch of paper that should be calculated" - Respondent 14	Time commitment: shift managers	Operational effects caused by the manual system
"Somewhere the computer counts incorrectly. The software could use more clear instructions to distinguish what should be counted as scrap" - Respondent 6	Doubts regarding the trustworthiness of the automatic system	Information and opinions about the automatic system

3.4 Comparative study of the two scrap counting systems

The comparison section of the study revolves around the performance of two different scrapping systems of the company. The company have already deemed the automatic too unreliable to base their scrap records from, but in order to ensure the validity of the research the authors performed an additional comparative study to confirm the company's decision. The purpose of the development of the automatic system is to reduce the manual handling and ensure the precision and accuracy of the scrapping system. In order to investigate the performance of the two systems, a comparative study will conclude the empirical findings chapter. A comparative study inhabits the prerequisites to answer the question whether two different available methods can be used to measure something equivalently. Worth noting is that a comparative study of processes does not aim to improve the processes directly, but merely identify areas of conflict and provide supporting data and knowledge for further improvements (Xiao & Zheng, 2012).

Ideally, a comparative study is based on samples of paired measures. The higher the sample, the more reliability is added to the study (Hanneman, 2008). The automatic scrap counting system was active on PRE-lines 1, 2 and 3 during the data collection period which resulted in these three lines being the only ones featured in the comparison section. Although a myriad of statistical tests and measurements exist to apply to these kinds of process performance studies, the authors deemed it uncertain to apply such methods due to the nature of the data collected. The general thumb-rule for sample sizes usually revolves around 30 measurement points (Cortinhas & Black, 2012). Although, the raw data collected in this study well exceeds 500 measuring points, the distribution of components and interference in the data quality during the data collection phase did not result in more than 30 succeeding measure points for components on specific lines. Caution was being taken not to combine data from different production lines as to not risk catching effects and trends due to inherent differences in the production lines when comparing the two scrap counting systems. While choosing not to conduct a statistical test in order to perform the comparative study, the authors opt for presentation of the raw data and relevant computation of these instead. Reasons for not achieving a larger number of data measurement points could largely be attributed to the outbreak of the covid-19 virus that had a very palpable effect on the examined company, as well as companies in general in Sweden, which in turn affected the data collection negatively. During week 12, in the middle of the data collection period, a perceived virus threat led the company to send an entire production shift home to be quarantined. Further business-related actions were later taken which led to the company releasing all their employees belonging to staffing companies, as well as having the regular employees reduce their work hours to 40 percent of their regular amount. With these new conditions the company was not able to keep their night shift running, and the following weeks saw only two shifts running with a vastly reduced production crew. These actions had severe effects on the data collection which naturally dropped due to the production lines standing still. The small amount of data generated due to the fact that only one production line was left running during w 13, as well as the present infection risk, the authors decided to terminate the data collection on Wednesday w 13. Presentation and analysis of the data will follow in subsequent chapters to continue the comparative study.

4. Empirical findings

All findings presented in this chapter is presented in order following the research questions. The chapter is initiated in 4.1 with information regarding the inventory flow in production, the company’s IS and an explanation of the current manual scrap management system, which has been collected from interviews and through performed walkthroughs. In chapter 4.2, the identified vulnerabilities in the current manual scrap management system are presented, which was collected through interviews as well as observations. The identified areas of operations that are affected by the manual scrap management system are presented in chapter 4.3 from data gathered from interviews. In the final subsections, findings from quantitative measurements of the scrap systems are presented. The manual scrap counting system’s performance is presented in chapter 4.4. In the concluding section 4.5, the comparative study between the manual and automatic scrap counting systems is presented.

4.1 The inventory flow and nature of the inventory system

4.1.1 The inventory flow up until end of PRE-lines

The process of manufacturing finished products at the company starts with the inbound function where pallets are unloaded from trucks. A visual inspection is performed to control the pallets’ content and potential damages and are transferred into the inventory system location RC, which is the company’s dedicated stock location for arriving goods (Respondent 8). From RC, pallets are transferred both physically and systematically to three locations: RF, PP or Other stock location. RF and PP are both so called “supermarket”-locations, meaning that they are accessible for manual handling by the internal supply “Kanban-truck”. The Kanban-truck is driven by an operator who manually picks up components used in the manufacturing process, which are triggered by a pull signal (i.e. the Kanban card). “Other stock location” refers to general inventory lots which are less accessible, usually requiring a forklift truck to reach. The components are transferred physically by Kanban to the PRE-lines 1, 2, 3, 4, 5 or 6 depending on which components are requested. This physical transfer is not registered in the inventory system. At the PRE-lines, the requested components are unloaded from the Kanban truck and placed in designated limited inventory lots. Components are manually loaded into “feeder-bowls” which supplies the machinery with needed components. From this step, machines are processing components into sub-assemblies through different manufacturing process steps. If the production process is successful, the components are automatically transferred in the IS from the stock locations RF or PP to the stock location PREG, where they are transferred from being components to being a finished sub-assembly (Respondents 7 and 13). PREG is the IS location from where the main production lines are consuming finished sub-assemblies.

4.1.2 The nature of the inventory system: Inventory system locations and physical stock locations are not aligned

The information system used by the company does not align the physical location with the IS location at several points in the system. These points visualized are within the current scrap process mapping, but also occurs at several other points in subsequent processes. Since these processes can have an indirect impact on the scrap management process, they will be discussed regarding how they are affecting the scrap management process, even though they are not visualised in Figure 7. There are two general explanations to why the physical location and IS locations are not aligned. The first explanation is related to that stock kept at IS location RF/PP may be at physical RF/PP, but might as well be located somewhere else as work-in-process. These locations include: 1) Kanban, where inventory is under transport, 2) at the production line, where inventory is stored temporarily before being processed, 3) in the production process, where components is being value-added to sub-assemblies or 4) in the scrap bin, due to being discarded in the production process. When the PRE-production process is successful, components are automatically transferred from the inventory system RF and PP to stock location PREG and the components transforms into finished sub-assembly which is the product used in subsequent production steps. When unsuccessful, the time of non-alignment between IS and physical location can be as long as one week, due to the shift managers collecting the scrap lists and transferring scrapped material from RF and PP to stock location SCRAP on a weekly basis every Thursday.

The other main explanation of why IS and PH are not aligned is due to transaction errors performed by the operators or by the IS itself. When this occurs, components and products are transferred physically or in the IS, but not vice versa. The transaction errors fall into two main categories with different consequences: over-reporting or under-reporting of products which can occur in different stages in the production process and on different levels of finished products.

Over-reporting occurs when IS-transactions consumes more components than what has actually been consumed physically in production and has been identified as a problem on PREG by Respondent 9 as well as on other, similar production processes, by Respondents 3 and 5. At several occasions, the over-reporting has led to inventory system locations RF/PP having negative balances, which makes the transfer between RF/PP to SCRAP performed every week by the shift managers impossible. An explanation to why this is the case is due to manual errors performed by operators in a subsequent process when finished sub-assemblies are assembled with other sub-products into finished products. In this process, operators press a button to print a label representing 240 finished units. Every time this is performed, 240 units is automatically consumed at lower levels, such as subassemblies from PREG. Whenever there are exceptions to the regular workflow, i.e. at start of production or when quality tests are performed, the operator is supposed to change the settings and print a label of 10 units instead of 240. This change of settings can easily be overstepped, according to Respondent 9. Another factor involved in this label issue comes from the label paper running out in the printer, which goes unnoticed by the operator who then press the button several times, which causes a consecutive consuming of 240 components for every press of the button. Another explanation for why scrap reporting cannot be performed is that the inventory system for unknown reasons automatically starts to over-report material at a higher frequency than what is actually produced. This can occur at the reporting point PREG, but can also happen in later reporting steps, which also affects the IS inventory level at PREG.

There are several consequences of the over-reporting errors. When inventory levels at stock location PREG is increasing at a higher phase than the physical inventory level of finished sub-assemblies, components on stock location RF and PP are consumed due to the backflush hierarchical structure of the system. This triggers a signal in IS to order more components from suppliers, which may have problems to cope with the new orders. The IS might warn for low stock levels on components, but the material planner needs to be able to distinguish the real problems from the problems created by the system itself due to over-reporting, according to Respondent 3, 5 and 12. Simultaneously, when the system over-reports, a higher level of finished sub-assemblies is shown than what actually exist physically, which makes the information system unwilling to produce more sub-assemblies used in the subsequent production processes. The problems with over-reporting creates *"a false sense of comfort...it all looks good but then the problems emerge later on"* according to Respondent 3.

Under-reporting occurs when components are physically consumed, but consumption is not registered in the IS. A common cause of this is due warehouse staff moving pallets with components from OTHER to RF and PP, but fails to register the transfer in the IS (Respondents 3, 5 and 11). As a precautionary move, the company has recently implemented a routine of checking inventory lots with suspicious inventory levels, such as inventory lots that are empty in the inventory system (Respondent 3). Another, less frequent cause according to Respondent 5 is that pallets with finished products are transferred by the quality department, before they have been transferred in IS to finished products. Since the components are shown as available stock in the inventory system until being transferred, this becomes a problem when inventory levels are low. It has also occurred that the project teams has taken components directly from RF and PP without registering the transfer with the logistics department, which becomes a problem as project production at the production lines is not registered in the IS the same way as the regular production is (Respondent 5). Another under-reporting issue identified at the company is related to that components gets stuck inside the machines during the production process. Since the reporting points in the IS covers either when a successful finished product is registered, or when components or subassemblies are scrapped, these components are not reported. As Respondent 5 described, they found hundreds of components inside a machine when opening it, and no one knew if they had been reported or not. Respondent 5 described devoting full working days to investigation work related to under-reporting of components and products, sometimes even without solving the problem.

The performance of the current manual scrap counting system has been investigated previously at the company since it has been identified as a vulnerable process and a source of IRI. This previous study was however not conducted for a long enough time for providing sufficient data for analysis. They could not conclude if the scrap counting were incorrect at certain occasions compared to other occasions, or if the scrap counting was a source of IRI at all. Inaccuracy due to counting of scrap was identified, but these inaccuracies could not explain the effect on inaccurate inventory levels. (Respondent 5)

According to Respondent 5 and 11, the inventory system will always have some level of inaccuracy, which is partially explained by the inventory audit routine at place. In the current inventory audit routine performed once a year, only full boxes of material in the warehouse is accounted for. Since there often is more inventory stored at the line and bound as work-in-process, this naturally accounts for more physical inventory than being showed in the inventory records. The primary reason for having this procedure is that it is not considered possible to account for exactly all material at an audit. Furthermore, Respondent 3 explained that there are difficulties with performing inventory audits which are related to the inventory systems transaction when components are being transferred into subassemblies and manufactured into finished products.

"You want to do the audit while the production lines are not running, because it is only at that time you really know what you are counting. If not, it is a risk that you take. If material is moving and the IS transferring material simultaneously, the audit can be for nothing. Depending on when you collect the data from the IS for what you are counting, you can delude yourself." - Respondent 3

Correcting suspicious transaction errors in the inventory system is perceived to be time-consuming as well as complex. Usually, it is not enough to check single components stock level and single stock locations since a problem can be caused at several dependent or independent transaction errors simultaneously. Respondent 3 exemplified this complexity with that finished products can be under-reported, while the components and sub-assemblies are over-reported at the same time. Respondent 5 expressed similar thoughts about this problem and further expanded Respondent 3's reasoning with that correction of inventory levels cannot be performed if the problem is not fully understood, since the inventory inaccuracy can be even worsened by the transaction. A conflicting view to this problem was given by Respondent 9 who did not share the opinion that complexity is the main problem, but rather that no one checks the transaction records for stock locations on a regular basis. This is not performed because there are other, more urgent tasks that needs to be performed.

4.1.3 Low traceability of inventory in the production flow

If the inventory system would offer a higher level of traceability, the troubleshooting process would be much easier performed according to Respondent 5 who explained the inventory systems traits with:

"It is a black hole in terms of traceability and accurate inventory records. It is hard to see, it is like a darkness. Components are located on the (IS) stock locations RF and PP, then they disappear, moves around in the production lines… it is like you are throwing everything into a

pot, then it suddenly just becomes finished, but you have no idea of how it happened or what it really contains" - Respondent 5

An example of problems generated with low traceability affects components A and C. These two components are supplied by two different suppliers each. In the case of component A the two suppliers delivers according to specifications, but in terms of output, the material do not behave the same and has different defect rates depending on what production line they are run on (Respondent 4). Therefore, the company has chosen to use component A from one supplier exclusively on some production lines, while using the other supplier on the other lines to cope with the problem (Respondent 3). In terms of keeping track of the actual inventory on hand, this has caused complexity of tracing the material. In order to have traceability of component A today, visual inspections of the physical stock locations are the only option according to Respondent 9. The fact that the company is unable to trace the material used on the production lines becomes problematic in several ways. As mentioned by Respondent 12, the procurement of components generally assumes a template scrap margin of 10 % due to insufficient information of the actual scrap levels. However, there is no guarantee that the template margin exceeds the actual scrap levels or vice versa. Higher template scrap margins mean that the inventory levels increase which has a large impact on the company's financial performance. The template scrap margin thereby results in that some material may have excessive stock levels, while other material has too low margins seen from how the defect rates are today. The lack of traceability also affects the company's decision-making regarding supplier selection negatively. Since they cannot derive defects to suppliers, it may be hard to make complaints towards suppliers when components do not match quality requirements which often appears from customer complaints (Respondent 4). Additionally, components from some suppliers are suspected to tear the process machines more than components from other suppliers. Since the company cannot trace the components today, it is very hard to make process improvements (Respondent 11).

Respondent 3 believes that the introducing more IS inventory locations could be beneficial to have a better alignment between IS and PH locations, but also perceives risks associated with the introduction of more IS locations. As many transaction errors already occur today, it is likely that this problem would be worsen by more inventory locations. On the contrary, more inventory locations would give the material more dedicated locations in the IS which would allow for better alignment between IS and physical inventory, according to Respondent 3.

Respondent 11 opposes the benefit of having more IS locations. The problem is not the lack of IS locations, since IRI always will be present in the type of manufacturing the company is engaged with. Instead, Respondent 11 is more concerned that the system contains leakage of different kinds which must be dealt with.

4.1.4 The current manual scrap management process

If any of the process steps at the PRE-lines are unsuccessful, the components are transferred from the production process into a scrap-bin either by automatic detection in the machine, or manually by the process operator at the line. At the end of the production shift, the scrap bins are collected, counted, and recorded on a list by the line operator. After being counted and recorded, the scrap transported by the operators to an assigned spot in the warehouse where it is disposed in a larger scrap container. Once a week, the production shift manager collects all the scrap lists from each production line and summarizes the total amount of scrap generated from the prior week of production, a step usually performed with a calculator (Respondent 2). After being summarized, the shift-manager transfers the scrap material from the IS stock locations RF or PP (depending on where the components are stored) to stock location SCRAP by using a barcode reader together with a list of barcodes for all components used in production (Respondents 2 and 6). The production manager finishes the process by authorizing to scrap components, and the components are removed from the IS.

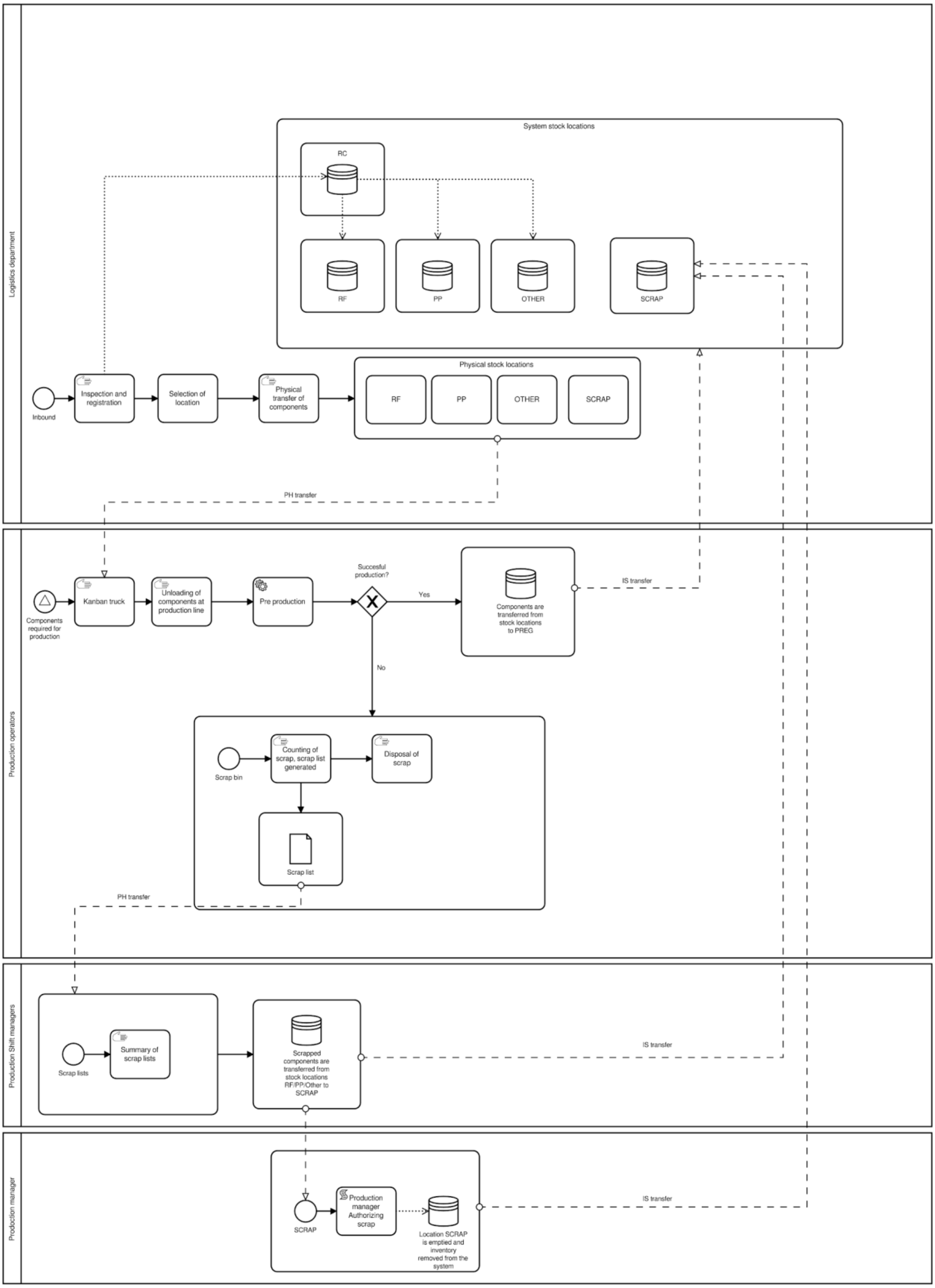

Figure 6: A visualization of the inventory flow related to the scrapping process. Physical inventory transfers are noted as “PH transfer”, and inventory system transfers as “IS transfer”.

4.2 Vulnerabilities generated in the current scrap management system

Based on the observations and the interviews conducted, two major areas of vulnerabilities for IRI has been found related to the scrap management process. The first area is related to the operations, where the scrap is counted and recorded on lists. The second area is related to the weekly summary performed by the shift managers. The system is in general considered vulnerable because of the many manual procedures performed. The manual counting and recording on lists, which is subsequently repeated by the shift managers is especially such point which arose during the interviews. Respondent 2 believes that the procedure of counting scrap manually and recording on lists "*belongs to stone age*". The system is not reliable, lists needs to be interpreted by the shift manager and might therefore generate opportunities of error which is also confirmed by Respondents 5, 6, 11, 12 and 14. Both Respondents 11 and 12 agrees that all processes which contains manual procedures and several different people are made for doing mistakes. Also, Respondent 11 believes that the human interaction in this type of manufacturing setting is the main source of variation in processes. Since the production lines have a high grade of automatization, the scrap procedure should be automated as well. Furthermore, the manual system is hampering the work towards reducing scrap levels, since the traceability of scrap disappears during the shift managers summary (Respondent 4).

4.2.1 Vulnerabilities related to the daily operations

Several risks have been identified related to operations of the current scrap management system. Firstly, it was found that small components such as components B and Dx are not always counted in detail, but rather estimated due to that the operators not having the time to count in detail (Respondent 5). Secondly, some components, like Dx and Ex that comes in different variations, are hard to distinguish since they can be very similar to each other (Respondent 6). This, in combination with the fact that the standardized scrap lists on each line contains rows for components not used on that specific production line increases the risk for committing mistakes, such as writing on the wrong row/column on the scrap list (Respondents 1, 2, 6 and 11). The scrap lists also have inadequate language, which mixes English and Swedish terms, which may be confusing, especially for new operators (Respondent 1). Thirdly, the process of counting and recording the scrap list is characterized by low grade of routines and standardization. How it is performed is much up to the individual operator, as long it is performed correctly (Respondents 1, 4, 6 and 10). Even though instructions exist, they often only tell what to do, but not how to do it which may be problematic.

"The (scrap management) instructions often tells *what* *to do, but if an instruction is sent to ten different people who reads it you will get ten different answers. I think this is a question of educating people. Things needs to be drilled in order to always do things the same way"* - Respondent 4

Based the authors' observations, it was found that counting correctly scrap can be difficult due to components having been scrapped in different stages of the production. When components have been scrapped, they all end up in the scrap bin but can physically be all from finished sub-assembly (ABCDxEx), to individual components (A, B, C, Dx, Ex), or different kinds of combinations of assembled components (AB, CDx). When they are all mixed, there is a need of a systematic approach in order to count all components correctly, and not risking missing counting components, or double-count components for that matter. Among the respondents, there were differences in opinion regarding the complexity of counting the scrap. Respondent 1 did not discuss the method used but stated that it was not generally a problem to count scrap, although it might be a problem for new and inexperienced employees. Respondent 6 described one way of approaching the counting issue as sorting all material initially before counting it, a method which might be more time-consuming but make the counting easier. Due to the lack of a standardized work instruction (SWI) for this process, this is also the method Respondent 6 shows to new employees which is under training. The lack of SWI is also confirmed by Respondent 10 who thinks the scrap counting process can be hard to learn for new employees, especially since the components differ between production lines. Another factor which can decrease the counting accuracy which was mentioned by Respondent 6 is being tired, especially in the end of the night shift.

"It is hard to learn since there is no standardized way to do it. You will have to find your own way of how to count all the scrap" - Respondent 10

4.2.1 Vulnerabilities related to weekly routines of the production management

Every week, the shift managers collects all the scrap lists generated from production to summarize it and remove the scrapped components from the IS. Since every PRE-line generates one list per shift, and there are six PRE-lines in total, 90 lists are generated per week (three shifts * six pre-production lines * five days a week). Worth noting is that this is only accounted for the PRE-lines, not scrap lists for the other sub-assembly lines and the main production lines. The number of lists may differ since the number of shifts and number of production days per week varies over time (Respondent 7) and due to that operators at times use the same list over several shift to reduce the amount of scrap lists generated (Respondents 1, 2 and 10). However, the amount of scrap lists generated is believed to generate errors in scrap reporting for several reasons. Due to the amount of scrap lists and material, the time for the summarizing process performed by the shift managers takes several hours to carry through, and doing a repetitive procedure for a long time may contribute for making errors (Respondents 2, 6 and 13). The amount of time doing a repetitive process of checking lists for scrap figures, types of components and summarizing with a calculator has several steps where errors can occur. Firstly, the shift managers, as well as others who are helping them, has expressed that it is sometimes hard to distinguish what number that is actually on the list (Respondents 1, 2, 6, 10, 11, 12 and 14).

For the logistics department, the frequency of the scrap reporting has also been a raised concern. The current procedure of doing the scrap reporting once a week affects the logistics department in several ways. Firstly, it affects the logistics department's ability to plan for production and keep track of inventory levels, since components still are shown as available inventory in the IS until the shift manager has made the transfer to SCRAP. As Respondent 12 mentioned, the production plans might look good before this transaction is made and turn unfeasible afterwards. Thus, the logistics department cannot plan production in an efficient manner. This becomes a major concern especially when some components have low inventory levels together with suppliers having problems according to Respondent 5 and 12. If the scrap reporting would be performed more frequently, it would result in more efficient decision-making according to Respondent 12.

4.3 Implications of the current scrap counting system

The implications the current manual scrap counting system has on other operations within the company is featured in the following sections. The phenomenon examined in this section encompasses the effects the current manual scrap counting system has on other operations within the company. The general term “operations” was decided since the authors wanted to capture as much different effects as possible. The presented findings are activities identified by the respondents that in some way are affected by the manual scrap management system the company employs today. The core of the studied phenomenon is what trade-offs supervene with the current manual scrap management system. Identifying the areas of the company's operations where these trade-offs occur composed an important part of the qualitative data collection. Naturally, trade-offs imply negative effects on some operations in order to enhance others. Respondents 1, 2, 4, 5, 6, 10, 11 and 12 all expressed negative views on the way scrap is handled today at the company. Descriptions of the manual scrap management system as “wasteful process” and “total waste” was stated by Respondents 2, 4, 6, 11 and 12. Common arguments criticizing the scrap management system concerned among others; the uncertainty due to the human factor, waste in terms of time usage for employees, unnecessary production downtime, or the lack of material tracing ability.

4.3.1 Production downtime

The current scrap management system affects the production time negatively. Several of the respondents referred to production downtime as a major consequence of the current system. One of the main factors that causes production down time beside machine breakdowns and model changeovers is when scrap is collected at the end of each shift (Respondents 1, 6 and 10). The PRE-lines must be shut off for operators to gain access to the scrap bins. Respondent 1 estimated the production time suffering approximately 15 minutes per shift due to the current scrap counting procedures. Other approximations were done by Respondents 4 and 6 who both estimated the time of unnecessary production downtime to around 10 minutes per line for each shift. Respondent 10 was more pessimistic and approximated the downtime to between 20 to 30 minutes per PRE-line and shift. To cope with this issue, counting scrap less frequently was a solution put forth by Respondent 6, which would enable more production time on the lines. However, due to the variety in scrap volumes generated in production, the scrap bins on the lines needs to be larger for such a solution to be implemented, as mentioned by Respondents 3 and 6. Unless the scrap levels are drastically reduced, reconstructing the production lines would be required if larger scrap bins were introduced. Respondent 10 noted that operators have been tasked with several administrative assignments lately that increases their workload and can affect the amount of time available to let the production lines go on. Respondent 12 remarked that production downtime due to operators lacking time to keep the lines running have notable effects on several key performance indicators such as production line efficiencies or takt times. This, in turn, affects the planning process of the logistic department.

4.3.2 Time usage

Time usage is a relevant subject connected to the current scrap management system and was mentioned by several respondents. In these cases, the time usage refers to the time the scrap counting process take for the line operators (Respondents 2, 5, 6, 10, 11 and 12), while it in some cases refer to the time spent by shift managers for concluding the weekly summary of the scrap lists (Respondents 2, 4, 6 and 13). The time operators spend on counting scrap and other activities of the scrap management system could be spent on value-adding activities, such as maintaining the production lines running and manufacture products.

”The time spent on the lists could be spent keeping the lines running for 10 minutes extra. Based on how you divide between the operators on the production lines you could achieve more production time and avoid much stress.” Respondent 10

However, the amount of time necessary for the scrap counting process could be very different between different individuals among the production staff. Some people are better at counting than others, and therefore spends less time for this process (Respondent 10). Shift managers could use the time it takes to summarize the lists on more value adding activities for the company such as handle improvement suggestions from operators (Kaizen) or performing 5S related assignments (Respondents 2 and 10).

4.3.3 Double work

The fact that the scrap lists are counted by the operators, and then repeated by shift managers is a case of double work at the company (Respondents 1, 2 and 12). One way of eliminating the double work and the wasteful process of summarizing the scrap lists could be to digitalize the list and make IS transactions on a daily basis instead of weekly basis. However, the company has been cautious since such a solution probably would demand several operators to have access to the IS (Respondent 2). This could lead to an increased workload on operators instead of a relief, with more duties to fulfil. Respondent 4 mentions that there definitely is a point in trying to log as much information as possible during the processes in order to be able to track the components when needed. Respondents 3 and 11 raised concerns about digitalize scrap lists since this only might lead to digitalizing already existing problems. However, there might be ways to achieve a digitalization of the scrap lists and eliminate at least one counting process. Respondent 12 elaborated around some solutions where operators would enter their counted figures into a shared excel sheet, which would rid the shift managers of their wasteful weekly summary since the figures would already be updated and summarized in the excel sheet.

4.3.4 Impact on logistics department

The current manual system brings additional workload for the logistics department (Respondents 2, 3, 4, 5 and 9). The weekly summary process leads to that substantial quantities of components are drawn from the stock locations. It is not uncommon for these transactions to not go through due the specific stock location not containing enough quantity. This means that shift managers must alert the logistics department that the stock levels need to be adjusted before the transaction of the accumulated scrap volumes can be followed through. Respondent 9 elaborates around how this notification begins a chain of activities to troubleshoot the incorrect stock location. However, as noted by Respondent 5, that sort of extra work could sometimes be beneficial for the logistics department. Although it require time to adjust the stock locations and the adjustment oftentimes have to be preceded by several other steps of inventory transactions due to incorrect performed transactions, it can sometimes allow the logistics department to spot significant errors in an early stage. Not having safeguards at the weekly scrap transaction and allowing volumes to be transferred even with negative inventory levels on the stock location, could contribute to significant problems in a later stage (Respondents 5 and 9). At the time of conducting this study, it was unclear whether this would be an issue even if the scrap counting system would have been fully automated. However, the extra work required for the logistics department must be considered as a consequence of the inherent characteristics of the manual scrap management system.

4.3.5 Facilitations of an automatic scrap counting system

When asked what differences an automatic scrap counting system would have had on their work assignments compared from today, several noteworthy thoughts arose from the respondents. Respondent 6 mentioned how an automated scrap counting process would have released more time for operators to focus on keeping the production lines running.

"I would have been able to spend more time keeping the processes going, both for the PRE-line as well as for the main line. And I doubt that the physical scrapping activity would take as much time as today." Respondent 6

An automatic system would provide better time management for operators (Respondents 1, 6 and 10). The current system comes with a certain amount of stress related issues for the operators, as mentioned by Respondent 10. Respondent 2 notes that an automatic scrap counting most certainly would have decreased the workload and time expenditures for shift managers as well, relating to the weekly summary.

4.3.6 Tracing and follow-up

The issue of tracking scrap on component level is another area where the current manual scrap management system leaves a lot to be desired. Being able to track the scrap would make it easier to know if certain errors in the production process occur more often than other errors. Being able to trace scrapped components with two suppliers is mentioned by Respondent 9, who sees an opportunity to gain more precise inventory data since the same article number is used for components different suppliers. Respondent 4 mentioned the difficulties in following up the company’s scrap goals when data cannot be extracted. A set scrap goal from the last stages in the production processes must for the time being be used due to not being able to track where the scrap originates earlier in the process. Respondent 11 noted the lack of scrap data on component level for following up the targeted scrap levels. Scrap levels are followed up by the company’s management at daily meetings, but only with regard to finished products, with scrap figures being extracted from another production information system retrieving data from the main production lines. However, the scrap measurement tools used for this is not quality assured in any way according to Respondent 12. The management has chosen this as a tool to follow up on scrap levels in lack of better, more accurate tool.

4.3.7 A question about priorities

Several of the respondents agree that the scrap management process within the company has been down-prioritized (Respondents 1, 2, 4, 10, 11 and 12). After an unsuccessful test-run of the automatic scrap counting system a few months before this study, the project has been set aside priority-wise (Respondent 10). Respondent 4 points out that scrapping was not something taken into consideration at the times the production lines were built, therefore making it hard to implement a functioning system in retrospect.

There some disagreement among the respondents what should be done to enhance the current scrap management process. For instance, one view is that the company should purchase a solution outside of the organisation since the issue has been going on for such a long time that there might be necessary to realize that the company neither has competence or the resources to undertake such a project (Respondent 4). However, Respondent 11 is sceptical to what people outside the organisation could bring to the table and suggests benchmarking solutions from other companies within the business group as a possible solution. Competences and resources do exist at the company, although it truly is a question of priority. Another automatic report system was implemented by an external partner a few years ago and although it has led to more reporting points in the production chain, it has also brought daily errors that has to be fixed according to Respondent 5.

4.4 Performance of the current manual scrap counting system

This section contains data which has been processed from data recorded in the raw data file during the collection period (w 11-13 2020). Since these findings only concern the current manual scrap counting system, data from all the PRE-lines (PRE-lines 1, 2, 3, 4 and 6. PRE-line 5 was not run at all during the data collection period) were available. Due to the uniformity of the manual scrap counting routines the data from the different PRE-lines could be aggregated in order to examine the counting accuracy for each component. From this data, three different types of error performed in the counting process by the operators were identified. The full version of the data set is present in Appendix C2.

4.4.1 Level of accuracy

During the data collection period, twelve out of fourteen components were recorded as scrap (components E5 and E6 were not recorded). The accuracy of the manual scrap counting system was controlled with two measurements. The first measurement used precise match and was used to control for three different types of error (see next section for more information). Out of 483 measuring points, 254 (52.6 percent) were classified as accurate. The second measurement used a margin of error of plus/minus five units per measurement to investigate the stability of the counting. With this measurement, 405 (83.9 percent) were classified as accurate.

4.4.2 Error types that causes inventory record inaccuracy

Three different types of error have been used to control for what causes deviation in the scrap counting process. All the errors were detected by inspecting the dataset together with classification rules set by the authors. The type one errors was defined by that operators counts scrap incorrectly, for example when the scrap bin actually contained 60 units of component A but the operator only recorded 50 on the scrap list. For type one error classification, the value of “manual scrap” had a value over zero together with deviation compared to “control count”. The type two error was defined by operators not recording anything at all, for example that 60 units of components A were present in the scrap bin, but nothing was recorded on the scrap list. Type two errors were classified by the “manual scrap” returned a value of zero together with deviation compared to “scrap control” which would indicate that scrap was generated but not recorded. The type three errors were defined by that operators recorded the wrong component compared to what was actually scrapped, such as that component D3 was scrapped but component D4 recorded on the list. Type three errors was classified by that “manual scrap” had a value over zero, but “control count” equal to zero together with another component of the same type that had the opposite transaction (manual scrap equal to zero and control count a value over zero). Due to the nature of this error, only the Dx and Ex components were controlled for type three errors. Negative values mean that the scrap list record is less than the scrap control count, which leads to overestimations in the inventory records. Positive values mean the opposite, i.e. that the inventory record will underestimate the actual quantity present.

Type one errors generated 34.7 percent of the total errors during the measurement period and were present for all components except for component E1. Component B had the highest frequency of type one errors (58, q: -155), followed by component C (34, q:-60), component A (30, q: -29), component D3 (28, q: -190), component D4 (11, q: -30), component E2 (9, q=3), component D1 (8, q=-36), component D2 (8, q:-18) component E3 (1, q: 23),

Type two errors generated 68.3 percent of the total errors during the measurement period and were present for all components except D1, D2, D5, and E1. Component C had the highest frequency of type two errors (6, q: -284).With regards to frequency and in descending order, the remaining components with type two errors were component B (5, q: -180), D4 (4, q: -175), A (4, q: -160), E2 (4, q: -38) and component E4, (1, q: -1)

Type three errors generated 2.9 percent of the total errors during the measurement period and were present for all Dx and Ex components except D1, D2 and E1. With regards to frequency and in descending order, the components with most type three errors were component E3 (4, q: -24), D4 (3, q: -11), E2 (3, q: 25), E4, (2, q: -3), D3 (1, q: 47) and D5 (1, q: 9).

4.5 Comparative study of the current manual scrap counting system and the parallel automatic scrap counting system

The findings presented in this section concerns the comparison between the two scrap counting systems. This section only uses data collected from PRE-lines 1, 2 and 3 since these were the only PRE-lines with activated automatic scrap counting system. Important to bear in mind is that in order to perform a fair comparison between the two methods in this section, focus has been aimed towards measurements and computations applicable to both the manual scrap counting system as well as the automatic system. As noticed with the scope of the other two research questions, the orientation of this study is aimed more extensively to examine the manual scrap counting system, which is the system that generates data to the company's IS. Unlike the manual system, where deviations from the control count performed by the authors could be examined and classified into the three categories of error presented in sub-section 4.4.2, the automatic scrap counting system does not leave any usable causes to deviations to draw particular conclusions from. Therefore, the comparative study was conducted through universally applicable computations such as mean, mean absolute deviation (MAD) and median to draw conclusions regarding the reliability of the two systems. Separating and tying the data to each line deemed necessary due to eventual inherent differences in each production line. Additionally, key data such as total scrap volume, total recorded scrap volume by each system, percentage deviation from the control count and the total amount of measurement points for each component was included in the table to allow comparisons to be made.

4.5.1 Regarding the data

The daily routine of data collection is described in section 3.2. One important initial step in processing the data meant to sort out and remove data that were corrupted or could impede the results of the study. One of the reasons for removing data measurement points were the occasions where the control measurements could not be computed as a result of the scrap bins being wrongly emptied in the scrap container instead of in the cardboard boxes placed out by the authors. Another factor is that some manual scrap lists might have been collected for weekly scrap counting and then thrown away without being entered into the data set. In such cases of unsureness, the data measurement points have been removed. Moving over to the automatic scrap counting system, data measurement points have mostly been removed due to a somewhat faulty mechanism in the process of the system. When operators end their shifts, a box labelled “End shift” in the automatic scrap counting program interface is supposed to be clicked to send the signal to the database and reset the interface back to zero for the subsequent shift to move on from. Since this is a new system which had not been run the weeks leading up to the data collection period it is understandable that operators would miss this step since it is not a part of their regular routine. However, it made both the data from the shift in question, as well as the data from the next shift, unusable due to the authors being unable to distinguish where the division between the two shifts were. One last contributing factor for data removal that goes for both the manual and the automatic scrap counting system are the occasions where larger maintenance work has been performed on the production line, and the authors could not determine whether or not the systems might have been impaired by it.

The data has been kept separated with regards to the line from which it was collected. This was a deliberate choice from the authors since it was assumed that each line has too much inherent differences that make generalizations between the performance of the systems risky and unreliable. Worth mentioning is that due to the authors keeping the data measurement points separated and not pooled together, mixing data from different lines, none of the individual measurement point reaches over 30 observations. As mentioned earlier the covid-19 virus outbreak had a severe impact on the data collection and the data measurement points not adding up to a number high enough to make up a sufficient sample limits the chances of running any statistical test to determine the performance of the scrap counting systems. However, not all components would have been used enough to provide a passable sample for testing even if the conditions were better, and some way of analyzing them would have to be found either way. The new situation ushered the authors to test all components in the same way, by starting from the raw data and observe the results from relevant computation of it. It is worth bearing in mind that the comparative data between the manual and the automatic scrap counting system is not paired samples in any way.

The computation of the data begins with three common “averages” of statistics. The deviation mean shows the computed means’ relation to zero, which is no deviation. The mean absolute deviation (MAD) is used to show whether or not the computed mean is indicative of the other observations, while the median indicates the “middle” value of the measured deviations. The total amount of the measured volumes from each of the systems is accounted for, and the corresponding control count. The total deviation in volumes, as well as in percentages follows, with the last column noting the total amount of observations on the line for the component in question. The value for total deviation will receive a negative value (-) if the control count exceeds the manual scrap counting, meaning more components are scrapped physically than what will be recorded in the IS.

4.5.2 Attributes and characteristics of the manual system

In order to clarify the results in this section an example of how to interpret the data in the subsequent tables will follow for *Table 4: PRE-line 1, data of manual counting.* Starting from the top of Table 3 component A returned a mean deviation of -0,57 out of 23 measurement points. MAD was 0,74, and the median was measured to 0. Total scrapped volume was 683 while the manual scrap counting system recorded 670, resulting in a total deviation of -13 and a percentage deviation of -1,90 %. Component B red a percentage deviation of -5,5 %. C showed the lowest mean deviation with -0,26, and the exact same MAD 0,26 although the MAD always will be positive. A median of 0 here turned a slightly higher mean of -1,96, a MAD of 2.22 and a median of 0. A total scrap volume of 823 while the manual system recorded 778 returns the largest deviation of these three components with highest measurement points (A, B and C) with a total deviation of -45 as well. Total scrap was measured to 681 while the manual system recorded 675, giving a trivial deviation of -6 and a percentage deviation of -0,90 %. D1 and D4 received 12 respectively 14 measurement points in the comparative data. D1 returned a mean of -2,5 and the same MAD 2,5. Here too, the median returned 0. Total scrap was measured to 305 while the manual scrap counting system recorded 275 giving a total deviation of -30, and a percentage deviation of -9,80%. D4 on the other hand had a mean deviation of -0,5 and a MAD of 0,64, with the median being 0 here as well. Five different components of the E-type were recorded in the comparative data. E1 had 5 measurement points, together adding up to a quantity of 8 pieces. These measurement points were all correctly recorded in the manual system and therefore mean deviation, MAD, median, total deviation, and percentage deviation all return 0. E2 had 2 measurement points, however worth noting is that no actual scrap was generated on these occasions, while the manual system altogether recorded 4 pieces as scrap. This gave a mean deviation, as well as MAD and median of 2. E3 was also recorded for 2 measurement points, which gave a mean deviation of -1, a MAD of 1,5, and a median of -0,5. Total scrap volume was 2, while the manual system recorded 1, giving a total deviation of -1, and a percentage deviation of -50%. E4 was the most frequently occurring E-type component in G1 PRE in the comparative data with 8 measurement points. The resulting mean deviation was -0,5, with the MAD giving the same value 0,5, and the median once again returning 0. A total volume of 20 pieces while the manual system recorded 16 gave a total deviation of -4, and a percentage deviation of -20%. E6 returned all fields 0 for 2 measurement points. As mentioned above, this is a result of the automatic system incorrectly recording scrap which still generates data points in the comparative data for the manual scrap counting system.

Table 4: PRE-line 1, data of manual scrap counting.

Component	Mean deviation	Mean deviation (ABS)	Median	Total Scrap (Manual)	Total scrap control	Total deviation	Deviation %	# of measurement points
A (Endcup)	-0,57	0,74	0	670	683	-13	-1,9%	23
B (Burst disc)	-1,96	2,22	0	778	823	-45	-5,5%	23
C (Nozzle)	-0,26	0,26	0	675	681	-6	-0,9%	23
D1 (Membrane)	-2,5	2,5	0	275	305	-30	-9,8%	12
D4 (Membrane)	-0,5	0,64	0	415	422	-7	-1,7%	14
E1 (Pressure vessel)	0	0	0	8	8	0	0,0%	5
E2 (Pressure vessel)	2	2	2	4	0	4		2
E3 (Pressure vessel)	-1	1,5	-0,5	1	2	-1	-50,0%	2
E4 (Pressure vessel)	-0,5	0,5	0	16	20	-4	-20,0%	8
E6 (Pressure vessel) *	0	0	0	0	0	0		2

Table 5: PRE-line 2, data of manual scrap counting.

Component	Mean deviation	Mean deviation (ABS)	Median deviation	Total Scrap (Manual)	Total scrap control	Total deviation	Deviation %	# of measurement points
A (Endcup)	-1,54	3,29	0	996	1033	-37	-3,6%	24
B (Burst disc)	-1,83	4,33	0	1064	1108	-44	-4,0%	24
C (Nozzle)	-1,79	4,04	0	1058	1101	-43	-3,9%	24
D3 (Membrane)	-9,54	12,29	0	1266	1495	-229	-15,3%	24
E2 (Pressure vessel)	0,09	0,27	0	136	134	2	1,5%	22

Table 6: PRE-line 3, data of manual scrap counting.

Component	Mean deviation	Mean deviation (ABS)	Median deviation	Total Scrap (Manual)	Total scrap control	Total deviation	Deviation %	# of measurement points
A (Endcup)	-3,38	5,38	0	1162	1233	-71	-5,8%	21
B (Burst disc)	-6,48	7,81	-3	1137	1273	-136	-10,7%	21
C (Nozzle)	-7,62	9,71	0	878	1038	-160	-15,4%	21
D2 (Membrane)	-2,25	2,75	-1,5	305	323	-18	-5,6%	8
D3 (Membrane)	7	10,5	0	382	326	56	17,2%	8
D4 (Membrane)	-18,43	18,57	-4,5	176	434	-258	-59,4%	14
E2 (Pressure vessel)	-1,35	3,94	0	145	168	-23	-13,6%	17
E3 (Pressure vessel)	-2,63	2,88	0	101	122	-21	-17,2%	8

4.5.3 Attributes and characteristics of the automatic system

The descriptive information provided in the beginning of section 4.5.2 is equally applicable to interpreting the comparative data for the automatic system.

Table 7: PRE-line 1, data of automatic counting.

Component	Mean deviation	Mean deviation (ABS)	Median deviation	Total Scrap (Auto)	Total scrap control	Total deviation	Deviation %	# of measurement points
A (Endcup)	26,9	28,9	13	1224	659	565	85,7%	21
B (Burst disc)	22,24	26,81	13	1300	833	467	56,1%	21
C (Nozzle)	12,62	17,86	3	924	659	265	40,2%	21
D1 (Membrane)	8,42	17,08	5,5	424	323	101	31,3%	12
D4 (Membrane)	12,17	19,67	1	528	382	146	38,2%	12
E1 (Pressure vessel)	2,2	2,4	2,5	30	8	22	275,0%	10
E2 (Pressure vessel) *	0	0	0	0	0	0		0
E3 (Pressure vessel) *	0	0	0	0	0	0		0
E4 (Pressure vessel)	5	6,71	1	54	19	35	184,2%	7
E6 (Pressure vessel)	1,5	1,5	1,5	3	0	3		2

Table 8: PRE-line 2, data of automatic counting.

Component	Mean deviation	Mean deviation (ABS)	Median deviation	Total Scrap (Auto)	Total scrap control	Total deviation	Deviation %	# of measurement points
A (Endcup)	12,68	22,44	1	1406	1089	317	29,1%	25
B (Burst disc)	8,72	25,44	0	1388	1170	218	18,6%	25
C (Nozzle)	21,6	30,64	10	1690	1150	540	47,0%	25
D3 (Membrane)	10,6	38,28	9	1829	1564	265	16,9%	25
E2 (Pressure vessel)	-3,91	5,39	-4,5	62	152	-90	-59,2%	23

Table 9: PRE-line 3, data of automatic counting.

Component	Mean deviation	Mean deviation (ABS)	Median deviation	Total Scrap (Auto)	Total scrap control	Total deviation	Deviation %	# of measurement points
A (Endcup)	33,84	40,47	0	1876	1233	643	52,1%	19
B (Burst disc)	30,89	39,94	1	1860	1273	587	46,1%	19
C (Nozzle)	25,53	31,32	0	1523	1038	485	46,7%	19
D2 (Membrane)	43,75	44,75	2	673	323	350	108,4%	8
D3 (Membrane)	9,86	17,29	0	395	326	69	21,2%	7
D4 (Membrane)	1,08	8,77	0	448	434	14	3,2%	13
E2 (Pressure vessel)	2,67	6,67	0	208	168	40	23,8%	15
E3 (Pressure vessel)	38,13	38,38	1	427	122	305	250,0%	8

5. Discussion

5.1 What vulnerabilities has been identified in the company’s current scrap management process that can cause IRI?

The inherent level of discrepancy between physical stock locations and inventory system locations due to the nature of the IS brings challenges for the company. Inventory at RF/PP might be located at the physical location but can also be present at several other locations as; on the Kanban truck, as work-in-process or even discarded and be in the scrap bin. Scrapped material is however still shown as available stock in the inventory system until it is transferred from RF/PP to SCRAP, which becomes an issue for the logistics department ability to plan production since it is unknown what the actual inventory levels really are. The situation of not aligning IS locations and physical stock locations constitutes a black hole of traceability for the company and has previously been acknowledged as a problem for coping with IRI by Raman, DeHoratius and Ton (2001). When the transaction between RF/PP and SCRAP is performed, and if no errors are present, the inventory records and the physical inventory should in theory align. This has not been identified as the reality for the case company since several processes may consume components in irregular ways and because of the system leakage of material in the scrapping process.

5.1.1 Lack of traceability

The IS’s logic makes lack of traceability, as well as non-alignment between IS and physical stock, an inherent issue since transactions in the IS are not performed simultaneously as the physical transfer. From the conducted interviews, disagreement of what type of problems this generates has been identified. Some respondent believed that a higher level of traceability would improve the trouble shooting in several ways. Improved traceability could reveal transaction errors between stock locations (Respondents 3 and 5). Secondly, a higher level of traceability could identify quality issues for components that has several suppliers and thereby enable a link between complaints from customers to specific production processes and suppliers (Respondent 4). Increased traceability could also give guidance of what processes to pinpoint and improve (Respondent 11). Even though not contradictory, Respondent 12 believes that the most significant issues are not related to the lack of traceability, but to different “leakages” in the system that results in non-alignment between IS and physical inventory levels. The leakage results in uncertain yield of processes, meaning that all input of components does not end up as finished products or in the scrap bin record-wise in the IS. The sources of these leaks are uncertain, but the scrap management system is perceived to be a potential source. From the literature reviewed, a commonly recommended solution to solve traceability problems is RFID (Fleish and Tellkamp, 2005; Kang and Gershwin, 2005; Xu et al., 2012). However, RFID may not be a feasible solution in this case due to several factors. Firstly, the processes are using great volumes of single components, which makes individual RFID-tags far too expensive in relation to the components value. RFID could be used at finished products, but this would not solve the problem of tracing components. As it is today, the company use barcode for identification, but only on an aggregated level (boxes and units in hundreds or thousands of components). The barcode identification is only used when transferring between stock locations, such as other to RF or from RF to scrap. Hence, no traceability exists for components between the warehouse stock locations and the production lines until the components are finished or being transferred to inventory location SCRAP by the shift managers. This study thereby confirms Chan and Wang (2014)'s statement of that mass-producing manufacturing companies typically do not have traceability on lower level material such as components.

5.1.2 Identified vulnerabilities in the scrap counting performed by operators

Three categories of error were identified as the sources of IRI in the scrap counting process. The type one error where operators incorrectly counts the scrap was the most common error based on frequency (82.1 percent of all errors found) but only accounted for 34.7 percent of the total quantity of deviation. This indicates that even though the type one errors are most common, these errors are not constituting large impact in terms of IRI. Several explanations of the frequent occurrence of this error has been provided from the conducted interviews. One common reason is that scrap is estimated rather than counted in detail when operators face large scrap quantities (Respondent 5), which suggests that these errors are performed with intent, although without an intentional goal of causing IRI. This statement is supported by the quantitative measurement, where the smallest components B, C and D constitutes 84 percent of the total deviation based on component (Appendix C1). Another explanation is that some operators simply are less capable of counting correctly (Respondents 6 and 12), which suggest that errors performed by operators are unintentional. This explanation can neither be supported or dismissed since the quantitative data collection disregarded the relationship between accuracy in counting and operators, due to ethical considerations stated in Chapter 3.

The type two errors, when scrap was not reported at all represented 11.8 percent of the error frequency, but a major part of quantity of deviation errors. From the conducted interviews, two main explanations have been identified that causes type two errors. The first explanation relates to time constraints in production, and that some operators prioritizes running the manufacturing processes rather than counting scrap (Respondents 6 and 10). Another explanation is related to operators not performing the extra work needed in collecting new lists when they run out on the production line, and by that choosing to not record the scrap properly (Respondent 6). With the research framework employed, the authors could not determine which one of these explanations that explains the occurrence of this error, but if type two errors could be reduced or eliminated, major improvements in the scrap counting process for accurate inventory records could be achieved. One way to do this is to raise attention to this problem and what consequences it brings, as suggested by Raman, DeHoratius and Ton's (2001) discussion about the importance of building employee awareness.

The type three errors which relates to that wrong components are recorded represented 3 percent of the total errors generated. For the components D3 and E2, these type three errors counteracted the type one and two errors performed at other measurement points, which increased the accuracy of the inventory record for these components during the measurement period. However, this might be seen more as a coincidence rather than systematic since the components D4, E3 and E4 did not show the similar pattern. Even though there were two explanations from interviews regarding the type three errors, tiredness (respondent 6) and new employees (Respondents 1 and 2), the type three errors only represented a fraction of the total deviation generated. Thereby, the results of this study show limited support for Raman, DeHoratius and Ton's (2001) discussion about error frequency based on product variety.

The current scrap counting process is characterized by informal rather than formal instructions and the procedure is highly dependent on the individual operators. With the current procedure, it becomes difficult to benchmark performance and implement "best-practice" (Raman, DeHoratius and Ton, 2001), since the current performance is unknown in terms of which counting practices that performs better than other practices. Standardization in terms of instructions and checklists might be needed (Ruankaew and Williams, 2013) but, as discussed by Respondent 4, it is very hard to create instructions that are interpreted in a similar manner by several persons. Such an informal process has by Rajeev (2008), as well as by Chuang and Olivia (2015) been identified as key vulnerability that causes IRI.

5.1.3 Identified vulnerabilities in the scrap summary process

The scrap summary performed by shift managers also has several vulnerabilities. Firstly, if the lists do not contain any figures, or if the list for some reason get lost, the scrap generated for that day cannot be recognized and the discarded components will still be present in the inventory system. Secondly, the system is highly dependent on the shift managers interpretation of what is actually written on the list, which increases the risk of making errors. This risk might also increase due to operators having recorded components not running on the line (type three errors), which requires special attention from shift managers to take notice of. Thirdly, the scrap summary is currently performed by using a calculator, which also increases the risk of errors since unintentional mistakes can easily be done. Since this process is currently only performed once a week, the shift managers spend several hours at the time which puts high demands on the shift manager’s awareness in arriving at the correct figures. The practices and data handling include several vulnerable steps which may amplify the risk of making errors. The actual counting, writing in the right column, interpreting numbers, counting again using calculator, to eventually recording the scrap volumes in the digital IS by the shift managers are all steps that needs to be performed correctly to avoid causing IRI in the scrap management process. This type of data handling shows similarities with Ruankaew and Williams’ (2013) discussion of manual data handling and the increasing risk of generating IRI.

5.2 What areas of operation are affected by the company’s current scrap management system?

The second research question examined the operations that are affected by the current scrap management system. This was not necessarily a phenomenon that was measurable through the quantitative research otherwise making up a substantial part of the study’s methodology. In order to find out what impact the current scrap management system has on other operations within the company, it was found vital to use the respondents who performs the actual counting of scrap and handles the system on a daily basis. Starting off the authors decided to aim the literature studies towards trade-offs. The knowledge of the existence of an automatic scrap counting system that was deemed too uncertain by the company’s management and therein leading to the usage of the current manual system led the authors towards the conclusion that compromises have to be present. The company’s aspiration towards accurate inventory records led them to deselect an unsure method, although it had many other properties desired, in favor for a method characterized by human interaction and manual handling. As mentioned earlier, the assessment and prioritizing of strategic objectives is a vital part when defining trade-offs in a manufacturing environment (Boyer and Lewis, 2002). Inventory accuracy is not an objective that receives much attention when trade-offs are discussed in the literature. Instead, comprehensive targets such as production volume, delivery lead-time and quality tend to be more pronounced among scholars investigating trade-offs in manufacturing environments. Adamides and Pomonis (2009) elaborates around how narrower objectives are dependent on the attitude of the manager to stand a chance of being prioritized above aforementioned company-wide objectives for example. Thus, the company’s decision of maintaining a system with many negative aspects as the current system possess, solely in order to receive better inventory record accuracy indicates that the company acknowledges the importance of inventory records and knows the consequences of IRI. That, or the scope of the negative aspects of the current manual scrap management system is something the management is somewhat oblivious to. Whether unknowingness on the managerial side is true in this case is not anything that this study can cover, for several reasons. Firstly, the true effect of the scrap management system might be unknown for the company due to the complexity of the operations involved. Phenomenons that are vague or unquantifiable can oftentimes be hard to grasp and it can be bothersome to see the consequences of them. Secondly, the authors deemed it difficult to get this kind of information from interviews. Knowing the orientation of the study, respondents would most likely assign correct inventory records such an importance as to justify the decision to run with the manual scrap management system.

5.2.1 Defining trade-offs

Earlier research into operational trade-offs in manufacturing environments have been somewhat divided regarding what strategies companies should keep when encountering trade-off situations. A general matter researchers tends to agree upon though, is the importance of always being aware when a company faces a true trade-off and act thereafter (Boyer and Lewis, 2002; Da Silveira, 2005; Shahbazpour and Seidel, 2007). In the case of the scope of this study even this can prove difficult at times. The manual scrap management system only explaining a portion of the total IRI at the company led to questions regarding whether specific affected operations had the scrap management system as a root cause. Issues described by Respondents 3, 5 and 9 exemplifies one such aspect where hesitations arose whether it should be considered part of the study's scope. The respondents refer to time constraints for the logistics department not allowing in-depth research trying to find underlying causes of current frequently occurring reporting errors. Oftentimes the most pressing concerns related to reporting errors occur late in the production process, and these issues logically receives the most attention from the employees responsible for correcting the errors (Respondent 3). A trade-off can therefore be argued to exist between, on the one hand establishing thorough preventive measures, and on the other hand to live with short-term solutions without never reaching the root causes as is shown often being the case at the company today. The manual scrap management system does play an important part in the company's inventory management and it could therefore be argued that the aforementioned trade-off is partly caused by the manual scrap management system. The preventive measures should also apply to this system, to ensure correct data and proper reporting.

5.2.2 Trade-offs and process quality

Moving on to what more findings were revealed through the interviews, several proper trade-offs were identified. Arguably the one most significant found in this study is the fact that the manual scrap counting system result in unnecessary production downtime. A trade-off between amount of production hours and more precise inventory records data could therefore be established. This is also the one trade-off that most easily can be quantified and given a cost figure, although that is beyond the scope of this study. For a manufacturing company the production is vital for the earnings of the company, and every aspect reducing the time available for production needs to be motivated. The sheer existence of this trade-off hints toward the importance the company lays in having correct records in their IS. In relation to the identified trade-off above the findings further revealed time usage among individuals to be a significantly affected by the current scrap management system. Most of the wasted production downtime could be argued to be attributed to operators not having time to oversee the production process and keep the production lines running. Their time is instead demanded for collection and counting of the scrapped components during the shift, a process that was found troublesome and advanced at times, particularly when large volumes of scrap should be counted. Additional to keeping the production lines running longer, this time could be spent training new employees, performing 5S-related assignments or preparing eventual upcoming model changes (Respondents 2 and 10). The weekly summaries were also an area where several respondents identified the current scrap management system as having an impact on the time usage. This process takes several hours and can arguably be considered to be completely wasteful since it constitutes a double work, as discussed below, summarizing already counted figures. These two aspects of unnecessary time usage can be described as a trade-off between effective time management for operators and shift managers and the strive towards more precise inventory records data.

The double work does not seem to be so much an effect of an operational trade-off as it seems to be a poorly designed operational process. As brought up by Respondent 12, it is difficult to see why the process has not been improved earlier. Although the arguments as to why not allow too many individuals access and accreditation to perform transactions in the IS, where the operators would draw the scrapped figures directly from the company's IS, is sound and reasonable, it is hard to understand what would obstruct the implementation of a shared excel sheet for the operators to enter their counted figures in. Naturally, this is also a wasteful process that would be considerably reduced, if not fully eliminated, should the automatic scrap counting system be fully functioning and reliable.

In line with poorly designed processes we have the issue of tracing related to the PRE-lines. After the weekly collection and subsequent summary of the scrap lists generated throughout the weeks the tracing option to determine what scrap volumes were generated on which production line disappears. Respondents 11, 12 and 14 all acknowledges that the current manual scrap counting system fail to provide records of the scrapped volumes on each PRE-line, giving the company no other option but to solely apply their routine follow-up on the main line, which generates scrap data for finished products via an additional production information system. It is an interesting point of discussion to view an attempt of strengthening the reliability of the inventory records, while at the same time effectively reducing the visibility of the inventory system by eliminating the ability to tie correct volumes of scrap to the correct PRE-line. Going back to the thoughts of Respondent 12, having the data of the scrap count in an excel sheet would probably provide this kind of information. Thus, the manual system does provide the company with better scrap records as it is today, but it has the drawback of the current process design disables scrapped components to be tied to specific lines. However, whether this issue should be viewed as a proper trade-off between correct inventory data and lowered tracing ability, or as a poorly designed operational process is debatable.

The theories brought forth by Miltenburg (2008) could be argued to be considerably relevant in the scenario of the scope of this study. The inability to use the automatic scrap counting system effectively visualizes the way technical boundaries generate operational trade-offs. With sufficient process improvement of the automatic scrap counting system, several of the aforementioned trade-offs would be trivial, if not totally eliminated, in line with Shahbazpour and Seidel (2007). Process improvement is often put forth as the single most efficient tool when handling operational trade-offs (Da Silveira, 2005; Shahbazpour and Seidel, 2007; Miltenburg, 2008; Adamides and Pomonis, 2009; Sarmiento, 2011). Managing to enhance the automatic scrap counting system would seem to have had a positive impact on the trade-offs and other impacted areas of operation identified in this study. The wasteful time usage among operators and shift managers would be among the identified trade-offs that would most certainly be eliminated. Some scrap-related production downtime would still be necessary in order to fetch the scrap bins from their location on each production line, which often require the line to be shut off (Respondent 6). With the manual scrap counting element gone, the production line would not have to be shut down until the very last section of the shift if the only work demand from the operators consisted of transporting the accumulated scrap volumes to the scrap containers at the assigned spot in the warehouse and subsequently place the scrapped components in said containers. This process would not require much time and would not have any severe impact on productivity since the lines generally stay shut down for the initial minutes of the shift to allow for a brief mandatory meeting among the production staff.

5.3 How do the company’s two scrap counting methods perform in terms of generating inventory record inaccuracy (IRI)?

Comparing the two scrap counting systems was deemed necessary by the authors to strengthen the validity of the study and gain valuable insight into the decision to reject the automatic scrap counting system as too unreliable. By performing a comparative study, the authors would have the means needed to either confirm the company’s decision to stick with the manual scrap counting system or dispute their decision should the two systems provide similarly stable result.

5.3.1 The manual scrap counting system

Glancing at the values obtained from Tables 4, 5 and 6 a few initial matters of interest could be noticed. The three PRE-lines 1, 2 and 3 all contained rather high numbers of observations of the three components A, B and C. This was rather expected results since these three products are one of a kind and are found in all finished sub-assemblies produced on the PRE-lines. In the case of PRE-line 2 the components D3 and E2 also received a high score on the amount of measuring points due to stable work orders that rarely demands changes of components.

A constant underreporting could be discerned due to the negative figures of the Deviation mean and the Deviation percentage. In the case of PRE-line 1 only E2 differed with a positive figure. However, the component E2 only had two measuring points, which together added up to a total of four components scrapped in the manual system. The control count showed no components at all which is reasonable due to the component not being used on the production line at all. E2 showed signs of over reporting again on PRE-line 2. However, the deviation mean being extremely low, and the MAD backing it up by showing a low figure as well indicated a very stable scrap counting process with very few errors in this specific case. The last component that was found to be over reported was D3 on PRE-line 3. Only containing eight measurement points it is arguably difficult to determine whether or not it should be acknowledged or dismissed as too uncertain data.

Moving over to what information could be gained by examining the median a striking number of zeros could be noticed. The fact that as many of the medians returned zero indicates that it is a very common figure in this context. Component B returned a median of -3 on PRE-line 3, indicating a more varied deviation of the measurement points. Interestingly, component C showed a significantly higher percentage deviation than B, while still returning a median of zero. This is indicative of a few larger deviations affecting the mean of an otherwise uniform distribution. Other than the one measured median of -3 for component B on PRE-line 3 the only medians diverting from 0 are found for components of the D and E groups. These are components that are very similar to each other and some mistakes in reporting them could be argued to be expected when examining the manual scrap counting system.

A relationship between measured scrap volumes and total deviation could be identified when comparing the three production lines. In order, the control count measured the lowest scrap rates for the most frequently occurring components, on PRE-line 1, followed by PRE-line 2, and the highest scrap volumes was found on PRE-line 3. PRE-line 1 generated very low total deviation for A and C, with B differentiating with a percentage deviation of -5,5 %. However, the total amount of scrap measured was significantly higher for B than for the other components which further strengthens the relationship. The measured scrap levels of PRE-line 2 are generally higher than for PRE-line 1. This is reflected in the percentage deviation of the manually reported scrap of A. B and C pooling at around -4 % deviation from the control count. D3 at PRE-line 2 had significantly higher scrap levels, as well as a higher deviation than other components. This percentage deviation is measured to -15,3, a high figure considering no other similar components being run on the line. The measurement points from PRE-line 3 produces the highest amount of scrap for the data used in this study. In line with earlier mentioning of the correlation between scrap levels and deviations, the three most occurring components A. B and C also produces the highest deviations between the manual scrap counting system and the control count.

5.3.2 The automatic scrap counting system

Relevant information related to this section is found in Tables 7, 8 and 9. As with the manual scrap counting system the most frequently measured components are A, B and C, which every sub-assembly produced on the PRE-lines contains. Also here PRE-line 2 produces a high amount of measurement points due to the line consuming a uniform flow of components without interchanging components D and E. Contrary to the manual scrap counting system, a significant over-reporting can be noticed with the automatic scrap counting system. Considering the three most common components, A, B and C, the over-reporting is most noticeable on PRE-line 1 and PRE-line 3. Here the automatic scrap counting system reports around 40-50 % more than the control count. An outlier is the reporting of component A on G1, which generates a value 85,7 % higher than the control count. The reporting of E2 on PRE-line 2 is the only occasion where the automatic system reports less than measured in the control count. This phenomenon is placed in stark contrast to other results in this section. The median is computed to of -4,5 suggesting a systematic under-reporting in this specific case. The MAD supports this lying reasonably close to the mean, indicating a rather low variability of the computed means. Components A and B on PRE-line 2 show significantly less total deviation from the control count on the other two production lines. However, the difference between the mean and the

MAD is larger for these components in comparison to the other cases, indicating more variation in the data, both in under and over-reporting.

The relationship between mean deviation and the deviation MAD is a valuable measurement tool when examining a case like this with a phenomenon of systematic over-reporting. Very rarely does the two values matches, which would indicate either a consistent under or over-reporting. D2 on PRE-line 3 gives the mean of 43,75 and the MAD of 44,75. Although this is a rather high mean, and the percentage over-reporting is 108,4 %, notes can be made that almost all the observations are over-reported and the variation in deviation does rarely reach below the control count. In contrast components such as B and D3 on PRE-line 2 gives means of 8,72 and 10,60, with the MAD of 25,44 and 38,28 respectively. These are both components that have rather low total deviation in comparison to other components reported by the automatic system. However, the difference of the mean and the MAD show a large variety in the collected data, indicating an unstable and unreliable process.

5.3.3 Comparison and general trends

The two scrap counting systems featured generates entirely different results which is elaborated around above. The most commonly used components with the most data measurement points are being discussed the most due to larger sample sizes than lesser used components. The core aspect of the performance of the different systems is how close their respective reported figures relate to the control count. Starting off with the manual scrap counting system and examining the total deviation and the deviation in percentages a slight under-reporting could be noticed. The deviation could be argued to be marginal since the deviation in itself was percentage-wise low in most cases, although some larger deviations was noted. Contrary to the manual system, the automatic scrap counting system over-reported the control count in close to every case in the data set. The deviation computed from this system was significantly higher than those from the manual system. Systematic over or under-reporting is an issue when handling inventory records, and either way it will require a reset to even out the developing divergence between the physical inventory and the IS inventory.

The variation in the data measurement points helps visualizing how stable the scrap counting processes in question is. For the manual system, the MAD as arguably low for almost all components for PRE-line 1 and PRE-line 2. Slightly higher values for MAD is seen on PRE-line 3 where the variation seem to be somewhat larger. Moving over to the automatic system the MAD is increased multifold over all of the production lines suggesting a significantly larger spread in deviation variation for the automatic system.

While the manual scrap counting system saw a trend of increased deviation correlating with increased scrap volumes to handle, the same could not be said for the automatic system. The deviations generated by the automatic system appear randomized in relation to both the control count and the performance of the manual system and cannot be heuristically derived to a certain variable. The inherent qualities of the automatic system can therefore be judged to demand more work and engagement to understand and draw conclusions from.

6. Conclusion

6.1 Findings and contributions

The contribution of this paper lies in the in-depth and detailed case study, examining the field of IRI at a manufacturing company through the assessment and exploration of their scrap management system. As presented by Ruankaew and Williams (2013) and Oliveira et al. (2019) case studies concerning inventory record inaccuracy have been somewhat scarce when it comes to manufacturing companies. Additionally, this study focuses on the scrap process, an inventory-affecting activity present among all manufacturing companies which was found to be neglected in earlier scholarly works. Drawing from Oliveira et al.'s (2019) inquiry of real-world application of research, this study contributes to the literature on the subject by providing findings from such a real and vital process in a manufacturing environment, and avoids setting up models and simulations with made-up figures that may or may not represent reality. Karim et al. (2018) suggested gaining more in-depth knowledge regarding inventory management issues through qualitative interviews with key personnel involved in order to discover and analyze real problems occurring in manufacturing environments. This study provides the in-depth qualitative approach requested by Karim et al. (2018), and identifies root causes of a specific IRI-related problem as to provide knowledge for elimination of some contributing root causes instead of continuously re-adjusting inventory levels, in line with the thoughts of Wild (2004).

The purpose of the thesis was to investigate three objectives. The first objective aimed to examine vulnerabilities and consequences of the manual scrap management system in terms of generating IRI. Based on the findings, the data indicates that even though roughly half (52.6 percent) of all scrap reports are totally correct, the majority of all counts are almost correct with a margin of +/- five components per measurement (83.9 percent). The deviation caused by incorrect counting only represented (-)34.7 percent of the total deviation between what was actually put in the scrap bin and what was recorded on the scrap list. A major part of deviation observed, (-)68.3 percent, was represented by that no scrap list was recorded at all, even though this was infrequent (5.6 percent of all measuring points). The third error only represented a minor part both in frequency (2.9 percent) as well as in total deviation (3 percent) and might therefore be considered as a minor issue for the company based on the results in this study. The case company makes use of all three philosophies of how to cope with IRI presented in the problem statement to some extent. The manual scrap counting procedures employed can be viewed as their attempt to prevent IRI from emerging from otherwise uncontrolled automatic transactions. Also, the routine implemented of checking for empty inventory lots can also be considered a preventive measurement since it can help mitigating other problems from arising, such as transfers to IS location SCRAP. However, the findings indicate that the time spent on the scrap counting could be somewhat futile since the lists are not always recorded, thereby causing IRI in spite of the measurements taken. Additional to the attempt of preventing IRI, periodic inventory audits in place corrects discrepancies between physical inventory and the inventory system. Since the company only counts full boxes present at the physical stock locations, IRI is also integrated in their inventory management, even though this integration should generate inventory records which underestimates the physical inventory levels. This does not however seem to be the situation for the company since transaction errors in subsequent processes also causes IRI. The manual scrap management systems' vulnerabilities originate from its high dependency of human interaction. To achieve accurate inventory records, several steps must be correctly performed. The operators must identify the right quantity, right material and record this on the scrap list. When this has been conducted, the shift managers need to interpret the information as the operator intended it to be. If this is not the case, IRI will inevitably occur as a consequence.

The second objective served to examine what impact the current manual scrap management system has on other areas of operation, and what trade-offs could be identified to exist in these areas. The company uses the manual scrap counting system out of necessity due to the failed attempts to launch the automatic scrap counting system which were not returning a satisfactory reliable result. The company's strive towards accurate inventory records has put them in a situation where their current system requires considerable resources to function, resources that could be used in more efficient manners. The results for exploring this objective was largely based on the qualitative data collected from interviews. The identified areas of operations that are affected by the current scrap management method can in a simplified way be put into three categories; proper trade-off situations, affected areas due to poor process design, and other affected areas not necessarily constituting a trade-off situation. More production downtime vs more accurate inventory records and wasteful time usage among operators and shift managers vs more accurate inventory records are two distinct examples of proper trade-offs identified at the company. An additional proper trade-off was identified earlier in the inventory chain, that of thorough preventive measures vs short term solutions regarding inventory inaccuracies. As discussed, this trade-off is debatable whether it should be considered an effect from the current scrap management system or more of an overall issue for the company without a specific root cause. The identified double work with the scrap lists as well as the lack of tracing ability for components on the PRE-lines could both be attributed to be an effect of poor process design. Both issues seem to be solvable without too difficult means, as discussed in the former chapter. An example of the third category is how the manual scrap management system affects the logistics department. The design of the current scrap management system with weekly transactions of large scrap volumes does relatively often result in issues with the transactions due to the stock location not containing enough volume. However, it is difficult to analyse if these transaction related problems would still occur if the automatic system would be functioning. As for now, it cannot be considered to be a trade-off, instead serving as a possibility to detect errors in an early stage even if it requires time and resources of the logistics department. In line with the literature in the field it was found that process improvement does seem to be the most viable solution in these kinds of operational trade-off situations. Not only would a functioning automatic system eliminate several of the identified affected areas, improving the current manual scrap management system would also solve the issue of double work as well as the inability to trace scrapped components to each specific PRE-line.

The third objective was to comparatively measure the two scrap counting system in question. While already possessing the information regarding the automatic system’s perceived unreliability and the company’s subsequent decision to run with the manual scrap counting system, the authors decide to compare the two systems themselves to gain a deeper understanding of the rejection of the automatic system. Results used to examine this objective was solely based on the quantitative data collected. The manual system has been further examined and elaborated on in earlier sections, this following section serves only to provide a fair comparison of the two scrap counting systems. Initially, the most significant difference between the two scrap counting systems was the nature of their reporting errors. The manual system returned a slight under-reporting, meaning more components were discarded than what was shown in the IS. The automatic system on the other hand returned a significant over-reporting. The proportion of the deviations also differed between the two systems. The manual system showed relatively low deviations percentagewise, while the automatic system returned substantially higher deviation values. The manual system showed a higher propensity to deviate from the control count as the scrap volumes increased. This was not seen with the automatic system where the deviations appeared to be completely random, indicating an unreliable reporting process. The authors can thereby, in the context of this third objective, confirm that the company in this study made a well-founded and substantiated decision opting to go with the manual scrap counting system due to the automatic system showing too much uncertainty and immaturity for a reliable inventory record process.

6.2 Study limitations

Some potential limitations were identified during the course of conducting this study. Firstly, only one company and their struggles with IRI was examined. The phenomenon of IRI can exist in any other manufacturing company and can have completely different causes. It is therefore important to emphasize that the findings presented here are not necessarily applicable to situations found at other companies. The study was also limited to focus on the scrap process of one of the subprocesses, the PRE-lines, and could not encompass all production processes active at the company. Secondly, the scope of the study does not encompass any cost analysis of the different components featured. Thirdly, the quantitative data collection was limited to a period of three weeks. With an extension of this period a larger sample would have been collected and could enable more detailed quantitative data analysis. This would be true for both the analysis of the manual system’s performance, as well as for the comparative part of the study. And lastly, regarding the automatic scrap counting system featured in the comparative part, the study lacks some further knowledge regarding the technical aspects of the system. The study could only take into consideration the outputted figures the system was generating and not the technical reasons behind the figures.

6.3 Further research

Several aspects around this study has given rise to related fields that could be favored by further research. The study only examined one case company, which may impact the generalisability of the findings presented, but in turn has allowed for deeper insight into the studied scrap management system at the case company. The objectives of this study were all tied to the company’s scrap management, and how it relates to IRI. However, the proportion of total IRI at the company that can be explained by the scrap management system is not covered by the scope of this study which make examining other processes that can cause IRI and determine their respective share a future field of research. As confirmed in this study, the automatic scrap counting system still shows signs of being an immature system in need of more process improvement. Identifying key factors for improving these processes therefore articulates further points of research. Should the system receive major improvements, collecting enough data points would be recommended for running appropriate statistical tests when comparing the two systems. Such tests could preferably be combined with analysis of the drawbacks of either system, i.e. trade-offs or other operational effects. Sections of this study has examined different components in relation to their contribution to IRI. However, each component comes with different prerequisites, making them more or less vulnerable to consequences of IRI. This could be expanded upon through sensitivity analysis or other further research. Likewise, could cost analyses be applied to determine the financial impact of the trade-offs identified in the study.

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8. Appendices

A. Interview guide

Basic questions

1. What are your work assignments?
2. To what department/function do you belong?
3. For how long have you been employed at the company? How long is your experience on other but similar positions?

Questions regarding the scrap management system

4. In what ways are you affected by the current manual scrap handling system?
5. In your opinion, in what ways do you think this system affects other functions at the company (logistics, production, quality etc.)
6. Do you believe that the scrap handling system is prioritized at the company?
7. In your opinion, are there ways to improve the current system?
8. If a functioning automated scrap handling system could be implemented, in what ways would your current work be affected?
9. How has the current scrap handling system been developed?

Specific questions regarding inventory management

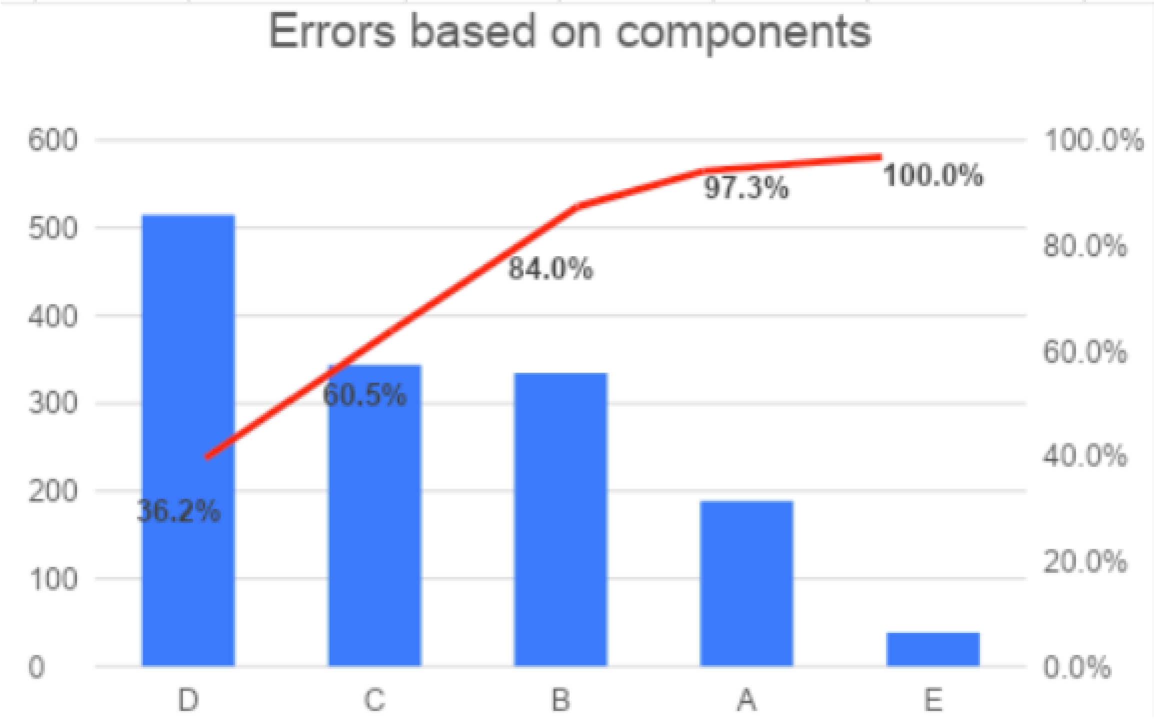
10. How is the current scrap management system affecting the logistics function?
11. What are the logistical consequences of incorrect scrap reporting?
12. In your opinion, could incorrect scrap reporting be accepted to some extent if other benefits can be made? To what extent, and which kind of benefits?

B. Schedule of interviews

Respondent	**Telephone interview**	**Physical interview**
1	March 16th, 0945-1015	
2	March 17th, 1945-2015	
3	March 19th, 1015-1115	
4	March 19th, 0930-1000	
5	March 25th, 1000-1045	
6		March 27th 1800-1830
7		February 12th, 1500-1600
8		February 12th, 1400-1430
9	March 18th, 0930-1000	
10	March 31st, 1030-1100	
11	April 3rd, 0900-0945	
12	April 3rd, 1030-1100	
13		February 25th, 0900-0930 and March 17th, 1330-1400
14	March 25th, 1900-1920	

C. Charts and tables of quantitative data

C1. Errors based on component



Note: Errors based on type of component (blue bars) together with cumulative proportion (red line). Variations of D and E components are not taken into consideration as all component groups are accumulated.

C2. Errors based on components. Full version.

Component	Total Scrap (Manual)	Total scrap control	Total deviation	Deviation in percentage	# of measurement points	# of accurate measurements	accurate measurement points in	# of measurements within +/-5	accurate measurement points within +/- 5 units	Error 1:			Error 2:			Error 3:		
										Frequency	Quantity	Percentage	Frequency	Quantity	Percentage	Frequency	Quantity	Percentage
A	4063	4252	-189	-4,4%	97	63	64,9%	87	89,7%	30	29	15,3%	4	160	84,7%	-	-	-
B	4449	4784	-335	-7,0%	97	34	35,1%	76	78,4%	58	155	46,3%	5	180	53,7%	-	-	-
C	3766	4110	-344	-8,4%	97	57	58,8%	83	85,6%	34	60	17,4%	6	284	82,6%	-	-	-
D1	648	684	-36	-5,3%	19	11	57,9%	18	94,7%	8	36	100,0%	-	-	-	-	-	-
D2	305	323	-18	-5,6%	8	0	0,0%	7	87,5%	8	18	100,0%	-	0	-	-	-	-
D3	2522	2776	-254	-9,1%	53	22	41,5%	41	77,4%	28	190	74,8%	2	111	43,7%	1	-47	-
D4	649	865	-216	-25,0%	29	11	37,9%	22	75,9%	11	30	13,9%	4	175	81,0%	3	11	5,1%
D5	9	0	9	100,0%	1	-	-	-	-	-	-	-	-	-	-	1	-9	-100,0%
E1	8	8	-		5	5	100,0%	5	100,0%	-	-	-	-	-	-	-	-	-
E2	334	344	-10	-2,9%	54	38	70,4%	44	81,5%	9	-3	-30,0%	4	38	380,0%	3	-25	250,0%
E3	102	125	-23	-18,4%	12	6	50,0%	11	91,7%	1	-23	-	1	22	-	4	24	104,3%
E4	27	32	-5	-15,6%	11	7	63,6%	11	100,0%	1	1	-	1	1	20,0%	2	3	-
E5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
E6	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	**16882**	**18303**	**-1421**		483	254	52,6%	405		188	493	42,2%	27	971	106,5%	14	-43	
Proportion			**-7,8%**			**52,6%**		**83,9%**	**87,5%**	**38,9%**	**-34,7%**		**5,6%**	**-68,3%**		**2,9%**	**3,0%**	

Note: Calculations for error types.