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REDUCING INTERNAL FAILURE QUALITY COSTS USING PLAN-FOR-EVERY-PART METHODS IN HIGH-MIX-LOW-VOLUME PRODUCTION WITHIN A LARGE MANUFACTURING COMPANY – A CASE STUDY

Master of Science Thesis

Examiner: Professor Jussi Heikkilä
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ABSTRACT

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In high-mix-low-volume production, the variety of items handled can be significant. In environments with numerous items and lots of variation, flexibility is often required. Still, obtaining the flexibility efficiently requires using human workforce. When humans are part of processes errors are likely to happen. Having all relevant item data collected in one place, creating straightforward procedures and instructions for handling of different item groups and making sure they are followed decreases the risk of defects and errors.

In this thesis implementing Plan-for-Every-Part methods, a centralised database for item information is discussed in the context of a large manufacturing company having production that can be defined as high-mix-low-volume production. This is done to reduce internal quality costs due to material handling defects. For finding the ways to utilise Plan-for-Every-Part methods in the Case Company the quality costs from the year 2017 were analysed and the greatest cost sources were recognised. People holding responsible positions at the Case Company were interviewed for understanding the processes and finding improvement areas. The relevant material handling processes were also observed. The Case Company's internal instructions and standard operating procedures were also assessed.

The quality costs caused by defected items accumulate due to machining rework (70 % of the total quality costs) and assembly rework (30 % of the total quality costs). The item group causing most of the quality costs are the end-products' body parts. Reasons for body part defects are insufficient protection of items during moving, careless handling and impurities on workstations. For preventing these kinds of defects from happening a Plan-for-Every-Part data sheet sketch and a step by step implementation plan for it were created. A test was conducted for adopting the solution in use. The Plan-for-Every-Part data sheet was adapted for the use of internal logistics operations. The Plan-for-Every-Part data sheet will be used as a tool in process standardisation and item protection planning with the aim to reduce material defects.

TIIVISTELMÄ

LAMPIMÄKI, JUHO: Sisäisten laatukustannusten vähentäminen Plan-for-Every-Part –menetelmiä soveltamalla suuren tuotevalikoiman ja pienen tuotantomäärän tuotannossa suuressa teollisuusyrityksessä – tapaustutkimus
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Avainsanat: laatukustannukset, Plan-for-Every-Part, PFEP, suuren tuotevalikoiman ja pienen tuotantomäärän tuotanto, sisäiset virheet, materiaalien käsittely, tuotetiedon hallinta, uusien käytäntöjen toimeenpano

Suuren tuotevalikoiman mutta pienten tuotantomäärien tuotannossa erilaisia osia saattaa olla runsaasti. Suurten nimikemäärien ja runsaan vaihtelun ympäristöissä vaaditaan usein joustavuutta. Jotta joustavuus voidaan saavuttaa tehokkaasti, ihmistyövoiman käyttöä vaaditaan. Ihmisten ollessa osa prosessia virheet ovat todennäköisiä. Keskittämällä nimiketiedot, luomalla suoraviivaiset prosessit ja ohjeet erilaisten nimikeryhmien käsittelyyn ja valvomalla niiden toteutumista voidaan virheiden riskiä pienentää.

Tässä diplomityössä käsitellään Plan-for-Every-Part -menetelmien, eli keskitetyn nimiketietotiedoston, soveltamista ja käyttöönottoa suuressa teollisuusyrityksessä, jonka tuotantoa voidaan kuvata suuren tuotevalikoiman ja pienten tuotantomäärien tuotannoksi. Tarkoituksena on selvittää, miten Plan-for-Every-Part auttaa vähentämään käsittelyvirheistä johtuvia laatukustannuksia. Aluksi vuoden 2017 laatukustannukset analysoitiin ja suurimmat kulujen aiheuttajat tunnistettiin. Kohdeyrityksessä vastuullisessa asemassa olevia henkilöitä haastateltiin, jotta keskeisistä prosesseista syntyisi hyvä ymmärrys ja jotta kehitysosa-alueita saataisiin selville. Keskeisimpiä materiaalinkäsittelyprosesseja havainnoitiin. Myös kohdeyrityksen sisäiset toimintaohjeet ja standardoidut toimintatavat arvioitiin.

Vaurioituneineista nimikkeistä aiheutuvat laatutukustannukset kertyvät korjauskoneistuksesta (70 % kokonaislaatukustannuksista) ja uudelleenkokoonpanosta (30 % kokonaislaatukustannuksista). Nimikeryhmä, joka aiheutti eniten laatukustannuksia, oli lopputuotteen runko-osat. Syitä runko-osien vaurioitumiseen ovat riittämätön suojaus, huolimaton käsittely ja epäpuhtaudet työpisteillä. Näistä syistä johtuvien vaurioiden ehkäisemiseksi muodostettiin Plan-for-Every-Part -tiedostoluonnos ja vaiheittainen toimintasuunnitelma sen käyttöönottamiseksi. Tiedostoa muokattiin sisäisen logistiikan tarpeisiin sopivaksi. Plan-for-Every-Part -tiedostoa tullaan käyttämään prossessien standardoinnin ja nimikkeiden suojaussuunnittelun työkaluna, jonka avulla pyritään vähentämään materiaalivaurioita.

PREFACE

The subject for this thesis was provided by the Case Company and I am very thankful for the opportunity. It was a challenging but also rewarding effort to make a research in a real business environment with practical application. I want to thank all the employees who participated somehow in the research process as interviewees or as workers who's working I followed.

Especially I want to thank the Purchasing Director for handing the assignment and the Logistics Manager who worked as the thesis supervisor on behalf of the Case Company. Also, thanks to the Quality Development Engineer who provided the quality cost data and gave excellent tips during the research. Special thanks go to my superior who helped also a lot during the research process and was very supportive with the thesis. Thanks go also to professor Jussi Heikkilä who always answered rapidly and profoundly to emails and gave excellent guidance when asked for help and comments for the thesis.

For excellent support during the research process at the times I wasn't writing the thesis I want to thank my beloved Inka who always cheers me and brings joy to my days.

Helsinki, 25.5.2018

Juho Lampimäki

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LIST OF SYMBOLS AND ABBREVIATIONS

ATO	Assembly-to-Order
CF	Castings & Forgings
CO	Customer Order
BOM	Bill of Materials
CM	Cellular Manufacturing
ERP	Enterprise Resource Planning
ETO	Engineering-to-Order
FIFO	First-In-First-Out
ID	Identifier
IPO	Internal Purchase Order
IT	Information Technology
MO	Manufacturing Order
MES	Manufacturing Execution System
MOQ	Minimum Order Quantity
MRS	Materials & Subcontracting
MTS	Make to Stock
NDT	Non-destructive testing
PAF	Prevention – Appraisal – Failure
PDM	Product Data Management
PFEP	Plan-for-Every-Part
PO	Purchase Order
POP	Purchase Order Proposal
QIF	Quality Implementation Framework
RFQ	Request for Quotation
SW	Supplier Web
VMI	Vendor-Managed Inventory

1. INTRODUCTION

1.1 Background

When people work in factories with low automation level and the processes aren't completely standardised, alterations in the processes take place. This can cause errors and mishandlings of items because their paths through the processes aren't completely clear. Damages, such as scratches and break downs, may cause lots of costs if a new item must be purchased or the damaged item must be repaired. This can cause delays and extra work in production. Worst case scenario is that an expensive item falls apart due to unnecessary moving and the lead time for the item is very long. If the item is a part of a product that is going into a big project the delay penalty can be significant. If this happens in the late stage of the production, all the work has been in vain. The total costs of repairing and, in the worst case, failing the customer's expectations can build up very high.

In this thesis the examined company will be called the Case Company to secure the anonymity. What is important to know is that the Case Company is a part of larger corporation which has specialised in serving customers in different industries mostly focusing on processing natural resources in sustainable way. The corporation provides equipment and services for the use of the customer companies. The Case Company operates in one business area and is mostly focused on providing equipment for customer companies' processes. The Case Company can be described as a mostly assembly oriented metal workshop providing automation solutions for processes in different industries. The Case Company is a leading provider of high-tech solutions which are highly tailored to fulfil the customer needs. Therefore, lots of products need to be engineered to order (ETO). The products are usually combinations of a main end-product and two or more additional parts which complement the functionality. The Case Company manufactures the end-products and the additional parts, but also third-party equipment can be used if customer requires so. Extra parts can be also added according to customer specifications. The end products and additional parts are also available separately. This research is focused on the main end-product production and item handling.

The main end-products' size varies from fist size to an item with outer dimensions of 2.5 m x 2.5 m x 1.0 m. A usual rule of thumb is the larger the main end-product the larger the additional part. That is why the size of the combinations varies even more. The combinations are used in different industries and different conditions. With these kinds of special products, the bill of materials (BOM) may consist of items that are unique in material, shape, size or in all these areas. This means the supply chain for the product's parts needs to be created. In most of the cases, the Case Company's usual suppliers and subcontractors can provide the items needed and the strategic parts are self-manufactured. With the more unusual strategic parts the blank materials may still need a new supply chain.

The Case Company has also products that are assembled to order (ATO) and there are also few types of products made to stock (MTS). For the parts of these kinds of products, there is a stock containing a certain number of items. The number of parts in the stock is based on sales forecasts, supplier's minimum order quantities (MOQ), ongoing production, supplier deliveries and other possible causes. For the special product parts stocks are rarely used and usually only the number of items or amount of material needed for the product manufacturing is purchased. This causes a risk of delays if the part is damaged, but on the other hand, buying extra parts, transporting them and creating space for a long time in the warehouse can be very costly. Especially if the item itself is expensive or big.

High flexibility in production is often needed and because of this many alterations in the processes are possible even though the processes have some level of standardisation. Because of the low level of automation, high variation of items, complex supply chains and worker experience dependent work tasks, people are responsible for many operations. This causes a risk of human errors. In high-mix-low-volume production automation isn't very effective solution because of the machine's low adaptability to constantly changing production. Different product families are produced in the same production lines and the work phases may be very different between the products from different families. This kind of production requires high flexibility that can still be achieved only by using human workforce.

The production facility that will be examined can be described as a facility with high-mix-low-volume production. One item can be used in several different products and some end products may be produced only once. The production is mainly assembly work, but also machining and tooling takes place. The plant examined is one of many plants among the Case Company's facilities around the world, but the main operations has been focused on this plant.

1.2 Research motive and objectives

The Case Company is facing quality costs due to item damages and material handling defects during the production. These costs are categorized as internal failure costs. Most of the items will be fixed by machining, but that isn't always possible or cost-effective. Sometimes new item must be purchased to replace the damaged one but the items may be so expensive that fixing the item is cheaper than buying a new one and usually it is also quicker. In current situation, fixing items is a common way of handling things. The repairing costs can be seen avoidable, and the delays may be harmful for the company. The alternatives for preventing the damages needs to be examined.

In automobile industry Plan-for-Every-Part (PFEP) methodology has been found a successful way of managing items. PFEP is a data sheet where all the important item information is gathered in one place (Harris 2004). The automobile industry differs from the Case Company's industry in many ways, but maybe some things could be adopted and used in the Case Company. A document that holds detailed information for all items could be a helpful tool in the attempt of reducing quality costs due to material handling defects.

Quality related costs are monitored and gathered so that the importance of quality related activities can be displayed for the management. The information can be used for identifying opportunities for improvement and to show the impact of quality related activities on key business. (Dale et al. 2016). These statements are also backing up this thesis. After finding out the current quality costs in the areas where PFEP can be helpful relevant data for decreasing these costs can be chosen in the PFEP data sheet. With the quality cost information and with the analysis of the PFEP's potential to reduce the costs the PFEP implementation can be justified for the management if the impact is found significant enough.

Similar study of adopting PFEP into high-mix-low-volume production within a large manufacturing company hasn't been done before. The uniqueness causes challenges for the study but it is also rewarding to examine a subject with practical application. As a result of the study there should be clear plan how to utilise PFEP in the Case Company's business environment and a well stated estimate of the impact of the procedures that are made possible by the PFEP implementation. The plan includes a model of the PFEP data sheet and a step by step plan for implementing PFEP in the case company.

The most important criteria for the study are the feasibility of the implementation plan and the plan's potential to reduce the material handling defects and the quality costs. Also, usefulness and clearness of the PFEP data sheet should be assessed. The decisions regarding what parts of the PFEP will be implemented in the Case Company should be well justified in order to reduce quality costs, but also the whole production and the total benefits for the company must be considered. The ultimate goal is to reduce avoidable costs and gain better quality by reducing waste.

1.3 Research questions

The main research question guiding the thesis is:

How internal failure quality costs due to material handling defects can be reduced by using Plan-for-Every-Part methods in the Case Company?

To properly answer the main question the three following subquestions needs to be answered:

1. *What are the main causes of the current quality costs due to material handling defects?*
2. *How PFEP helps preventing these costs?*
3. *How PFEP can be utilised in a company with high-mix-low-volume production?*

The main research question will be answered by finding answers to these subquestions.

1.4 Scope of the research

The research takes place in the Case Company's plant in Helsinki Metropolitan Area in Finland. The research focuses on the main end-products manufactured in the plant and the material handling of those product's parts. The quality costs arising from the poor material handling are in the scope of interest.

This thesis focuses on processes where material handling defects happen and which are dependable on the Case Company itself. Also, the processes that affect the material handling, like engineering, purchasing and item data management are examined. In this thesis the scope starts from the point where items are under the influence of the Case Company and it reaches to the point when the items are attached to the end-product. This means that the primary focus is on storing, moving, picking, unpacking and other handling of the items. Defects and damages that happen during the end-product assembly that don't deal with assembly techniques are inside the research scope. Manufacturing, machining and tooling of the items and materials don't belong to the scope. Improving the efficiency in those areas deal more with production and manufacturing techniques. Also picking errors are left out even though they cause extra work and delays in the production but picking errors don't cause material defects, unless the item is damaged during the unnecessary moving.

Some materials are very likely damaged during the transportation, but this can't always be proven. Claims are sent to the transportation company or to the supplier if there is any reason to believe that the defect in the item is due to mishandling of another party than the Case Company. Claims are approved when the evidence is clear but sometimes there is lack of proof and the Case Company ends up paying the bill. The cases where the Case Company carries the cost are within the research scope.

1.5 Research process and the structure of the thesis

The research process started in January 2018 and the process took five and a half months to complete. The thesis was a part of a development project of the Case Company which aimed at reducing part damages during material handling at the plant. The development project continued after the thesis was handed in. The research process proceeded as presented in the Table 1.

Table 1. *Timetable for the research (year 2018).*

Week(s)	Action
2 – 3	Starting the Master's Thesis project. Making the research plan and getting to know the subject more thoroughly and finding relevant literature.
4 – 12	Reviewing the literature continuously. Thesis starting meeting with the supervising professor and the company's thesis supervisor in the week 8.
5 – 10	Finding out the relevant current quality costs and their reasons and mapping the relevant production processes regarding the research. • Analysing Case Company's error reports and related cost data. • Interviewing Case Company's workers about the material handling defects and the processes the defects take place.
10 – 15	Finding out the ways the PFEP can be implemented and utilised in the case company in a suitable way. • Observing the processes where material handling defects take place. • Interviewing Case Company's workers about the material handling defects and the processes the defects take place.
16 – 18	Forming a step by step plan for the implementation based on the findings from the research.
19 – 20	Final touches to the thesis.
21	Sending the thesis for evaluation.

The proceeding of the thesis was self-monitored but the supervisors were reported time to time. The original research plan was followed quite accurately. Small alterations took place, but no significant changes were made.

The thesis consists of seven chapters and their subchapters. In the Chapter 1 the background of the thesis and the Case Company were discussed and the first chapter works as an introduction to the thesis. The objectives and research questions are structured in this section.

In Chapter 2 the theoretical frames considering the subject are discussed. Quality costing, complex supply chains, PFEP and its fit and fitting it to the Case Company's production are discussed. Also, the matter of implementing new practices in organisations is covered.

Chapter 3 covers the questions related to the methodological choices and the research strategy. In this chapter the data gathering and analysing methods are presented and the implementation of the research is described in detail.

Chapter 4 deals with the current state of the Case Company. In this chapter there is presented how the processes related to the research subject work and why they are related to the subject. The accumulation of the quality costs in scope is presented in this chapter. Also, the matters dealing with new practice implementation and carrying out development projects in the Case Company are discussed. Findings from the research are presented at the end of the Chapter and research subquestions are answered.

In Chapter 5 the PFEP implementation is thoroughly discussed. The suitability of the PFEP for the Case Company is assessed. The information included in the PFEP data sheet is discussed as well as the platform and the management of the PFEP data sheet. The linkage between quality cost reduction and PFEP is evaluated from more practical perspective and the main research question is answered. A step by step plan for the PFEP implementation is formed in this chapter.

Chapter 6 summarises the above-mentioned subjects. The most important findings are recapped. In Chapter 7 conclusions are made and the validity and the contribution of the research is evaluated. Implications for the Case Company are discussed and future research subjects are suggested. Also, the future development areas in the Case Company are discussed.

2. THEORETICAL BACKGROUND

2.1 Quality costs and reducing them

In the Case Company the quality costs are monitored and reported on monthly basis. The quality costs are categorized in a way the Figure 1 shows. The figure by Buthmann (2018) follows the Prevention – Appraisal – Failure (PAF) model presented by Feigenbaum (1956). The model has been utilised by many agencies, for example British Standards Institution recommended to use this model in companies for quality cost categorisation (BS6143 1981). Dale et al. (2016) state that the PAF model is universally accepted, even though, it has faced some criticism.

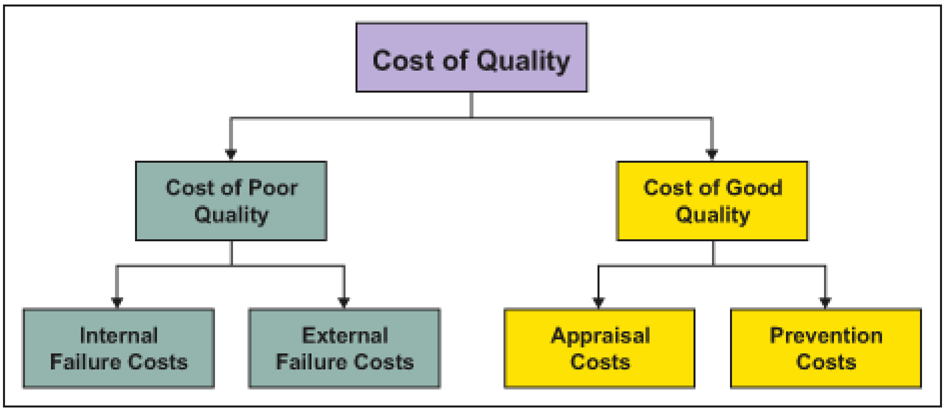

Figure 1. *Cost of Quality formation* (Buthmann 2018).

Prevention costs arise from company's activities to prevent poor quality of products or services. Appraisal costs associate with measuring, evaluating and auditing them. When the products and services don't conform to customer requirements we deal with failure costs which can be divided into two categories: internal and external failure costs. Internal failure costs are the ones associated with the failures found before shipping the product or providing the service to the customer. External failure costs are the ones occurring after the product or service reaches the customer. (Summers 2005)

Intangible costs are often left without quantification, like in this case, because they are hard to identify and quantify. Intangible costs are hidden costs which are due to failing customer expectations and involve the company's image. The way the customers see the company and its ability to provide products and services certainly have impact on long term profitability. (Summers 2005). That is why intangible costs should always be considered even though those are hard to portray explicitly. Categories of quality costs and examples of the reasons behind them are presented in the Figure 2.

Prevention Costs

- Quality planning
- Quality program administration
- Supplier-rating program administration
- Customer requirements/expectations market research
- Product design/development reviews
- Quality education programs
- Equipment and preventive maintenance

Appraisal Costs

- In-process inspection
- Incoming inspection
- Testing/inspection equipment
- Audits
- Product evaluations

Failure Costs

Internal:

- Rework
- Scrap
- Repair
- Material-failure reviews
- Design changes to meet customer expectations
- Corrective actions
- Making up lost time
- Rewriting a proposal
- Stocking extra parts
- Engineering change notices

External:

- Returned goods
- Corrective actions
- Warranty costs
- Customer complaints
- Liability costs
- Penalties
- Replacement parts
- Investigating complaints

Intangible Costs

- Customer dissatisfaction
- Company image
- Lost sales
- Loss of customer goodwill
- Customer time loss
- Offsetting customer dissatisfaction

Figure 2. *Categories of quality costs and their possible causes (Summers 2005).*

Total quality costs arise from different kind of activities, such as the sales and marketing functions, design, research and development, purchasing, storage, handling, production planning, operations, delivery, installation, service, etc. (Dale et al. 2016). Under the scope of this thesis are the internal failure quality costs caused by material handling defects. Failures in the PAF model can be defined as costs resulting from products and services not conforming to quality standards or performance requirements. These include the procedures for correcting defected products or services or other losses associated with poor quality. (Loduca 2011). Scratches on the profile surface and breaking of an item because of dropping it are few examples of the quality defects which cause internal failure costs for the Case Company. The actual costs in these cases arise from assembly and machining rework and, if necessary, scrapping the item and the following purchase of the new item. Those can be seen as attempts to correct defective products which Loduca (2011) and Summers (2005) mention in their failure descriptions.

Distribution of quality costs among the cost categories reflect the state of company's quality system. The cost distribution can be used in identifying possibilities for more effective use of money. (Sower 2011). Money saved in total quality costs will turn out as increased earnings (Campanella 1999; Sower 2011; Summers 2005). Changing the proportions of different quality cost categories don't bring any savings yet though. By increasing appraisal costs, one can achieve reduction of external failure costs but will probably find increase in internal failure costs, because the failures are detected in earlier phase. By finding out the root causes of failures, which can mean temporary or long-term increase in both appraisal and prevention costs, the quality system can be improved. Eliminating the reasons of failures usually means reduction in failure costs and when the root cause has been eliminated also appraisal and prevention costs can possibly be decreased. This means the total quality costs have decreased. (Sower 2011)

Sower (2011) encourages to view prevention costs as an investment because the money allocated for this cause work to prevent nonconforming products and services. Summers (2005) state that companies that are free of product and process defects benefit from faster cycle times and reduced scrap and rework costs, which leads to other benefits, like gaining more market share. The primary focus on cost improvement should be on the largest cost contributors, because this way the greatest improvement can be achieved (Summers 2005).

2.2 Plan-for-Every-Part

2.2.1 The idea of PFEP

PFEP is a crucial tool in creating a lean material handling system for purchased parts. The PFEP itself is a data sheet where all the necessary information of parts is collected. PFEP's function is to centralise useful item information in one place and make item related data available and visible to everyone in the organisation. The idea is to accurately specify all the details of the items and how every part is handled and used. (Harris et al. 2003). Well executed PFEP implementation helps providing quick answers for operations regarding items and suppliers and it eases the plant-to-plant movement of items (Harris 2004). Fan & Deng (2016) argue that PFEP has a crucial impact on the entire process of value-added activities.

For example, PFEP used in an engine plant includes the basic information of material, supplier, inventory and replenishment (Fan & Deng 2016). Song et al. (2010) include also descriptions of containers and information of production hours related to the item in their PFEP data sheet. Harris (2004) includes all the above-mentioned traits in his example of PFEP data sheet and he also adds information of supplier performance in it. However, Harris et al. (2003) remind that the information needed in the PFEP data sheet is individual and depends on the company. The item information collected in the PFEP data sheet depends on what is found valuable information to have for further use.

With PFEP the item data and other important information related to the items are shared in the organisation. Utilising PFEP isn't a value-creating process on its own, and because of this, PFEP itself isn't lean. PFEP, though, helps in increasing the percentage of value-creating processes. (Harris 2004). All in all, by improving the internal material handling, more efficient distribution and manufacturing flows are possible (Rocha et al. 2010).

2.2.2 PFEP utilisation and implementation

Song et al. (2010) present a PFEP-oriented in-plant logistics planning method for assembly plants. They extended PFEP from purchasing to production and described the ways how the approach supports the logistics planning inside the plant, including designing the warehouse space, handling of materials and packaging. Their study showed that that applying PFEP-oriented planning method in internal logistics planning is efficient. (Song et al. 2010)

Harris (2004) and Harris et al. (2003) state that a key element of PFEP is flexibility and this should be considered, so that the information management system is able to accommodate continuous change. Harris & Harris (2008) describe how PFEP data can be updated and the updated information can be shared simultaneously in the organisation, even though they recommend that only one person should be responsible for the actual updating of the PFEP data sheet, a person they call PFEP manager. An important aspect in their code of practice is a triangle of involvement, so all the important stakeholders will be informed when data is updated and their consent for the update is expressed in a form of signature in a PFEP change request form (Harris & Harris 2008).

Only the PFEP manager should be managing the PFEP data sheet, but the data should be available for everyone in the organisation. Everyone in the organisation should be able to look, sort and find information from the PFEP data sheet. In this way the valuable information the PFEP data sheet contains can be shared through the organisation. Usually the companies have the data PFEP contains, but it is scattered all around and in different places and finding and analysing it can be problematic. The easiness of access and the centralisation of data helps to avoid many types of waste. (Harris 2004)

PFEP connects especially purchasing to production, because PFEP helps identifying the purchased parts used or brought to production. By checking information from the PFEP data sheet, production workers can get the same supply chain information regarding the items than the purchasing department has. To get the information flow the other way a purchased parts market would be a suitable construction. In this way procurement department can easily see what parts are consumed in the production and what items need to be purchased to refill the inventory. (Harris & Harris 2008). PFEP offers valuable information for production control processes, because it works as a quick reference to know the part’s supplier information. Operations can use PFEP for detecting quality problems and for solving them. (Harris et al. 2003).

Harris et al. (2003) point out few things to consider when implementing PFEP:

- Information included in the data sheet (data should support the functions)
- Data entered in the smallest possible element (helps in sorting data)
- Stakeholders using the information (data should support the functions)

- Platform (the data should be available for everyone in the organisation and it should be easily sorted and used)
- Managing the PFEP data sheet / PFEP manager (the fewer people managing the sheet the more accurate the sheet probably is)
- Updating the PFEP data sheet (triangle of involvement, PFEP change request form)
- Piloting the PFEP (start with a scope you are certain you can manage)

Harris et al. (2003) also state that collecting the data in the first place, when creating the PFEP data sheet, can be very time consuming and it may require more than one person to collect it. After the data is on its place, the PFEP manager should be the only one managing the data sheet. The piloting process is a good way to see how the PFEP works and what elements should be possibly added if something is found missing. The main point though is to secure the quality of data and make sure the data sheet works. (Harris et al. 2003). Pyke (2016) points out that many organisations have failed to implement PFEP due to lack of knowledge of the system and the poor execution of the implementation process even if there lies a great potential in the PFEP system.

Flinchbaugh (2005) argues that using lean material handling tools should not be only an extension or single addition of a lean manufacturing implementation, but the idea should be more about lean principles and constant progress. Harris et al. (2004) present implementing PFEP as the first step of lean material handling system development. This means even there wouldn't be other traits of lean material handling system, creating PFEP is a good starting point for starting to develop one. Other parts should be added later, to gain all the benefits of lean material handling.

2.2.3 PFEP's contribution to quality cost reduction

The original idea of PFEP isn't straight forward related to improving quality but creating an efficient material handling system, as stated above in the Chapter 2.2.1. For many manufacturers material handling itself can cause more than half of the manufacturing costs (Green et al. 2010). The quality problems as they are may not be solved by collecting a PFEP data sheet, but the data the PFEP sheet contains can be used for analysing the current procedures and for planning more efficient ways for material handling. When more details can be taken into account, for example in the planning of packages and item protection, damages and defects are probably reduced. Other systems should be used for detecting and identifying the quality problems. The PFEP sheet's data can be used when solving the problem.

Harris & Harris (2008) state that the people who have the first-hand quality information are the people facing the quality problem. Those people are usually working in production or in the areas associated to it. Harris & Harris (2008) say that sometimes it is possible that production workers can even foresee quality problems before they have even emerged. To avoid and solve quality problems they suggest using *Andon* system. Andon is a system for detecting, indicating and solving quality related problems. The origins of Andon are in the Toyota production system. When a worker detects a quality problem the worker sends a visual and audible signal that informs the production supervisors and other production workers that a quality problem of some sort has occurred. The idea is to solve the root causes of the problem as effectively as possible and prevent the defect from happening again. (Harris & Harris 2008)

An Andon system isn't a part of PFEP but there can be seen a clear connection and ways how they can support each other. If an error is detected Andon could be a great system for signalling the problem. On the other way around, if a problem is signalled via Andon system PFEP can be a helpful tool for analysing the problem. When PFEP data sheet is formed, possible lack of data will force the organisation to find it out and add it in the sheet. This brings the problems related to the item and its usage in the production on the table. This way quality problems are assessed as well. PFEP data sheet may also contribute in reducing defected and unusable items ending up in the assembling if pickers and workers in previous work phases detect the problems. The identification is easier when a worker has access to database where he or she can check the item specification if there is any doubt.

PFEP can contribute to packaging and moving of items which enables especially defects during the transportation and unpacking. With PFEP data the use of warehouse area can be planned more efficiently, when being able to categorise the items in different ways. The greatest potential of PFEP in reducing quality costs associates with the idea of PFEP reducing the number of times the item is moved, lifted or handled in any way. If the number of handling the item can be reduced also the probability of the item defecting is reduced. Also, the PFEP data sheet can be used for planning right kind of item protection. It can be clearly pointed out if the item belongs to a category which requires special attention and what procedures should be done to protect the item from damages and defects.

2.3 Product and item data management

A company can manage industrially manufactured product during the product's whole life cycle using product data management (PDM) system. PDM is a systematic method for managing and developing a manufactured product. Usually the letter combination PDM refers to an information system or application developed for the product data management. The core of PDM is to develop, maintain and store the data related to the manufactured products so the information needed in daily operations can be found, distributed, processed and re-used as easily as possible. In large companies the data quantities are enormous and when millions of complex, tailor-made items from wide product portfolio are manufactured, it is clear, that without effective PDM it is impossible to operate globally. (Sääksvuori & Immonen 2002)

In high-tech companies, challenges related to PDM are numerous. Greatest challenge usually is to get employees to understand the product data correctly and follow the processes so inaccurate and incomplete data wouldn't get to the system. Personnel using the system is one of the vital aspects in the effectiveness of the PDM system. (Kropsu-Vehkapera, Haapasalo, Harkonen, & Silvola 2009)

For every product there is specific data that defines its physical and functional properties. The information can consist of very specific technical details and more abstract information regarding the nature of the product. Product specifications are usually connected with bill of materials (BOM). BOM is a list of parts and items used in the product, which differs from product structure. Product structure tells how the parts are related and attached to each other. Product data is the core of the company's functions and business. Handling of product data connects the material and immaterial know-how in the company together. (Sääksvuori & Immonen 2002)

PDM relies on functional use and management of items. Item categorisation is a systematic standard to identify, code and name a physical object, product part, component, material or service. What is categorised as an item depends on the company. For example, packages could be left out or counted as items. For the functionality of PDM the consistency in item management is crucial. Items should follow company's own or some commonly used standard and the architecture of the item system should categorise the items into different categories and sub-categories in an expedient way. (Sääksvuori & Immonen 2002)

PDM systems are usually used simultaneously with other applications and systems and together they form the company's information technology (IT) infrastructure. It is quite common that PDM system and the enterprise resource planning (ERP) system are used side by side because they have traits that complement each other. They are mostly used for different things but sometimes PDM and ERP systems can have similar functions. In that situation it is important to decide which system is used for which operation. A good practice is that the information is maintained in one location and other systems can read the information from there. It is crucial to know where the original information is kept and who is responsible for it. (Sääksvuori & Immonen 2002)

PDM systems are usually used by the ones who create product and item data, like engineering and development departments. ERP systems are usually used by the product and item data users, like production planning and logistics departments. PDM is often used for creating new items and item structures but very seldom for managing inventory levels or customer orders. Those are often managed in ERP system, but the basic information of the items is usually read from PDM system. The relationship of PDM and ERP systems can be presented as in Figure 3.

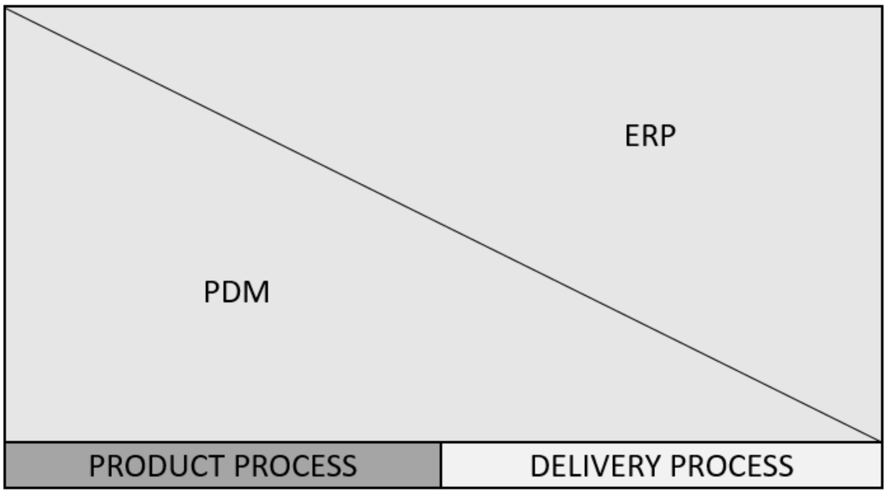

Figure 3. *The relationship of PDM and ERP systems (Sääksvuori & Immonen 2002)*

From the Figure 3 can be seen that PDM involves more with the products and creation of them. ERP deals more with the different functions linking the customer to the products. ERP systems are often module based and they have modules for different functions. Modules can be divided so that purchasing, logistics, production, financial administration and services have their own ones. Most of the basic information used in these functions can be found from the PDM system. That is why a linkage must be built between the PDM and ERP system so the information can be transferred easily from PDM to ERP system. (Sääksvuori & Immonen 2002)

ERP helps in the administrative operations regarding manufacturing, but the actual production process may need more detailed guidance or follow-up. For this purpose, manufacturing execution system (MES) may have a better fit. MES is usually used in the manufacturing level of the company. MES helps and guides the operations in the manufacturing and it also forwards data from there to be analysed on the administrative levels. (Cottyn et al. 2011). The Case Company uses MES in the manufacturing operations. The ERP system and MES are connected to each other, but they work separately.

2.4 Complex supply chains

A supply chain is defined as a set of three or more entities (organizations or individuals) directly involved in the upstream and downstream flows of products, services, finances, and/or information from a source to a customer (Mentzer et al. 2001, p. 4). With the Case

Company the description of ultimate supply chain describes the reality in the best way. Mentzer et al. (2010) describe the ultimate supply chain as presented in the Figure 4.

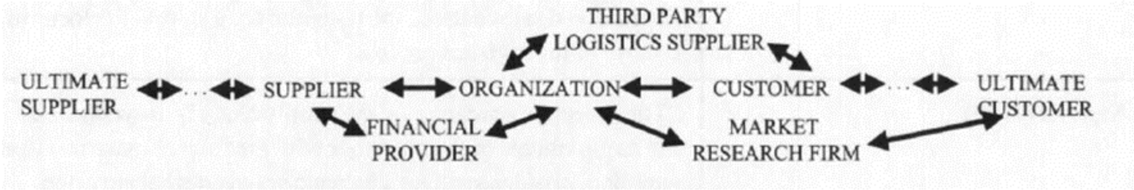

Figure 4. *Ultimate supply chain (Mentzer et al. 2010, p. 5).*

Still the reality is even more complex in the Case Company's case, because many items purchased from the suppliers are sent to subcontractors for extra work phases, for example to be coated. This doesn't happen with every item, though. Also, the supply chains are global so lots of transportation, packing and material handling takes place. This thesis focuses on the interface of the suppliers, transportation companies and the Case Company's operations. Naturally the supply chain ends up all the way to the end customer, but in this study the supply chain is examined only up to the production phase. Still, the end customer can't be completely ignored. The Figure 5 gives a representation of the scope of interest regarding supply chains in this research.

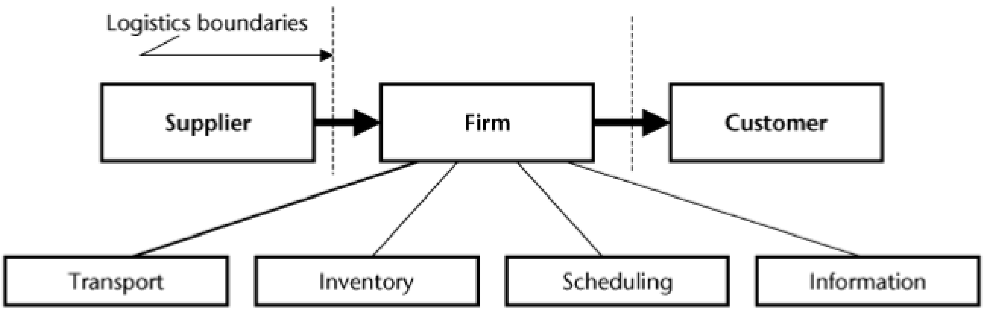

Figure 5. *The areas of interest regarding supply chains in this research (adapted from Skjøtt-Larsen 2007, p. 24)*

It is argued that nowadays supply chains compete rather than firms and brands (Christopher 2005). To improve the competitiveness of a supply chain one must either tighten the co-operation with the organisations forming the supply chain or coordinate the material, information and financial flows better (Lee 1998). PFEP methodology answers the need for better coordination of information flows. To achieve well-functioning supply chain suitable partners and co-operation are also needed (Stadtler & Kilger 2008).

Skjøtt-Larsen (2007) lists five fundamental themes regarding the changes happening in today's corporate environment: customer orientation, decline of mass production, smaller inventories, development of electronic commerce and smaller organisations. All these themes are present in the Case Company's environment. Product and service customisation are consequence of customer orientation and also niche marketing encourages this. (Skjøtt-Larsen 2007). Especially lean thinking has reinforced the trend of smaller inventories (Womack & Jones 1996). Electronical commerce has made procurement more efficient and supply chains more responsive. Downsizing and, in the Case Company's case, outsourcing reduces the size of the organisations when different functions, like transportation and warehousing are outsourced. (Skjøtt-Larsen 2007)

Stadtler & Kilger (2008) describe how supply chains can be analysed and what should be considered when doing so. What comes to procurement they mention the batch sizes, lead times, flexibility and reliability of suppliers and the sourcing types. The sourcing type refers to how many suppliers there are for certain kind of items to fulfil the demand, cf. single sourcing (one supplier supplies all) vs. double sourcing (supplier A supplies 70 % and supplier B supplies 30 % of the total demand of the item). Things regarding production that should be considered when talking about supply chains are the actual organisation of the production process, repetition of operations, working time and production flexibility. Also, the bill of materials is very valuable element, and the information regarding it must stay intact, so the customer gets all the relevant information in the end. (Stadtler & Kilger 2008)

Customer specifications for different parts and items can vary from the use certain materials to very specified origins and strict testing and certification criteria. This means that defining all the materials and parts used correctly is an important element in the final cost of the process. The financial influence is more crucial for companies that work with various specifications in an environment with high level of customer orientation. (Matías et al. 2008)

The global presence of the companies and use of existing global supply chains makes it easier to fulfil the wishes of the customers. On the other hand, managing global supply chain means dealing with political, economic, cultural and social complexity. The materials wanted and the capacity for production can be located anywhere on the globe. (Skjøtt-Larsen 2007).

Transportation forms the physical links between the organisations (Skjøtt-Larsen 2007). It is an important logistic function which is done using established transportation technology (Lukinskiy & Dobromirov 2016). Six basic practice for transportation can be identified: ship, barge, rail, truck, air and pipeline. Usually mixture of these is needed, for example ship-truck combination. (Infante et al. 2009). The primary way of transport in international trade is through ships. Some high-value and urgent delivery items are transported through airplanes. (Gurtu et al. 2017; Ke et al. 2015). When using foreign suppliers these are the preferred ways for the Case Company as well. Sometimes, if possible, trains are used also. In domestic business trucks are the most common transportation method for the Case Company.

During the transportation the items transported need cover and protection. This can be achieved by using different packing materials. Characteristics of a good packaging are that the package is informative, practical and economically the most optimal solution. Good packaging enables that the products can be handled, transported and stored in an economic way. (Logistiikan Maailma 2018). As reasoned in the Chapter 2.2.3 PFEP can contribute to packaging and moving of items which could enable defects during the transportation and unpacking. Also, unnecessary moving can be reduced with more efficient product and package identification.

Sustainability has become more and more discussed subject in the area of supply chain management. Sustainable supply chain management gives more value to the role of economic, environmental and social goals of stakeholders, but controlling sustainability in complex and long-stretched supply chains can be difficult. (Frostenson & Prenkert 2015). Even if the customers have become more demanding on the sustainability aspects, this research doesn't cover the questions related to this. PFEP and the better flow of information may still have a positive impact on this area as well.

2.5 Production modes and high-mix-low-volume production

Flexibility in manufacturing has become one of the most wanted properties in modern manufacturing systems (Upton 1997; De Toni & Tonchia 1998; Iravani et al. 2005). These days, growing number of companies provide great selection of products so they can meet the largely variable customer needs because companies can't rely on high profits by producing large volumes of standardised products anymore. Manufacturing moves towards a configure-to-order and make-to-order environment with high product mix and low order volume. (Zhang & Tseng 2009).

Mass customisation is becoming one of the mainstream production modes for 21st century manufacturing (Lu et al. 2008). Mass customisation tries to bridge classic mass production and one-of-a-kind production (Deradjat & Minshall 2017). Pine et al. (1993) state that mass customisation calls for flexibility and quick responsiveness. They also remind that mass customisation doesn't fit for all industries. For example, commodity products with no demand for differentiation don't need alteration and variety itself doesn't automatically mean customisation. (Pine et al. 1993). In the Case Company's business, though, mass customisation has its place, and mass customisation has been applied in the production.

The Case Company's production streams are mostly assembly oriented so they are basically assembly lines. Becker & Scholl (2009) describe assembly lines to be production systems with flow-orientation. Assembly lines are typically used in the production of industrially manufactured articles which are produced in large quantities and are highly standardised. Still they mention that assembly lines are also important in low volume production of customised products as well. In the Case Company the end products can be categorised in many ways, for example based on product family, construction and assembly time. The plant layout and assembly lines have been designed using the categorisation based on the end-product assembly lead time and end-product size. There are three different assembly lines: ATO-stream, Special-Stream and Heavy-stream, and the ATO- and the Special-streams have been divided into 4 subcategories based on the size and type of the end-product or its need for painting. All items and end products that weigh more than the cranes on other streams can lift are handled and produced in the Heavy-stream no matter the other traits.

Lu et al. (2008) use mass customisation categorisation where four modes have been identified: Sales-to-Order (STO), Assembly-to-Order (ATO), Make-to-Order (MTO) and Engineer-to-Order (ETO). Other researchers use Make-to-Stock (MTS) as one category rather than STO, but the other categories stay intact (Mukherjee et al. 2009; Kalantari et al. 2011; Guillaume et al. 2013). MTS, ATO, MTO and ETO categorisation is used in the Case Company as well. The ATO-stream produces MTS, ATO and some of the MTO products and the Special-stream produces rest of the MTO and the ETO products. Products produced in Heavy-stream are MTO and ETO products. Most of the MTS product production has been centralised to other plants and the plant under examination has specialised more to the MTO and ETO products. Lots of ATO-production still takes place too.

MTS products satisfy customers' wishes with their existing traits, so no customisation is needed (Kalantari et al. 2011). ATO products generally have low degree of customisation, so design of this type of customised product can be achieved through configuration only, and there is no need to design new modules (Lu et al. 2008). MTO products are prepared from components according to the specifications of the customer's orders. Therefore, lead time is longer for MTO than for ATO products. With ETO products, degree of customization is very high. Customer can partly work as a co-designer. This can be called pure or collaborative customization. (Mukherjee et al. 2009).

High degree of customisation means low volumes of products are produced, because other customers don't want the same traits than others and in the Case Company's case also the number of the products ordered by the customer is usually low. On the other hand, high customisation means large variety in production. The term *high-mix-low-volume production* originates from these bases. Kusuda (2010) argues that solving the problem of effective high-mix-low-volume production is one of the most urgent issues in manufacturing community nowadays. Human workforce deploying cellular manufacturing has been the solution for now, but Kusuda (2010) portend improvement of automation in the area cellular manufacturing in following years.

At the moment, cellular manufacturing and group technology are applied in the Case Company's production streams. Cellular manufacturing system allows more flexible low volume production (Wang 2015). Group technology exploits the component similarities and the similarities in the production and the tooling processes (Akturk & Balkose 1996). Cellular manufacturing has been derived from group technology by applying it in manufacturing and layout planning. In cellular manufacturing all or a part of company's manufacturing has been modified to cells. (Wemmerlöv & Hyer 1989). Wang (2015) defines a cell as a small scale, clearly defined production unit within a factory. The idea of cellular manufacturing is to reduce setup and flow times by taking advantage of the similarities of the items handled and the procedures done in the manufacturing cell (Mukattash, Adil & Tahboub 2002).

In cellular manufacturing, the working areas and tools in the production are put in order in a way that the material and component flow in the production process is as efficient as possible. The idea is to move one piece at a time rather than get many items ready at the same time. The pace is determined by the customer's needs. The goal is to optimise the time for one product to flow through the production process. The cells include the necessary machines and manpower for producing the part or the whole product, depending on what is the function of the cell. This gives each cell the ability to work on its own independent from other cells. Workers of a specific cell are expected to have all the required skills for operating in the cell. (Wang 2015)

2.6 Complexity of inbound and inhouse logistics due to numerous items

Logistics operations can be divided into external and internal logistics. External logistic chains are formed by stations outside the company and by transport connections between shipping locations, reshipment points and logistics centers. Internal logistic chains are formed by the stations and connections inside these hubs. (Gudehus & Kotzab 2011). Rocha, et al. (2010) argue that more and more internal manufacturing logistics should be fully coordinated with manufacturing resources (machines, tools and operators) and should support the changing environment concerning product complexity, variability and changing product volumes. Also, an important thing to consider is that the internal logistic system is dependable of the production systems, in terms of type and volume (Rocha et al. 2010).

The starting point for an internal logistic chain is in the receiving area of the goods. After the items are received they need to be handled in the plant and other necessary administrative activities need to be performed. These activities are unloading the arriving vehicles, controlling the quality of arriving goods, unpacking and repacking the items and converting the received goods into storage units. (Gudehus & Kotzab 2011). For the Case Company there are hundreds of different suppliers supplying different types of items in different types of packages. Managing the handling and receiving of the items delivered requires knowledge and flexibility.

In the plant under research there is separated goods entry at one side and goods dispatch area at another side of the plant. The items are planned to flow from one end to another. There is storage area in the middle of the plant. The items are stored on shelves either on pallets or in drawers. The place modules have certain dimensions, such as height, length and depth which are freely designable parameters of shelf rack stores (Gudehus & Kotzab 2011). 800×1,200 mm Euro-pallets are standard pallets mainly used in Europe, but it is also the most widely-used exchange pallet in the world (European Pallet Association 2018). The Case Company uses its own pallet standard 800×1,000 mm. The shelf racks have been adjusted according those dimensions.

The Case Company utilises and mixes different storage techniques. Some items are stored using fixed storage order. This means some store places have been reserved for an article and it is prohibited to use it for other articles even the place would be empty at the moment. For some items the storage order is free and they can be placed as found convenient. That means free storage places are available for storing any article. Also, article-pure placing can be identified. That is, one store place is strictly appointed for storage units of a specified item or an item batch. For some storage areas there can be made certain categorisation which type of articles or storage units are stored in that area. This is called zone-fixed storage order. For example, one shelf stand can be reserved for the parts of one end-product family. (Gudehus & Kotzab 2011)

Gudehus & Kotzab (2011) point out that any company that needs storage services must consider, if the storage services should be executed by the company itself or should a third party be involved to handle them. Certain advantages can be achieved if the functions are outsourced. Logistic service providers have specialised in planning, setting up and operating storages. They usually achieve better efficiency in those areas compared to companies which core competencies lies elsewhere. Because third-party logistic service providers usually have built large stores for the use of multiple clients the economic and technical economies of scale and lower operating costs can be achieved. Savings in staff costs can be achieved because generally the income level in the storage and logistics business is lower than in other industries. (Gudehus & Kotzab 2011). Case Company utilises services of a third-party logistics service provider. Also, inventories of some items are manged by vendors. Vendor-managed inventory (VMI) means a type of co-operation between two companies where the supplier is authorised to manage inventories of the items it is supplying at its customer’s location (Waller et al. 1999, Cetinkaya & Lee 2000). VMI operations aren’t suitable for all items and companies (Niranjan et al. 2012). The use of VMI in the Case Company has been limited to bulk items, such as often used screws, bolts and nuts.

Gudehus & Kotzab (2011) state that applying dynamic storage strategies aim to maximise throughput performance, fulfil time requirements and keep the storing restrictions. Possible restrictions for storing are for example strict and moderate First-In-First-Out (FIFO) and Last-In-First-Out. The Case Company follows moderate FIFO in all inbound logistics. Receiving of goods and shelving aim to fulfil FIFO as good as possible. The shelving must be done so the FIFO restrictions can be followed in picking. The restrictions are moderate because for similar items with no expiration date the using order isn't so critical.

Commissioning is a very important part of intralogistics and it comprehends more than just picking articles. *Commissioning is the collection and consolidation of required quantities from an assortment of articles due to given orders.* (Gudehus & Kotzab 2011). Nowadays automation in picking is possible, but picking is still usually executed manually by people – pickers. Picking of units of different shape and size is difficult to automate. The quality of order picking can be figured out by comparing the total number of commissioning orders in a period of time, to commissioning orders that are executed in a correct way and in time. The availability of items in the storage effect on the commissioning quality. Orders can't be executed, if there are no articles to pick. (Gudehus & Kotzab 2011)

Things affecting the order picking quality are the order structure and the number of lines on an order. These are important aspects for customers expecting the orders to be delivered correctly. (Gudehus & Kotzab 2011). In the Case Company's case the main customers are the assembly streams. The errors in the picking process affect the most on the figures describing commissioning quality. Picking from the wrong access unit, mixing-up articles, picking wrong quantities of articles, positioning articles in the wrong units, skipping positions, leaving picking orders without attention and completing orders late are typical examples of picking errors. If the articles being picked are constantly different in their size and shape and the quantities also vary, it is recommendable to consider the commissioning system carefully so it is expedient. (Gudehus & Kotzab 2011)

Faccio (2014) states that one of the biggest challenges in operating a mix-model assembly system is the feeding of parts to the productive units. Kitting is one way to operate. It means that all components of an item or a product must be collected before being sent to assembly (Faccio 2014). In the Case Company the pickers pick all the items on a same pallet before sending them to assembly-streams. Picking operations for Heavy-stream differs a bit, because of the size of the items. For ATO- and Special-streams all the end-product parts are delivered at the same time. The picking doesn't start before all the parts are available in the warehouse, because delivering an incomplete set of items has no point. End-product can't be assembled if any part is missing.

2.7 Implementing new practices in organisations

New practice implementation is essential for organisations to remain competitive in the changing business environment. Some organisations may be lulled into the delusion that old practices work as effectively today as they did many years ago. Globalisation, new technology, changing demographics of workforce, and shortening project schedules require organisations to implement improved practices in engineering and construction departments even if they have been successful in the past. Stagnation is the inevitable outcome if there are no new ideas to test and apply in action. When there are ideas, ways to overcome numerous obstacles that emerge during an implementation process and successfully convert these ideas into sustainable practices are needed. Introducing new or improved processes, even if they are found best practices, is a challenge for all types of organizations. (Chinowsky 2008)

Instilled practices in industries, corporate culture, and the need to minimize risks often cause challenges when implementing new ways of doing things or completely new processes. Because of these reasons an implementation plan is required. The implementation plan should provide instructions detailed in a way that all the stakeholders affected by the new process or practice are familiar with the roadmap followed when the implementation takes place. (Chinowsky 2008)

Gaining understanding of the reasons why some employees may resist change can have significant implications for the organisation. Quite often many employees experience a resistance to change, sometimes in the form of change-specific cynicism. It means that the employees believe that the employing organization lacks integrity. (Grama & Todericiu 2016). The risk for this kind of attitude towards any new practice is worth finding out so the adaptation can be taken into account in the implementation plan. Also, employee involvement in the planning phase and in the implementation, is highly recommended (Handel & Levine 2004).

Chinowsky (2008) argues that the key in implementing new practices successfully is to have a clear perspective on the overall steps required for the entire implementation process. Meyers et al. (2012) argue that similar steps exist in the implementation processes regardless of the type of innovation, target population, and desired outcomes, so they state that previous cases can be used as reference for other implementation processes in different fields. There are numerous “how-to-implement” models which are intended to provide support for planning and managing implementation attempts (Nilsen 2015).

The how-to-implement models typically emphasize the importance of careful, considerate planning, especially in the early stages of implementation process. They manage to present quite well the idealistic practice for implementation as a process that proceeds one step at a time in a linear way. It needs to be noted, that many authors who have been developing the models emphasize that the actual process isn’t necessarily sequential. Models like quality implementation framework (QIF) have been tested and evaluated in many environments, and some, like QIF, have been extensively applied in empirical research, which underscores their usefulness. (Nilsen 2015)

The QIF can be used if evidence-based innovations are wanted to be incorporated into daily practices. It can assist on approaching implementation in a systematic way (Meyers et al. 2012). QIF consists of 14 critical steps and these steps comprise four QIF phases: initial considerations regarding the host setting, creating a structure for implementation, ongoing structure once implementation begins, and improving future applications. These are presented in Figure 6. (Meyers et al. 2012).

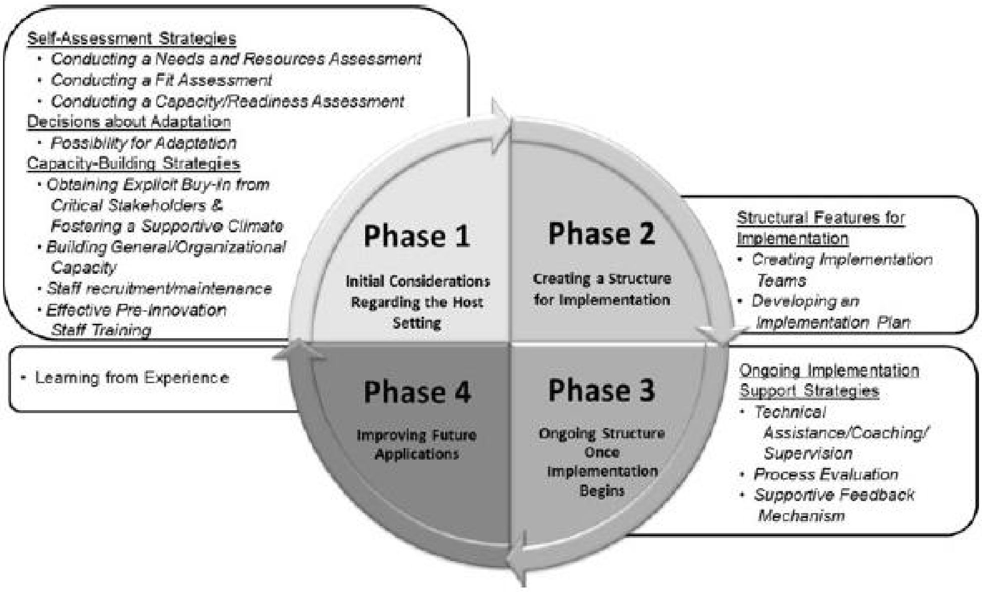

Figure 6. *Dynamic interplay among the critical steps of the QIF (Meyers et al. 2012).*

Regarding the Figure 6 Meyers et al. (2012) state that the arrows linking the phases are meant to suggest that the steps in each of the phases should be considered the whole time during the implementation process. Matters dealt in previous steps may need strengthening, revisiting, or they need to be adapted continuously when innovation is used in the organization. Because a logical order was needed to develop a logical and consistent framework, the researchers mention that the way the phases and steps are implemented in practice are dependent on many factors like environment, resources, and logistical matters. (Meyers et al. 2012)

This Master's Thesis focuses on the QIF phases 1, initial considerations regarding the host setting, and 2, creating a structure for implementation, and after this the implementation and the improvement work lies under the Case Company's responsibility. Phase one deals with initial considerations regarding the host setting. It involves 3 assessment strategies which also form the three first steps of the 14 steps path. The first thing to do is conducting a needs and resources assessment. The second thing good to do is to conduct a fit assessment. As third step QIF recommends conducting a capacity/readiness assessment. Including in the phase one decisions about adaptation needs to be made. The fourth step is finding out the possibility for adaptation. To facilitate the new practice or innovation, capacity-building strategies are needed. The four following steps deal with that. Obtaining explicit buy-in from critical stakeholders and fostering a supportive organizational climate as fifth step is important and it mitigates the resistance to change and gives the justification for the phase one. As sixth step building organisational capacity is required so the functionality of the innovation can be secured. The seventh step, staff recruitment/maintenance, links with the capacity as well, when the group performing the possible implementation is formed. As eighth step effective pre-innovation staff training is recommended. To ensure that providing sufficient training is possible and that the training covers all the important areas is good to do beforehand so it can be affected and dealt with. (Meyers et al. 2012)

Phase two is about creating structure for implementation. To get the structural features for the implementation correct QIF recommends following two steps. First step of the phase two and the ninth step in total is creating implementation teams. This means developing a support team to work with workers who are delivering the innovation. Specifying the roles, processes, and responsibilities of team members is also needed. The tenth step in total is developing the actual implementation plan. The target is to create a clear plan that includes specific tasks and timelines so the responsibilities and deadlines are clear during implementation. Addressing the challenges to effective implementation proactively beforehand easies the work in practice. (Meyers et al. 2012)

Phases three and four, which deal with the matters when the implementation begins, form the last four steps left. Phase three holds in three of these steps. It deals with the ongoing structure once implementation starts. Following support strategies for implementation, such as, securing technical assistance, coaching and supervision, carrying out process evaluation and creating supportive feedback mechanism form these steps. Phase Four, and the last step, is about improving future applications, which basically means learning from experience so the mistakes aren't repeated. (Meyers et al. 2012)

2.8 Synthesis

In this Chapter the theory behind the research subject has been summarised. The number of concepts grew up to be quite high, but this reflects the complexity of the business environment. Especially the theory to describe the functions of the factory included many different terms related to the Case Company's production and its functions. The traits of high-mix-low-volume production and internal logistics in that type of environment were covered. Other subjects covered in the literature review were related to quality costs, PFEP, product and item data management, supply chain management and new practice implementation.

It was found out that there are many types of quality costs and the distribution between the cost categories describe the state of the total quality system. PAF model categorises the quality costs into prevention, appraisal and failure costs. In this thesis the scope is on internal failure costs. The actual costs are usually created when correcting the defected products. Finding the root causes for the accumulation of the quality costs is needed for improving the total quality system. The decrease of total quality costs will likely increase the profits.

The Case Company's business environment demands high flexibility from the production. Mass customisation and group technology provide ways to gain flexibility in manufacturing industries. ATO, MTO and ETO production modes together make it possible to satisfy the needs of different types of customers. Lots of customer specific customisation causes variance in production and leads to low production volumes. Therefore, in high-mix-low-volume production there are usually large diversity of items and materials used.

For creating functioning and flexible production system the material resources must be kept in order. The internal logistics functions must be arranged so the production can be served as well as possible. In high-mix-low-volume production it can be complicated because of the variety of the items. Mixing different storage techniques may be needed. Especially feeding the parts to the productive units must be considered carefully in mix-model assembly system. Operating a large inventory of items is usually cheaper if the warehouse operations are outsourced to third-party service provider.

In global business environment the supply chains can be complex and the parts and materials needed may come a long way and take a long time before arriving to the factory. Suitable protection is needed during the transportation so the parts and materials arrive undamaged. Managing the whole supplier network may need lots of work, but having an extensive supplier base makes it easier to serve own customers when there are possibilities for fulfilling different customer requirements.

PDM and ERP systems are often used for manging products and production. Also, MES is often used for guiding the production in more detailed manner. The PDM systems hold usually the product related data and there are usually systematic ways when creating the items in the system. ERP systems focus on how to deliver the products to the customer. ERP systems are often module based and information regarding only certain aspect of production can be seen.

PFEP is a centralised data base where all relevant item information has been collected and can be seen at one glance. What is categorised as relevant information is company dependent. The PFEP can be used for guiding and planning the functions of the plant. The information on the PFEP data sheet should be divided in as small elements as possible so the items can be grouped and sorted easily. That is why the PFEP sheet should be constructed on a platform where the sorting can be done. Some sort of spreadsheet would be adequate. The PFEP sheet can be used for creating more efficient material handling system. By improving the quality of handling the items and materials the quality defects are likely to be decreased.

Implementing new innovations and practices in organisations is essential for them to stay competitive. Planning the implementation carefully beforehand has been found recommendable and for this there are different how-to-implement models available. One of these models is QIF, which consists of four phases and 14 steps. It has been found as a good assisting framework for systematic innovation implementation.

3. RESEARCH METHODOLOGY

3.1 Methodology choices

The conducted research can be described as a qualitative embedded case study with constructive research approach where multiple research methods have been applied (Saunders et al. 2009; Kasanen et al. 1993). The research is a cross-sectional study conducted by doing semi-structured interviews and observing processes (Saunders et al. 2009).

Case research has been found very effective method of operations management research many times (Voss et al. 2002). Case study as a research strategy *involves empirical investigation of a phenomenon within its real-life context using multiple sources of evidence* (Robson & McCartan 2016). Saunders et al. (2009) recommend using case study as a research strategy if one wishes to achieve broad understanding of the context and the process being enacted. In this case, case study is very suitable research strategy and multiple data-gathering methods are justified so broad understanding of the subject can be achieved. Using multiple data sources and data gathering methods is also justified because in this way triangulation can be performed and the reliability of the research is increased (Saunders et al. 2009).

Voss et al. (2002) suggest that when starting a research that aims to theory building or generating something new, we need to have a prior view of the general constructs or categories we are going to study and, also the relationships of these matters. Constructing a conceptual framework is suggested in such situation (Miles & Huberman 1994). Knowing the context and the surroundings is essential when deciding what to include in the study (Voss et al. 2002). Before starting to create something new, in this case the PFEP system, to be familiar with the environment and the base where the new structures and procedures are implemented sounds like a good idea.

Kasanen et al. (1993) suggest constructive research approach for generating new applications and innovations. What is meant by constructive approach is problem solving through the construction of models, diagrams, plans organisations, etc. Constructions refer to entities which produce solutions to well defined problems. By developing a construction, something new that is different from everything else is created. Because of this, constructions also have the tendency to create new reality. (Kasanen et al. 1993)

Kasanen et al. (1993) divide the constructive research process into 6 phases:

1. *Find a practically relevant problem which also has research potential.*
2. *Obtain a general and comprehensive understanding of the topic.*

3. *Innovate, i.e., construct a solution idea.*
4. *Demonstrate that the solution works.*
5. *Show the theoretical connections and the research contribution of the solution concept.*
6. *Examine the scope of applicability of the solution.*

The first step was covered automatically when the Case Company gave the assignment to reduce quality costs by utilising PFEP methods. The second step covers the above-mentioned things Voss et al. (2002) and Miles & Huberman (1994) suggested, which requires to get concerned with the matter. The third step requires the actual examination and attempt to apply PFEP in the Case Company's environment in order to reach the goal of reducing quality costs. The fourth step is based on the idea that it is important for constructions that their usability can be showed and confirmed through implementation of the solution (Kasanen et al. 1993). However, in the cases of Masters' theses, time for implementing and testing the construction is usually very limited. Therefore, weak market test is preferred way of proving the construction's usefulness. Weak market test means that any manager responsible for the financial results would be ready to apply the construction in the specific surroundings in question. The strong market test would require actual proof of constructions ability to create better results in those areas it is utilised compared to those not using it. It is noted that an invalid construction is very rare to pass even the weak market test. (Kasanen et al. 1993)

All exercises trying to solve problems aren't constructive research. A characteristic and important part of the constructive approach is tying the problem and its solution with accumulated theoretical knowledge. (Kasanen et al 1993). Similarities between design science research and constructive research can be seen, or constructive research can almost be categorised as a sublevel of design science research. This is because design science research focuses on developing propositions that solve real problems (Holmström et al. 2009). Holmström et al. (2009) state that: *''Problems and solutions are not as much discoveries as they are constructions by active research subjects with idiosyncratic frames of reference and unique professional backgrounds''.* Holmström et al. (2009) suggest using design science approach to bridge practice to theory rather than theory to practice. Bridging the created construction to theory is also essential in this case so the criteria of constructive research are fulfilled.

Even though the scientific contribution is an important feature of constructive research, this specific case study aims at solving the Case Company's problems. Therefore, the features, value and potential of the construction created for the Case Company during this research should be the primary measure for evaluation rather than the general scientific contribution of the research.

3.2 Data gathering methods – semi-structured interviews and observing

As Kasanen et al. (1993) state that obtaining comprehensive understanding of the subject is crucial. In order to do so, a literature review was done in relevant areas and the findings worth mentioning were presented in the Chapter 2, people from the Case Company who are responsible for and are dealing with the matter were interviewed in semi-structured interviews and the relevant processes and work phases were observed. The quantitative measures of the quality costs in the Case Company were given, but it was originally collected from the Case Company's Quality Development Engineer's quality reports from the year 2017. The quality cost data had been enriched with the defect reports from MES matching the defect cases on the cost reports, so there was already some knowledge about what were the things actually causing the quality costs. With this knowledge the questions presented in the interviews were structured to get more deep understanding of the subject and to collect ideas for improvement from the people who are associated with the every-day operations regarding the research. Also, the relevant processes to observe for gaining the biggest impact in quality cost reduction when designing and planning the PFEP data sheet were identified partially based on the information got from the quality reports. The other thing influencing what processes to observe were the answers from semi-structured interviews.

Qualitative data for gaining understanding of the surroundings, the business environment and the processes under examination were collected by conducting semi-structured interviews. As usual, in these semi-structured interviews the researcher had a list of themes and questions to be covered, although the themes changed depending on the specific subject or area that was covered (Saunders et al. 2009). The questions were altered in a way they would be as expedient as possible to gain valuable information from the people working in different areas as managers or as a part of the processes under the examination. The interviews were recorded with a smart phone's recorder and relevant sections were transcribed to text with Microsoft Word, also notes were written during the interviews. The interviews were conducted in Finnish because all the people interviewed spoke Finnish as their mother tongue. Total of eight people were interviewed. The people selection for interviewing inside the Case Company was based on the titles and responsibilities people have in the Case Company's organisation. The titles and the responsibilities of the interviewees are presented in the Table 2. This kind of selection method can be categorised as purposive sampling (Saunders et al. 2009). This kind of sampling is often used in case study research to gain deeper understanding (Neuman 2013). Also, snowball sampling was used. This means people interviewed were asked who would have relevant information about the subject, and then these people were interviewed, if it was seen necessary. Saunders et al. (2009) state that this kind of sampling eases to achieve the characteristics desired.

Table 2. *Interviewee's title and responsibilities*

Interviewee's title	Responsibilities in the Case Company
Senior Engineer	Engineers the end-products according to customer specifications
Item Data Team Leader	Coordinates the team responsible for ERP system's procurement and production related data
Purchasing Director	Responsible for the Procurement & Logistics department
Logistics Manager	Responsible for the internal logistics operations in the plant
Logistics Supervisor	Supervises the logistics operations and guides the workers in their work
Quality Engineer	Responsible for the acceptance inspection and the claim process
Value Stream Manager	Responsible for operations and manufacturing in Special- and Heavy-streams and in machining
Development Manager	Responsible for operations and manufacturing development at the plant

The processes where the material handling defects are likely to happen which were recognized based on the quality cost report data and the information gained from the interviews were observed. Qualitative descriptions of the relevant processes and the paths the items are moved were obtained by using the participant observation method. The role adopted by the observer was participant as observer (Saunders et al. 2009). When using this role both the observer and the subject are aware of the arrangement (Ackroyd 1992). This way observer can increase understanding of the subject by asking questions from the person participating the observable process (Saunders et al. 2009). If lucky, in this observation method persons under observations may reflect the processes analytically and valuable information can be gained (Robson & McCartan 2016).

The observations were conducted by following the processes that make up the whole path the item goes through one by one so that a holistic view could be formed when adding the parts together. Observing the processes separately rather than following some specific items flow through the whole path is justifiable, because some items may stay still for many hours and even days. Notes were written to describe the procedures and actions performed in the work phases in detail. Total of 5 different processes were observed and every process was observed at least 2 times for at least 1 hour. Longest observation session took over 2 hours. The observed processes were reception of goods, acceptance inspection, shelving the items, picking including washing the items and assembly. Multiple observations were done in order to reduce bias caused by single workers performance and working habits. In one hour, several items are handled and the basic process cycle is completed many times in reception of goods and in shelving and picking. Quite extensive understanding of the areas for risks for item defects related to the processes was obtained during the observations and by the knowledge gathered from the interviews. Rare exception cases weren't detected during observations, so information about these remain on theoretical level.

To complement the gathered data the Case Company's own internal instructions and standard operating procedure (SOP) documents regarding the processes under examination were assessed. This way it was easy to find out if the processes were executed as planned. Also, assessment if the instructions could be improved was done. Instructions and SOPs are kept in the Case Company's data bases and they are classified as internal or even restricted, so they aren't displayed in the thesis.

Also, data for creating the new construction was gathered during the interviews and the observing. The interviewees were asked what is relevant data for the processes they are responsible for. They were also asked what information would be good to know that they now lack. This was done to find out what is relevant data for the processes so the PFEP data sheet would be as useful as possible.

3.3 Analysing qualitative data and using it for the construction formation

The data gathered from the interviews was scrutinised. Based on each interview the process the interview regarded was outlined and critical details about the origins of the material handling defects were searched. If the same area or process was underlined in different interviews this was kept in mind when performing the observing. Area's known to be problematic were observed with extra attention.

Notes were written down during the observing and the notes were looked through and assessed together with the notes from interviews and the SOPs and instructions. On those bases the processes were described in detail, so the flaws of current system could be identified. Conflicts between statements and actual operation actions were booked down and the reasons for these were analysed. Possible areas of improvement for processes where different types of items are handled were searched through analysing the processes. Finding out the reasons for certain procedures gave understanding of the root causes for different actions and the problems related to them.

The information about the data needed in the operations was assessed based on the results from the interviews and the observations made. Comparing the statements given in interviews and the impressions formed by the observations, the realistic picture of the need and requirements for the item related data for each process was achieved. This way these aspects could be considered in the new construction formation. Also, the wishes from the Case Company's executive board were listened when forming the construction.

The results from the process analysis were used for determining the ways the different items are characterised on the PFEP data sheet. The analysis for the characterisation on PFEP data sheets columns was conducted also using the information from the quality defect reports and the suggestions found usable stated in the interviews. Based on the research findings, suggestions for improvement efforts were given and development procedures were started. New procedures and ways to do things that didn't exist before were taken into account when forming the PFEP data sheet.

4. ANALYSIS – CURRENT STATE OF THE CASE COMPANY

4.1 Accumulation of the quality costs

The quality cost information was given by the Case Company's Quality Development Engineer. The data consisted of ERP information and defect reports from the floor shop reported in MES. The item codes, item names, work phases, defects and machining and scrapping costs could be identified from the data set. Only relevant defect cases were sorted out from the data by looking through the MES reports where the item defects were described. Costs from item scratches and other defects caused by poor material handling were considered when they were detected and reported in or before the assembly phase. By sorting the item defects in this way, it was possible to find out the total sum of quality costs accumulating from material handling defects in the processes inside the research scope. There were gaps in the data about the defects detected in the Heavy-stream, because all the cases aren't reported in MES and all machining rework can't be separated from the actual machining that the item requires, because the repairing is usually executed as one of the work phases. If the item is defected after the planned machining is done, then the machining rework could be identified.

Two main categories causing the costs were identified: assembly rework and machining rework. Assembly rework costs contain the cost of working time consumed in the assembly line without being able to assemble the product because of the defected part. The machining rework costs contain the costs of the work and use of machines based on the pre-set machining rework price and the time used for the repairing. Almost all machining rework is done in the Heavy machining area but some small defected items that are too small to be fixed in those machines are machined with expedient equipment in other machining areas.

The cases that were considered in the assembly rework cost accumulation were situations that caused extra work or idle in the assembly cell. Most of the cases were item scratches, dents or dirty items that required unplanned washing. Picking errors were left out. Cases that lacked proper description of the defect were included if the rework comments backed the selection or if the selected defect categorisation gave a reason to believe it would be a relevant case.

The machining rework costs included were cases that could be identified as machining rework caused by poor material handling which wasn't caused by the supplier, so a claim hadn't been sent. The machining rework cases due to scratches and dents could be identified because only certain machines dedicated for machining rework were used when working on the item. The rework comments were also checked so that the cases were relevant. Machining rework done for defected items for which pre-planned machining have been done during the same manufacturing order haven't been included.

Machining rework causes 70 % and assembly rework 30 % of the total quality costs caused by material handling defects. According to the quality cost reports no items were scrapped because of bad material handling. The main item types needing machining rework and causing rework in assembly lines were the end product's body parts. The size of the body parts varies from few centimeters in diameter and few kilos in weight to two and half meters in diameter and hundreds of kilos in weight. Certain surfaces of the body parts have strictly defined tolerances for scratches and defects, and when detected they must be removed before proceeding in the production.

Defects in body parts were the cause for 75 % of the machining rework costs and cause for over 50 % of the costs from assembly rework. The smaller percentage of body parts in assembly rework costs can be explained, because all the parts cause equal amount of costs if the assembly can't be executed as planned no matter the item's shape or size. The number of body part defects was about 50 % of all the defects under scope. Many of the defected items can't be fixed by machining so they don't cause machining rework.

In the assembly rework costs there are also included some cases where the items picked for assembly have been dirty and the assembly work could not be executed as planned. These have been counted as material handling defects, because the items should have been washed. Items that can't be used in assembly cause either extra work or idle in the production. Most of the dirty items were also body parts which had been protected with storage greases that should have been removed before delivering them to assembly cell.

There are two main things explaining the big difference between the assembly rework costs and machining rework costs. The mean of machining rework price is 47 % higher than assembly rework price and the average time consumed for machining rework is 2,56 times longer than the time used for assembly rework. The price of machining rework is higher than assembly rework's price, because the machining requires both the machine and the person who uses it.

The numbers behind the chart in Figure 7 lack some of the Heavy-stream's own machining rework because the scratches and other defects that there have been in the parts are machined away as a part of the planned machining work. Also, some of the assembly rework data from Heavy-stream may be incomplete because the parts don't go through rework area. Heavy-stream's items are fixed in the Heavy-stream and possible extra work may leave without reporting. Bigger disturbance cases are reported. The costs caused by Heavy-streams unreported assembly rework are probably relatively small and they don't change the ratio of cost categories significantly. The lacking machining rework cost would probably influence the current total machining rework cost value increasingly.

Evaluating the increase is difficult because there is no data to separate the cases of repair work and actual machining work. Only thing that can be said is that the total quality costs are higher and the share of machining rework is even bigger than 70 %.

4.2 Management of the item data and the supply chains

The main system for handling item data and especially the supply chain related data is the Case Company's ERP system. All the customer orders (CO) are entered in the system and based on the order requirements for items are created. If all the items needed for producing the end-product required on the CO are usable in the warehouse the production planners can coordinate the end-product production immediately. If the items are found in ERP, but there is shortage of items, purchase orders emerge for the procurement. If the needed item isn't found in ERP it needs to be added there and the supply chain information must be entered so the procurement department can purchase the item. The enrichment is done by Item Data Management Team. All the information of Case Company's own products and the parts needed for them can be found from the Case Company's PDM system. The engineering department can change the information in this data base and create new items. Other departments can view the information but can't change it. The PDM system contains information of all the end-products, their BOMs and parts. Information of both active and inactive items is stored and information of old versions of products and items is also maintained in the system.

Identifier (ID) codes are used for identifying items and end-products. There are multiple different ID systems in use at the same time, because due to system updates, acquisitions and new sales system integration different ID coding systems has been embedded to existing ones. Different systems follow internally pretty much the same logic: ID codes with higher number in them are newer than the ones with smaller number. Exceptions exist. IDs can also contain alphabets. Item order between different ID coding systems though can't be specified.

ID code as such doesn't tell much about the item. In some cases, it doesn't tell anything, but some codes are only for sales items, basically end-products, or the code can tell which warehouse is supplying these items for customers. Also, the sales system from which the customer order has been entered can been tracked based on the ID code. The alphabets in ID codes are usually the ones carrying the information. Description about the item must be added after the ID to tell what the item actually is when they are handled in the IT systems. On the floor shop, the items appearance with ID can tell everything needed for an expert, but one can't remember all the ID codes so description is a good addition for the item identification anyway. The item description usually holds the information of item type, size in millimeters or in inches and material. For end-products the item types have been coded and the codes contain the information of the construction, materials and functionality. The item type codes need to be encoded with data sheets which tell what a marking in that type code stands for. Similar kind of coding is used for different product families, but same markings can mean different things with products of different product families.

For items fulfilling some sort of special specification a tail code has been added in the end of the ID. The tail code can indicate that the item fulfils some certification criteria, a specific test has been done to it, it has painting of some sort that it usually doesn't or it fulfils some country of origin criteria. There are many standard tail codes for often faced specifications, but new ones are created every time a mixture of customer specifications that haven't been fulfilled before are faced.

If an item is needed in manufacturing, it must be in the ERP system, so it can be administrated. The Case Company's factories under same business area all around the world share the same ERP system. Every plant has its own warehouse environment in the ERP where the items are handled. The ERP system used in the Case Company is a module based application. Different operations have their own modules in the ERP system for carrying out their responsibilities. The most important data that defines the items functionality in the factory and the item's supply chain are scattered in few different modules. All the relevant data for creating a general view of the item, its requirements and its supply chain isn't available at one glance.

The Case Company has several applications and data bases for different operations. Item related data has been focused on ERP and PDM systems. The supply chain data is created based on the information given by the suppliers or the contracts with them. The Case Company mainly uses verified suppliers and only very seldom items and raw materials are procured from completely new suppliers. For purchased parts the supplier number must be entered in the ERP's supplier field and to do this the supplier's information must be already entered in the ERP system. The contact information for the suppliers is stored in other data bases. For communication with suppliers, email is often used, but there is also a specific tool for handling and following the orders – Supplier Web (SW).

The purchased items are divided into three categories: Castings & Forgings (CF), Components & 3rd party products and Materials & Subcontracting (MRS) items. In every plant for each category there is a category manager who is responsible for the operative supplier collaboration in that category. They are supported by the sourcing department, where global category managers operate, and by their colleagues in other factories. Category managers usually have the best information of the supplier performance and capabilities in their own category locally.

The sourcing and procurement departments together are responsible for the suppliers. Certain contracts are made regarding payment and quotation procedures, but usually purchases are done based on suitability, price, quality and time. The items are needed at the right place, at the right time, at the right price and at the right quality. At the moment, there is a lack of packing instructions for most item types and only some of the suppliers use the Case Company's pallets for delivering the items. The pallets used in the Case Company differ from the standard sizes. This makes it possible to fit more items on the storage shelves in the Case Company's plants. On the other hand, pallet change is often needed and this requires handling the materials by hand, forklifts and cranes.

4.3 Overview of the material handling process in the Case Company

The materials and items are intended to flow only one direction in the plant, but there are exceptions. The lay out of the plant under research has been presented in the Figure 7. The materials and items arrive to the reception of goods from where they proceed to acceptance inspection, storage area or to machining areas. Heavy machining has own reception area which can be used if the items arriving are exceptionally large. Accepted items from acceptance testing go to storage area or to be machined. Some items may also need tests required by the customer or own quality standards that the supplier has not been able to carry out. These are usually some sort of non-destructive testing (NDT) procedures, like performing liquid penetrant test. Items are returned to acceptance inspection after the tests are made and the items are cleared out and accepted in the system. Machined parts will move to storage areas where a storage location is appointed to them like for the items coming straight from reception area. The item flow can turn backwards if some items are sent to third-party warehouse after reception or acceptance inspection. The items going to the third-party warehouse are loaded to trucks at reception area after the items arriving from there have been unloaded.

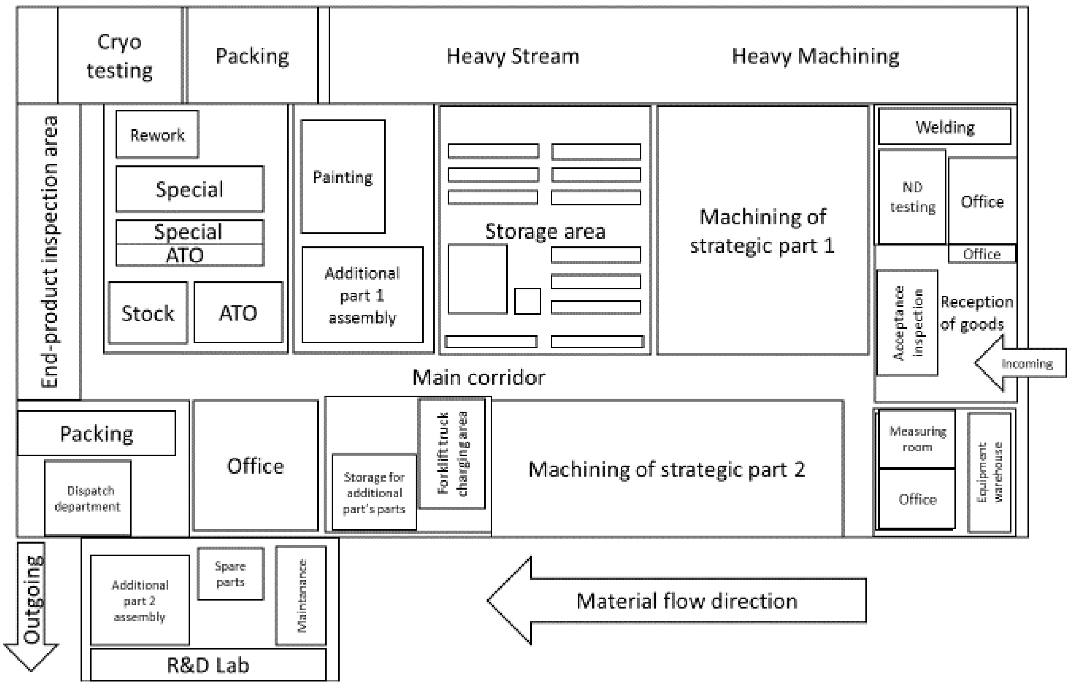

Figure 7. *Lay out of the plant under research (modified from Case Company's rescue plan).*

Items staying in the plant are shelved on storage locations on the storage area. The items will be picked when they are required in the production and washed if needed. Then the items will proceed to production. Picked items will be delivered to the correct stream where the end-product will be assembled. The Case Company manufactures also additional parts for the end-products. The combinations will be assembled in the production streams after the end-product and the additional parts are ready to be combined. After the whole combination is ready it will be tested in the inspection area. If the combination will be used in very cold environment, cryogenic testing may be performed. If the combination passes the tests it will be packed and sent to the customer.

If a quality problem is detected then item's path may differ a bit. Where and when the problem is detected affects the item's flow in the factory. If there is a problem, best case is that the defect is detected in the acceptance inspection. Then the item can be sent for repairing straight away and a claim can be sent for the supplier if the defect is likely caused by it. Dents and scratches can be machined away and after new inspection they can be let forward in the factory. Machining rework is mainly done in Heavy machining area. The next point where the items are scrutinised with detail is the end-product assembly. If defects are detected the item will go to rework area to wait for the repairing procedures. If possible, a new item will be picked and the production can continue, but it can be that the defected part is one of a kind in the factory, so the customer order is probably delayed.

The reason why the items aren't carefully checked in each phase is that the warehouse workers aren't expected to have the training for detecting small defects which can be critical. Of course, the workers perform a quick visual check for the items before passing them on but there aren't clear processes if defects are detected. If a defect appears every case is handled separately with the supervisor.

4.4 Descriptions of the processes related to PFEP implementation and the critical points for material handling defects

4.4.1 Engineering of new items

One of the Case Company's Senior Engineers was interviewed about the engineering process using pre-planned set of questions which were supplemented with extra questions for gaining deep understanding of the subject. The creation of new items and the process how customer specifications are met was clarified. Engineering process is the place where item data is created so it is important to know, what actually happens in that process and why.

The engineering process starts when an internal purchase order (IPO) has been entered to the system and the engineers receive it. From an IPO one can read what has been promised to a customer. Then the engineer checks if there already are products that meet the requirements and can be used without modification. Sometimes the construction needs to be updated just a bit, because some parts have been revised. If none of the existing product constructions is suitable for customer as it is, then the first attempt is to utilize existing parts and create a new construction by using them. If this isn't possible, then the parts needed that don't exist yet are engineered.

Especially the parts that help in fitting the end-product to customer's system need to be engineered quite often, because the traits are very specific. Also, the end-products that are needed for more exotic purposes than usual need engineering. In these cases, the whole structure may be modified. These kinds of changes concern usually change of materials and modifications in some item structures.

Every item has its own ID code. New ID is generated if item's color, material, size, shape, structure or any other trait changes or completely new item is created. Updating an old, existing item is also possible, and in that case a new version of the same item is created. The ID code doesn't change in that case. When making a change or an update for an item it must be made sure that the change doesn't affect negatively to the other constructs where the item is used, because same ID code can be found from several BOMs.

The ID codes make it easier to handle items in the PDM and ERP systems. The BOMs are easy to read and identifying items is simple. It is possible, that there are items with exactly same functionality having different IDs, but that is quite rare, and happens only if some attributes have been entered in a different way even the value should be same. This can happen because different ratings and classification systems are used in the business or the form for item creation has changed over time.

The customer specifications work as signal for engineer to work. The most important information for engineer is the end-product's purpose of use. With that information engineer can make the right decisions regarding the construction, but in addition, different customers require different things. Sometimes the things wanted can be strange. The Senior Engineer states:

''*Sometimes the Purchasing department contacts us and asks, why there are these weird specifications for this item. The answer usually is: ''Because the customer wanted it so'' … and sometimes we have to contact the Sales department and clear things up … like ''Are you guys serious you really want it like that?'' and then some things may be missing, like the temperature limits and such*''.

The clarifications take place before the new item is engineered. Procurement can also make requests for alternative items, if the manufacturing for some item takes too long. For example, a CO can be promised to be delivered on a certain date and if a casted body takes too long to manufacture by supplier, then an alternative item with same traits that can be manufactured by machining from a bar material faster can be changed for that specific CO.

The Senior Engineer estimates that there must be thousands of new items created every year. Because the old items work as spare parts they don't expire or go out of use that easily. That is why the item data base grows and is quite extensive. Day to day business requires some engineering and creates new items, but the projects have usually more specifications and demand more engineering. This means there are many project specific items.

Engineering tries to make the use of the items in the factory as easy as possible, but the functionality in the end-product is the main thing to consider. For example, places or holes for lifting can't always be engineered for the item, even if those would have significant effect on the handling easiness of the item, because it would make the end-product not to work as planned.

The Senior Engineer interviewed stated that the challenging thing in engineering is that one should know basically everything: what customer really wants, all the standards and supply chains both the customer's and the supplier's. The schedules are strict and sometimes the background check up and clarification of customer requirements can take the lion share of the target time. The Senior Engineer thinks that PFEP database could help the engineers to know more about the supply chains of the items they have created and also how they are handled in the factory. It could give references when creating new items.

4.4.2 Item data management and new item transfer to ERP system

The Item Data Management Team Leader was interviewed about product and item data management in the Case Company's plant under research. The relevant data bases, processes and stakeholders were mapped using similar questions than with the Senior Engineer but the questions concerned item data management. The knowledge gained from the interview has been supplemented with info from procedure instructions available in the Case Company's data bases.

As told before, the item data is focused on two places: ERP and PDM systems. All the information related to item specifications, item relations, the measures and materials is stored in the PDM system. To use this information for production planning and for purchasing the item data must be transferred to ERP system. In the ERP system the item data must be enriched with the supply chain information for the procurement to do the purchases. The most critical information that needs to be provided is the item's supplier, price and the lead time. This information is obtained by sending requests for quotation

(RFQ) to pre-selected suppliers most likely to be able to supply the item. With CF category the supplier choices are usually narrower than in other categories because the casting models have been sent to only for few foundries. The model information can be checked in SW. For all categories there are supplier matrixes that guide the sending of RFQs and help in estimating and determining the lead times for items beforehand.

Item Data Management Team is also responsible for the end-product enrichment, which basically means adding the work phases and their times for the end-product assembly. Product's assembly stream is decided by the Item Data Management Team based on the product type, size and the BOM of the item. There are rules for this. If the items in the BOM can be found already from the warehouse as stock items then the end-product assembly can be directed to ATO, but if the body parts, for example, have some certain specifications and they need to be purchased, then the item is directed to Special-stream. Large end-products that other stream's cranes can't lift go to Heavy-stream. Production planning uses the enrichment information when deciding the production schedule. Every plant has its own facility and warehouse information in the ERP system. If an item is used in other factories as well it must be enriched in those warehouses too. Case Company's every plant is responsible for the ERP item data under its facility code and in its warehouses.

Item Data Management Team is responsible for the new item transfer to ERP and the item data enrichment. There is already over 150 000 active items and over 350 000 items total in the ERP system. The Item Data Management Team is responsible for correcting and maintaining up-to-date data for the active ones. There are also phase out items in the ERP system. These items are either no longer used or they haven't been used for a long time. If item is in Phase out -status also in the PDM system then it must not be used. If the item is good for use according to PDM then it can be turned to active in ERP as well if it is needed in the production. There are also some configuration items in the ERP system that aren't actual items existing in the PDM system. These configuration items have a supporting role in some procedures in the ERP system, but they don't have a physical object existing somewhere in the warehouse.

From time to time revisions of active items and end-products takes place and Item Data Management Team's task is to check how the changes affect the stock balances and the ongoing purchases. There may be no effect on these areas but if there is, procurement, production and logistics must be informed so they can make necessary procedures. When the stakeholders have been informed about the change Item Data Management Team approves the changes in PDM to transfer into the ERP system also. Larger and more profound changes in items are handled through own engineering change order (ECN) process where stakeholders are informed and engaged in the change process automatically. All changes don't go through this process.

Item Data Management Team manages the Case Company's item data, which the Item Data Management Team's Leader describes to be ''*the heart of the company*''. According to the Team Leader, it is crucial that the data is correct and in good order and also that the data is optimized so it can be used in the functions. The Team Leader states:

''The item portfolio must be maintained in such a condition it satisfies the demands of today's business. ... The entity must be in shape. ... All the ''levers'' must be in right positions''.

For Item Data Management especially the processes where item changes are made cause trouble. The changes aren't timed optimally and critical information may be received too late. For example, an end-product was produced using old information even a new revision had been released. This information hadn't reached Item Data Team on time, or it had got lost among other cases, because no signal of urgency could be detected. Development of these processes would be needed. The daily enrichment of new items goes well, but from time to time there are problems too. Some items may be more demanding and suppliers may have trouble producing them or finding the right materials, so the quotation process takes time. This delays the proceeding of the related CO.

4.4.3 Procurement

The Case Company's Purchasing Director who is responsible for Procurement & Logistics department was interviewed about the procurement processes. The interview proceeded as before and area specific questions were used. The knowledge gained from the interview has been supplemented with info from procedure instructions available in the Case Company's data bases.

The procurement has been divided to Global Sourcing and Operative Procurement. Global Sourcing sources the suitable suppliers and negotiates the contracts. Operative Procurement does the purchasing and is responsible for the transportation and inhouse logistics. The main task for Operative Procurement is to ensure that right items are in the production at the right time at right quality and that the items have been purchased at the right price. The items are purchased from the suppliers pre-selected by Global Sourcing.

Items are categorized as manufactured, distributed or purchased. Manufactured parts need the blank material so they can be machined or produced in some other way. Distributed items are ordered from Case Company's other factories. Purchased parts are purchased by Purchasing. Purchasing has been divided into ATO and Special Purchasing. ATO-products have already been enriched in the ERP system and they have safety levels and usually MOQs set. Special Purchasing is responsible for purchasing new items generated from customer order specifications designed by Engineering and enriched by Item Data Management so in Special Purchasing MOQs are used only if supplier sets one. Usually the buyers make the purchases only for the needed number of items. If requirements for same item are close together and they would be purchased separately, advancing the other is possible. Items laying in the warehouse is unwanted situation, because warehouse capacity is limited and reserving the place for only few items for a long time is inefficient. On the other hand, placing orders for larger quantities is usually cheaper and economies of scale can be taken advantage of. This is quite rare for Special Purchasing though.

When the item is in the ERP system and it is needed in the production, a purchase order proposal (POP) will emerge for the buyers if the time to the date the item is required in production is near the item's lead time. This can be finetuned with safety time. Other option for the POP to emerge is that the item's safety stock level drops below critical or there are more requirements for items than there are items in the warehouse. For placing the purchase order (PO) supplier information, price and lead time estimate must be known and entered in the ERP system.

The actual purchasing means selecting the supplier, if there are alternatives, releasing the POP and making sure the order is confirmed by the supplier. Expediting the order may be needed. Purchasing is the main department with Item Data Management working in the supplier interface. Nowadays Item Data Management Team and Special Purchasing work in close collaboration forming three sub-teams in the CF, Components & 3rd party products and MRS categories.

For big and often used suppliers, SW is used for communicating and following the orders. With them also weekly or monthly meetings are arranged so critical aspects, such as supplier performance, supplier quality and development areas and projects can be discussed. Communicating with the suppliers during purchasing is mostly in a specified form so it works quite fluently. Errors and mistakes are detected only very seldom.

Purchasing Director was asked about the necessary information for procuring the items:

''*For Procurement to operate, the information about supplier network and the supplier capabilities is very important. ... Price information and knowledge of agreed lead times in contracts is valuable information. Also, information about the actual customer need and specifications and quantities in customer order are critical so the purchase can be made correctly. Actually, all the detail information needed for placing the purchase order in a way the customer order is satisfied is critical''.*

Customer specifications can usually be satisfied quite easily, but certain combinations can be hard to handle. There are different certifications, different materials and different origins and sometimes fitting these in a way the customer requires can be problematic. Sometimes suppliers need to be instructed in providing the item as wanted. If the supply chains capabilities could be taken into account more thoroughly already in the selling phase the procurement would be easier.

When the purchases are made the suppliers are only rarely informed about the packing requirements. Some general instructions have been sent to suppliers, but more specific details about packing are submitted only if the CO holds some extra details and requirements about packing. The customers very seldom take a stand on the end-product part packaging.

4.4.4 Logistics, transportation and packaging

The following information are collected from the interviews of the Purchasing Director, Logistics Manager and Logistics supervisor. The statements have been supplemented with observations made in the reception area. Also, SOPs, instructions and ERP data was used for the analysis.

The Case Company has suppliers all around the world. Also, the Case Company's factories abroad supply end-products and items to the plant under research and vice versa. If the items must be transported from far away sea freight is the primary option. Air freight is used if the items need to be delivered quicker than usually, but only if necessary, so the costs stay tolerable. The freight containers are transported the rest of the way by trucks. Trucks are the primary transportation method for other items than the ones coming by sea and air. Trains are used for some items, if it is logistically efficient.

The items are packed during the transportation and the packing is supplier dependent. The Case Company's instructions for packing the items are limited and they don't take a stand in every item category. The body parts and some machined and plate made items have separate general packing instructions. There are stated which surfaces should be covered and protected and what kind of protective substances should be used for preventing rust. Also, the fastening of the items, pallet sizes and the markings that should be used on the packages are told on the packing instructions. Some suppliers pack the items on the Case Company's pallets, but some use the ones in accordance with general standards and some items arrive in wooden boxes or in other packaging. These items need to be moved to pallets according to Case Company's measurements. Some suppliers have also their own pallets which cause problems if, for example, the forklift truck's forks can't fit properly under the pallet.

Most of the items are packed in wooden or cardboard boxes. Wooden boxes are sealed with screws, nails or bands, cardboard ones with tapes and wrappings. The items in the boxes may be covered with extra covers and plastic protection. Sometimes wooden planks may be attached to the boxes so the items stay still during the transportation inside the box. Some items are only lightly protected and they are fastened to a pallet with bands that can be tightened.

The Case Company uses own warehouse and external warehouse that is operated by a third party. The external third-party operated warehouse is next to the plant under research and it was visited during the research. Sea freight containers are unpacked by the third-party warehouse and the items are stored there until they are called for production. There are 8900 pallet spaces in the third-party warehouse reserved for the Case Company's use. Not all storage locations are used for storing parts, but also, ready end-products and combinations are stored at the third-party warehouse if customers aren't ready to receive the order or the entire customer delivery is not complete yet. The transportations from the third-party warehouse to the Case Company's own take place three times a day and the length of this transportation is roughly 600 meters. The condition of the road at that journey isn't the best it could be. There is roughness on the ground that can cause unwanted trembling. Items move also from the Case Company's plant to the external warehouse. These items are usually stock items which stock level is full at the moment in own warehouse or the item's need in production isn't in near future, because the item has arrived earlier than expected or the production plan has changed.

The deliveries unloaded at the Case Company's receiving area are truck deliveries which have been transported through land or as air freight. Sea freight containers are unloaded at the third-party warehouse. The items arriving to the third-party warehouse don't come to the Case Company's plant before they are called in. Some air freight deliveries are first directed to the third-party warehouse depending on the size and weight of the freight.

The wooden boxes can contain mould and other microbe growth on them after sea freight. Packages of the items coming from tropical areas must protect the items from humidity and other weather conditions. If the protective constructs have decayed during the transportation the handling of packages can be problematic when unloading the cargo.

4.4.5 Receiving and acceptance of the items and materials

Both the Logistics Manager and the Logistics Supervisor were interviewed regarding the inhouse logistics. The areas under this category are receiving the deliveries, unpacking the items, shelving the items and picking them for production. Details about these operations and the reasons for doing the procedures in certain way were gathered. The processes were also observed. The Quality Engineer responsible for acceptance inspection of items was also interviewed regarding the acceptance inspection. Acceptance inspection process was also observed.

When a delivery arrives, the cargo is inspected so the consignment note adds up with the packages. If the packages are damaged before unloading pictures are taken and a reservation is made if items are found damaged. The truck is unloaded and the delivery is acknowledged. The contents of each package are checked with quick visual inspection if there is the right number of correct items in it. If the package had been damaged during the transportation then the items are checked with extra carefulness. The packages are unpacked and if the items need to be moved to Case Company's own pallets it is done. The items must be placed on a pallet with a clean cardboard on the bottom. If there are items missing from the delivery then the consignees contact the purchaser who contacts the supplier. If everything is as it should be, then the delivery is entered into ERP system as received and the reception documents are printed, stamped and archived. The parts received are entered into the ERP system and item tags are printed for them. Item tags are just A4 papers with information of items’ ID, description, material and PO. One pallet can hold several different items which means that there can be many item tags on one pallet.

The items arriving to the factory are tried to be handled following FIFO order. The layout on the goods receiving area doesn’t support this very well because the area is wide but lacks depth. Because the space is limited, boxes need to be stacked on each other and not always the package first received is put on the top of the pile. The packages are usually unpacked on the place the package has been stacked and after the required procedures it is moved to place for the next procedures. Purchased items without acceptance inspection needed are received, unpacked and entered into the ERP system in the reception area and put on the right location to wait for the pallet to be moved to the storage area. Distributed items coming from the Case Company’s other factories are only unpacked on the reception area and put to wait for the moving to the storage area where the items are entered to ERP system. The items coming from the third-party warehouse are handled the same way. Some blank items that will be machined are also passed on straight away and the Machining department takes care of the item receiving administration.

Items that must fulfil certain quality criteria or customer specification go through acceptance inspection, so the quality of the items can be verified. Body parts are items that require acceptance inspection. Not all items can be checked, because this would require significantly more resources. That is why sampling is used. If a defected item is detected in a batch then all items are checked. Otherwise only a certain percentage of items go through the acceptance inspection. The Acceptance Inspection department is responsible for matching of the documents and items and making sure that the items really fulfil the traits the documents claim. Acceptance Inspection also checks that the item is the kind it is supposed to be.

In acceptance inspection visual and measurement inspection are performed and it is verified that the documents check out and match the CO requirements. The inspection follows a certain order and the traits verified are reported in a reporting system on an inspection form. In the visual inspection the external appearance is checked with precision and if scratches or dents are found the item is sent for repairing if it is necessary. If the scratch or dent has presumably been there already during transportation a claim is sent to supplier. If there is no way to show the damage was there before unpacking, the Case Company pays the bill. Damaged items are moved to a location dedicated for items going for machining rework. In measurement inspection the items measurements are compared with the measurements stated in the drawing according which the supplier has manufactured it. Certain tolerances must be satisfied. If the item doesn’t fulfil the requirements it is rejected and supplier is informed and a claim is made. The document verification means checking that the supplier has delivered all the documents and certificates required and that the items match the information in the documents. For the documents there is an own data base where the suppliers send them and where they are available for authorised users. Sometimes deliveries lack important documents and the items can't be sent forward to be used in production. These items are put to a shelf dedicated for items waiting for the documents. The items that have passed the inspection are moved to a location where the items will be moved to the storage area or the third-party warehouse. The items are instructed to be protected after the inspection testing and the protections should be kept on the items all the time before they go to assembly cell. Especially the profile surfaces of the body parts should have covers attached to them with tape or wrapping.

There is own Acceptance Inspection Team in the third-party operated warehouse. They are Case Company's own employees, so the inspection hasn't been outsourced, but they operate in the third party's premises. According to the Quality Engineer more defects are reported in the third-party warehouse. The Quality Engineer states about receiving deliveries in that warehouse:

'' *They may, during the unpacking, put the items on top of each other without cardboards in between, and even if there would be the cardboard it won't necessarily be enough. It is lack of knowledge when orientation is done poorly''.*

The third-party operated warehouse receives most of the body parts because those are the ones delivered as sea freight. When visiting the third-party warehouse, it came clear that the basic rules for handling the items are actually well known but the supplier packaging causes problems, especially with certain suppliers. These suppliers have been contacted many times without progress or change in action. What comes to the instructions for handling items in the third-party operated warehouse, the Case Company has handed an instruction of the matter last time in 2011. Those instructions are mostly still valid, but they need updating. Examples of wrong and right handling were hoped by the third-party operated warehouse's supervisor.

The Quality Engineer thinks that clear instructions for handling the parts in every work phase would be very good idea, especially for the gap between the third-party warehouse and the Case Company. Instructing suppliers about protecting items from defects would be also helpful, especially for very delicate and critical areas. There are already instructions that critical parts and surfaces must be protected but how it should be done is without instructions. Also, not packing the pallets so full would ease the handling of items.

Acceptance inspection is very critical phase in the production process because it prevents the invalid items proceeding and causing idle and labour lost. Items that have been fixed in machining rework are returned to Acceptance inspection to be inspected that they fulfil the requirements and standards. Defecting the items in when doing the acceptance inspection isn’t very probable, but it is possible. Especially, when items are lifted with cranes there is a possibility for item to hit surfaces it is not supposed to touch. This is rare and of course unintentional, but mistakes happen.

4.4.6 Claims

If a defect or other mistake is detected in the item and there is a reason to believe it is because of the supplier’s or transportation company’s error, a claim will be sent. There is a claim process the items go through if a defect is found. The Quality Engineer responsible for Acceptance Inspection is responsible for the claim process as well. He described the process in following way:

‘*’When the inspectors detect a defect and they have made the report, they shelve the item to a claim location. There is a place on the shelf. They fill a red ‘’Waiting for a claim’’-ticket. Write down information of the item, purchase order number, number of the molten steel and then the defect in the item. If it is a measurement error then mark measured value and the value it should be. Preferably attach a picture and circle the spot which is defected’’*.

There are two workers handling the claims. They send the claims for suppliers if the defect is likely caused by supplier’s handling. The items defected in own handling before the acceptance inspection or during it go through the claim process as well. These items are marked with info about it, so no actual claim is sent to supplier in vain. Repairing work orders are made for the items and they are fixed if possible. The claim usually consists of machining rework cost or scraping cost and sometimes both are included, if the item has been found unusable after machining. Claim data is available in the Case Company’s data base. Not all claims are approved, because there may be lack of evidence where the defect is caused. If the transportation company or the supplier refuse to pay the claim, the Case Company pays the bill.

The claims sent may take a long time to be processed by the supplier. Especially in those cases when the items are fixed using the Case Company’s machines and only a bill for the costs is sent to the supplier. These are usually eventually paid, but it can tie up capital in claims for quite a long time. Also, the unplanned machining work causes extra work that is away from value adding operations.

4.4.7 Moving the items

Case Company uses both manually operated and automated forklifts. The automated forklifts operate according to visual buffers. Pallets are put to certain locations and a forklift gets a signal to move the pallet to another pre-set location. Items that are ready for shelving are moved from receiving area to so called midfloor, where the main storage area is, with automated forklifts and then, after picking, the picked items are moved to production streams for assembly with the automated forklifts as well.

Manually operated forklifts are used for shelving and picking, as well as for unloading the cargo when deliveries are received and moving the packages in the receiving area. Basically, all the item moving that needs to be done somewhere else than on the main corridor is done by manual forklifts. Also, when an item exceeds the pallet's limits, the pallet is moved with manually driven forklift.

The automated and manually driven forklifts operate with low speeds under 8 kilometers per hour (Rocla 2018). With manually driven forklifts the accelerations can be more powerful, of course depending on the driver, and collisions are more likely to happen than with the automated forklifts. Quick alterations in speed can cause items on the pallet to move. If there are dirt, chips, rocks or other items on the pallet they can be defected when hitting against each other or gliding on a dirty surface. Dirt and impurities are tried to keep away but somehow, they manage to find their way back on the pallets and places they are not wanted. The machined parts may hold chips in their threads and these can easily drop to the bottom of the pallet.

For lifting items that aren't easily lifted with bare hands cranes are used. There are cranes for different weight ranges. The items have either a place for a hook where it can be lifted or a lifting sling is passed around the item. Smaller items are lifted manually. When lifting the items can drop and when putting the item down it can hit another item or land over a piece that can defect it. Extra cautiousness is required in the Case Company when lifting items. Lifting anything over a person is prohibited and going under a lifting work is also forbidden.

Lifting with cranes is done when the heavy items are taken for work in acceptance inspection, machining, washing or assembly. A lot is dependent on how experienced the worker doing the lift is. Usually the covers have been removed already when starting the lifting so if the item hits anything it shouldn't hit the item can be easily damaged.

4.4.8 Shelving and storing the items

The main storage area is located on the midfloor. The items end-up there eventually before they go to production. Items under the research scope arrive from the reception of goods area and from the machining areas. The items arriving from the reception can be already received and entered to ERP system or they can be distributed items that need to be administrated before shelving. The items coming from the third-party warehouse quite often go straight away to production, therefore some consideration can be used when deciding the storage location because the item will be picked very soon. This needs to be checked because the delivery may also be a stock replenishment.

Every item will be directed to a shelf location. There are standard locations only for standard parts which are mostly used in ATO-stream. This means that the storage location of an item that is used only every now and then changes. This is efficient because there is no guarantee that the same item will be used again in the near future, so reserving the shelf place has no point. If there are already items with same ID in the warehouse they will be very likely put to same location. Exceptions are possible if the items that are already in the warehouse are going for an end-product which is assembled in a different stream than the ones now being shelved. This kind of storage location consideration can be done only if the items are dedicated and reserved for certain customer order. There are general instructions for the shelving which are followed. The items can be picked for production only after the shelving has been done.

The items are stored in the condition they arrive to shelving. If the items are protected, they stay protected. If there are no protection, then the item is stored without protection. Sometimes some protection may be added. The instructions say that the body part’s profile surfaces should be covered and they shouldn’t be facing down when stored. When observing the shelving there were body parts missing proper protection in both own and third-party warehouse.

For the parts of different types of end-products there are separate shelve racks. This narrows down the search area for parts if something goes wrong in the shelving process and the part goes missing. The same end-product type may have different product families so lots of similar items are stored on the shelves. Similar items can be stored in same drawers, because having only one item reserving the whole storage place isn’t efficient either. Item tags move along with the items, but when having similar items in the same drawer and the item tags being nothing more but A4 paper sheets which can easily get mixed, the mix up is quite easy. Identification of the items is critical so different parts don’t get mixed.

For small items, like screws, bolts and nuts there is a small item shelf area. Other items are stored on pallets or in drawers depending on their shape and size. The drawers are basic wooden boxes without cap moving on rails. Inside the drawers there may be some padding, but usually the only paddings are the wraps around the item if they are left on in the reception of goods or put back after the acceptance inspection. For the body parts there are instructions that the profile surfaces must be covered with protections which must be taped or attached with film on the body part. These protections must be placed during moving and storing and can be detached only for washing and when the assembly starts.

4.4.9 Picking the items

Picking lists are created according to manufacturing orders (MO). The MO contains a list of parts needed in the production. The pickers are the ones feeding the parts to the production. The pickers pick the items according to the picking list. All the items needed for one end-product are picked on the same pallet. In the Heavy-stream this isn’t possible and there are own pickers for the Heavy-stream who do the picking because the items can be very massive. Sometimes the stream’s organizer needs to be involved in the picking so the parts can be placed conveniently on their places one by one. For other streams the picking is easier and there are general instructions to be followed.

The picking starts after a tag for the end-product has been created. The tag is put in the same plastic folder with the picking list, which holds the list of items that are required to assemble the end-product that fulfils the information on the tag. If the picking list contains items stored in the third-party warehouse these items must be requested to be delivered in the next shipment. Picking other parts can be started but considering the time before the picking can be completed is suggestable. Picking items for work should be started only if there is an empty location where the picked items can be delivered.

The items must be picked from those storage locations marked on the picking list, even if the items could be found from some other locations as well. This prevents inventory balance errors. The visual appearance of the items should be checked. The items must be compatible on their physical and visual traits and condition must fulfil requirements. The items are placed on a pallet with a clean cardboard on the bottom and a pallet boarding attached to the pallet. It prevents the items from dropping. The automated forklifts deliver the pallets with item kits to the small end-product assembly streams and the ones for the large end-product assembly streams are delivered using manually driven forklifts.

The items that are going to end-product that will be painted after assembly must be washed before they are delivered to the assembly cell, so the paint attaches to the surface. There are also other reasons why some items must be washed. The washing procedure which is an essential part of the picking process is presented in the next sub-section. Some items are washed by the assemblers.

When the items are delivered to the assembly cell there should be covers that can be used after the end-product has been assembled and pre-tested, so the surfaces can be protected from scratches and dents in later procedures. The body part’s profile surfaces should be covered when they are delivered to the assembly cells and these protections could be used. When observing the picking process not always the body parts’ profile surfaces were covered and protected.

4.4.10 Washing the items

Some items need to be washed before they go to the assembly cells. Some items are washed by the assemblers. All the parts of end-products that will be painted are an example of parts needing washing. The items must have clean surface so the paint sticks to them after assembly. Some items may have thick layer of grease or other substance that prevents rust developing on the surface, others may be just dirty. These items need to be washed as well.

The items are washed using washing machines. There are few smaller washing machines next to the assembly cells in the assembly stream areas and the main washing machine in the storage area. Only trained workers are allowed to use them. Relatively big items are laid on a wire tray and small items are placed in a cage from where they can't escape during the wash. Washing liquid is sprayed on them inside the machine. The solution used for the washing contains powerful chemicals which are able to remove the greases from the parts. They also contain substances that prevent rust developing on the items. Still, after the washing, the items need to be dried carefully. The drying is done using a compressed air. If rust develops it must be grinded away in the assembly cell which causes assembly rework costs or it may even require machining.

Multiple picking orders are encouraged to be washed simultaneously because the washing takes about 16 minutes and washing capacity is limited and the demand of the production streams need to be supplied. The picker using washing machine needs to be careful so the items aren't mixed and the picking can be executed correctly after the wash.

The wire tray is hard and it is made of metal. The parts can be defected if they are rotated or dragged on the surface. In some washing machines there is a plastic net covering the wires, but not all wires are completely covered and metal surfaces may contact each other. Some washing machines have hard plastic bars attached on the metal wires. They prevent metal surfaces from touching.

4.4.11 Assembly

When the items for an end-product arrive to an assembly cell they should be on one pallet and they should be protected as guided in instructions. From the pallet the items are taken on to the bench where the assembly is performed. One person carries out the end-product assembly and passes the product for pre-test where the end-products functionality is tested before it is possibly painted and additional parts are added in the combination. If defected items are detected or the items are defected in the assembly they will be directed to rework area. The same place waits the end-product if it doesn't pass the pre-testing.

The assembly is done by following the work orders given in MES. MES shows the work phases the Item Data Management Team has set for the end-product assembly. Different end-product families differ from their shape and from their traits. That is why all the end-product families have their own assembly instructions. The experienced assemblers usually have the ability to assemble any of the end-products in the Case Company's portfolio.

The Value Stream Manager of Special and Heavy Stream was interviewed about the procedures of the assembly cells. He was also asked what item information is needed in the assembly cell. He stated:

‘’ *I don’t see that we should meddle with the item information anymore at the assembly phase. The decision that it is the right part should be made when the item is picked, I wouldn’t want it to be handled a second time to ensure it is the right part. If the item goes through acceptance inspection and it gets a stamp, it is right material and it is on the right place at the warehouse and it is picked for the right work. We should focus on the challenges of the assembly not to ensure that it is the right component’’.*

The items are attached to the body which is the largest item of the end-product. It is rotated, moved, and tilted during the assembly. The bench is covered with rubber cover, but it may hold small chips of metal inside which can cause scratches on the body’s profile surface. The rubbers are changed two times a year or when needed. The Development Manager of the Case Company stated about the greatest cause for material handling defects in the plant:

‘’ Biggest problem with the parts coming from rework (to machining rework) are scratches and dents on profile surfaces. We have clear messages, or actually observations, where they come from, and that is when the item is rotated on the work station’s bench. ... But what comes to that rotating the item on the work station’s rubber bench, if there have gone some chips inside, well then there is a crease ‘’.

According to the Development Manager sometimes tools can accidentally scratch the delicate surfaces but this is only very seldom. Now there is a project going on for developing a working jig that makes possible not to lay the body down on any surface during the assembly. The jig testing will be started in the early 2019.

4.5 Machining rework and reporting of the material defects

There are two processes that feed items for machining rework: acceptance inspection and rework. The items coming from acceptance inspection to the machining rework are waiting on the shelves near the acceptance inspection area. Items coming from assembly cells and end-products that haven’t passed the inspection go to the rework area to wait for repairing. Some end-products need to be taken to pieces so they can be fixed, which can also cause the parts to break down, but these cases are not included in this research. The items waiting for machining rework are very seldom protected. This also exposes them to more defects.

Machining rework is mostly performed in Heavy machining area but some items which are too small to fit in the machines used there are fixed with suitable machines in other areas where self-manufactured strategic parts 1 and 2 are machined. The items needing machining rework may be damaged, they can have wrong measurements or there may be porous areas on the surfaces of the items which need to be removed. The items waiting for machining rework will be given a repair work order. The supervisor responsible for machining rework takes care of the prioritization of the repair work orders and points the works for machines. Two machines have been completely reserved for machining rework. Other machines will be used if needed.

The items waiting for machining rework have either a blue or a yellow note with them. Blue note means that there is a defect needing urgent attention and yellow note means that the item has come through claim process from acceptance inspection. The item defect is fully reported during claim process. The problems with items coming from rework area are be reported in MES. The disturbance report has been made when the defect is detected in the assembly. Details of the defect are written down and categorization is done. The same things are written down on the blue note. The notes include details of the item and the defect. Machining drawings may be attached with it and the problem areas may be circled and highlighted. Usually the scratches and dents are circled with black marker on the item as well.

4.6 New practice implementation in the Case Company

The Development Manager of the Case Company was interviewed about leading development projects and implementing new practices in the Case Company. When asking about the challenges of carrying out a project the Development Manager pointed out the managing of the resources, and especially the workers contribution regarding it. The input of different workers may vary a lot and motivating the workers is a critical aspect for development project's success. Another thing that had caused trouble repeatedly was the multidisciplinarity of many projects. Knowledge from various areas is often required.

What had been found successful way when implementing new ways of working was employee involvement. Employees have been taken along in the planning process and feedback has been collected from them. The employees have been in critical role when developing new processes that affect their everyday work. The goal has been that every employee who is affected by the change is involved or has a chance to affect the development and implementation. Mostly this participation has been carried out using different kind of workshops where the workers have had a chance to bring out their ideas and critically analyze the current plans and current state of the implementation. After a big development project where the factory streams were created a survey was conducted about the employee involvement. Over 87 % of the workers answered that they felt like they had participated in developing their work. The Development Manager thought it is very important that all the knowledge and ideas are brought out so there is a chance to use them. He also kept the involvement a crucial way of motivating the workers and making the development a shared effort.

There are many development projects ongoing in the Case Company in different departments. Many of them deals with the functions of the whole global organisation and some are just projects regarding the plant under research. The development projects are monitored on manager level and the status updates are reported on monthly basis. Every month a plant's monthly overview meeting is held where the key performance indicators are reported to the staff and the plant manager gives an overview of the business situation. Also, the advancement of the development projects is reported, and everyone can see what kinds of projects are ongoing and how they proceed.

4.7 Findings

The answer to the first research question can be formed based on the analysis made in Section 4.1. Two categories causing the current quality costs on the scope were identified. The first category causing the quality costs due to material handling defects is assembly rework. This is because of defected items ending up to production and the assembly work can't be executed as planned. This covers 30 % of the costs. The larger contributor, which covers 70 % of the identified costs is machining rework. Machining rework happens when defects like scratches and dents must be removed from items that can be fixed by machining.

For both categories the end-product's body parts were significant contributors. Over 75 % of the machining rework costs were because of fixing the body parts and 50 % of assembly rework was due to defected body parts ending up to assembly cell causing idle or extra work. The handling of body parts should be assessed thoroughly and considered in the PFEP data sheet, because as stated in the literature review, the greatest cost contributors should be on the primary focus.

The body parts' profile surfaces are instructed to be protected at all times when they are moved and stored with a cover made of plastic or plywood. The covers should be attached in a way they don't drop of. The pallets and pallet framings used should be clean and free of nails and staples pointing inside. Clean cardboards should be used on the bottom of the pallets. The body parts shouldn't be laid on pallets and worktops profile surfaces facing down. If this can't be avoided because there are profile surfaces on two sides and the body part can't be kept on its side, it is even more crucial that the profile surfaces are well protected. For large items rubber covered planks should be used during transportation and moving under the body part. The planks are intended to hold the body part in place and reduce the area in contact with the pallet. Body parts that go over the pallet should be handled with extra cautiousness. The pallet used should also be expedient. If many similar body parts are placed on a pallet it should be made sure that the parts don't get in contact with each other. When the body parts are lifted to the bench at assembly cell or at the acceptance inspection it should be made sure that the bench is clean. There are similar instructions for plate made machined items.

Even there are quite comprehensive instructions how the body parts and other delicate items should be handled the instructions aren't always followed. It doesn't take long to walk on the warehouse area to find a body part without covers. In the rework area and on the shelves for items waiting for machining rework the parts are usually without protection. There are also lot of gaps in the instructions and important things are left without specifications. For example, things like how the parts should be packed so that they don't contact each other have been left without specifications. Sometimes it is good that own consideration can be used how to carry out a procedure, but an example of correct way of doing things is good to include in the instructions. The third-party warehouse's supervisor made a wish that the instructions would be visual and that there would be examples of wrong and right way to do things.

It could be also a good idea to put clear restrictions and prohibitions for handling that is found harmful for the items, for an example using knives when opening the packages and wrappings if there is any chance that the item can be damaged. Even a restriction stated by a supervisor should be followed, writing the restrictions on a document is more effective in many cases if it is referred to repeatedly.

The body parts are often the heaviest items and that is why they are often lifted with cranes. The lifting work is highly dependent on the skills of the worker operating the crane. The items can start rotating or swinging and because they are usually heavy, stopping them isn't easy. When the item is in an uncontrolled state it can be damaged if it hits workstation's table corner or a shelf rack, for example.

The answer to the second guiding research question can be formed on these bases. The PFEP data sheet should hold information that enables forming the guidelines for item handling in more detailed way. The PFEP data sheet should contain information that helps in determining how the items should be protected and in what kind of units the items should be handled. The item's dimensions and the consumption rates are needed for the planning. With the information collected on the PFEP data sheet it should be able to design more sufficient instructions for suppliers to deliver the items. Especially for the distributed end-products that are supplied by the Case Company's other plants could be designed more efficient handling if all the relevant data would be available. The warehousing of all items could be planned better if the item information could be analysed more thoroughly. Also, the workstation could be finetuned based on the information what are the dimensions of most commonly handled parts. The PFEP data sheet helps in preventing the quality costs by containing information that can be used for designing better packages, protection, warehouse places, handling equipment, workstations and all in all more straight forward flow paths for the items.

Even if the parts can be unique and the item with the exact ID can be faced only once in the factory the items have lots of similarities. These similarities can be used for categorising components and standardising critical procedures as far as possible.

Repeating things in the same way prevents mistakes and damages from happening. The PFEP sheet's information can be used in finetuning the instructions. Making sure the instructions are followed is a challenging task and requires efforts from supervisors and workers whom must be made follow the instructions and not apply them in their own ways. Involving the workers in instruction creation is one way to tackle the challenge. Revising the instructions for supplier packaging also will hopefully reduce the number of items that are damaged already when they are received. Even if the costs that are created when these kinds of items are fixed are claimed from the suppliers the delay and the lost capacity for value adding manufacturing cause loss of profit. Reducing the number of claims needed is beneficial for all; supplier, transportation company and the Case Company.

There can be seen a conflict in the current ways of working. The Value Stream Manager stated that the assembly workers shouldn't concern themselves with the item information, details and quality anymore and they should focus on the assembly work. The Development Manager on the other hand stated that the assemblers are the best experts regarding the items and they are the ones tackling the quality problems because the warehouse workers don't probably have the required expertise on the product parts. The problem is that not all parts can go through acceptance inspection and even with the ones that should be inspected sampling is done. The percentage of items being inspected is around 10 % of all the items handled at the plant according to the Quality Engineer. With body parts most of the items in a batch are inspected. If the assembly streams expect to receive items with right quality then there should be more ways to tackle the defected items ending up to the assembly cells. Now the only official way is that the defects are detected in acceptance inspection, even though consignees, warehouse workers and pickers should check the condition of the items when they handle them. Straightforward procedures how to act if a defect is detected should be made for most critical items, like body parts. Even better way is to create the material handling system to be free of item damages and reduce the number of risks on the way.

The idea of the use of PFEP in high-mix-low-volume production isn't that different compared to mass production. The idea is to utilise the collected item information in further analysis for planning and improving the operations. What is different is that the number of alternative cases and paths for items is much larger in high-mix-low-volume production than in mass production lines. In high-mix-low-volume production there are more different variables that affect the pre-planning and the item base is probably larger. That is why describing the item path isn't possible with the PFEP data sheet, but it can be used for other causes. With the PFEP data sheet the level of standardisation may be increased and opportunities for mass customisation in high-mix-low-volume production are more easily identified.

The answer to the third guiding research question, how PFEP can be utilised in a company with high-mix-low-volume production, can also be answered. Some items are used more often than the others and even if an item arriving to the plant can be completely new ID that hasn’t been handled before the item probably has similarities with existing ones. Similar items can be used as references for the handling of the new items. The similarities can be used for grouping the items and planning in advance. Currently the items have been categorised only roughly using the descriptions of the items’. With the PFEP data sheet the categorisation can be made easier and more detailed using different filters. When filtering the massive data base, the items can be pooled in smaller groups and detailed instructions for item groups can be made. Making specific instructions for every item isn’t expedient nor possible because the number of active items is over 150 000 and it grows daily. Having a categorisation that divides the items into groups based on item similarities using many different attributes and not only one or two makes it possible to analyse similar items more specifically. Large items need usually much more attention than smaller ones. Items made from certain materials may also need special attention. When increasing the number of filters in the categorisation even more specific item groups can be formed. If defects are detected in certain groups the handling instructions can be reassessed on their part.

5. CONSTRUCTION – SUGGESTION FOR PLAN-FOR-EVERY-PART IMPLEMENTATION IN THE CASE COMPANY

5.1 Suitability of the PFEP for the Case Company

The PFEP data sheet is generally intended to provide information for guiding procurement and logistics operations and hold detailed information of all items in one place. The PFEP data sheet should hold information how each part is handled in certain phases when going forward through different operations inside the plant. The PFEP data sheet should be available for different operations and it should hold correct information about the items.

The Case Company has its ways to guide the procurement operations and stock levels, but the PFEP data sheet could be used to guide these operations from the internal logistics viewpoint. The managers of the Case Company wished to use the PFEP for the guidance of material handling and internal logistics. The wish should be followed. Focusing on the material handling viewpoint on the PFEP data sheet makes sense, because the quality costs caused by bad material handling can be affected more effectively.

From this point of view the PFEP has potential. The PFEP data can be used for more effective storage planning and especially for more clear item allocation. With these traits the items can be handled more effectively. Having more information for planning operations usually increases the quality of decisions made as long as the information used is correct and easily available. For doing this the PFEP sheet must be filled with right kind of data so planning can be done.

Like Harris (2004) states, the item information usually exists but it is scattered in different places. This is the case with the Case Company as well. The ERP system holds lots of data regarding the items, their supply chains and procedures done to them. Different types of information are usually presented in different modules so seeing all information at once isn't possible. Collecting the data on the relevant parts on one sheet can be done quite easily as long as the data is there.

The problem is that the item information is insufficient with many items. The PDM system is the origin of the ID's and most of the attributes are defined there. The information is usually available in the ERP system but the PDM system's attribute fields may lack information which means that the ERP lacks the information too. The insufficiencies in attribute fields may be because the engineers haven't listed the attributes in the PDM system, because the system holds a picture or machining drawing of the item where all the measurements are defined in detail. This information can’t be obtained without opening the picture manually. These kinds of gaps in the easily achievable data can make it difficult to create the PFEP data sheet. Manual work should be avoided as much as possible so the collection of the PFEP information doesn’t require too much effort.

The ERP system contains also item IDs that aren’t actual items. Some IDs have been created to help in the ERP configuration. That is why the ERP data can’t be straight forward used as the basis for the PFEP data sheet. The PDM system’s data can’t be used as such either because it holds information of all items in all factories. The PFEP data sheet should be kept on plant level so it doesn’t grow too much and there is a chance to manage it. A way to get information of relevant ID’s on the data sheet need to be examined. First thing is to decide what are the relevant ID’s and how they can be separated from the whole item data. It needs to be also decided, what is valuable information to have in the PFEP data sheet, and what needs to be done so it can be collected there. For deciding this, forming a clear picture how the PFEP data sheet will be used is needed.

5.2 Goals for PFEP implementation and the function of the PFEP data sheet

The goal for PFEP implementation is to create a data sheet which holds critical item related data regarding the items’ physical traits, supply chain and handling. The data sheet should be available for everyone so the information can be used for breeding development ideas and bringing them into action. Especially the PFEP data sheet will be designed for the use of the internal logistics functions, so logistics planning can be conducted in more detailed manner. The sheet can be further developed later to support other functions as well, and if something is found missing it is possible to add to the sheet. The possibility of using PFEP data sheet should be communicated to all employees, but the main users are the ones who are in charge of the internal logistics operations. The data sheet should support the functions and offer accurate and correct information. Especially, the manager level wish was, that the PFEP supports the material handling in the factory and guides the protection and moving of the items.

The function of the PFEP data sheet is to provide easily usable data for analysis to support development actions and daily operations. In the internal logistics the PFEP data sheet can be used in many ways to improve the operations. In the Table 3 there have been listed development actions which will improve the internal logistics operations and where the PFEP data sheet’s information can be utilised. How PFEP can be utilised is also considered.

Table 3. *Improvement actions in internal logistics functions and how PFEP helps in conducting them.*

Improvement action	How PFEP data sheet helps in conducting the action?
Creating more precise packing instructions for suppliers	Items can be categorised based on acquisition method, supplier, material, item type, size, price, lead time and order quantity.
Planning suitable order sizes in terms of storing	Items categorised based on dimensions, safety stocks and consumption.
Planning more suitable covers and protection for items	Items categorised based on item type, dimensions, materials.
Creating more efficient storing rules	Items categorised based on item type, size, product family, safety stock and consumption.
Pre-planning efficient storage keeping units	Items categorised based on item type, size and consumption.
Planning suitable storage places	Items categorised based on item type, size, product family and consumption.
Planning more efficient workstations	Item dimensions, variations and consumption rates are essential information when planning the tools and functionalities of work stations, for example the new assembly jig mentioned in Chapter 4.4.11.

For conducting all the above listed improvement actions, the data included in the sheet must be selected carefully. It must be even further considered what data is truly needed for conducting the improvement actions. If the actions can be carried out it is possible to reduce the current quality costs due to material handling defects quite significantly. With the help of the PFEP data sheet the operations can be improved but other actions where PFEP isn't that helpful are also needed if all the quality costs due to material handling defects are wanted to be eliminated. For most parts more carefulness would solve the problems. If workers would follow the current instructions precisely less items would be damaged. Changing the ways of working is usually very challenging.

Involving the workers for finding ways to improve the current situation can be counted as one goal. It should be found out what kind of ideas the workers have for improving the operations. The PFEP data sheet will be modified if something important is found missing. Involving the workers will probably bring up details that may have left without notice during the observations and interviews. Hearing the ideas of everybody is beneficial for the company so no good ideas will be missed out and left unutilised. A workshop where workers can bring out their ideas will be held.

The time frame for getting PFEP up and running is as fast as possible so the item damages can be reduced immediately. A sketch of the PFEP data sheet will be presented in this thesis, but filling the sheet with the wanted information and securing the validity of the data can take time. Especially the dimension data for body parts can be hard to collect. After all data has been collected in a form it can be digitally handled the formation of the sheet can be conducted with simple download and query procedures.

5.3 Creating the PFEP data sheet

5.3.1 Choosing the platform

The PFEP data sheet must be created on some platform where data can be put after it is downloaded from another data base. Manual operations must be also possible so the data can be supplemented. There are few possibilities for platforms. The PFEP data sheet can be made web based and a specific application could be used where different functionalities and visual effects could be created. This would require buying license for the application and learning to use a new software. Another option is to utilise the Case Company's existing IT infrastructure and applications. The Case Company uses Microsoft's Windows operating systems in the computers and Microsoft Office 365 cloud environment is also in use. Microsoft Excel spreadsheet program is available for all Windows operated computers in the Case Company. Creating the PFEP data sheet using Excel is probably the most expedient way to proceed. Downloading the base data can be made efficiently using existing tools and commands. Sharing the sheet for everyone to see is also possible in the Office 365 environment at SharePoint.

In Microsoft Excel data can be requested to the sheet by making queries from data sources and data warehouses. The ERP system's data from different modules can be requested on one spreadsheet. When making the query it can be pre-selected what information is wanted. The query will get the chosen information for all the items in the chosen facility. After the data is on the sheet it can be filtered and sorted, also formulas can be used if something needs to be defined based on some other information. Excel has hundreds of existing formulas and self-made formulas can be formed if some details need to be added. The further analysis from PFEP data can also be conducted with Excel, so using it as the PFEP platform is justified.

When using Excel, many sheet management procedures can be automated but also manual operating is possible. The sheet can be edited in many ways so the clarity and readability of the sheet can be secured. Excel is also quite familiar for most of the employees in the

Case Company so teaching the use of a new application isn't required, only the use of the PFEP data sheet must be trained. New costs aren't created either because existing tools will be used. Also, managing the PFEP data sheet can be made simple in this way and it won't require much capacity. The updating speed of the sheet will be dependent on how much information must be added using formulas or even manually. Excel itself doesn't set significant limitations for the updating speed but the sheet can't be made real-time for every second. The data queries can take 1-2 minutes because the item base is big, over 350 000 items, but for the planned use in internal logistics daily or weekly updates could be adequate.

All the data required in the sheet isn't currently stored in a data warehouse from where it can be downloaded using queries. For example, the item dimensions for body parts aren't available. After the information have been collected it can be added to data warehouse and then it can be downloaded among other data and forming the sheet with updated information is easier.

5.3.2 Information included in the PFEP data sheet

The PFEP data sheet should hold the basic information of the purchased items in the smallest possible element. Because the idea is to serve the needs of internal logistics self-manufactured end-product parts should be included in the sheet as well as the distributed end-products and items. This way the PFEP data sheet will have information of all the items stored in the warehouse.

In the Chapter 5.2 it was clarified what is planned to do with the data collected on the sheet. There was also already thought what information needs to be included so the PFEP data sheet can be utilised as planned. In the following Table 4 there have been presented what information is included in the sheet and why it is there.

Table 4. *The information included in the PFEP data sheet.*

Information	**Why is included in the sheet?**
ID code, name, description, item type, specifications, product group, dimensions, weight, material, status	**Basic information of the item.** Used for sorting the items, calculating volumes and areas of the items and determining suitable packing and protection materials.
Material certificate requirement, order type, acquisition method, planner, buyer, supplier, supplier's country, order quantity, supply lead time, transportation lead time, price	**Important supply chain information that affects the handling at the plant**. Used for sorting the items, determining suitable packing materials and planning efficient handling and warehousing rules.

Safety stock quantity, minimum order quantity, maximum order quantity, reorder point, storage location, on-hand quantity, reserved quantity, quantity on order, average on hand quantity, annual usage	**Information that affects the storing of the item.** Used for sorting the items, designing storage places, determining more efficient warehousing rules and planning the use of warehouse space.

The insufficiency and disorganisation of the item data may cause some problems. With some items the dimensions are given in inches and with others in millimeters. Making sure which unit is used in each case can be problematic, but in the PFEP data sheet all the dimension data must be in the same unit, preferably in millimeters. Getting all the information regarding the item dimensions may require lots of manual work at first. For some items the only place where the item's dimensions are stated is the item's machining drawing. This is the case with body parts. For some others the dimensions are given in the item description and the dimensions must be separated manually. These types of items are usually bolts, pipes, bars and plates. The number of these type of items will be big, but the PFEP data should be made as whole as possible so the sheet can be used as planned. Especially regarding the greatest cost contributors, the information on the sheet should be as complete as possible. Because the dimension data isn't easily available, but it is very useful, it should be collected and while forming the PFEP sheet is a good time for doing so. Without the dimension information the PFEP sheet loses most of its value.

When using an Excel sheet as a platform and including the item information presented in the Table 4 the planned kind of PFEP data sheet is formed. The sketch of the sheet is presented in the following Figure 8. The PFEP data sheet has been wrapped and is presented in many rows so the columns fit on the page in a way the sheet is readable. The sketch holds the information of two example items both active in the ERP system (status 20). The example items are both body parts, but the other is used in ATO-stream and the other is used in Special-stream. The item information that makes it possible to recognise the Case Company has been replaced with marking ''XXX'' or is presented in coded form. For example, the decoded item group details hold information of end-product families so they are now presented in number form.

A	B	C	D	E
Item Type	Item Group	Item status	Item number	Item name
610	15260	20	H076003	BODY XXX_12 XXX150 CF8M
610	12350	20	H090634=1522	BODY XXX10D S CF8M

F	G	H	I	J
Item description	Material	Specification	Dimension1	Dimension2
BODY	ASTM A351 gr. CF8M	XXX_12 XXX150	541	485
BODY	ASTM A351 gr. CF8M	XXX10D S	579	552

K	L	M	N	O
Dimension3	Weight	Material cert.	Order type	Acquisition method
341	100	3.1	103	Purchased
357	175	3.1	103	Purchased

P	Q	R	S	T
Buyer	Planner	Supplier	Supplier's counrty	Supply lead time
HKIATOCF	HKIATOCF	502913	IN	84
HKISPECF	HKISPECF	199878	CN	70

U	V	W	X	Y
Transportation lead time	Lead time (total)	Standard cost	Average cost	Order quantity
63	150	1395,7821	1395,782123	8
63	136	0	1782,98	1

Z	AA	AB	AC	AD
Safety stock qty	Reorder point	Min order qty	Max order qty	Location
3	0	0	0	W-I13.7.1
0	0	0	5	

AE	AF	AG	AH	AI
On-hand qty	Reserved qty	Qty on order	Average on-hand qty	Annual usage
8	0	0	8,916666	2
8	8	0	2,5	0

Figure 8. *The PFEP data sheet with information of two example items.*

The PFEP data sheet has 35 columns and the total number of rows is 352 035. Filtering only relevant items for analysis is needed. For example, selecting only active IDs the number of items reduces to 163 122. The filtering conditions need to be thought based on what kind of analysis is going to be conducted. The columns from A to L hold the items' basic information. The columns from M to Y have the supply chain information that affects also how the item is handled at the plant and the columns from Z to AI have the information that is relevant for the storing.

Most of the information on the example sheet is collected from the ERP system. A query script that can be easily run is possible to form so the sheet is formed automatically in the form presented in the Figure 8. When collecting the sketch of the PFEP data sheet all the other information but the dimension data was collected by using a query from a data warehouse that holds the ERP information. The dimension information was manually added after reading it from the machining drawings. As stated before, the dimension data needs to be collected and added in the data warehouse so it is in usable form.

The PFEP data sheet can be used, for an example, to determine for the more regularly used parts what would be an optimal number that can be fitted to a package that can be easily handled at the plant. Especially reducing the unnecessary transportation of items between the factory and the third-party warehouse would be beneficial so the probability for item damages would be reduced and non-value adding work could be eliminated.

5.3.3 PFEP data sheet management

Because the PFEP data sheet will be mainly used in the internal logistics operations, the logistics department, which is responsible for the internal logistics, should manage the PFEP data sheet. The management of the PFEP data sheet should be appointed to a person who the Logistics Manager finds suitable. Ideally there should be only one person making changes and updates in the PFEP data sheet, but the responsibilities can be divided for a team, but then standard ways for operating the sheet must be agreed.

Even only one person would be appointed to manage the sheet there must be instructions how to operate it. A document holding the instructions for managing the PFEP data sheet will be made as a part of the implementation. The instructions secure that even if the person responsible for the sheet would be prevented from managing it someone else can take care of it. The sheet should be formed so it can be updated in few minutes, but in the implementation phase it will probably require more attention. If major changes are needed at some point that may also require more time, but the idea is that the management of the PFEP data sheet can be appointed as an extra task without significantly increasing the workload.

The update speed of the PFEP data sheet should be decided when piloting the system. First it would be good to try to update the sheet every day so it would hold real-time information on a day level. By forming a new sheet every day and storing the old one history data can be collected and the changes in item on-hand levels can be further analysed as well. By analyzing history data regularities and abnormalities can be spotted. If the daily update cycle is found too quick it can be changed to be longer. Making the update quicker, using the Excel and the data query from the data warehouse, isn't possible because the data warehouse updates only once a day. After a piloting phase the PFEP sheet should be managed as found expedient. Developing the sheet to work more automatically is suggestable.

As discussed in the Chapter 2.2.2 the triangle of involvement should be realised when the PFEP sheet's data changes. Now the PFEP sheet is planned to hold information that can be different on daily basis and the PFEP is planned to be used more as a tool for analysis to find out how things should be done rather than an information table that tells the way to do things. The idea of change request form should be flipped upside down and the users of the PFEP data sheet should ask the stakeholders deciding the values in the ERP system to make the changes to the values based on their analysis. A change request form where the stakeholders that are affected by the requested change are listed should be created so they are informed. When the people authorised to sign the form have countersigned the change they are responsible of communicating the information to others. The usual stakeholders that need to be involved and informed are the internal logistics, purchasing and the assembly streams so the information is widely spread to departments that are possibly affected by the planned change.

5.4 PFEP’s contribution for quality cost reduction in the Case Company

In Chapter 1.3 the main research question was formed. The strategy to answer the main research question was to first answer the three guiding subquestions. The answers for subquestions can be found from Chapter 4.7. The answer to the main research question, how internal failure quality costs due to material handling defects can be reduced by using Plan-for-Every-Part methods in the Case Company*,* can now be answered.

The PFEP data sheet presented in the Figure 8 has been designed for the use of internal logistics and it is planned to hold information that can be used for analysing the current operations and re-planning them to be more efficient. With the sheet’s information the handling and storing of items can be improved so the risks for item damages are reduced. This reduces the number of defected items ending up to the assembly cells which causes idle in the production and it reduces the need for machining rework. However, this requires conducting improvement actions, but the information what should be done can be obtained by analysing the PFEP sheets information.

The PFEP data sheet can provide information how many items can be fitted to a pallet or to a storage location. It can also be analysed if the storage places should be readjusted so more suitable number of items could be fitted to the shelf racks. With this information more optimal orders can be placed for often used parts. This helps in standardising the procedures which makes possible to plan them further. Also, having dimension information and being able to find out the number of similar items usually in the warehouse makes it possible to design more expedient storage places for different item types. For example, round items require places where they stay still when moved. Also, rearranging the storage orders so that the kitting of the parts requires less moving in the warehouse is possible and PFEP can help in that. The items can be grouped based on their item groups which link them to their end-product families. Based on their size there can be appointed more strict guidelines where the item should be stored. The PFEP sheet makes possible to take the actual consumption into consideration in the planning. The rearranging reduces the number of accelerations and stops when picking the items and damages because of items moving on the pallet are reduced.

The PFEP data sheet can also help in planning more detailed packing instructions that will secure the item staying without damage during transportation but also ease the handling during the unpacking and other work phases. The items coming from the same supplier can be analysed and the packing instructions can be made more supplier specific. Better protection during transportation reduces the need to send claims to suppliers and transportation companies. With more careful order size planning the unnecessary moving of items between third-party warehouse and factory could be reduced and the possibility for item damages would decrease. Unnecessary transportation of items between the third-party warehouse and the factory should be avoided.

Because lots of item damages are due to impurities on the workstations, the development of more suitable workstations and handling equipment must be supported. The PFEP data sheet provides information that can be used in designing multifunctional equipment to support the assembly of different end-products. Because there is large variety of items, the equipment must be suitable for most of them and especially for the ones that are handled most often. The PFEP data sheet provides statistical information of the most often used items so they can be recognised.

All in all, the PFEP data sheet can help in improving the material handling system significantly. Many small improvement actions will summarise into bigger entity. If there can be conducted improvement in every step when the items are handled the need for repairing should decrease and the operations should run more smoothly.

The sheet itself is a tool for analysis and the procedures must be put in shape. The SOPs and handling instructions need revision and more specific instructions must be made. The PFEP data sheet should be used for determining the correct ways to operate. After the procedure instructions have been revised it must be secured that the instructions are followed. With these actions it is possible to gain reduction in the internal quality costs.

5.5 Implementing PFEP in the Case Company: A step by step plan

The QIF and Case Company’s own processes and practices will give guidelines to the PFEP implementation. The QIF will be followed on suitable parts, but if a step is found unnecessary it will be left out. Like Meyers et al. (2012) state the innovation implementation is always dependent on many factors and the QIF itself may need some adaptation to facilitate the implementation. The QIF’s steps seem useful but the order has been revised and some steps will be skipped to fit the QIF for the PFEP implementation purposes.

In the QIF there are four phases as presented in the Chapter 2.7. Phase one, initial consideration for host setting, consists of eight steps and few of them have already been taken and iteration has also been done. The three first steps in the QIF’s phase one are resources, fit and readiness assessments. These have been already conducted for the current PFEP data sheet. The Case Company’s IT infrastructure has been found suitable and it is possible to manage and use PFEP data sheet, so the resources can be stated adequate. The PFEP data sheet that is planned to be used fits for the Case Company as well. The readiness for the use of the PFEP data sheet needs to be improved by collecting the dimension data into usable form.

These steps were retaken after they were first conducted for a PFEP data sheet that was planned to guide the operations and the fit of the PFEP data sheet as such wasn’t found suitable or needed in the Case Company. The fourth step of phase one, possibility for adaptation, was considered and the PFEP data sheet was adapted to its current form. Now there is no new need for adaptation. Changes can be still made in later phases to the current PFEP data sheet if they are found necessary.

The fifth step in phase one is critical, because it basically works as the weak market test, which is an evaluation criterion for the thesis. The fifth step, obtaining explicit buy-in from critical stakeholders, especially from the leadership level, must be satisfied. The step by step plan and the sketch of the sheet will work as the tool to obtain the buy-in. These elements with the background work should justify the proceeding to implementation phase. In the QIF forming an implementation plan is the second step of phase two. Now it needs to be taken already in the phase one. This means steps six, seven and eight; capacity building, staff recruitment and preparatory staff training, must be considered in the step by step plan as well as the other steps before it. There should be enough information for planning these steps already.

Because the cause is to reduce quality costs, there have been also included actions in the step by step plan that are meant to focus on the quality cost reduction alongside the PFEP implementation. The greatest cost contributors have been recognised during the research, but finding more ways to tackle them are in place. Some ways have been already found, but the workers' ideas should be also listened more carefully and utilised in the development of the operations.

The Case Company's managers wished that the implementation plan will be made on a level that the plan implies when each step will be taken and who is responsible for the step. The implementation plan should include the instructions what needs to be considered and what are the concrete actions. It was also requested by the managers that the development of the PFEP data sheet and the possibilities for other uses for it would be assessed. The following Table 5 shows the step by step plan for the PFEP implementation in the Case Company. In the first column, Step/QIF step, there has been stated which step of the implementation plan is in question and after the diagonal mark there has been stated which step in QIF the step is comparable to. The next column, Timetable, implies in which implementation week the step should be taken after the implementation plan has been approved. In the third column the step has been described shortly and in the fourth column the procedures required in that step has been clarified with more detail. In the fifth column there has been stated who is the responsible for carrying out the step.

Table 5. Step by step plan for the PFEP implementation

Step/ QIF step	Timetable	Step description	Things to consider	Responsible
1. / 6.	Week 1	Building capacity	Creating the query script to compile the PFEP data sheet. Start collecting the dimension data and transfer it to usable form Creating instructions for PFEP use and management	PFEP owner, support from Logistics department and IT department
2. / 7. and 9.	Week 1 - 2	Staff recruitment /creating implementation team	OPERA workshop where stakeholders will be involved: Collecting ideas from the workers how to improve operations Find ways to collect dimension data effectively If dimension data must be collected manually, gather a team * Collect complete dimension data for few often used body parts for testing the sheet Appointing a PFEP manager	PFEP owner, workers on the floor level, Logistics Manager *Possible data gathering team decided with the managers. (Collecting all dimension data can take weeks)
3. / -	Week 3	PFEP adjustment (if needed) and test launch	PFEP sheet revision according to ideas presented in OPERA Continue collecting the dimension data for rest of the items Compile the PFEP data sheet with the collected dimension data Conduct a test analysis for creating new handling instructions for the item group	PFEP owner and PFEP manager

Step/ QIF step	Timetable	Step description	Things to consider	Responsible
4. / 8.	Week 4	Pre-innovation staff training	Continue collecting dimension data Providing general instructions for the use Communicating the possibility to use PFEP sheet in the organisation	PFEP owner, PFEP manager
5. / -	Week 5-9 PILOT	Launch a PFEP pilot	Starting the active use and everyday compiling of the sheet Conducting test analysis on the items	PFEP owner, PFEP manager
6. / 11.	Week 5-9 PILOT	Coaching, supervision and technical assistance	Securing the functionality of the PFEP sheet	PFEP owner, PFEP manager, IT department
7./13.	Week 6	Supportive feedback mechanism	Find ways to collect information of the results achieved	PFEP owner, PFEP manager
8. / 12.	Week 10	Process evaluation	Analyse the implications of the PFEP data sheet with the internal customer Analyse the results from development actions based on PFEP analysis Changes needed for the sheet Deciding if upkeeping the PFEP data sheet is found useful	PFEP owner, PFEP manager, Logistics department
9. / 14.	Week 11 →	Follow-up	Learning from experience Developing the PFEP sheet and its use	PFEP manager

The step by step plan has 9 steps. The first step after the implementation plan is approved is to collect the dimension data. Finding good ways for gathering all the measurements need to be mapped. It is very much possible that the dimension data needs to be collected manually by going through machining drawings one by one. The dimension data is good to gather, because having dimension data in listed form is beneficial for many other purposes as well. The script for compiling PFEP data sheet should be done with the help of IT department. The instructions must be created for compiling the PFEP data sheet so the PFEP manager or a substitute can do it.

In the Table 5 the PFEP owner means the creator of the PFEP data sheet, which in this case is the thesis writer. The thesis writer will be responsible for carrying out the PFEP implementation as far as a PFEP manager is selected by the Logistics manager. The PFEP owner will work together with the PFEP manager and follow the implementation. The PFEP manager will be trained to manage the sheet by the PFEP owner. The responsibility of the PFEP implementation will move to the PFEP manager after week seven, but during the piloting phase already the PFEP owner will set aside and only follow up the piloting. As stated in the Chapter 5.1 the PFEP manager should be a member of the Logistics department. The PFEP manager is good to be appointed in early phase so the tool becomes familiar. That is why it has been suggested to be done during the step two.

The step two is to involve the personnel in the project. Many have been involved already during the research in the interviews and when doing the observations. The idea is to gather people around one table from each process and work out ways to reduce the material handling defects and to develop ideas for the use of the PFEP data. OPERA workshop is an often-used method in the Case Company and it has been found a great way to collect ideas.

OPERA is an acronym and comes from words Own suggestions, Pair suggestions, Explanations, Ranking and Alignment. The idea is to present the task for the people in the workshop and then each person lists own suggestions regarding the task. Then the people pair up and in pairs they choose few ideas they mutually agree. Then pairs shortly explain their suggestions for others and the suggestions will be ranked on mutually agreed criteria. Then the workshop leader aligns the suggestions according to the results of ranking. With the top ranked suggestions concrete plans for proceeding can be made. (Innotiimi 2018). The goals for OPERA workshop are to find effective ways to reduce item damages during the handling at the plant and gather ideas how PFEP data sheets data could be used for process improvement. If the dimension data takes a long time to gather, it should be collected for some pre-selected item group first, so the PFEP data sheet can be tested.

The step three is to modify the PFEP data sheet according to the suggestions presented in the OPERA workshop if there emerge ideas that require it. After the possible modification, the PFEP data sheet can be launched and it should be tested that it works with the dimension data that has been collected. Conducting a test analysis is needed so it can be made sure that the PFEP gives right results. The results are very dependable on the data quality the sheet holds.

After the functionality has been tested the implementation can proceed to the step four. Because the main user group is internal logistics the training should be mostly done with the PFEP manager. The instructions for the PFEP use should be done in co-operation with the PFEP owner and PFEP manager. After there are instructions for the use of PFEP sheet, the possibility to use the data sheet shall be communicated in the organisation. Other stakeholders may be interested in using the data as well. When the workers have the competency to use the PFEP sheet the step five will be taken, the PFEP sheet will be launched and the PFEP piloting will start for four weeks. This should be enough time for finding ways to improve logistics operations and for bringing them to action. The PFEP sheet will be taken to everyday use and the step six starts immediately because the assistance and support must be available. The functionality of the collection of history data can be also now achieved.

During the piloting, the step seven needs to be considered. There should be created ways to analyse how the use of the PFEP sheet affects the processes. Performance indicators should be created to show the benefits of the PFEP. There should be also information how the amount of internal quality costs has developed. After the piloting, the PFEP implementation will be evaluated with the Logistics department. This is the step eight in the implementation plan. At this point there needs to be decided if the PFEP sheet is worth upkeeping. If the PFEP sheet is found worth of use the recognised development areas should be taken on an action list and the development actions on the sheet should be carried out.

The implementation will proceed to step nine if the use of the PFEP shall be continued. The ninth step is to keep following the use of the PFEP sheet and improve the tool. The PFEP data sheet should be developed among the Logistics department operations and it should be adapted to serve the logistics operations in the best way. The internal logistics in the Case Company can be developed into direction where more operations have been automated. This requires that the as complete set of information as possible is available for the items. With the PFEP data sheet more optimal ways for managing the inventories and logistics operations can be found.

5.6 Conducting the weak market test for the construction

Passing weak market test requires that a manager who has responsibilities for the financial results of the company or the department is ready to apply the construction in practice (Kasanen et al. 1993). The construction, the step by step PFEP implementation plan and the sketch of the PFEP data sheet, was presented to the Case Company's Logistics Manager after it was revised based on the comments from Purchasing Director and the Logistics Manager.

The Logistics Manager found the planned PFEP sheet to hold adequate information. Possible additions to the data set should be assessed after the dimension data will be available and the sheet's functionality is tested. The implementation plan was assessed to be executable, but the details need to be refined during the execution. The PFEP sheet and the implementation plan has found to hold potential.

Now that the construction passed the weak market test the implementation plan can start to be followed. The construction created as a part of the constructive research has been approved and it has been demonstrated that the construction has the potential to work. The demonstration of the constructions functionality and usability was one of the criteria set for constructive research. This criterion has now been met.

6. SUMMARY

In this thesis implementing Plan-for-Every-Part methods in a large manufacturing company having high-mix-low-volume production has been discussed. This has been done in order to reduce internal quality costs due to material handling defects. The matter has been dealt with constructive research approach and the construction has been based on qualitative data gathered with multi-method research. Semi-structured interviews and participant observations were conducted in the Case Company. Also, Case Company's instructions and SOPs were used as secondary material. In this way information for constructing a new application for the Case Company's use has been gathered.

First it was found out how much internal failure quality costs are faced in the Case Company and what causes them. It was found out that 70 % of the quality costs are due to machining rework and 30 % because of assembly rework. The items causing most of the quality costs were the end-products' body parts.

The engineering, procurement, item data management and material handling procedures of the Case Company were examined to find out how the Case Company operates and to find out possible reasons for the item damages. Employees responsible for the beforementioned operations were interviewed and the material handling procedures were also observed. It was found out that reasons for body part and other item defects are insufficient protection of items during moving, careless handling and impurities on workstations. For tackling these problems it was planned what kind of improvement actions should be conducted and what kind of item information would be needed for improving the operations.

As a resulting construction a sketch of the PFEP data sheet was created. The PFEP data sheet contains the basic information of the items, supply chain information that affects how the items are handled at the plant and items' inventory information. The sketch of the sheet is presented in Chapter 5.3.2. The construction includes a step by step plan for implementing PFEP in the Case Company. It was created by utilising quality implementation framework as a base for the implementation plan. The step by step plan consists of 9 steps. The plan is presented in Chapter 5.5.

Differing from the normal use of the PFEP data sheet, the formed construction is planned to serve as a tool for analysis in the logistics department. The information obtained by the use of the PFEP data sheet should help in ordering the logistics operations more efficiently. The items can be categorised in expedient groups based on different traits. By forming appropriate item groups more category specific guidelines how different items should be handled can be formed. This requires that the instructions for logistics procedures are changed based on the findings and that the instructions created are followed. The data for existing items on the PFEP data sheet can be used as a reference when creating parameters for new items by utilising similarities between them. When the items are handled correctly and possibilities for damaging the items are reduced then the internal failure quality costs should also drop because items don't require repairing and damaged parts don't end up in the assembly cells. This can cause small increase in the appraisal costs, but the total quality costs should decrease and the total quality system is likely to be improved. The reduction in the number of item defects will probably have a positive impact on unwanted delays and in this way the customer satisfaction is also expected to improve.

By using the sheet suitable improvement actions can be conducted to reduce the costs accumulated from material handling failures. For example, by finding out more optimal order sizes in terms of storing by calculating how many stock items can be fitted to a storage location the unnecessary moving between third-party warehouse can be reduced. The storage locations can be also modified to be more suitable for the items in terms of size and consumption. The kitting of items can be also made easier by appointing the storage locations so the items likely going for same end-product are even closer together than they are now. This reduces the probability of items damaging on the pallet because less accelerations and stops are needed. The picking will also be faster.

There were found severe gaps in item data that are crucial for the use of the PFEP data sheet. The item dimensions must be collected in usable form so the sheet can be used as planned. The dimension data is possible to be gathered in listed form, but it probably requires manual work. Most of the dimension data must be collected from the machining drawings and it may take time.

7. CONCLUSIONS

7.1 Implications for the Case Company

As the result of this research there has been created a sketch of the PFEP data sheet and a step by step plan for implementing it in the Case Company. The Case Company should follow the plan and do the required steps and actions listed. The managers have approved the construction created during the research which justifies its use.

The greatest challenges are expected to arise from the collection of the dimension data. Enough resources should be appointed for this task because the dimension data is crucial in the use of the PFEP data sheet. The dimension data can be also used for other purposes and it is hard to understand why it hasn't been gathered in listed form before.

The Logistics Manager must consider who will be appointed to manage the PFEP data sheet from the Logistics department. There must be also made time for the OPERA workshop. The time must be scheduled so that the everyday operations aren't compromised. The PFEP owner will schedule the times with the Logistics Manager.

The development of the internal failure quality costs should be monitored so a realistic view of the contribution of the PFEP implementation can be evaluated. The quality cost information used in the current state analysis was from the year 2017. The general view was that the number of defects had already decreased before the researched started. The quality cost data can be analysed from the time before the PFEP implementation starts from the year 2018 and then the development afterwards can be evaluated separately. This will give a clue if a positive impact has been achieved. It should be considered that the Case Company has also other development projects that have an impact on the development of the quality costs. Most likely they have a positive, decreasing effect on the quality costs.

After all the steps of the implementation plan have been taken the use and development of the tool should continue. The PFEP data sheet should be complemented with purchased parts market so the creation of lean material handling system continues. Finding ways for more efficient quality problem reporting should be assessed.

7.2 Academic contribution

In this research ways to reduce internal quality costs by applying PFEP methods were mapped. The research was conducted in real life environment in a large manufacturing company with high-mix-low-volume production. Similar research which connects quality cost reduction with PFEP methods hasn't been conducted before. This research fulfils a research gap on the area of PFEP's ability to reduce quality costs. This research also contributes to the adaptation of the PFEP for company specific use.

Ways to implement the PFEP data sheet and utilise it in the Case Company were assessed in the thesis. Quality implementation framework was selected as a base for the implementation plan. This research contributes to the research done in the area of innovation implementation and can be used as reference material.

The use of the PFEP data sheet in high-mix-low-volume production environment is also without academic research. This case study contributes to that field by showing example how the PFEP methods can be adopted in an environment other than mass production. This research also contributes in the area of product and item data management by pointing out the incompleteness of product and item related data and the problems related to them that can be found in the companies.

7.3 Limitations and credibility

To claim a study to be a credible research it should have the generally accepted traits of validity, reliability, generalisability and the study should be conducted with carefulness (Stenbacka 2001). These concepts differ when speaking about quantitative and qualitative research. Reliability traditionally means the methods ability to produce the same result repeatedly. When speaking about qualitative research, a thorough description, so others can relate to the findings, is what indicates good quality and reliability rather than the research's repeatability. Validity can be achieved if the data and material can be gathered from informants who deal with the problem area and they can speak freely according what they know without restraints. Analytical generalisation, which means that the study lifts the empirical matter to a general level, is important. Generalizing the study to represent the whole "population" isn't even possible with qualitative studies examining small unique entities. Carefulness can be achieved with systematic and cautious description of the whole process and reality under research. (Stenbacka 2001)

The research has been described carefully and thoroughly and the qualities and traits of the surroundings where the research has been conducted have been described from the relevant parts. Specific information regarding the Case Company couldn't be used in the report because Case Company wanted to retain its anonymity. The traits left out of description may have had some influence on some analysis and decisions made during the research process that can't be reasoned based on the report. This kind of reasoning has been kept in minimum. The informants used were experts in their fields and there wasn't any recognized reason why they couldn't speak their minds. The traits of a constructive research described by Kasanen et al. (1993) have been fulfilled.

Young (1969) reminds that the quality of the data is too often taken for granted in different research approaches. Cicourel (1972) demands that the quality of data should be assessed thoroughly and sweeping up any data shouldn't come to question. If thinking like this then all data would be equal and worthy of analysis (St. Pierre & Jackson 2014). Collecting the data in this research has been performed using careful consideration in the selection of the interviewees. The persons interviewed are people who should obtain good knowledge of the matters in that area they were interviewed about. What they have said has been verified with the help of Case Company's internal instructions and SOPs and, also performing observing on certain processes for most areas. Not all what the interviewees have stated have been confirmed, but their statements have been treated as facts. This poses a threat that something that has been treated as a fact would be inaccurate and invalid. The triangulation for most of the data used mitigates the risk.

Saunders et al. (2009) list few things regarding the participant observation that cause limitations for the research. Because of the time-consuming nature of observing and the limited time for conducting the research the data set may be limited. This has been tried to avoid by spending several hours on doing observations. Observer bias can cause distorted data, but this has been mitigated by the triangulation. Still, there is no doubt that some observations are affected by the observer bias. Recording the data during the observing can also be quite difficult and relevant observations may stay without notation. This means something relevant can be missing from the data set. Lack of significant data is very unlikely, but nuances related to different things could have remained unnoticed. (Saunders et al. 2009)

In the Case Company there were simultaneous bigger and smaller development projects that would have effect on the quality costs. There could be seen overlapping in some areas. It is hard to say what affects what and which development project was more important in gaining the positive or negative results and what will be their combined effect on the Case Company.

There were also some limitations regarding the data. The data set available in the Case Company was broad but most of the data sets that were used in this research were already edited and used for the Case Company's monthly quality reports. This means the data used was already handled by someone else. On the other hand, the Case Company's managers have the exactly same numbers, because the intermediary is the same, so that wouldn't affect their consideration. On the other hand, the absolute correctness of the quality cost data can't be confirmed.

There was also inaccuracy in the reporting of the material defects. The reporting system on the floor level was implemented in 2016. Adapting new processes takes a while and all operations haven't yet fully internalised the use of the reporting system. There was significant inaccuracy in the defect descriptions and in some cases, it was impossible to tell what the actual defect was. The cases included in the research were all recognised to fulfil the in-scope criteria.

All of the Heavy-streams machining rework isn't reported on the reports because in the Heavy-stream the rework is often done among other production if the mistakes are noticed. It is challenging to tell if fixing or other extra work has been done when it can't be separated based on the information available on the system reports. Following the process for a short time wouldn't be very expedient because there could be zero or excess number of cases. Also, because historical data was analysed, present state wouldn't probably have portrayed the history accurately. Estimates could have been used, but in this case, it probably wouldn't have made a big difference in the present state analysis.

7.4 Future research and development areas

Regarding the conducted research a follow-up research could be done to find out if the Case Company has managed to improve the operations by using the PFEP data sheet. Also, the strong market test could be conducted for the construction. This would give excellent data about the construction's performance and usability, but it would also be valuable reference of the credibility of the weak market test. Also, valuable knowledge of PFEP's suitability in other similar companies could be enhanced. Research of PFEP implementation using similar methods in other companies would be also interesting so the generalisability of the step by step plan could be determined.

During the research many interesting topics were assessed and encountered. When gathering material for the research many areas needing development came up. The Item Data Management Team Leader pointed out that there are shortcomings in the item alteration process. It could be an interesting topic for research how the changes in items could be managed efficiently and with no errors in production.

Also, one even larger area for development occurred. The ID system could be more efficient and informative. Now the ID codes don't contain barely any useful information even they could. Also, the name and description system should be made even more coherent, so the classification of item data would be easier for later item data related projects. The item data management would be also easier and automation in administrative processes could be more widely used.

The reporting system for quality defects could be also assessed so the categorisation when reporting production problems in MES would be more straight forward. Now there are categorisations which can be misleading and similar defects can be reported under different sub-categories. Also, more detailed instructions for defect reporting could be handy for the workers on the factory floor so more relevant and rich data would be given in the reporting system. Also, creating an effective way to tackle the quality problems immediately when they emerge is recommendable.

Continuing the lean material handling system creation requires implementation of other parts of the system. Supermarket for purchased parts could be a valuable tool for indicating the demand of parts for the procurement and it could work nicely together with the third-party warehouse and VMI items. The picking and shelving would be harnessed more effectively to supply the production's demand. Also, creating a way to imply quality defects and solve them immediately would probably reduce the quality costs significantly.

REFERENCES

Ackroyd, S. (1992). Data collection in context. Longman Group United Kingdom.

Akturk, M. S., & Balkose, H. O. (1996). Part-machine grouping using a multi-objective cluster analysis. International Journal of Production Research, 34(8), 2299-2315. doi:10.1080/00207549608905026

Becker, C., & Scholl, A. (2009). Balancing assembly lines with variable parallel workplaces: Problem definition and effective solution procedure. European Journal of Operational Research, 199(2), 359-374. 10.1016/j.ejor.2008.11.051

BS6143 (1981). Guide to the Determination and Use of Quality Related Costs. London: British Standards Institution

Buthmann, A., (2018). Cost of Quality: Not Only Failure Costs. iSixSigma, Available online: https://www.isixsigma.com/implementation/financial-analysis/cost-quality-not-only-failure-costs/, Retrieved 16.1.2018

Campanella, J. (1999). Principles of quality costs: Principles, implementation, and use. Quality Congress. ASQ's. Annual Quality Congress Proceedings, 507.

Chinowsky, P. S. (2008). Staircase model for new practice implementation. Journal of Management in Engineering, 24(3), 187-195. doi:10.1061/(ASCE)0742-597X(2008)24:3(187)

Christopher, M. (2005). Logistics and Supply Chain Management: Creating Value-Adding Networks, Financial Times Prentice Hall, Harlow

Cicourel, A. V. (1979). Field research: The need for stronger theory and more control over the data base. In W. E. Snizek, E. R. Fahrman, & M. K. Miller (Eds.), Contemporary issues in theory and research (pp. 161-176). Westport, CT: Greenwood Press

Cottyn, J., Van Landeghem, H., Stockman, K., & Derammelaere, S. (2011). A method to align a manufacturing execution system with lean objectives. International Journal of Production Research, 49(14), 4397-4413. doi:10.1080/00207543.2010.548409

Dale, B. G., Bamford, D., & van der Wiele, T. (2016). Managing quality: An essential guide and resource gateway (6th ed.). Chicester: John Wiley & Sons Inc.

De Toni, A., & Tonchia, S. (1998). Manufacturing flexibility: A literature review. International Journal of Production Research, 36(6), 1587-1617. 10.1080/002075498193183

Deradjat, D., & Minshall, T. (2017). Implementation of rapid manufacturing for mass customisation. Journal of Manufacturing Technology Management, 28(1), 95-121. 10.1108/JMTM-01-2016-0007

European Pallet Association (2018). EPAL Euro pallet (EPAL 1). Available online: https://www.epal-pallets.org/eu-en/load-carriers/epal-euro-pallet/ Retrieved: 27.3.2018

Faccio, M. (2014). The impact of production mix variations and models varieties on the parts-feeding policy selection in a JIT assembly system. The International Journal of Advanced Manufacturing Technology, 72(1), 543-560. 10.1007/s00170-014-5675-0

Fan, L., & Deng, J. (2016). Application of lean logistics in engine plant. Paper presented at the 1-6. doi:10.1109/MIES.2016.7779984

Feigenbaum, A. V. (1956). Total quality-control. *Harvard business review*, *34*(6), 93-101.

Flinchbaugh, J. W. (2005). Lean material management. *Material Handling & Logistics*, April 2005. Available online: http://www.mhlnews.com/facilities-management/lean-material-management, Retrieved 1.3.2018

Frostenson, M., Prenkert, F. (2015). Sustainable supply chain management when focal firms are complex: A network perspective. Journal of Cleaner Production, 107, 85-94. 10.1016/j.jclepro.2014.05.034

Grama, B., & Todericiu, R. (2016). Change, resistance to change and organizational cynicism. Studies in Business and Economics, 11(3), 47-54. doi:10.1515/sbe-2016-0034

Green, J. C., Lee, J., & Kozman, T. A. (2010). Managing lean manufacturing in material handling operations. International Journal of Production Research, 48(10), 2975-2993. 10.1080/00207540902791819

Gudehus, T., & Kotzab, H. (2011). Comprehensive logistics (2nd ed.). Berlin, Heidelberg: Springer.10.1007/978-3-642-24367-7

Guillaume, R., Grabot, B., & Thierry, C. (2013). Management of the risk of backorders in a MTO-ATO /MTS context under imperfect requirements. Applied Mathematical Modelling, 37(16-17), 8060. 10.1016/j.apm.2013.03.019

Gurtu, A., Searcy, C., & Jaber, M. Y. (2017). Emissions from international transport in global supply chains. Management Research Review, 40(1), 53-74. 10.1108/MRR-09-2015-0208

Handel, M. J., & Levine, D. I. (2004). Editors' introduction: The effects of new work practices on workers. Industrial Relations: A Journal of Economy and Society, 43(1), 1-43. doi:10.1111/j.0019-8676.2004.00317.x

Harris, C. (2004). The Plan for Every Part (PFEP).

Harris, C., & Harris, R. (2008). Lean connections: making information flow efficiently and effectively. CRC Press.

Harris, R., Harris, C., & Wilson, E. (2003). Making materials flow. Lean Enterprise Institute.

Harris, C., Harris, R., & Wilson, E. (2004). Steps to Implementing a Lean Material Handling System. Lean Directions.

Holmström, J., Ketokivi, M., & Hameri, A. (2009). Bridging practice and theory: A design science approach. Decision Sciences, 40(1), 65-87. 10.1111/j.1540-5915.2008.00221.x

Infante, D., Vocaturo, F., & Paletta, G. (2009). A ship-truck intermodal transportation problem. Maritime Economics & Logistics, 11(3), 247-259. 10.1057/mel.2009.6

Innotiimi (2018). OPERA. Available at: http://www.cittametropolitana.mi.it/export/sites/default/welfare_e_pari_opportunita/enGaging/doc/AcademyDoc/m4_OPERA.pdf, Retrieved 8.5.2018

Iravani, S. M., Van Oyen, M. P., & Sims, K. T. (2005). Structural flexibility: A new perspective on the design of manufacturing and service operations. Management Science, 51(2), 151-166. 10.1287/mnsc.1040.0333

Kalantari, M., Rabbani, M., & Ebadian, M. (2011). A decision support system for order acceptance/rejection in hybrid MTS/MTO production systems. Applied Mathematical Modelling, 35(3), 1363-1377. 10.1016/j.apm.2010.09.015

Kasanen, E., Lukka, K., & Siitonen, A. (1993). The constructive approach in management accounting research. Journal of Management Accounting Research, 5, 243.

Ke, J. F., Windle, R. J., Han, C., & Britto, R. (2015). Aligning supply chain transportation strategy with industry characteristics. International Journal of

Physical Distribution & Logistics Management, 45(9/10), 837-860. 10.1108/IJPDLM-06-2014-0130

Kropsu-Vehkapera, H., Haapasalo, H., Harkonen, J., & Silvola, R. (2009). Product data management practices in high-tech companies. Industrial Management & Data Systems, 109(6), 758-774. 10.1108/02635570910968027

Kusuda, Y. (2010). IDEC's robot-based cellular production system: A challenge to automate high-mix low-volume production. Assembly Automation, 30(4), 306-312. 10.1108/01445151011075753

Lee, H. (1998). Preface to Global Supply Chain and Technology Management [w:] H. Lee (ed.), Global Supply Chain and Technology Management, POMS Series in Technology and Operations Management, Vol. 1. Production and Operations Management Society, Miami, Florida.

Lee, R. M. (1993). Doing research on sensitive topics. Sage.

Loduca, D. P. (2011). Exploratory study of barriers to use of Feigenbaum's quality cost strategy within design engineering firms

Logistiikan Maailma (2018). Packaging. Available online: http://www.logistiikanmaailma.fi/en/logistics/packaging/, Retrieved 6.3.2018

Lu, Y., Wang, C., & Tang, Z. (2008). Research on configuration process of ATO product for mass customization. Paper presented at the Second International Symposium on Intelligent Information Technology Application, 3, 751-755. 10.1109/IITA.2008.521

Lukinskiy, V., & Dobromirov, V. (2016). Methods of evaluating transportation and logistics operations in supply chains. Transport and Telecommunication, 17(1), 55. 10.1515/ttj-2016-0006

Matías, J. C. H., García, J. P., García, H. P., & Idoipe, A. V. (2008). Automatic generation of a bill of materials based on attribute patterns with variant specifications in a customer-oriented environment. Journal of Materials Processing Tech, 199(1), 431-436. 10.1016/j.jmatprotec.2007.08.038

Mentzer, J. T., DeWitt, W., Keebler, J. S., Min, S., Nix, N. W., Smith, C. D., & Zacharia, Z. G. (2001). Defining supply chain management. Journal of Business logistics, 22(2), 1-25.

Meyers, D. C., Durlak, J. A., & Wandersman, A. (2012). The quality implementation framework: A synthesis of critical steps in the implementation process.

American Journal of Community Psychology, 50(3), 462-480. doi:10.1007/s10464-012-9522-x

Miles, M. B., & Huberman, A. M. (1994). Qualitative data analysis: An expanded sourcebook (2.th ed.). Thousand Oaks: Sage.

Mukattash, A. M., Adil, M. B., & Tahboub, K. K. (2002). Heuristic approaches for part assignment in cell formation. Computers & Industrial Engineering, 42(2), 329-341. doi:10.1016/S0360-8352(02)00020-7

Mukherjee, K., Sarkar, B., & Bhattacharjya, A. (2009). Supplier's selection strategy for mass customization. Paper presented at the 892-895. 10.1109/ICCIE.2009.5223861

Neuman, W. L. (2013). Social research methods: Qualitative and quantitative approaches. Pearson education.

Nilsen, P. (2015). Making sense of implementation theories, models and frameworks. Implementation Science, 10(1), 53.

Niranjan, T. T., Wagner, S. M., & Nguyen, S. M. (2012). Prerequisites to vendor-managed inventory. International Journal of Production Research, 50(4), 939-951. 10.1080/00207543.2011.556153

Pine, B. J., Victor, B., & Boynton, A. C. (1993). Making mass customization work. Harvard business review, 71(5), 108-11.

Pyke, D. (2016). How to spoil a good idea. *Accenture Academy Blog*. June 2016, Available online: https://www.accenture.com/us-en/blogs/blogs-how-to-spoil-a-good-idea, Retrieved 2.3.2018

Robson, C., & McCartan, K. (2016). Real world research. John Wiley & Sons.

Rocha, L. F., Moreira, A. P., & Azevedo, A. (2010). Flexible internal logistics based on AGV system's: A case study. IFAC Proceedings Volumes, 43(17), 248-255. doi:10.3182/20100908-3-PT-3007.00049

Saunders, M., Lewis, P., & Thornhill, A. (2009). Research methods for business students (5th ed.). Harlow: Prentice Hall.

Skjøtt-Larsen, T. (2007). Managing the global supply chain (3.;3rd; ed.). Copenhagen: Copenhagen Business School Press.

Song, Y., Yang, G., Weng, W., & Schnidt, R. (2010). PFEP-oriented in-plant logistics planning method for assembly plants. (pp. 1396-1404)10.1061/41139(387)192

Sower, V. E. (2011). Essentials of quality: With cases and experiential exercises. Hoboken, NJ: Wiley.

Stadtler, H., & Kilger, C. (2008). Supply chain management and advanced planning: Concepts, models, software, and case studies (4;4th; ed.). Berlin, Heidelberg: Springer.10.1007/978-3-540-74512-9

Stenbacka, C. (2001). Qualitative research requires quality concepts of its own. Management decision, 39(7), 551-556.

St. Pierre, E. A., & Jackson, A. Y. (2014). Qualitative data analysis after coding. Qualitative Inquiry, 20(6), 715-719. 10.1177/1077800414532435

Summers, D. C. S. (2005). Quality management: Creating and sustaining organizational effectiveness. Upper Saddle River (NJ): Pearson Prentice Hall.

Sääksvuori, A., & Immonen, A. (2002). tuotetiedonhallinta - pdm. Helsinki: Satku

Upton, D. M. (1997). Process range in manufacturing: An empirical study of flexibility. Management Science, 43(8), 1079-1092. 10.1287/mnsc.43.8.1079

Voss, C., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. International Journal of Operations & Production Management, 22(2), 195-219. 10.1108/01443570210414329

Waller, M., Johnson, M. E., and Davis, T. (1999). Vendor-managed inventory in the retail supply chain. Journal of Business Logistics, 20 (1), 183–203.

Wang, J. X. (2015). Cellular manufacturing CRC Press.

Wemmerlöv, U., & Hyer, N. L. (1989). Cellular manufacturing in the U.S. industry: A survey of users. International Journal of Production Research, 27(9), 1511-1530. doi:10.1080/00207548908942637

Young, O. (1969). Professor Russet: Industrious tailor to a naked emperor. World Politics, 23, 486-511.

Zhang, Q., & Tseng, M. M. (2009). Modelling and integration of customer flexibility in the order commitment process for high mix low volume production. International Journal of Production Research, 47(22), 6397-6416. 10.1080/00207540802266474