CHALMERS
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# Knowledge Management in the Procurement Process

## Maintenance Organization's Role in Failure-free Production

Master's thesis in Product Development

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2019

Master's thesis 2019

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# Abstract

In order for organizations to stay competitive in the future with increased complexity and demands, failure-free production is a necessity. It has been seen that maintenance related losses losses due to equipment failure are the main root causes. Production losses can possible be prevented during the design and development phases during the procurement of the equipment. Knowledge management is particularly central in order to successfully incorporate experience and knowledge into the procurement process, called Early Equipment Management (EEM). Given also that the design and development are performed by the equipment supplier, creates an unique dependency on the knowledge sharing towards the supplier.

This thesis, that is a part of the research project KIDSAM, investigates how knowledge is captured and transferred into the procurement process of production equipment, with the main focus at how knowledge from maintenance organization can prevent future production disturbances. The procurement process depends on knowledge capturing and transfer from two perspectives; (1) capturing and sharing knowledge internally from maintenance to the procurement process and (2) sharing the knowledge to the supplier, which are both covered. In order to study these aspects, in-depth face-to-face interviews, internal documents and a literature study were used as research approach. The research was performed at a global case company at three different production plants, covering three executed projects and one ongoing project. Results show that the case company has a working and well defined process of procuring production equipment, transferring explicit, implicit and tacit knowledge. It was shown that explicit knowledge was reused, together with positive initiatives to transfer also implicit and tacit knowledge, creating a high level of trust. However, it was seen that the organization possibly lack of a holistic view of EEM with e.g. a too high focus on tools. A standardized and stable process for a reactive approach to problem solving is found, the reactive and proactive approach is developing in a promising direction. The interviewed team members were found pleased with the current level of supplier collaboration but referred to documentation as a challenge. Recommendations for a holistic view of EEM, improved knowledge sharing and supplier documentation are lastly given.

Keywords: procurement, production equipment, lean, early equipment management, industry 4.0.

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Jonny Blomberg, Martin Håkansson, Gothenburg, June 2019

# Contents

# List of Figures

# List of Tables

# Terminology

EEM - Early Equipment Management
EWO - Emergency Work Order
HERCA - Human Error Root Cause Analysis
IPAP - Industrial Project Assurance Plan
LCC - Life Cycle Costing
PM - Preventive/Professional Maintenance
PSM - Project Steering Model
RFI - Request for Information
RFQ - Request for Quotation
TPM - Total Productive Maintenance
TS - Technical Specification
WCM - World Class Manufacturing
ECS - Engineering Check Sheet

# 1 Introduction

## 1.1 Background

Society have changed from time to time but are now doing it in a faster phase than before. This is starting to put pressure on industry that is manufacturing the products that society are using. Some of the effects of this pressure are increasing demands for short development periods and resource efficiency (Lasi et al., 2014). To meet these expectations, a trend called "Industry 4.0" has started to arise from the industry and academia. Industry 4.0 as a concept focuses on the next paradigm shift for the industry (the three first being mechanization, electricity and IT), towards enabling the usage of Internet of Things (IoT) and Collaborative & Proactive Solutions (CPS) (Bokrantz et al., 2017). When in place, the industry 4.0 factory should have developed into an intelligent environment where production equipment are exchanging information, triggering actions and controlling each other autonomously (Weyer et al., 2015). To achieve this, more emphasizes needs to be put on the interface between the development and production of the products for the future.

One term for this interface is the procurement of new production equipment, Early Equipment Management (EEM), associated with Total Productive Maintenance (TPM), that was rather well studied during the 90s but the research have lost momentum since and now there is limited amount of research in this area (Salonen, 2018).

Studies leading up to this thesis have shown that the second and third largest contributors to the total losses in production is related to maintenance and equipment breakdowns(Machado and Sathyan, 2018). Further, the importance of extraordinary maintenance management to cope with new demands is also emphasized by Bokrantz et al. (2017). Researchers in the field of product development have shown the importance of using knowledge gained from earlier projects to try and eliminate future design weaknesses (Morgan and Liker, 2006). The involvement of suppliers to reach success in new equipment projects is also emphasized (Petersen et al., 2005; Hoegl and M. Wagner, 2005). This combination makes it interesting to examine how maintenance related knowledge is captured and transferred into the process of procuring new production equipment, and possible effects related to this. The aim of this thesis is to add knowledge that will enable the industry of the future to better meet the mentioned demands with higher efficiency. To accomplish this, the study will explore the knowledge transfer within a case company, as well as the possible effect of supplier involvement in the procurement process of new production equipment.

# 2
# Objectives

How is the current process for procuring production equipment with supplier-collaboration viewed and managed in order to prevent future production disturbances, from a maintenance perspective?

1. Are there any differences and similarities between theory and how project members defines the procurement of production equipment process?

   *How the procurement process is defined gives an as-is analysis, which can be compared to theory.*

2. How is knowledge captured and transferred from the maintenance organization into the process?

   *Capturing and transferring knowledge related to maintenance is important to prevent future production disturbances. Studying how this is performed is important to further answer research question 4.*

3. Does the supplier collaboration affect the knowledge transfer in the project and if so, how?

   *Involving and collaborating with suppliers are inevitably a part of procuring production equipment. Thus, it is of interest whether the knowledge transfer is affected by the supplier collaboration, and if so, how it is affected.*

4. What possible improvements can be identified to the knowledge capture and transfer in the procurement of production equipment process?

   *Using the findings from research question 2, it will provide possible improvements.*

## 2.1 Delimitations

- Equipment failures will be the main production disturbance.
- Knowledge management covers several process activities. In this thesis report, mainly

*capture* and *transfer* of knowledge will be covered.

- The supplier collaboration, is two-sided. In this report, only the buyer-perspective will be covered.

# 3
# Theory

*In this chapter, relevant theory and research are presented.*

This research report is based upon on a theoretical foundation consisting of four main areas; World Class Manufacturing, Early Equipment Management, Maintenance and Knowledge Management (see Figure 3.1). These theoretical areas also serves as a framework for what new knowledge this report aims at producing. In the following chapters the four different areas are introduced separately to give the reader a basic understanding of the alignment of the report.

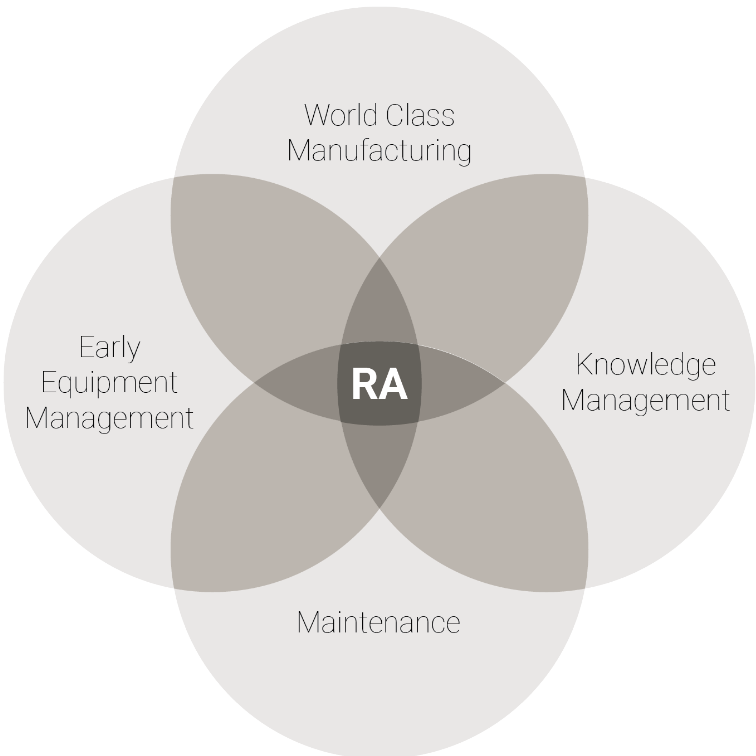


**Figure 3.1:** Illustrating how the different areas of theory frames the project with the research area situated in the centre

## 3.1 Knowledge Management Theory

Knowledge can be described as a pyramid consisting of data, information and knowledge (see Figure 3.2), where the amount of structure and context is increasing as you move up the structure. Numbers, letters and pictures are often referred to as data. Information can be described as data set in some level of context with some amount of structure. Knowledge, which is at the top of the pyramid, demands an understanding of a given situation and the context to such a degree that it is possible to identify leverage points and weaknesses, in short a more meaningful awareness and understanding (Stenholm, 2016).

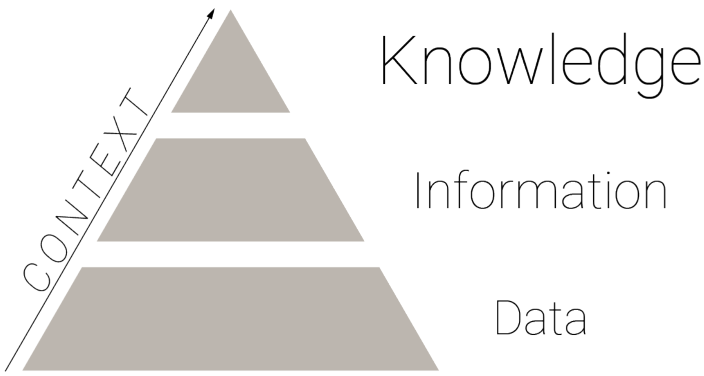


**Figure 3.2:** The knowledge pyramid that illustrates the dependency between data, information and knowledge (Alavi and Leidner, 2001)

.

Tryon Jr (2016) describes that there are three major knowledge categories; individual, global and organizational knowledge. The individual knowledge can be described as the mix of both formal education and personal experiences. Two people with the same education and real-life conditions will end up with different individual knowledge. Global knowledge is that which can be found in e.g. textbooks, internet or databases. In an organization this is often realized in a document management system with possibilities for tagging, storing and organizing. However, the issue still remains in that organization still need to make sure that the right knowledge and information is obscured in the mass of content. Organizational knowledge is defined by Tryon Jr (2016) as "...the knowing required by an enterprise to produce the products and services necessary to perform the work of the enterprise". It is this knowledge that is unique for the organization, built upon all employees' knowledge creation, development and transfer. Tryon Jr (2016) describes organizational knowledge and divides this into three sub-groups.

**Explicit knowledge** is knowledge that easily can transmitted to others, in the form of e.g. written content on a paper, audio- and video recordings. There should be little or no questions to the meaning of the message (Tryon Jr, 2016).

**Implicit knowledge** is a type of knowledge that could become explicit but at the particular moment of interest, for different reasons, is not. Converting implicit knowledge into explicit knowledge could be a matter of asking the right person the right question and capturing the results (Tryon Jr, 2016).

**Tacit knowledge** on the other hand is knowledge that is difficult to transfer through words or physical media. By some it is referred to as intuition or judgment (Tryon Jr, 2016). An example is riding a bike; it is difficult to create a how-to-video that enables a person to ride a bike just by watching it.

### 3.1.1 Knowledge Management Process

The process of managing knowledge (as illustrated in figure 3.3) can be described in six parts; discovery, capture, organization, use, transfer and retention.

- *Knowledge discovery* is the formal discovery methods that are used. It is to e.g. gather needs, investigate problems or test and validate results. All of which to discover knowledge.
- *Knowledge capture* aims to capture knowledge, preferably in a standardized and formal manner. One form is using templates, which can encourage a consistency. On the contrary, if no formal templates exists, each and every practitioner in an organization can create their own version. This can lead to captured knowledge that is more difficult to reuse in the organization which hinders knowledge reuse (Tryon Jr, 2016).
- *Knowledge organization* is the part of which the captured knowledge is stored, organized to facilitate an optimal environment for knowledge reuse. Commonly, this consists of a repository product such as a database, containing documents, files and records. The ability to find the right knowledge in this repository is dependent of the system's ability for organizing. Issues such as recreation and duplication of already existing content are results of a lacking repository system. Hence, the ability to organize its content is critical for the success of managing knowledge (Tryon Jr, 2016).
- *Knowledge use's* main goal is to reuse organizational knowledge and covers all parts of the knowledge management. It is when the discovered, captured and organized knowledge is being reused that the benefits of knowledge management can be seen (Tryon Jr, 2016). Success of knowledge is when a knowledge management initiative has led to a knowledge reuse (Stenholm, 2018). The organization needs to create a culture and an infrastructure that encourages and enables the users to reuse existing organizational knowledge (Tryon Jr, 2016).
- *Knowledge transfer* refers to the activity of transferring the knowledge. Mechanisms of knowledge transfer are e.g. documentation, training or communication. Documentation can be classified as being explicit and can consist of any medium, e.g. text and images, both in electronic or physical format. Apprenticeship and mentoring/coaching are methods to transfer tacit and implicit knowledge. Cross-training is similar to apprenticeship, where both are using experienced people with less experienced people to exchange and

transfer tacit and implicit knowledge (Tryon Jr, 2016).

- *Knowledge retention* deals with the issue of how the captured and stored knowledge should be retained. Together with knowledge use, it covers the entire knowledge management initiative. Knowledge is in constant change, and needs to be updated and revised (Stenholm, 2018), implicating that only discovering, capturing and organizing knowledge on a single occasion is not sufficient for a long-term approach, it needs to be maintained. Retaining knowledge concerns e.g. what is most significant for the operation of the organization, how and by whom should knowledge be maintained and when should knowledge be archived and/or destroyed (Tryon Jr, 2016).

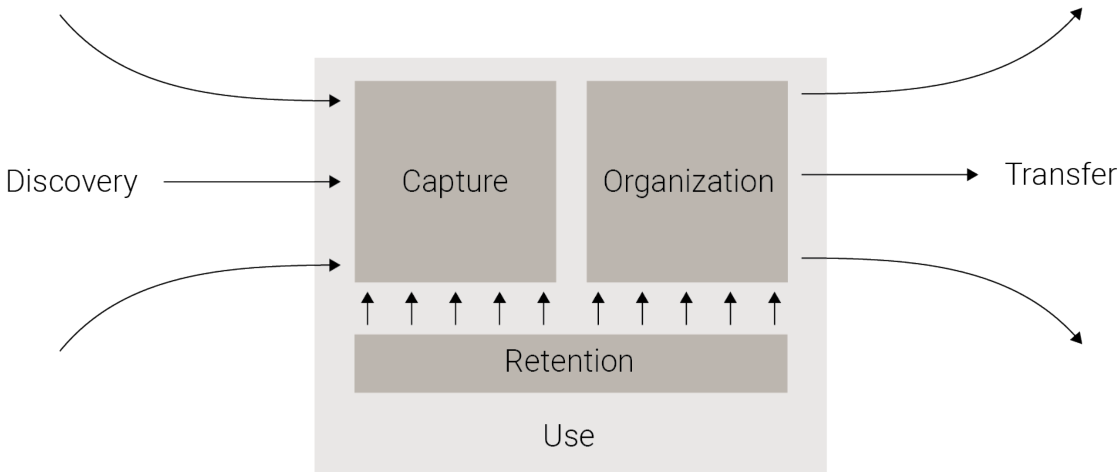


**Figure 3.3:** Illustration of the knowledge management process described by (Tryon Jr, 2016)

### 3.1.2 Knowledge Management in the Procurement Process

Managing knowledge is one of the core parts in the process of procuring production equipment (Yamashina, 2008; Bellgran and Säfsten, 2010; Axelsson et al., 2005). Bellgran and Säfsten (2010) emphasizes the importance of identifying, keeping and transferring knowledge. This is specifically valid in the phases of early design and start-up of new equipment and production systems. Axelsson et al. (2005) even argues that capturing the competence and knowledge that an organization has is *crucial* in order to develop a robust production system. It is crucial that the organization also has knowledge of supplier collaboration, more specifically orderer competence. Working with a supplier will require the organization to have competence in how to transfer and communicate knowledge. It is the exchange of information and knowledge that will be of great importance for the final result. Bruch and Bellgran (2013) wanted to address the research gap of what capabilities and resources are needed for an efficient production design process. After identifying several characteristics affecting the management of information, it was concluded that it may have severe consequences for the production performance if the design information is not managed appropriately (Bruch and Bellgran, 2013). Managing knowledge is also of great importance when collaborating with suppliers in order to achieve a robust equipment (Bellgran and Säfsten, 2010).

Capturing and transferring knowledge and experience into the procurement project is crucial for the result. By using knowledge reuse support, that acts as a tool or method for an organization, it can learn by its mistakes and experiences. Examples of these tools are blogs, wikis or checklists (Bergsjö et al., 2018). Bergsjö et al. (2018) studied in particular one form of checklists, called engineering check sheets (ECS), in an engineering environment by implementing these. These were seen to be effective as a knowledge carrier both for experienced and inexperienced worker. One of the success factors for ECS is that it transfers three different types of knowledge in one knowledge element (see Table 3.1).

**Table 3.1:** The different types of knowledge that is included into knowledge element in a ECS (Stenholm et al., 2018)

| **One knowledge element includes** | **Know-what** | **Know-why** | **Know-how** |
|---|---|---|---|
| | Action/decision that needs to be taken/made | Why does this specific action/decision need to be made? why is it important? | How will the action/decision preferably be performed? What is important to keep in mind/consider? |

Also in the work by Yamashina (2008), there is a form of check list called design review checklist. Design review checklist is used as a tool for the project quality. In the checklist are different points, checking that important aspects are covered in the right phase. It includes e.g. design rules, standards and other forms of empirical knowledge, covering all aspects, such as quality, maintainability, reliability and safety. It will act as a tool for knowledge reuse where it will grow organic over time for each new project that the organization conduct (Yamashina, 2008). Further, the usage of checklist can also be found in the Toyota product development process, as a tool for organizational learning. Morgan and Liker (2006) describes adopting the lean philosophy as evolving a culture that captures the tacit knowledge and turns this into standards which others can take part of. It can thus be summarized that managing knowledge is of importance in the procurement process.

### 3.1.3 Barriers in Knowledge Management

Despite the importance of managing knowledge, it exists challenges in doing so. Riege (2005) reviewed three dozen barriers of knowledge-sharing activities. In Table 3.2 potential individual and organizational barriers are presented, that originates from the review of Riege (2005). With the premise that managing knowledge is central in EEM, any potential barriers for managing knowledge can thus potentially also affect the end result. Therefore, it is of interest to be aware of potential barriers.

**Table 3.2:** Barriers for knowledge sharing (Riege, 2005)

| **Individual** | |
|---|---|
| IB1 | Lack of time to share knowledge and to identify colleagues in need of specific knowledge |
| IB2 | Sharing knowledge may risk people's job security |
| IB3 | Low awareness and realization of the benefit of possessed knowledge to others |
| IB4 | Dominance in sharing explicit over tacit knowledge |
| IB5 | Use of strong hierarchy, position-based status and formal power |
| IB6 | Insufficient knowledge capture and tolerance of past mistakes that would enhance individual and organizational learning effects |
| IB7 | Lack of social network |
| IB8 | Differences in education levels |
| IB9 | Lack of trust in people because they may misuse or take unjust credit of the knowledge |
| IB10 | Lack of trust in accuracy and credibility of knowledge |
| **Organization** | |
| OB1 | Integration of knowledge reuse into the company's goals and strategy is missing or unclear |
| OB2 | Lack of practices, leadership and managerial direction that clearly communicates the benefits and values of knowledge sharing |
| 0B3 | Shortage of formal/informal spaces for knowledge sharing |
| 0B4 | Lack of a transparent rewards and recognition systems that would motivate people to reuse more of existing knowledge |
| 0B5 | Sufficient support for sharing practices are not provided by corporate culture |
| 0B6 | Knowledge retention of highly skilled and experienced staff is not a high priority |
| 0B7 | Shortage of appropriate infrastructure supporting sharing practices |
| 0B8 | Deficiency of company resources that would provide adequate sharing opportunities |
| 0B9 | External competitiveness within business units or functional areas and between subsidiaries can be high (not-invented-here syndrome) |
| 0B10 | Flows of knowledge and communication are restricted into certain directions |

## 3.2 Lean

The lean manufacturing method that by now is well known among producing organizations around the world started back in 1927 with a publication from Ford Production System (FPS). It was later studied and perfected by Toyota in 1937 into what was the start for the lean system we see today. Lean is most often described from one of two perspectives, the philosophical or the tools/practices perspective (Shah and Ward, 2007). However, the goal of the lean method is the same no matter the perspective; minimize waste and other production disturbances (Liker, 2004).

### 3.2.1 Implementation of lean

Research has been conducted on the area of lean implementation and is commonly focused on the factors of success and failure. One of the reasons that the implementation of lean fails seems to be a too high focus on the tools of lean, one of the big mistakes many companies does according to (Morgan and Liker, 2006). Wilson (2010) explains the phenomenon of focusing on the tools of lean with an analogy of an auto-repair person who gets a wrench it could be used on, instead of first identifying a problem and after that a suiting tool. Business metrics that is not adapted to lean is also something that has been found troublesome during implementation since typical business metrics not always are in line with efforts of implementing lean principles and practices (Emiliani and Stec, 2005; Wilson, 2010). It can also affect the amount of investment on the lean implementation (Pearce et al., 2018), a potential effect of managers not completely understanding the total cost of a purchase but simply focuses on the purchase price (Emiliani and Stec, 2005). Another aspect of lean implementation is trust that drives people engagement (Yamashina, 2008; Morgan and Liker, 2006; Liker, 2004), which Pearce et al. (2018) has found to be lacking in several implementation cases. A reason for this could be that organizations can have a culture that tolerate a certain level of irresponsibility according to Wilson (2010). He continues with defining responsibility in this context as knowing about it, being able to answer for it and being able to respond to it. Instead of accountability, which it often is mixed up with, that simply means that you know about it and are able to answer for it. This can be illustrated as accountability being a subset of responsibility, meaning that accountability is contained within responsibility but not vice verse (see Figure 3.4). Irresponsibility could therefore mean that the people in the organization are not able respond, making it difficult to be engaged.


**Figure 3.4:** Illustrating the definition of accountability as a subset of responsibility

## 3.3 WCM - World Class Manufacturing

The concept World Class Manufacturing (WCM) is sprung out of lean and shares many parts with the lean philosophy (Schonberger, 2008). This thesis report will focus on the WCM version designed by Dr. Hajime Yamashina, professor emeritus at Kyoto university (Yamashina, 2008). The WCM system is today made up of eleven pillars, or focus areas, that create a temple (see Figure 3.5). One of them is the, to this report, concept of Early Equipment Management (Yamashina). The system also includes ten management areas that together with the focus areas is assessed by the VPS-team. The analogy of an ice berg is sometimes used where the focus areas make up the top of the ice berg and management areas the bottom, referring to the two parts as being the visible and invisible sides of change (Yamashina, 2008).

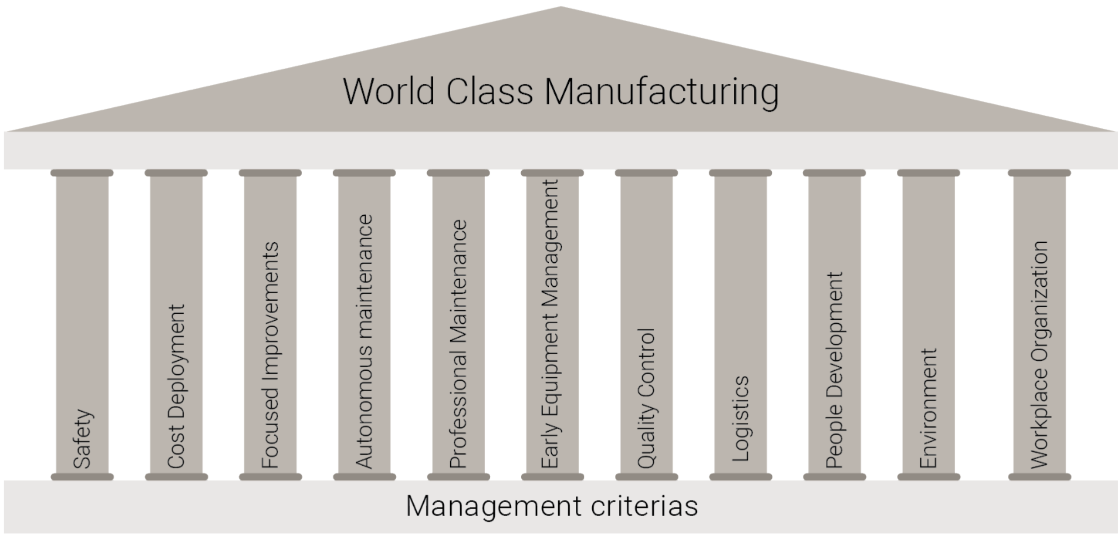


**Figure 3.5:** The temple of World Class Manufacturing that consists of eleven pillars with management criteria as foundation

### 3.3.1 Production Disturbances

Bellgran and Säfsten (2010) describes production disturbances as an undesirable disruption occurring during running production. These disturbances are unwanted and it is these disturbances that amongst other, WCM tries to reduce. Disturbances in running production can for example be; equipment breakdowns, small stops, lack of material or software errors. The production disturbances can also be regarded as being losses and wastes in production, affecting the production's performance and availability (Bellgran and Säfsten, 2010).

Increasing performance can be achieved by measuring production disturbance factors and systematically improve on these. A prerequisite for this, is that there is a common understanding and definition of what these are. Bokrantz et al. (2016) concludes that many companies are registering many production disturbances, however there are several different definitions on what production disturbances are. In the same article it was concluded that mainly the unplanned events such as "equipment failure", "failure of software" and "media error" were mutually seen as production disturbances among all the respondents. Bokrantz et al. (2016) raises the potential consequence of having divergences in the classification of production disturbances which in turn will lead to differences in how to resolve these. Therefore, the importance of having a common understanding of what factors are classified as production disturbances, is emphasized. This further motivates the delimitation of this thesis of concentrating on "equipment failure", which is a production disturbance that is mutually agreed to.

### 3.3.2 Dependability

In the Swedish Institute of Standards, dependability is expressed as a combined term for availability that in turn consists of reliability, maintainability and maintenance support (SIS, 2000). **Availability** is as mentioned above, a term summarizing reliability, maintainability and maintenance support in the Swedish Institute of Standards. The term is described as the ability for a given unit to perform specific functions during a specific time span with the premise that external maintenance resources that are needed are provided (SIS, 2000).

**Reliability** is described by (SIS, 2000) as the ability for a given unit of the production to perform a specific function, under specific circumstances and time span. It is often quantified and expressed in the terms of *Mean-Time-Between-Failures (MTBF)* or as a percentage (Gulati, 2013).

**Maintainability** is described as the probability for a given maintenance activity to be performed under given time span and circumstances with the support of given procedures and resources (SIS, 2000). By using a basic calculation model of *Mean-Time-to-Repair (MTTR)*, maintainability can be expressed by using the average time for maintenance activities to achieve full operational conditions. It is calculated by the total time of maintenance activities divided by the number of failures (Gulati, 2013).

**Maintenance Support** is the ability of an organization to provide sufficient resources needed for the maintenance organization to perform its work under a given maintenance philosophy (SIS, 2000).

## 3.4 EEM - Early Equipment Management

The process of investing in new production equipment is at the case company called EEM (Early Equipment Management) (Yamashina, 2008). The reason for investing in new production equipment can be increase of capacity, replacements or when a new product is introduced. Investing in production equipment, also called major equipment procurement, differs from equipment investments. The supplier usually has no inventory buffer, leading to longer lead-times and higher procurement cost (Yeo and Ning, 2006). To meet this challenge in product development (PD), a well developed collaboration between supplier and buyer is advocated (Hoegl and M. Wagner, 2005). Since EEM has similarities with PD and acts as an interface between production and PD (Yamashina, 2008) it could be deemed positive also for EEM. The collaboration with the exchange of knowledge and experience is illustrated in Figure 3.6.

Equipment investments is usually conducted in projects, this entails projects metrics as time and cost (Jha and Iyer, 2007). However EEM is not only about investing in equipment but rather to procure the best possible equipment by using existing knowledge and experience (Yamashina, 2008). To make sure the adequate knowledge is available for ongoing projects, several activities needs to take place outside of the project environment (Stenholm et al., 2018). Knowledge should be collected from several parts of the organization to ensure that sufficient knowledge is captured. It is by collecting all knowledge that is related to weak points in the current equipment, and taking these into consideration, that improvements in the design phase can be achieved. It is therefore important to incorporate the existing knowledge into the procurement process. This thesis will only focus on the knowledge transfer from production and maintenance organizations, together with the knowledge and experience of earlier performed projects, as described in Figure 3.6.

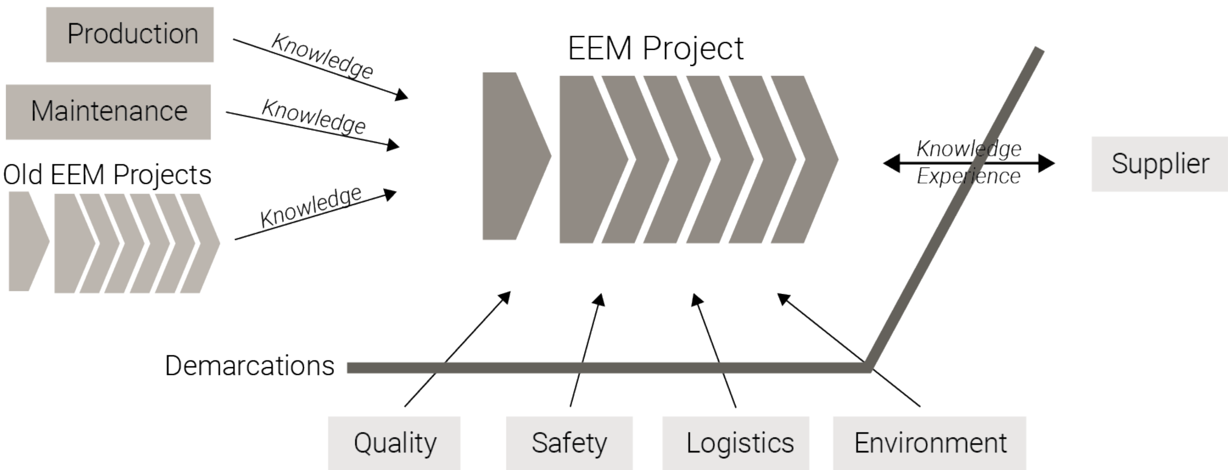


**Figure 3.6:** Schematic illustration over the information flow explored during the study

Maintenance has been found to be a major contributor for achieving equipment stability and is one of the success factors in EEM (Yamashina, 2008; Gulati, 2013). Numerous of production disturbances are often experienced; difficulties in maintainability, complex equipment, safety issues and difficulties to achieve high efficiency right after installation. It is by identifying the potential root causes for these future production disturbances already in the development phase that it is possible to eliminate these causes for future production disturbances (Bellgran and Säfsten, 2010; Axelsson et al., 2005; Gulati, 2013).

To achieve this in EEM three approaches to problem solving (see Figure 3.7) is discussed by Yamashina (2008); 1) reactive 2) preventive 3) proactive. The first approach describes an organization that is reacting to problems that already have occurred (Swanson, 2001). Preventive approach refers to an organization that knows what problems usually occurs and have routines in place to avoid these (Thun, 2006). The last approach is achieved when the organization learns from the past and implement that knowledge. By doing so, creating new innovative solutions to avoid future problems (Swanson, 2001). Both the initial and running costs will be reduced, going from a reactive approach to a proactive approach (Yamashina, 2008).

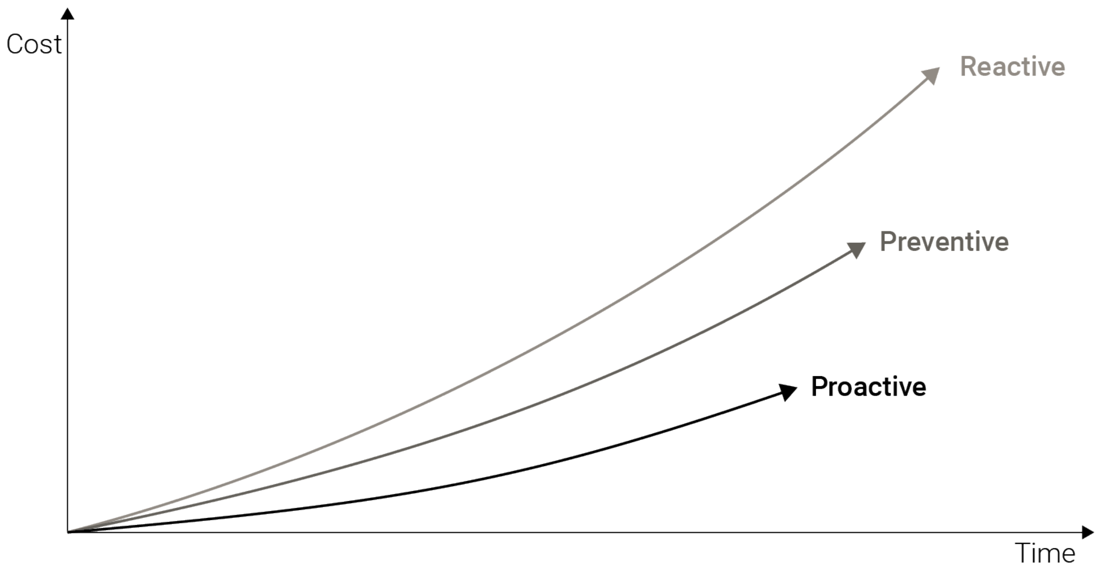


**Figure 3.7:** Illustrating the difference in cost and time between the three different approaches of problem solving discussed by (Yamashina, 2008)

### 3.4.1 Supplier Involvement

In a project of investing in new production equipment, a supplier will be involved. It is the supplier that is designing, manufacturing, installing and performs training of the personnel at delivery. There is thus a buyer-supplier relationship in a project that should be considered, with a flow of information and knowledge travelling between (see Figure 3.6). Research in buyer-supplier relationship can often be seen in the area of product development which can be comparable to the procurement process (Hoegl and M. Wagner, 2005). The effects of having a stronger buyer-supplier relationship can increase quality and decrease costs of development (Hoegl and M. Wagner, 2005; Agan et al., 2018) and improve decision making (Petersen et al., 2005). Lambert and Cooper (2000) divide different actors in a supply chain into primary and supporting members. A supplier that supply production equipment is regarded as a supporting member since supplying the equipment does not create any value, even though the equipment itself will add value (Lambert and Cooper, 2000). Petersen et al. (2005) divides the supplier responsibility into different relationship "boxes"; white box, grey box and black box. In white box relationship, the responsibility is at the lowest where the buyer consults with supplier on the design. On the contrary, the supplier responsibility is at the highest in the black box where the design is based on the buyer's performance specifications. Grey box relationship is a joint development between supplier and buyer, with intermediate supplier responsibility (Petersen et al., 2005). A supplier collaboration in a procurement process of production equipment can be regarded as a black box, where the design is made based upon the requirements that are set. Hence, the collaboration and design can be regarded as being dependent on the requirements set in the project (Axelsson et al., 2005). Also, grey-box and black-box integration is consistent with knowledge management with information/knowledge sharing and co-development efforts. This emphasizes the relevance of knowledge management also in the supplier involvement and collaboration (Agan et al., 2018).

### 3.4.2 LCC - Life Cycle Costing

The concept of Life Cycle Costing (LCC) is used in EEM. LCC can according to Woodward (1997) be defined as *"The life cycle cost of an item is the sum of all funds expended in support of the item from its conception and fabrication trough its operation to the end of its useful life"*. Or a shorter definition given by Lundgren et al. (2018); *"A model which considers an estimation of the overall life cycle cost from cradle to grave"*. Most of the expensive procurement decisions associated with engineering, uses life cycle costing models rather than only focusing on the initial procurement cost (Dhillon, 2009). A reason could be that businesses need to broaden their scope regarding procuring new production equipment to cope with the ever intensifying competition of business (Woodward, 1997). The reason for this being that the product ownership cost (defined as *logistics and operating cost* (Dhillon, 2009)) of the equipment during its entire lifespan can be ten to hundred times the acquisitions cost (Dhillon, 1989).

It exists several different models for calculating the LCC value depending on the area. This thesis will not cover in depth knowledge but rather devote a holistic perspective. Dhillon (2009) has a general model that can provide an understanding of the concept (see equation 3.1).

$$LCC = RC + NRC \tag{3.1}$$

*where*
LCC is item or system life cycle cost.
RC is recurring cost.
NRC is nonreccuring cost.

$$RC = OC + IC + SC + MC + MTC \tag{3.2}$$

*where*
OC is operating cost.
IC is inventory cost.
SC is support cost.
MC is manpower cost.
MTC is maintenance cost.

$$NRC = C_p + C_i + C_q + C_y + C_t + C_r m + C_s \tag{3.3}$$

*where*
$C_p$ is procurement cost.
$C_i$ is installation cost.
$C_q$ is qualification approval cost.
$C_y$ is research and development cost.
$C_t$ is training cost.
$C_r m$ is reliability and maintainability improvement cost.
$C_s$ is support cost.

The life cycle cost is divided as recurring- and nonrecurring cost, as described in equation 3.1 (Dhillon, 1989). Figure 3.8 illustrates when the different costs occur during the life time of the equipment.

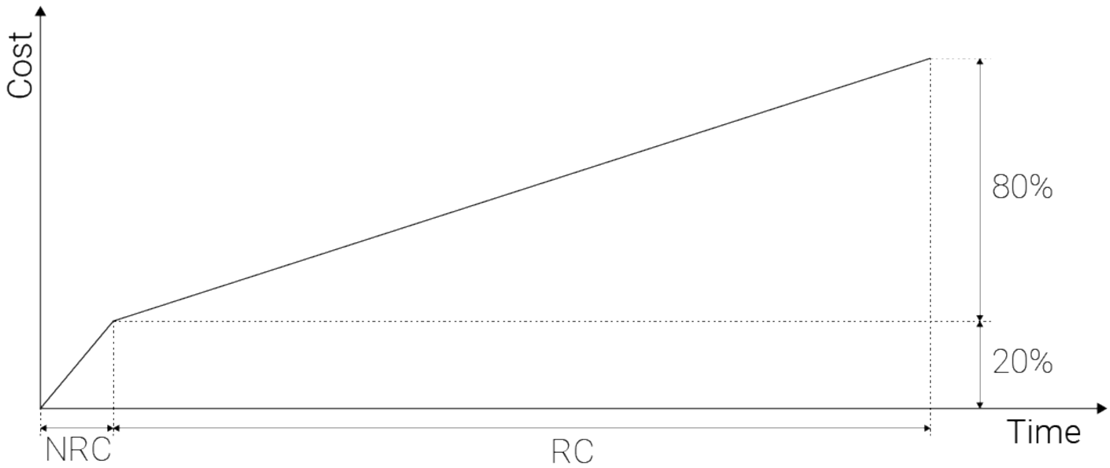


**Figure 3.8:** Illustrating when the different cost occur and the relation in terms of cumulative cost between them according to (Gulati, 2013)

### 3.4.3 PSM - Project Steering Model

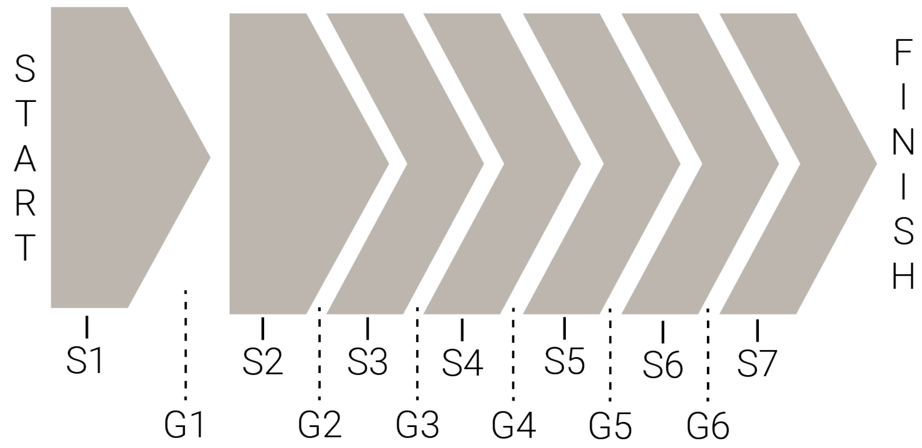


**Figure 3.9:** Schematic figure describing the PSM-model used to manage projects

The Project Steering Model (PSM) is a stage-gate model used to manage projects at the case company, where stages (marked with "S" in Figure 3.9) is followed by gates (marked with "G" in Figure 3.9) that have certain criteria that needs to be fulfilled in order for the project to proceed to the next stage.

**S1 - Investigation** refers to the stage where the primary focus is to investigate the potential of an idea. Activities includes e.g. describing the background, problem, assuring alignment to business plan and planning feasibility study activities.

***Gate 1 - FSG***. Feasibility study gate aims to approve the project scope, starting the project.

**S2 - Feasibility study** stage defines the project's applicability and benefits. Main objective is, based on the PSM project targets and end effects, to establish the Feasibility study report and project cost calculation. This will act as input to the PSM project directive. Activities that are included are e.g. performing different analysis, defining project goals, time, costs, project organization and plan development activities. *Request for Information (RFI)* is sent out to chosen suppliers.

***Gate 2 - DG***. In the development gate, the concept gets approved and the development stage can be initiated.

**S3 - Development stage**. In the development stage, activities related to design solutions are started. It is in the development stage where *Request for Quotation (RFQ)* is sent out the the suppliers.

***Gate 3 - IRG***. Investment request gate is a request for releasing money for the rest of the project.

**S4 - Final Development**. In the stage of final development design solution, the order has been placed at the supplier. The final activity is a *pre-acceptance test*. The test is performed at the supplier's site, with the intention to control that the equipment fulfills the requirements stated in the contract and that the equipment is ready for delivery.

***Gate 4 - IG***. In industrialization gate, the project gets an approval to go for full industrialization after the equipment pre-acceptance test is accepted.

**S5 - Industrialization stage**. The main activities of industrialization stage is installation and trial production. After installation of the equipment, trial production approval make sure that the equipment shall meet quality and performance contained in the contract documentation. First and second step of handover (H1, H2) to production is made.

***Gate 5 - TG***. In trimming-in gate, the aim is to approve to go for full production with hand over to production.

**S6 - Trimming-in**. During trimming-in stage, full implementation of the equipment should be achieved, with a final report written.

***Gate 6 - EG***. Final report is approved, a decision to close the project is decided and another equipment handover to production is performed.

**S7 - Follow-up**. During follow-up stage, a warranty follow-up is performed. All warranty items are handled during the warranty period to claim repairs and/or compensations that are included in the contract.

## 3.5 Framework for Process Models

Wynn and Clarkson (2018) organizes product development models into different categories, creating a framework. In this framework, all models are categorized into the dimensions *scope* and *type*. In scope, there are three levels; micro-, meso-, and macro-level. In type there are four different levels; abstract, ms/or, procedural and analytical type. These are summarized in Table 3.3. The framework aims to aid researchers in position, both existing and new models to better understand them. Since product development share characteristics with the procurement process, it can be of interest to position the models used in this thesis. In the Figure 3.10 below, the framework is presented (Wynn and Clarkson, 2018).

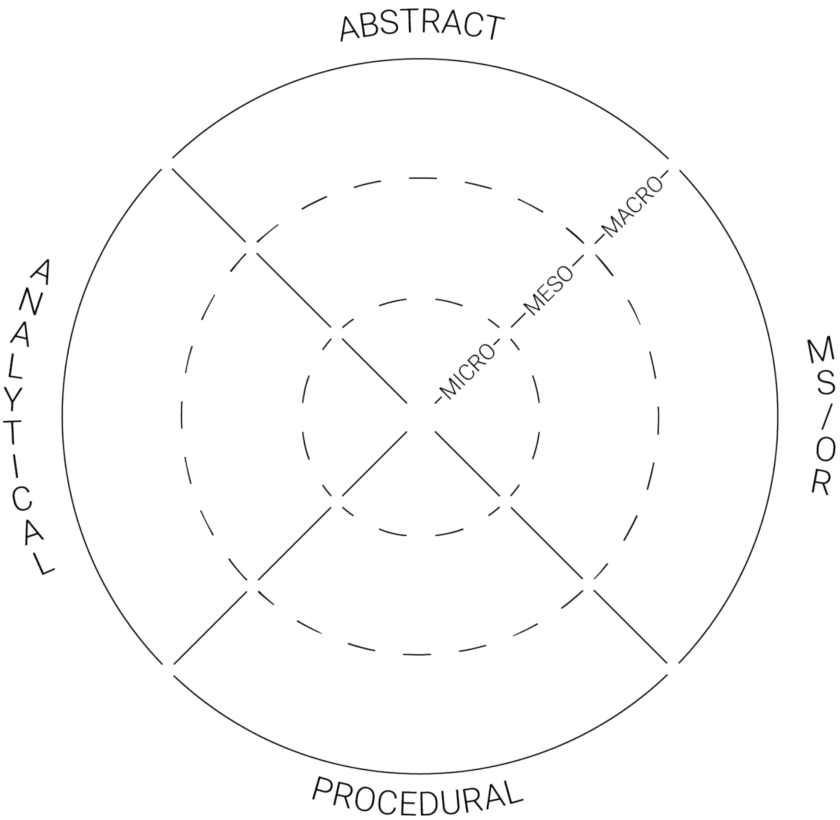


**Figure 3.10:** Illustrating the process model framework presented by (Wynn and Clarkson, 2018)

| Dimension | Category | Models in this category |
|---|---|---|
| Scope | Micro-level | Focus on individual process steps and their immediate contexts |
| | Meso-level | Focus on end-to-end flows of tasks as the design in progressed |
| | Macro-level | Focus on project structures and/or the design process in context |
| Type | Procedural | Convey recommendations of best practice |
| | Analytical | Provide ways to model specific situations for analysis/improvements/support |
| | Abstract | Convey theories and conceptual insights into the DDP |
| | MS/OR | Develop insights by mathematical/computational analysis of representative cases |

**Table 3.3:** Explaining the different dimensions of the model

### 3.5.1 Micro-level analytical models

The aim of analytical models is to guide individuals through the process by offering support to create rational models as base for decisions. The guidance is often structured to help the individual ask the right questions about history to understand and reuse past designs. Creating an environment to find improvements by reapplying knowledge at a point in time where it makes the biggest impact. An example of a model that is categorized as micro-level analytical model, is agent-based decision network (ADN) (Wynn and Clarkson, 2018). ADN focus on two things 1) decision-making by individuals using a process model and 2) the coordination between dependent activities. This focus should support the decisions made by multiple individuals on different levels in the organization, rather than data that is a common focus in collaborative design (Reza Danesh and Jin, 2001).

EEM is a process aims to bring forward information from different functions within the organization. This is performed while it also offers a systematic method to bring individuals with the right competence together, so that they can define objectives with the design from the organization information (Yamashina, 2008). Considering the broad definition of a micro-level analytical model, together with the example of ADN, several similarities can be identified with EEM. For example, both models focus on guidance of individuals making decisions based on large amount of information. Decisions that furthermore are dependent upon each other. It can therefore be argued that EEM could be classified as a micro-level analytical model as seen in Figure 3.11 .

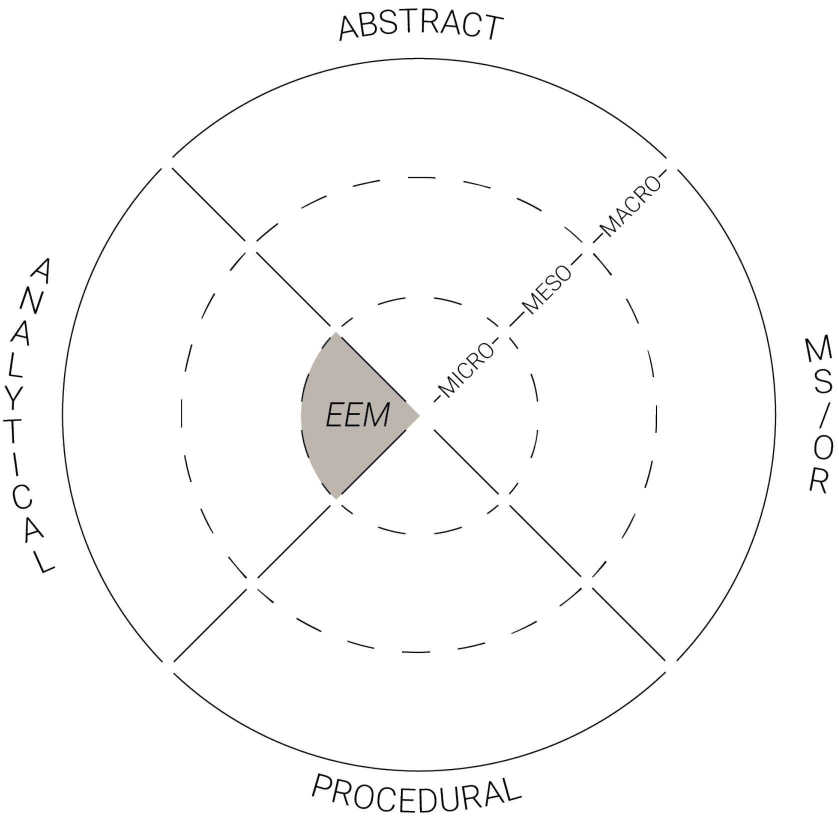


**Figure 3.11:** Showing where in the model EEM is positioned

### 3.5.2 Macro-level procedural models

The third level of dimension in scope is the macro-level. In this dimension, the procedural type can be found, and those being combined creates macro-level procedural models. In this area, models such as dynamic product development, set-based concurrent engineering and the stage-gate process can be found. The stage-gate process is described as a model that strives to prevent costly loop-backs by ensuring that a design is sufficiently mature to proceed. Wynn and Clarkson (2018) describes that one challenge with macro-level procedural models is the high level of abstraction. It does not provide enough guidance for the organization to improve on an existing situation, during implementation. Each company is unique and will create unique set of issues (Wynn and Clarkson, 2018).

As described in previous chapter 3.4.3, PSM is a stage-gate process model used at the case company. The PSM process exists of several formal stages and gates with formal documents in each, as Wynn and Clarkson (2018) describes a macro-level procedural model to have. It can thereof be argued that the PSM model can be placed in this part of the organizational framework as seen in Figure 3.12.

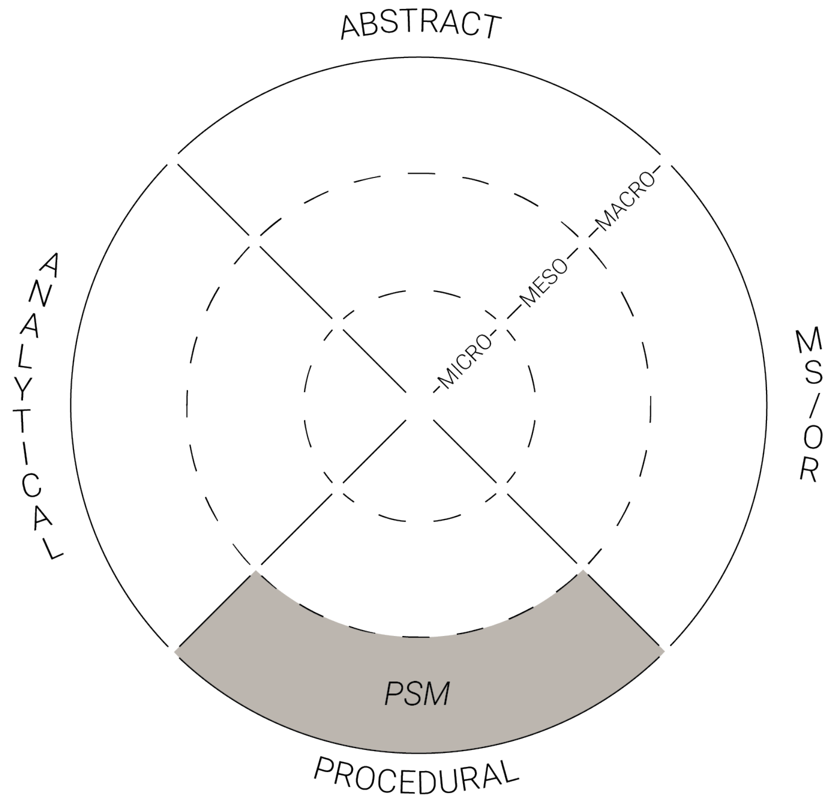


**Figure 3.12:** Showing where in the model PSM is positioned

## 3.6 Maintenance

Maintenance is central to this thesis since the objective is to study how the maintenance related production disturbances can be prevented. The Swedish Standards Institute (SIS, 2000, p.5) describes maintenance as *"the combination of technical and administrative actions, including monitoring, intended to maintain or restoring a device to such a state that it can perform a required function"*. Further on, Gulati (2013) describes maintenance as the work of keeping the condition of the production equipment so that it can achieve its intended production efficiency.

Events that disturb the intended production condition can be regarded as disturbances and losses for the production. These disturbances can be seen through for example equipment failure or reduced speed. From a maintenance perspective, these disturbances can be seen as interruptions in the production, all of which the maintenance work can affect. The activities in the maintenance work involved are both activities that prevent any failures of the equipment, but also activities that restores the condition into its original condition. How these activities are managed is set in a structured maintenance program. There are different approaches of conducting a maintenance program, but they all share the same goal of maximizing production capacity and reducing overall costs of the production (Bellgran and Säfsten, 2010).

Three major strategies of a maintenance program is presented by Gulati (2013) and also described in following section 3.6.1; Condition-based Maintenance, Preventive Maintenance, and Corrective Maintenance. All strategies co-exists, meaning that all strategies often are used simultaneously.

### 3.6.1 Maintenance Strategies

**Condition-based maintenance** (CBM), also known as Predictive maintenance, is a strategy that aims at performing maintenance activities during a predicted point when it is most cost effective. This is possible by analyzing and evaluating the condition of the equipment, by using technologies that can collect data regarding e.g., vibration, ultrasonic, pressure or flow. Hence, when using condition-based maintenance strategy, there is no preset scheduled maintenance activities compared to the other strategies. Implementing a condition-based maintenance strategy can yield in cost reductions in maintenance, downtime and an increase in production. However, it is based on needed technology to collect and analyze data to create an understanding of the current condition. This technology can require costly investments that needs to be considered (Gulati, 2013).

**Preventive maintenance or Professional maintenance** (PM) aims at preventing failures by a systemic process of performing maintenance. These inspections is systematic by calender or run-time of the equipment, where these can involve inspecting and detecting activities such as tests and measurements. These can then be followed by correcting activities such as adjustments and replacement, that aims to prevent equipment failures (Gulati, 2013). Bokrantz et al. (2016) raises the paradox regarding preventive maintenance. If carried out during production, it can be regarded as a production disturbance as it disrupts the normal operation. There is a trade-off between minimizing the risk of unplanned downtime, but at the same time cause inefficiency in production since it often requires the production to be shutdown during PM (Lundgren, 2019). Classifying it as a production disturbance would enable the organization to focus and reduce the time of preventive maintenance (Bokrantz et al., 2016). On the contrary, as described by Gulati (2013), preventive maintenance can also be seen as a strategy for reducing the risk of equipment failures. This paradox relates back to the the importance of having a common understanding of the classification of production disturbances described earlier in section 3.3.1.

**Corrective maintenance, or Reactive maintenance** is performed only after a failure has occurred and it is also known as a run-to-failure approach. With this strategy, the costs of the maintenance manpower is less but the production will experience higher fluctuations and an unpredictable production capacity compare to the other strategies (Gulati, 2013). This was a common strategy used decades ago, when systems often had excess capacity and when minimizing downtime was not a focus (Lundgren, 2019).

**Operator-Based Maintenance (OBM) or Autonomous Maintenance (AM)** is a maintenance strategy that involves operators. Since operators work with the equipment daily they therefor have first-hand insight. This gives the operators the possibility to predict and prevent potential failures. It is possible by using visual inspections, lubricating, cleaning and using human senses such as listen for abnormalities, smelling abnormal odors or feel abnormal temperatures. These activities are formulated into an autonomous maintenance program, which the operators follow. Further on, Gulati (2013) concludes that involving operators and maintenance organization into the equipment design will enable a design with high reliability and maintainability, which will be further elaborated in chapter 3.6.2

### 3.6.2 Maintenance in Early Equipment Management

The cost increases nearly exponential closer to the end of the equipment's life cycle and it is in the design stage that it is possible to prevent many of the causes for production disturbances in a cost efficient way (Bellgran and Säfsten, 2010; Gulati, 2013). Gulati (2013) is arguing for potential cost savings, based on the estimates that approximately 80% of the total life cycle costs are accumulated during the operations and maintenance stage. Despite the potential in cost savings, a study from Salonen and Tabikh (2016) showed that the awareness of the cost implied with breakdowns and maintenance costs is low among the respondents in Swedish industry. This is further strengthened by Lundgren (2019), who addresses the issue that even though the importance of maintenance has been acknowledged, industry underperforms due to underinvestments in the maintenance organization. The term *investment* is even used to emphasize that the procurement of production equipment is not only procuring and installing equipment, but instead a possibility to gain future benefits. An important challenge raised is how to quantify and therefore also justify maintenance-related investments. *Smart Maintenance* is presented as a concept for organizations to achieve production disturbance free equipment in future digital manufacturing. In order to achieve this, it will require resource investments and more focus on the linkage between maintenance and production disturbances already in the procurement process (Lundgren, 2019). Lundgren (2018) concludes several factors influencing the investment process, including; fact-based decision-support, integration and well-defined investment process. Fact-based decision-support is described as an important and challenging factor, which includes e.g. collecting data to justify cost avoidance and hence justify investing resources in the procurement process.

Salonen (2018) studied the breakdown data of eight automotive sites in Sweden to discuss the holistic view of a dependable production system, from a maintenance perspective. The study showed that 65% of the recorded breakdown data had a registered root cause of design weakness. In addition 23% of the breakdowns was caused by poor professional maintenance. Salonen (2018) concludes and further emphasizes that companies need to focus more on both the early equipment management process but also on other human factors such as skills and routines among the production staff. This would increase the dependability of the production system. The article also mentions that there is a missing area of research on how to manage the procurement and/or design of dependable production equipment (Salonen, 2018), which further highlights the research gap this thesis is covering.

## 3.7 Tools for Knowledge Transfer

In this section the formal tools used by the case company to transfer knowledge is presented and explained. Formal tools refers to tools explained by the case company in the formal process.

### 3.7.1 Emergency Work Order (EWO)

It is a template that is used when an unplanned failure has occurred and a corrective maintenance work has been set out as a response. The purpose of an EWO is to record and track all work performed by the maintenance technicians. The technician needs to define and describe the problem, perform a root-cause analysis in five steps and suggest countermeasures. Among the possible countermeasures to choose from are e.g. one-point lessons of operators, updating the PM-schedule or updating the technical specification in order to make sure that future equipment will not have these weaknesses. In the root-cause analysis, the possible choices are e.g. external influence, insufficient operator skills or design weaknesses. These EWOs are saved into the maintenance system. Updating the technical specification and choosing design weakness as a root-cause, can both be used as input to the procurement process. The template of an EWO can be found in Appendix 2.

### 3.7.2 Human Errors Root Cause Analysis (HERCA)

HERCA can be used a complementary tool for further root cause analysis, if the initiator suspect that it is potentially human-related. It is a template with a two-step process with a concluding action plan. It seek to clarify in what areas that there can possibly be any weaknesses; in knowledge, process, environment, attention/forgetfulness and attitude/behaviour. The template of a HERCA can be found in Appendix 3.

### 3.7.3 Whitebook

Whitebook is a document that summarizes the lessons learned of the project members. It is usually written after the completion of a project and can contain what was successfully accomplished during the project and recommendations for future projects. However, the mistakes are often emphasized, instead of the learning outcomes for the members of the project. This is often referred to as *"lessons learned"* and aims at describing how the organization in future projects could avoid doing the same mistake again. The goal with a whitebook is to manage the transition from individual's experience (tacit knowledge) into reusable knowledge for the organization (explicit knowledge), see chapter 3.1 for different knowledge definitions. To put it into the context of the knowledge management process described in chapter 3.1.1, a whitebook tries to *capture* and *transfer* knowledge.

### 3.7.4 IPAP

Industrial Project Assurance Plan (IPAP) is a list that is meant to work as support for project leaders to remember which tasks they need to perform throughout the project. It consist of a number of list items together with descriptions for activities collected under several different headings, with EEM being one of them. Each list item is combined with a scheme for during which PSM-phase (see chapter 3.4.3) the task needs to be performed.

### 3.7.5 Technical Specification

Technical specification (TS) is a document with 658 points of requirements. The aim with the specification is to achieve a safe, reliable and environmentally friendly facility designed in an ergonomically correct way with highest possible uptime availability and low operating costs. It forms the basis for new procurement and modification of production equipment. Any deviations from the specification must be stated in the supplier's quotation. Local deviations from and additions to the TS may occur and are then specified explicitly. The requirements covers e.g. documentation, instruction, software, training, system standards, design principles, reliability, mechanics, safety, hydraulics, pneumatic and lubrication.

### 3.7.6 Scope of Supply

In addition to the TS, the scope of supply further specify specific demands. These requirements covers e.g. media system, control system, measuring unit, washing equipment and part trace system. All knowledge and experience are processed and concentrated, creating the scope of supply. It is the scope of supply, together with TS, that forms the requirements specification of the equipment that will be delivered.

# 4
# Research Approach

*This chapter will present the research approach that was used in this thesis in order to answer the research questions.*

Three sources of data were used to conduct this thesis; semi-structured interviews, literature study and internal documents. There are two main reason behind this decision; confirmation and complementing. The basic idea is that it can be possible to verify findings from one type of data with finding derived from another one, and by doing so confirm the findings as valid. The other intention is to cover for the weaknesses of one type of data with the strengths of another one, thereby complementing each other (Small, 2011).

## 4.1 KIDSAM

Vinnova is Sweden's innovation agency and has the role of funding projects and stimulating collaboration. One of the projects funded by Vinnova is called KIDSAM which name is a Swedish acronym for *Knowledge- and information sharing in digital cooperation projects*. The KIDSAM project consists of several research studies, where this specific project acts as a pre-study for next coming research studies. The focus of the project is digital security and stability in collaboration projects.

The research project extends over several years, combining several industry companies and different functions at Chalmers University. It will derive from the overall challenges but go more in details of the specific needs for equipment procurement and the link to maintenance. It will contain requirement studies regarding knowledge transfer for wastes and losses in production and test findings through experiments with demonstrators. The outcome of this pre-study should be to capture the needs that the procurement process has on its suppliers. Needs that later on will be used as input by the KIDSAM project to create demonstrators that will be part of a complete model showing how collaboration over time should work to answers to the demands of effective collaboration where knowledge is created, shared and reused over time.

### 4.1.1 The Case Company

This study will be conducted together with Volvo Group that is Sweden's biggest company if comparing turnover (Affärer) with an annual turnover of 391 Billion SEK (Group). Volvo Group consists of the business areas Volvo Trucks, Renault trucks, Mack trucks, UD trucks, Volvo Construction Equipment, Volvo Penta and Volvo Buses. The common production organization for the truck division is called Group Truck Operations (GTO) and a subgroup of GTO is Volvo Powertrain (see Figure 4.1). The Powertrain organization is responsible for producing the powertrain for the companies different products. Consisting of, for example, engine and gearbox. Inside Volvo Powertrain, the Volvo Production System (VPS) team is found, supporting all sites in Powertrain Operations and staff functions with continuous improvements and lean principles. Support that mainly is performed by coaching in eleven competence areas. One of these focus areas is Early Equipment Management.

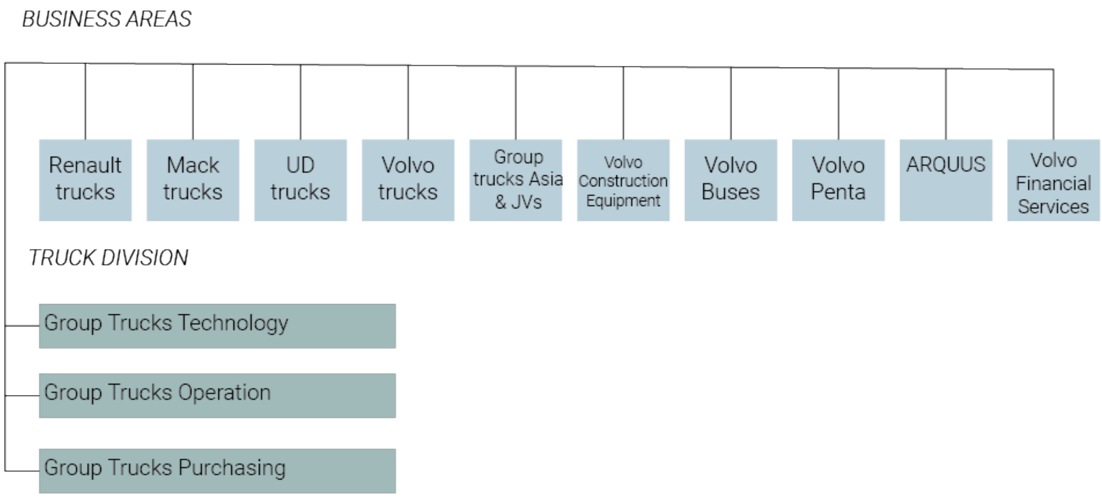


**Figure 4.1:** Illustrating the organization structure of Volvo Group

With several big production plants the case company has a great opportunity to capitalize on the new efficient production trend of industry 4.0 but also faces several big challenges with how this transition should take place. There is a strong connection between the area where this report tries to add knowledge and the tacit expertise of the case company.

## 4.2 Semi-structured Interviews

In-depth semi-structured interviews were conducted, supporting all research questions, which was the main source of data for this thesis. Interviews give an in-depth understanding of the topic that is studied (Denscombe, 2014), making it suitable as a method for understanding the practise of the process of procuring production equipment.

### 4.2.1 Structure and Planning

There are three main categories regarding how structured an interview is. Going from *structured*, *semi-structured* to *un-structured*. The major difference between a structured and semi-structured interview is that the semi-structured approach puts more emphasize on letting the interviewee develop ideas and speak freely about the topics introduced by the interview leader. This is achieved by designing open ended questions unlike a structured interview where the questions are designed much like a questionnaire i.e. closed-end questions (Denscombe, 2014).

To be sure that the information regarded as important was extracted from the interview, an interview guide was created (see Appendix A). The interview structure was based on four main themes; general role, EEM, supplier and knowledge. Among the questions in "general role", the aim was to get an introduction of the interviewee, allowing valuable background information. In the area of "EEM", questions related to the interviewee's definition, challenges and experiences of previous and current projects. The same approach was used in the area of "supplier" and "knowledge" where the focus was to elicit experiences from supplier collaborations and knowledge management. During the interviews, one of the authors asked the questions and led the interview. Meanwhile, the other author was monitoring the progress, taking notes and asking questions whenever it was needed.

### 4.2.2 Sampling

An exploratory sample does not take any particular population into consideration unlike a representative sample where the goal is to get a cross-section of a certain population. Instead the goal is to generate insights and information to enable the discovery of new ideas and theories (Denscombe, 2014). Probability sampling uses statistics rather than the experience of the researcher to make sure that the sample used represent the population intended to be studied, an approach that often is related to large surveys of quantitative data. The opposite approach is non-probability sampling where the researcher have a more active roll in choosing the participants, often used in qualitative studies and where the sample size for different reasons is not big enough to use normal distribution with good reliability (Denscombe, 2014).

Because of the small scale of the interviews and the relatively unexplored topic of the subject EEM, an exploratory sample was decided to be used together with non-probability sampling. The sampling method was also deemed positive because it gave the authors the option to decide interview participants based on the purpose of the data collection and the participants expertise (Denscombe, 2014).

For this thesis, four projects were studied at three different production plants. In Figure 4.2, the relation between projects and plants is illustrated. Two of the projects had finished and another two projects were ongoing. Project 1 was carried out at Plant A and the new equipment was installed in 2014. Later, plant C needed to invest in the same type of equipment from the same equipment supplier, producing the same components. Once again, plant A needed to increase capacity and invest in the same type of equipment from the same equipment supplier. Hence, the same type of equipment was procured from the same supplier in 3 projects, but from two different production plants. In the fourth project there is another type of equipment. Plant C needed to invest in new equipment which they had no previous experience of. However, in plant B they already have long experience which means they now intend to support plant C in this ongoing project.

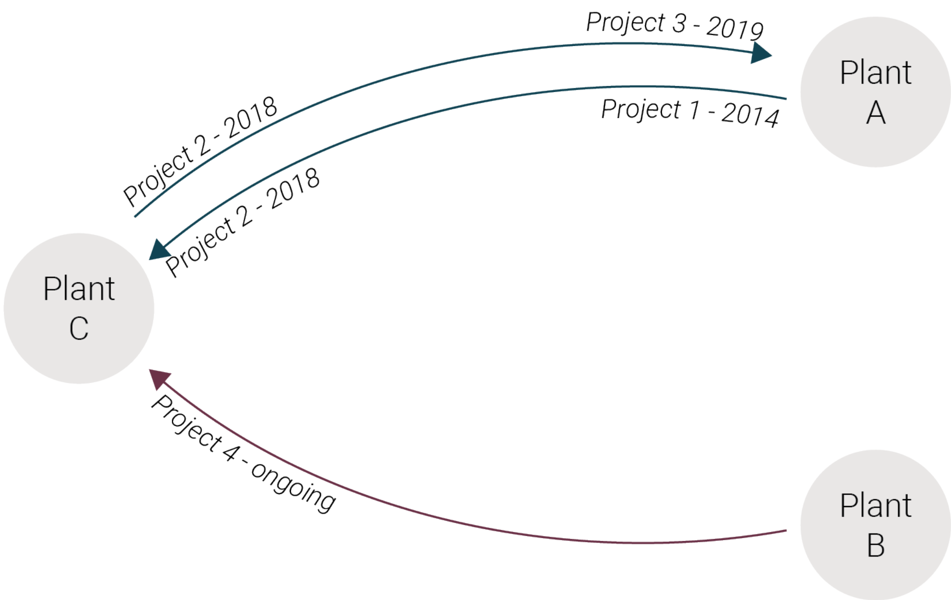


**Figure 4.2:** Showing in what order the different projects was carried out at what plants together with the flow of knowledge

The semi-structured interviews were 42 minutes long on average and were all face-to-face. In total, all 19 interviewees were interviewed once. In Table 4.2.2, the different functions with corresponding plant are shown. The choice of interviewees was based on the structure of a team in a project were all of them are central.

| Function | Plant A | Plant B | Plant C |
|---|---|---|---|
| Project Leader | I1 | | I13 & I14 |
| Process Owner | | I7 & I8 | |
| Maintenance Manager | | I9 | I15 |
| Mechanical Maintenance | I2 &I3 | I10 | I16 |
| Electric Maintenance | I4 | I11 | I17 |
| IPS/Purchasing | I5 | I12 | I18 |
| Operator | I6 | | I19 |

### 4.2.3 Data analysis

Denscombe (2014) presents five stages of data analysis for qualitative data which was followed, as seen in Figure 4.3. In the first step, the data was being prepared. All interviews were recorded after the interviewee's consent. This audio material was later transcribed into text. The text files were then imported into a qualitative data analysis software, NVivo (version 12). The second step was to initially explore the data. In the software, the transcribed audio files were coded according to the different questions asked during the interview. Reoccurring themes or issues were identified, coded and then also grouped together into categories and themes. The third step was to analyze the data. That involved comparing categories and themes from the previous step. The fourth step was to present and display the data, which involved illustrating the findings by quotes, visual models, figures and tables. The last step was validation of data. That was made by triangulating the interview data, internal documents and the liteture study (Denscombe, 2014). All of this was performed by both of the authors in parallell.

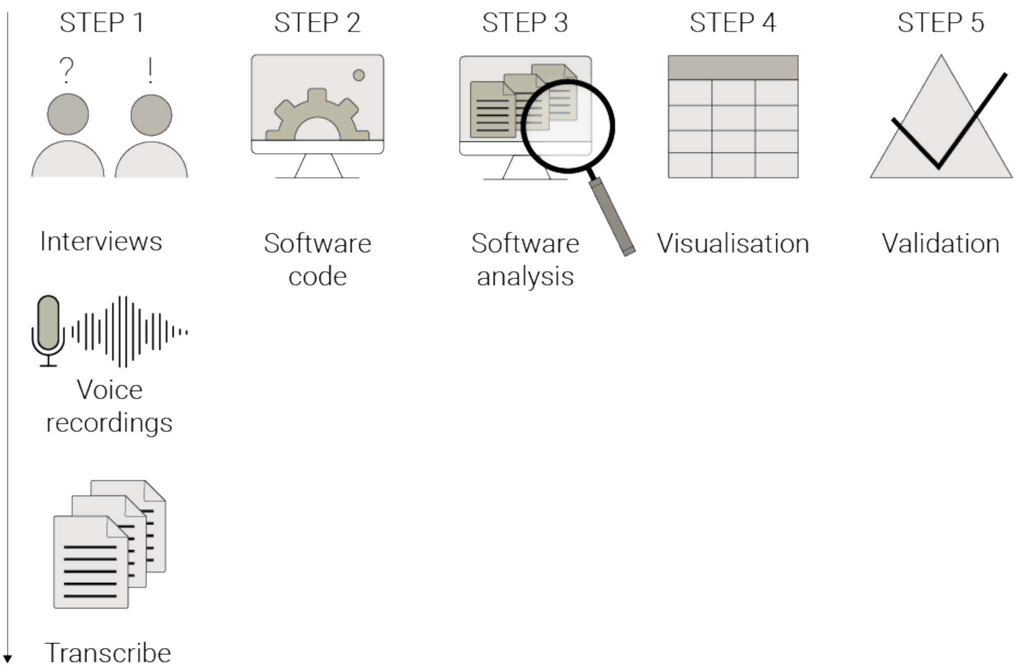


**Figure 4.3:** Illustrating the process of data analysis

## 4.3 Literature study

The structure for literature study described by Webster and Watson (2002) was used to find appropriate theory that later was analyzed. The literature study was performed to increase the authors knowledge regarding the areas covered in the report. This minimizes the authors' bias on the result of the qualitative study by taking their "pre-knowledge" into consideration (Long and Johnson, 2000). Bengtsson (2016) also points out that the planning of the study is the groundwork for its credibility, which the literature study support. The literature study covered the areas of lean, production, maintenance, knowledge management, research methods and industry 4.0.

## 4.4 Internal Documents

The third source of data used were internal documents, received from the case company. It enable to cross-reference data gathered from other sources, to strengthen the reliability. The documents was retrieved both from the intranet of the case company and by asking selected interviewees. The reason for reviewing internal documents was mainly to make sure that the interviewees had been understood correctly. It was also used to gain a wider understanding of the way knowledge is transferred internally at the company, creating a possibility to connect interviewees experiences with theory.

## 4.5 Reliability and Validity

A qualitative study, as the one conducted, face several challenges when it comes to reliability. Reason being that the criteria most often used is adapted for quantitative research. As Golafshani (2003) mentions there are three types of reliability in quantitative research 1) to what extent a measurement remains the same when given repeatedly 2) how stable that measurement is over time and 3) the similarity of a group of measurements during a given time period. Putting these criteria into the context of qualitative research and this study several dilemmas becomes apparent. Even though the environment of the interviews is perfectly recreated, a challenge in itself, the interviewee most probably will give another version of the answer. This because a set of questions only can cover a part of the interviewees behaviour, leading to a limited picture of the interviewee being created. This therefore becomes vulnerable to external factors the interviewee are subjected to between the occasions (Crocker and Algina, 1986). To meet this challenge Golafshani (2003) suggest that a big enough sample is used to cover for this phenomena. This study have a sample of 22 interviewees from three different plants in two countries, from an organization of 100,000 employees worldwide. Making this study still vulnerable for such deviations. Instead a clear audit trail as suggested by Denscombe (2014) is presented in earlier chapters. The purpose of this is to present relevant details for the reader to base a comparison on, and evaluate to what extent the findings are transferable. Being a small exploratory study it could be argued that the aim is not necessarily to prove a concept but as Stenbacka (2001) explains rather to generate an understanding. This study could then be the base for further research in the area with a bigger sample to prove the thesis presented in this study.

Another implication with qualitative research is the impact of the researcher (Denscombe, 2014). The involvement of the researcher is accepted in qualitative research because as Patton (1990) explains; *"the researcher is the instrument"*. However, it is still necessary to demonstrate credibility in the study (Golafshani, 2003). Denscombe (2014) states that there are two extreme of this spectra; on one side the researcher distance her-/himself as much as possible from normal, everyday beliefs and suspends judgment of social issues. One the other side the researcher explains from what social background and personal experience the research agenda originates. Being conducted by two students the study have the upper hand of the interviewees probably not feeling threatened nor worried for internal repercussions. On the other hand, since the authors are not being a part of the organization, the interviewees could feel restricted regarding what to disclose. This creates a problem with to what extent it is possible to reproduce this study.

One commonly used method to strengthen the validity and reliability of the study and overcome earlier mentioned challenges is triangulation (Mathison, 1988; Patton, 1990). In this study qualitative data is complemented with a literature study (see chapter 4.3) and review of internal documents (see chapter 4.4). The literature study is to some extent the base of the study. However, it also fills the purpose of making it possible to determine the fairness of the conclusions being made. To verify that the interviewees had been understood correctly internal documents mentioned during interviews was later reviewed in depth. Together these three different approaches creates a triangulation meant to give the study increased validity and reliability.

# 5

# Results

*This section presents the data collected according to the research approach presented in previous chapter, without reflections or analysis.*

## 5.1 Definition of EEM

In Table 5.1, interviewees' statements are summarized. In plant A, EEM was defined as being a structured framework for procuring equipment by using previous experience. Three of the interviewees mentions that EEM is a process where lessons learned from previous projects are to be included. All of them describes it as a structured process for procuring equipment. In plant B, EEM was defined as structured framework to get improvements in the new equipment. Also here, all of them describes it as a structured process for procuring equipment. It was also described by interviewee I10 that working with EEM was a possibility for inputs of improvements. In plant C, EEM was defined as a structured framework for procuring equipment with highest possible up-time, by involvement of different functions. The maintenance manager, interviewee I15 was the only interviewee describing it as being a process with focus on longevity with the goal of procuring the highest possible up-time and minimized downtime. The interviewee expresses a concern of the lack of understanding of the EEM philosophy among the colleagues.

**Table 5.1:** Definition of EEM

| Plant | Int. | Statements |
|---|---|---|
| A | 1 | In general, a good structured way of working in order to know what/when/how to work. |
| A | 2 | Knowing exactly what is needed to do as early as possible by including lessons learned from previous equipment. |
| A | 3 | EEM is about documents, gates, and being able to choose an equipment that meets the criteria. |
| A | 4 | Procurement of equipment. |
| A | 5 | Method in which you work in groups and use methods and tools to minimize risks in procurement and learn from previous experiences. |

| Plant | Int. | Statements |
|---|---|---|
| A | 6 | EEM is about knowing exactly what is needed to do as early as possible by including lessons learned from previous equipment. |
| B | 7 | A framework for how they should work when procuring equipment, before, during and after. |
| B | 8 | An effort to work structured in the procurement process. |
| B | 9 | EEM is standardized procurement process in order to set requirements for the supplier. |
| B | 10 | EEM is about making improvements in new equipment through white books. |
| B | 11 | A structure with a list of points to work with. |
| B | 12 | An effort to work structured with investments. |
| C | 13 | EEM is a way of working. A checklist with reminders how/when to do activities. |
| C | 14 | It is a systematic process for procuring equipment, making sure all requirements are covered. |
| C | 15 | EEM is about longevity. The meaning of the philosophy is to find out how to maintain the machine with the highest possible up-time and minimize the downtime. |
| C | 16 | It is a process that allows them to give input to the project. |
| C | 17 | EEM means setting up a workable PM process complaint with what they are used to before the machine is installed. |
| C | 18 | EEM is a structure that support their function during the procurement process. |
| C | 19 | Involving operators during the procurement process and to get the sufficient training to run the equipment. |

## 5.2 Objective of EEM

In Table 5.2, interviewees' statements are summarized. Plant A focuses on satisfying the production department, referred to as the customer, by delivering better equipment. Indicators as "reliability" and "availability" are often mentioned as measurements for better equipment. To include all the departments different requirements are mentioned as the objective of Plant C as well as delivering better equipment, the electric maintenance technician defines better equipment as having more up-time and less down-time. Plant B is instead focusing on delivering equipment without disturbances that produce in line with expectations, aspects as knowing what do to and minimizing risk is also mentioned.

Interviewee I15 states that the equipment is performing better, as a result from the invested time in making sure that the project has captured all knowledge and experience.

**Table 5.2:** Objective of EEM

| Plant | Int. | Statements |
|---|---|---|
| A | 1 | The goal is to get better equipment, not only a replacement. |
| A | 2 | The goal is to buy equipment that is reliable and available, production organization should be satisfied. |
| A | 3 | The goal is to get a better machine with 98% availability. |
| A | 4 | The goal is to be able to deliver and make the customer satisfied. |
| A | 5 | The goal is to minimize risk and buy the optimal equipment, in terms of cost over time. |
| A | 6 | The goal is to get equipment that is reliable and available, production should be satisfied. |
| B | 7 | To invest in an equipment that we will use in our production. |
| B | 8 | To get a process that is a disturbance free as possible. |
| B | 9 | To know what to do and when to do it. |
| B | 10 | To get equipment without early defects, with recommended spare parts and maintenance lists. |
| B | 11 | That the equipment should be able to produce and deliver results but also be maintainable. |
| B | 12 | To get equipment that live up to expectations and demands on time to the right price, also to minimize risk. |
| C | 13 | To get everybody's requirements. |
| C | 14 | To purchase an equipment that meets all requirement. |
| C | 15 | To make sure that the equipment is easily maintained, to achieve highest possible up-time and minimized downtime. |
| C | 16 | To have a better machine coming into the building. |
| C | 17 | More up-time and less downtime. |
| C | 18 | Making sure that purchasing organization is involved during each step rather than when it is too late. |
| C | 19 | Avoiding prior experience of less successful projects by involving production and maintenance. |

## 5.3 Challenges of EEM

In Table 5.3, interviewees' statements are summarized. All three plants find the high workload or limited amount of time challenging. Plant B find the lack of resources and competence restricting. Plant A also finds competence as a challenge, specifically how to know what competence to include into the project in order to achieve success. Individuals of plant C finds it difficult with the high workload and making other people in the organization to understand the philosophy.

Maintenance representative interviewee I15 describes one of the main challenges: *"So if you build a better house it last longer so most people have their job to do. Project managers have to be on time and under budget, that is their philosophy. But that kind of collides in the holistic view, it kind of collided with trying to make this the best machine possible."*. The interviewee describes the challenge being the campaigning, making other understanding the philosophy. The interviewee also describes the conflict between the traditional view on a project, time and budget, with the holistic view of EEM.

**Table 5.3:** Challenges of EEM

| Plant | Int. | Statements |
|---|---|---|
| A | 1 | To only buy one piece of equipment when part of the process is created to build entire lines. |
| A | 2 | Limited amount of time. |
| A | 3 | To install equipment into a producing line. |
| A | 4 | To get a good overview of large projects. |
| A | 5 | Limited amount of time and knowing what competence you need. |
| A | 6 | Limited amount of time. |
| B | 7 | The internal customer needs to know what they want in order to set the right requirements. |
| B | 8 | Limited amount of time, usually result in the usage of shortcuts. Copy-Paste solutions. |
| B | 9 | Lack of competence. |
| B | 10 | Limited amount of time and too many projects at the same time. |
| B | 11 | The challenge is to get input from maintenance into the project. The balance between the operator's and the maintenance's work environment. |
| B | 12 | Limited amount of resources and an internal resistance for standard equipment. |
| C | 13 | The biggest challenge is that its labor intensive so it becomes very busy. |
| C | 14 | The balance between using suppliers and processes that are known to the company and getting the best fit for the plant. |

| Plant | Int. | Statements |
|---|---|---|
| C | 15 | To get other people to understand the philosophy. |
| C | 16 | Being new to the process, knowing what to keep an eye on. |
| C | 17 | Co-operation is the biggest challenge. |
| C | 18 | Getting the supplier to agree on the high workload. |
| C | 19 | Making sure that the operators gets involved and trained in order to run the production after installation. |

## 5.4 Supplier Collaboration

In Table 5.4, interviewees' statements are summarized. All interviewees in all three plants experienced the supplier collaboration as good and close to optimal. The documentation in one form or another was seen as an issue among all three plants. Five of the interviewees in plant A express that documentation has been, and often is, an issue. Interviewee I2 however describes the supplier improving, after receiving feedback. Interviewee 5 expresses a concern that the case company is getting harder to find suppliers due to their rigorous requirements of documentation.

Four of the interviewees in the plant B expresses issues with the Technical Specification (TS) regarding supplier choice of specific components. One example by interviewee I7 is described where it is given in the TS that a specific supplier for control systems should be chosen. From a maintenance perspective, it is beneficial having the same supplier for control systems in all equipment. However, if the equipment supplier has no or little experience of implementing such control system from that specific supplier, it can possibly increase risks. Interviewee I10 even expresses that it sometimes would be beneficial to circumvent TS, because it only hinders the supplier collaboration. The same person also expresses that the possibilities to give input to TS is lacking.

All interviewees in plant C describes the supplier collaboration as good or close to optimal. Interviewee I15 explains that the supplier was receptive to design changes. However, it was difficult for the supplier to understand the requirements of the case company's level of documentation, an experience interviewee I18 also shares. Interviewee I13 elaborates the importance of doing all work upfront in order to reach an agreement of the scope of supply.

**Table 5.4:** Supplier Collaboration

| Plant | Int. | Statements |
|---|---|---|
| A | 1 | Good experience. Documentation is often an issue. |
| A | 2 | Good experience. Improved documentation after feedback. |
| A | 3 | Good experience. Documentation is often an issue. |

| Plant | Int. | Statements |
|---|---|---|
| A | 4 | Good collaboration. Inputs were noticed by supplier. |
| A | 5 | Good experience. Is becoming harder to find suppliers due to the company's requirements on documentation. |
| A | 6 | Good experience. Beneficial using same supplier as previous project. |
| B | 7 | Good experience. Trade-off between supplier's choice of components and TS. |
| B | 8 | Good experience with multiple project. Risks of sharing information. Trade-off between supplier's choice of components and TS. |
| B | 9 | Good experience. Trade-off between supplier's choice of components and TS. |
| B | 10 | There is no possibility to give input to TS. Trade-off between supplier's choice of components and TS. |
| B | 11 | Good experience. Optimal is to choose supplier early. |
| B | 12 | Need to support supplier with documentation. Single source vs. multiple source trade-offs. |
| C | 13 | Close to optimal collaboration. Agreement of Scope of Supply is critical. |
| C | 14 | Issue of choosing supplier, communication and format of quoting. |
| C | 15 | Supplier being receptive for design inputs. Difficult for supplier to understand requirement of documentation. |
| C | 16 | Close to optimal collaboration. Supportive. |
| C | 17 | Close to optimal collaboration except few issues. |
| C | 18 | Difficult for supplier to understand requirement of documentation. |
| C | 19 | Good experience and training. |

## 5.5 Knowledge Management used in EEM

In the following sub-chapters findings regarding how the organization is managing knowledge will be presented. Findings regarding how the tools, described in section 3.7, are used in the organization will be highlighted. Tools for knowledge transfer that was discovered during the interviews will also be presented.

**Table 5.5:** Knowledge Management

| Plant | Int. | Statements |
|---|---|---|
| A | 1 | Uses IPAP as a to-do-list to remember what and when to do important activities. Never updates it. |
| A | 2 | Contacts different people, e.g. operators and maintenance, in order to collect knowledge and experience during the project. |
| A | 3 | Uses MPAP as a to-do-list for knowing what activities to do and when these should be performed. Has performed interviews with maintenance personnel, technicians and operators to get their knowledge and experience of the current equipment. |
| A | 4 | Contacts the maintenance organization and extracts data from all emergency breakdowns in the maintenance system. These are then analyzed and concentrated into a list of improvements for the supplier. Tries to involve an influential operator to gain influence. |
| A | 5 | Shares a lot of information and knowledge with the supplier, specifically if there has been reoccurring procurements. However, feels that the case company does not shares enough information during operation to the supplier. There will be challenges in Industry 4.0 |
| A | 6 | Took own initiative to collect a list of potential improvements among the operators. Did a study visit to an outside company to benchmark and get ideas for improvements. |
| B | 7 | Whitebooks are often never written, they keep them in "their head". They are cautious of sharing all knowledge since they see themselves as knowledge leaders in industry. In project 4, operators will be invited for knowledge sharing through learn-by-doing. |
| B | 8 | Whitebooks are used primarily to develop from previous projects. The level of knowledge is low and it is difficult to find appropriate knowledge. |
| B | 9 | Whitebooks are used primarily to develop from previous projects. Difficult to capture and develop knowledge since the projects occurs so seldom and high degree of employee turnover. There has been lack of knowledge in several previous projects. All knowledge are implicit. |
| B | 10 | The level of knowledge is low. No possibility to capture new ideas for improvements into future projects. Previously, there has been a process of incorporating EWOs into the project, not anymore. |
| B | 11 | The level of knowledge in EEM has decreased past 15 years. Lack of possibility to capture new ideas for improvements into future projects. |
| B | 12 | The Technical Specification (TS) is a form of whitebook used to the eliminate risk of repeating the same mistake twice. |

| Plant | Int. | Statements |
|---|---|---|
| C | 13 | If you follow the formal process, it will make you avoid missing any knowledge needed in the project. |
| C | 14 | Reviewing EWOs, study visit at plant B with entire team and weekly meetings with experienced team members in plant B is main way sharing knowledge. |
| C | 15 | Large variation on lessons learned depending on whom writes them. EWOs and HERCAs are most important knowledge for the project. |
| C | 16 | Study visit at plant B with entire team. Not aware of any way to give feedback for future equipment. |
| C | 17 | Has experience of projects where knowledge about needs are not shared to the supplier. New ideas for improvements are shared through meetings. Weekly meetings to integrate maintenance, that has been seen successful. |
| C | 18 | Hopefully the technical group learns from past mistakes and re-writes the spec to reflect that. |
| C | 19 | Worked together with operators at plant A to gain and share knowledge. Training from supplier at delivery has improved. |

In Table 5.5, interviewees' statements are summarized. Different process tools are used as to-do-lists, in order secure that the right knowledge is brought into the project. Majority of the interviewees describes how they also performs different activities such as study visits, benchmarks and training in addition to the stated process. Involvement of operators, maintenance and technicians is seen by engaging these through interviews and the creation of a list of improvements. On the contrary, several other interviewees describes lack of knowledge in EEM and the process of capturing knowledge and experience. Level of knowledge has decreased past years and it is mentioned being difficult to find the appropriate knowledge.

**Table 5.6:** Table showing the tools used to capture and transfer knowledge

| Tool | Knowledge type | Plant | | |
|---|---|---|---|---|
| | | **A** | **B** | **C** |
| EWO | Explicit | X | X | X |
| HERCA | Explicit | | | X |
| Whitebook | Explicit | | X | X |
| IPAP | Explicit | X | | |
| TS | Explicit | | X | |
| Scope of Supply | Explicit | X | X | |
| Operators list | Explicit | X | | |
| Benchmark | Implicit | X | | X |
| Study visit | Tacit | X | X | |
| Training | Tacit | X | X | X |

Majority of the tools in Table 5.6 are used by all plants. However, the Table shows what tools the interviewees mentioned as tools used to transfer knowledge from maintenance into the project. Each tool is labeled with a specific knowledge type, depending on how the interviewees described that the tool was used.

### 5.5.1 Barriers for Knowledge Transfer

The resulting data from the interviews were analyzed using the barriers presented in section 3.2. The identified knowledge barriers can be seen in Table 5.7. Only the identified barriers are presented.

| Interviewee | Individual Barrier |
|---|---|
| I7 | IB2. Sharing knowledge may risk people's job security |
| I3 | IB3. Low awareness and realization of the benefit of possessed knowledge to others |
| I15 | IB6. Insufficient knowledge capture and tolerance of past mistakes that would enhance individual and organizational learning effects |
| I8 | IB7. Lack of social network |
| I15 | IB8. Differences in education levels |
| I7 | IB9. Lack of trust in people because they may misuse or take unjust credit of the knowledge |
| I15 | IB10. Lack of trust in accuracy and credibility of knowledge |
| **Interviewee** | **Organizational Barrier** |
| I10, I11 | OB1. Integration of knowledge reuse into the company's goals and strategy is missing or unclear |
| I9, I10, I11 | OB5. Sufficient support for sharing practices are not provided by corporate culture |
| I9 | OB6. Knowledge retention of highly skilled and experienced staff is not a high priority |
| I8, I9, I10, I11 | OB7. Shortage of appropriate infrastructure supporting sharing practices |

**Table 5.7:** Barriers for knowledge reuse (Riege, 2005)

It is described by interviewee I10 and I11 that the process of capturing and incorporating knowledge to the project is lacking. It is even mentioned that a process for knowledge reuse which previously was present, is no longer used. It can thus be related to barrier OBO7, shortage of infrastructure supporting knowledge sharing.

Interviewee I8, I9, I10 and I11 further elaborates that one of the reasons is that the knowledge level of EEM is low and has been decreasing past years, relating to the barrier OBO1, OBO5 and OBO6. Using knowledge and incorporating it into the project is seen among these interviewees as less prioritized in the organization.

Interviewee I7 described concerns about sharing knowledge with supplier or other external parties with the motivation that they might misuse or give the information to competitors, relating to barrier IB9 and IB2. However, no such concerns was found related to sharing information internally at the organization. Another knowledge barrier that existed externally but not internally in the company was IB7, described by interviewee I8. Among all interviewees, seven of them described a potential knowledge barrier that they had experienced. Among these, in total eleven different potential barrier for sharing knowledge was identified.

### 5.5.2 Whitebooks, EWO, HERCA

The EWO-process (see section 3.7.1) is described by interviewee I4 as something used by maintenance to see what problems that have occurred with earlier equipment. Interviewee I7 continues to explain that this information is then used as input to the project. It used to exist a person that had the responsibility to transfer EWO knowledge into projects according to interviewee I10, something that was deemed as positive. In Figure 5.1, it is illustrated how a breakdown failure is registered and analyzed in an EWO. If there is a possibility that the breakdown is related to human error, a HERCA can also be performed. The experience and knowledge of this breakdown is thus captured and stored into the maintenance system, acting as the repository. From this repository, it is possible to elicit and transfer all previous breakdowns, acting as knowledge for the project.

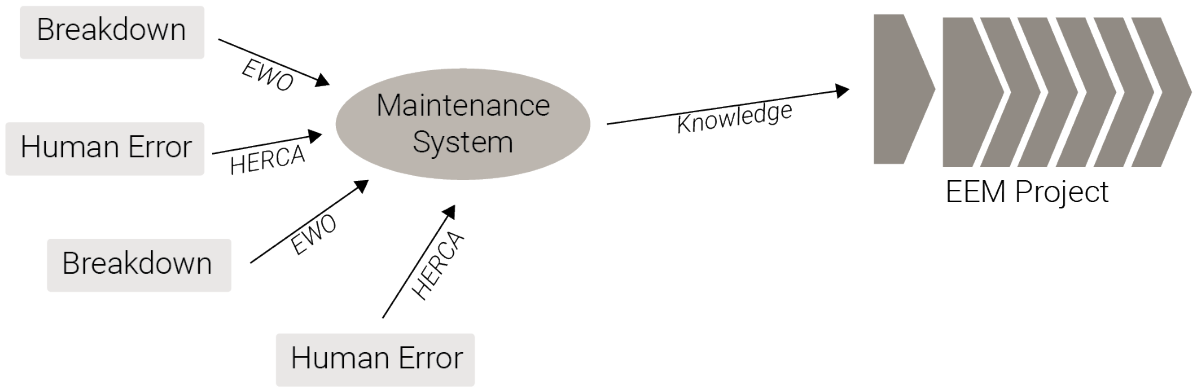


**Figure 5.1:** Using EWO as codified knowledge into the project

Interviewee I1 describes whitebooks (see section 3.7.3) as useful but not something that is read in the beginning of projects nor as something that is written systematically in the end of the interviewee's own projects. Interviewee I7 & I8 agrees that whitebooks are useful and continues by explaining that known suppliers get to take part of plant B's whitebooks. It is also described that plant B sometimes writes whitebooks before starting a project to try and find possibles risk that particular project could imply. However, interviewee I7 adds that some whitebooks are in "the back of your head" rather than actual written down.

From project 2 and 4, interviewee I15 at plant C emphasized their usage of EWO, HERCA (see chapter 3.7.2) and whitebooks as being main sources of knowledge and experience. These were manually extracted from their own maintenance system and plant A. The interviewee states that around 1000-1200 EWOs and 650-750 HERCA were manually extracted and analyzed. The output was 250 points of input that was delivered to the supplier.

### 5.5.3 IPAP

Interviewee I1 and I4 describes IPAP as good support to remember what they should do and that they regularly use it during projects, it is a form of to-do-list. However, interviewee I1 does not deem it as sufficient support for someone who is not experienced. Some examples of what an IPAP may contain are shown in Table 5.8.

**Table 5.8:** Examples of items from IPAP, addressed for EEM

| # | Description | Phase | | | | |
|---|---|---|---|---|---|---|
| | | **F** | **D** | **FD** | **I** | **T** |
| 1 | If needed, is benchmark planned? | X | X | | | |
| 2 | Has product changes been taken into consideration | X | X | X | X | |
| 3 | Process FMEA | X | X | X | X | |
| 4 | Life cycle cost (LCC) updated | X | X | | X | X |

### 5.5.4 List of Inputs from Operators

In project 1, the operators created a list of 31 points of potential improvements. Interviewee I6 states that this list was created by the operators, after an initiative from them. The list was created by placing a piece of paper on the equipment that was supposed to be exchanged, together with a written prompt telling the current operator to write down any potential improvements. The list was later discussed during a project meeting where the team members decided which improvements that was possible to implement. Examples of points from that list are presented in Table 5.9.

**Table 5.9:** Examples of Inputs from Operators

| **Improvement** | **Potential Design Improvement** | **Reason** |
|---|---|---|
| Axial adjustment of the pendants | New index and new brakes | This is a major weakness in the process, requiring a lot of maintenance as well disturbances. |
| Cover | Cover these parts with some type of plastic glass cover. | A lot of dirt around. May have more problems cleaning the chucks during AM. |

### 5.5.5 Benchmark, Study Visit, Training

In plant A the whole project benchmarked their old equipment against a similar equipment located in another collaborating production facility. This was performed by a study visit at the production facility and talking to the staff. This enabled them to capture knowledge, experience, lessons learned and inspiration. The project also visited the supplier to study the process. It was expressed by interviewee I1 as being crucial for the knowledge and information sharing.

In plant C, they did benchmarking, supplier visit and training. In project 2, they went to plant A in order to benchmark their equipment, since they had just bought a similar equipment. The project leader I13 states that they analyzed their equipment with maintenance, operators and performed a PPA (Processing Point Analysis) and embedded that into the scope of supply. The team also travelled to the supplier, analyzed the equipment and ongoing concepts but the main purpose was to build a relationship with the supplier. There was also a study visit to the supplier in project 4. In this project, also team members from the supporting plant B participated. This enabled more knowledge sharing between the two plants and the supplier.

### 5.5.6 Technical Specification (TS)

The interviewees who mentions TS which all agrees is being needed and that projects perform better with it. However, different functions define and use it differently. Interviewee I7 and I8, both process owners, defines TS as a list that maintenance use to incorporate their preferences for the new design. Maintenance representative I4, I10 and I11 agrees with the process owners but express that the link between maintenance and TS is too weak. Maintenance also express that they often need to compromise on what requirements are included and not. The interviewees working with purchasing (I5 and I12) are somewhat doubtful and discuss if the cost of TS really pays of.

**Table 5.10:** Examples of requirement from TS

| # | **TS Demand** |
|---|---|
| 1 | Drawings on hoses must be supplied according to templates (see template X). |
| 2 | It must always be possible to manually control all machine movements. |
| 3 | The cooling unit, heat exchanger and condenser must be dimensioned for and equipped with replaceable air filters. |
| 4 | Hydraulic systems with adjustable pressure must be equipped with digital pressure sensor for monitoring and be equipped with digital reading. |
| 5 | Pneumatic piping must not be located on the floor. The minimum height for piping between freestanding units must be at least x m if the distance exceeds x m. |

### 5.5.7 Scope of Supply

Project leader I13 describes how the project team tried to incorporate findings from benchmark of plant A into the scope of supply. Another project team lead by project leader I14 copied the scope of supply from plant B to get create a knowledge foundation. In both cases the scope of supply is described as a central point for discussion about potential improvements (see table 5.11 for examples of demands). Interviewee I11 has been involved during the process and sees the scope of supply as a opportunity to affect the projects outcome. However, it is expressed as being difficult to remember ideas of possible improvements discovered before the project started.

**Table 5.11:** Examples of specific demands in scope of supply in project 1

| Area | Specific Demand |
|---|---|
| Quench System | Separate tank for quench water, not integrated in machine bed |
| Measuring Unit | Sliding block has to be harder than x HRC |
| Washing | A separate safety interface with loading gantry is needed |
| Washing | The tank shall be easy to clean and the bottom of the tank shall be double angled to a drain |

# 6

# Analysis

*In this section, the data presented in previous section is analyzed using the presented theory and later discussed by the authors.*

## 6.1 A Need for a Holistic View of EEM

In order to answer RQ1 and RQ4, the view and definition of EEM will be analyzed in the following sections 6.1.1-6.1.3.

### 6.1.1 Focus on Tools

In section 3.3 two different perspective of lean is described; the philosophical- and tools approach. Out of nine teen interviewees one described EEM from the philosophical approach, talking about mindset and the challenges of trying to get other people to understand the philosophy (see I15 in Figure 6.1 ). The remaining eighteen interviewees described different tools used and how EEM gave them structure and/or a way of working. A too big focus on the tools of lean is defined as a factor for non successful implementations of lean (Morgan and Liker, 2006; Wilson, 2010). Since EEM is a part of WCM that is founded from lean principles, it could be deemed valid to use findings from lean implementation also on the implementation of EEM. If so, the lack of interviewees expressing the philosophy approach could be signs of an implementation of EEM with a too big focus on the tools of EEM.

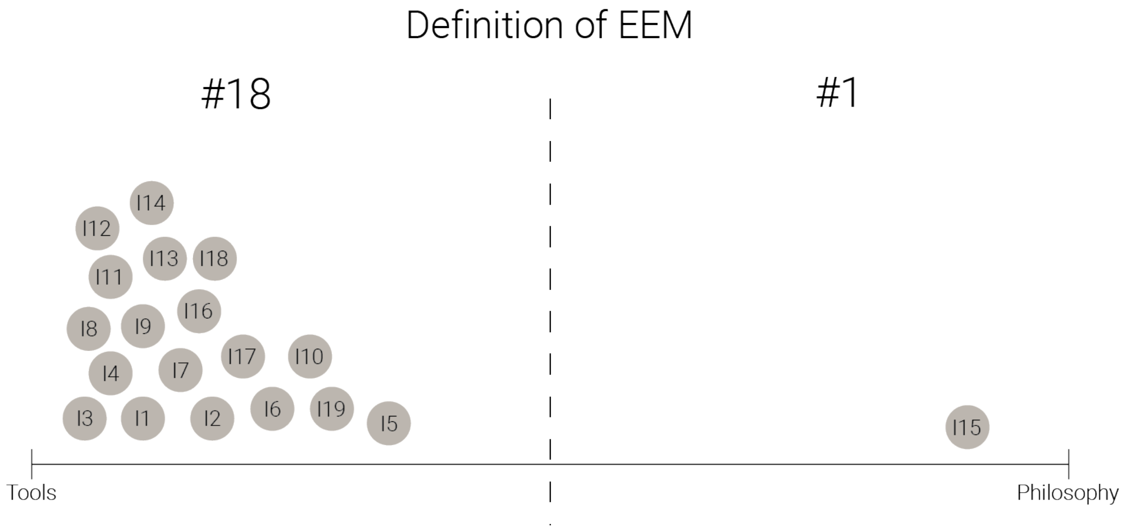


**Figure 6.1:** Showing the distribution of interviewees defining EEM with tools or philosophy

### 6.1.2 EEM Defined as PSM

When discussing how the interviewees worked with knowledge in EEM it was common that they defined what they did and when they did it accordingly to the stages and gates of the PSM-structure (see section 3.4.3), defining EEM as PSM. When continuing by asking *"How do you define EEM?"* Twelve interviewees defined the EEM process as a structured way of working, a framework and/or a standardized process (see table 5.1). Answers regarding the objective of EEM differs to some degree depending on the role of the interviewee (see table 5.2) but common denominators were project typical objectives such as being on time and on budget. Instead of perceiving EEM as a philosophy where the focus should lie on collecting all knowledge and experience in order to prevent future production disturbances, the focus instead is on the phases and gates. Hence, the perception of what EEM is, coincide with how a typical macro-level procedural model is defined (Wynn and Clarkson, 2018) and that interviewees have a difficult time to separate the model of PSM from EEM. This misalignment between the organization's classification of EEM and the theoretical classification of EEM can be related to the framework presented by Wynn and Clarkson (2018). The organization considers EEM as being a macro-level procedural model, a stage-gate model with focus on being structured with formal documents. Meanwhile, it can be argued that EEM is in fact a micro-level analytical model. An abstraction of the misalignment is presented in Figure 6.2.

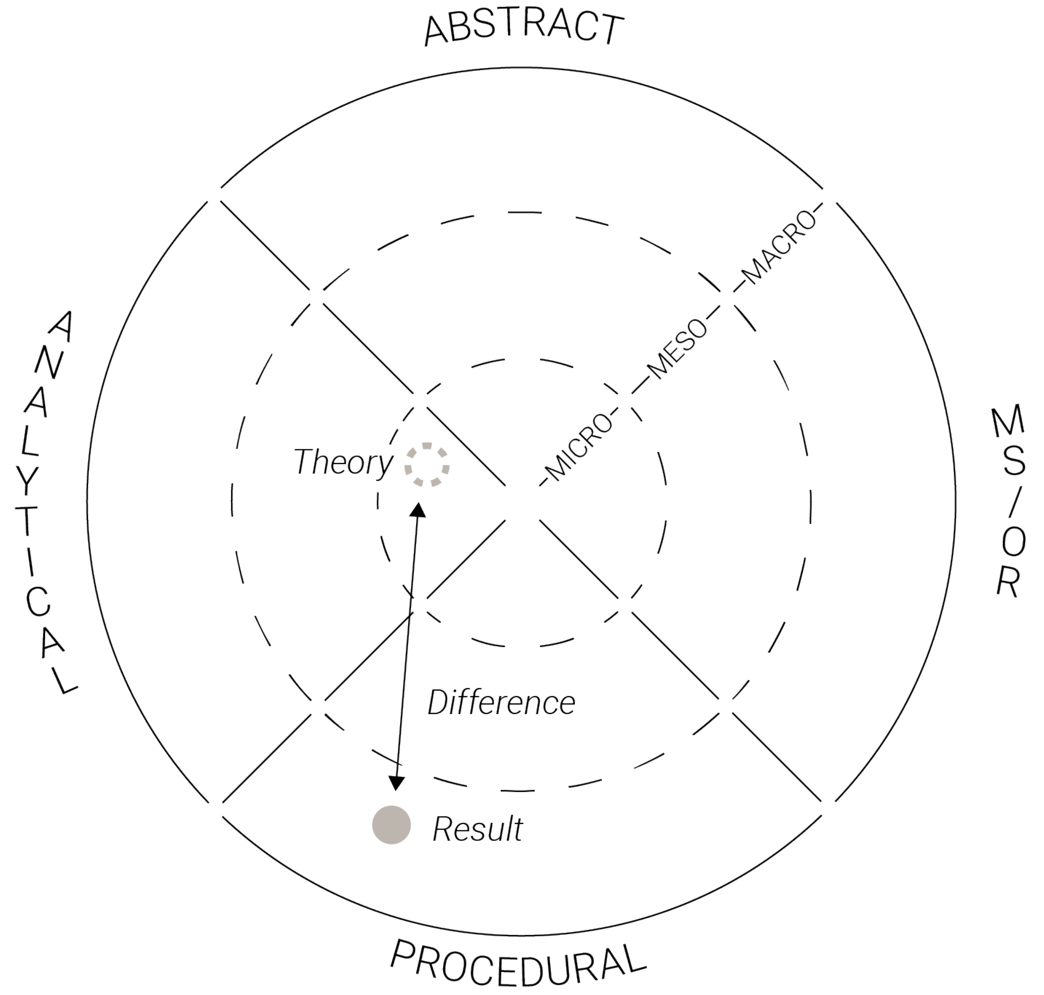


**Figure 6.2:** Illustrating where in the process model the common view of the EEM is mapped together with where the theory of EEM is mapped

A misalignment that could be a result of limit amount of information towards employees from middle management, due to limit amount of time. As interviewee 15 explains middle managements situation; "If I have to choose between getting production to run, finding the right parts and making sure the right parts goes out and explaining to my team of employees the good effects of EEM... I am going to shrink back from that and I am going to do more for the daily grind". A statement that shows a lack of management commitment, which is one factor for failure according to Wilson (2010); Pearce et al. (2018), because they are being forced to choose between EEM and fulfilling their other work duties. A dilemma that could show traces of old business metrics interfering with the implementation of lean that Emiliani and Stec (2005) mentions as troublesome for successful implementation. Not having business metrics in line could make it challenging to justifying investments, both in terms of money but also in the terms of time from middle management, since it is difficult to see the direct effects of a change towards an investment mindset (Lundgren, 2019). Resulting in a situation that interviewee I15 continues to explain; "The people on the floor, the people who truly need to buy in to this system they get the stomp speech or they get all the information from of a podium, as it cripple down through people who already has to much to do".

### 6.1.3 Broadening the View of EEM

Front-loading is described as an important factor among several interviewees and strengthen in literature. The purpose is to reduce the risk of costly late design changes by making more of the design changes early (Yamashina, 2008; Gulati, 2013; Bellgran and Säfsten, 2010), hence front-loading the project. However, the front-loading concept covers only the time of the project which includes the nonrecurring cost and not the recurring costs during operation. The front-loading concept also relates to the previous analysis that the procurement process seems to be regarded more as a project, than a possibility for an investment. Taken into account that a majority of the life cycle costs of an equipment occurs during operation and recurring costs, the front-loading concept can be argued to be too narrowly applied.

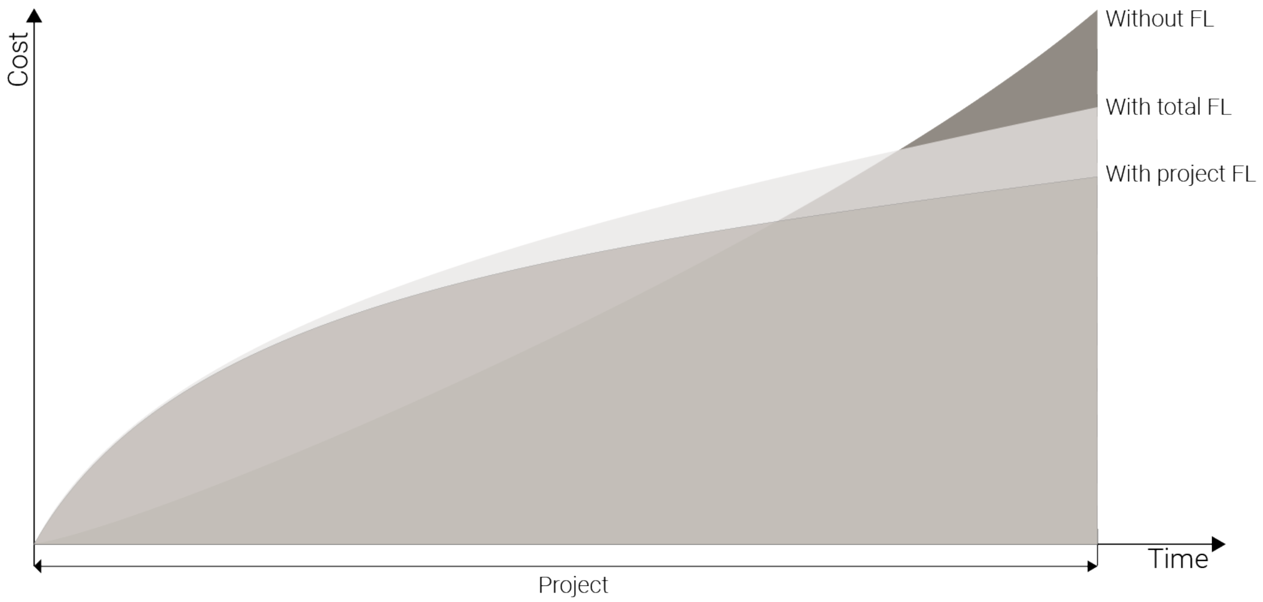


**Figure 6.3:** Illustrating the difference between three types of front loading from a project perspective

Hence, if the organization view the investment process as being a short-term project, the front-loading concept will only cover this (marked as "project front loading" in Figure 6.3), missing out on majority of the equipment life cycle. Broadening the view and applying the front-loading concept on the entire life cycle would imply investing more resources during the procurement phase to avoid future costs during the operation phase (marked as "total front loading" in Figure 6.4), thereof front-loading the entire equipment life cycle.

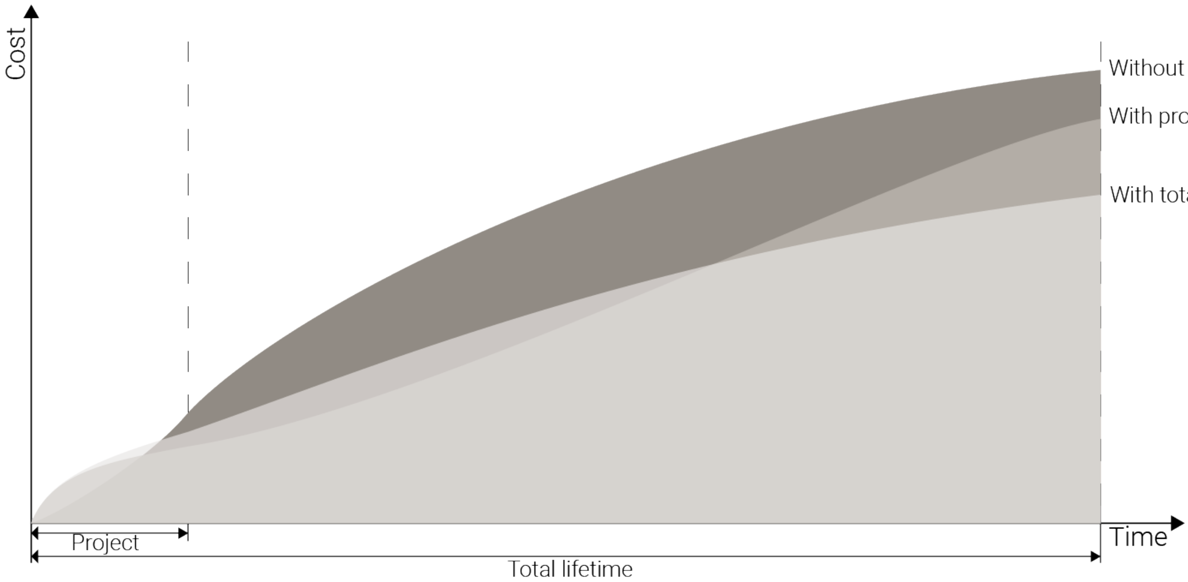


**Figure 6.4:** Illustrating the difference between three types of front loading from a total lifetime perspective

### 6.1.4 Quantification and Justification

Broadening the view of EEM would however require justification and quantification of the potential future cost savings in the project, in order to argue potential increase in investment resources. One key issue is that a cost is clear and well-defined, contrary to the effects from cost avoidance that is deferred. This makes it more difficult to argue for what an investment could yield in upfront (Lundgren, 2019). An interviewee even specifically describes the challenge of justifying different concept ideas, due to the implications on the project costs. The potential cost savings lacked quantification, which made it difficult to argue for. A potential proposal would be to perform calculations of cost avoidance, meaning that calculations would show the avoided future costs when investing in a specific feature, e.g. a benefit-cost ratio. The interviewee that described the challenge of justifying different ideas, described an example of an idea to implement vibration analysis equipment in order to monitor critical components, which was decided not to be proceeded with due to increased project costs. In this case, there was no quantification or estimation of the potential cost avoidance of implementing the possibility to monitor vibrations, which could have been used for justification. However, any calculations made with the intention of estimating future costs are just estimations, which is important to keep in mind. Another proposal would be to perform retroactive calculations to validate past estimations, which in turn would provide new experience and knowledge for future estimations. According to the formal process, projects should perform LCC calculations retroactive, implying that the organization in fact should do this. However, it is revealed that retroactive LCC calculations are never actually performed. The benefits of performing these accordingly to the process does not seem to be seen, further strengthening the depiction of a need for a more holistic view of EEM. Quantifying, and thus justifying, the effects of maintenance-related investments would be the starting point for a deeper understanding of the philosophy of EEM.

## 6.2 Knowledge Management Analysis

In order to answer RQ2 and RQ4, the way knowledge is transferred and how it is transferred is analyzed in the following sections 6.2.1-6.2.2.

### 6.2.1 Transferring Tacit Knowledge

According to table 5.6 all plants acknowledged EWO and the maintenance system to be sources of experience and knowledge that are incorporated into the project. Interviewees had positive experience from using tools like EWO earlier described to transfer knowledge from maintenance into the project. However these tools can only transfer part of the knowledge possessed by the organization, namely explicit knowledge. Today the tacit knowledge possessed by the employees in the organization is transferred by study visits, benchmarking of different sites and training (see table 5.6). Some of these activities are not suggested in the formal process but rather a result of the project team's own initiative. Interviewees who had conducted any of these activities deemed it as highly important for the success of the project. Not having formal processes for tacit knowledge transfer could be seen as the organization trusting the team with realizing which activities that facilitate tacit knowledge transfer and the benefits of using it.

It could be argued that such trust makes the success of the project vulnerable for personal deviations among the project members. In the long-term affecting the stability of the quality delivered by the organizations project portfolio. However, according to Pearce et al. (2018) trusting the people of the organization with responsibility is important to achieve a successful lean implementation. Something that will lead to people engagement, another success factor according to (Yamashina, 2008; Liker, 2004; Morgan and Liker, 2006). It was seen that interviewees experience trust in each other and that they share knowledge. Interviewee I7 states that plant C representatives have been visiting plant B and that operators will be invited again for tacit knowledge transfer. A perception that is strengthened by plant C representative (I13, I14 & I16) who describes the visit as positive and a possibility for knowledge transfer. The fact that employees in the organization trust each other enough to share knowledge should be deemed as positive since lack of trust is a common knowledge barrier (IB9 described it Table 3.2). The study visits and training occasions that have been organized on the project teams own initiative could also show signs of a established social network. Interviewee I19 explains that; *"I can send a email to [plant A operator] if I have any questions, or contact him directly on social media"*, after attending a training session at plant A. The same experience of the ability of using social network within the organization to share knowledge is described by representatives from plant A. Interviewee I4 also describes how there has been a direct contact with a technical representative from the supplier; *"I usually get an answer within an hour"*. Showing that the organization also has successfully overcome the knowledge barrier related to lacking social network in some plants (IB7 in Table 3.2).

This makes it interesting to evaluate if there exist a trade-off project quality and trust among the organization's employees. Verifying that all project team members work in a standardized way with tacit knowledge transfer could ensure a higher average project quality level (see Figure 6.5). On the other hand, implementing a too stiff framework might affect how trusted the project members feel and how personally engaged they are in projects.

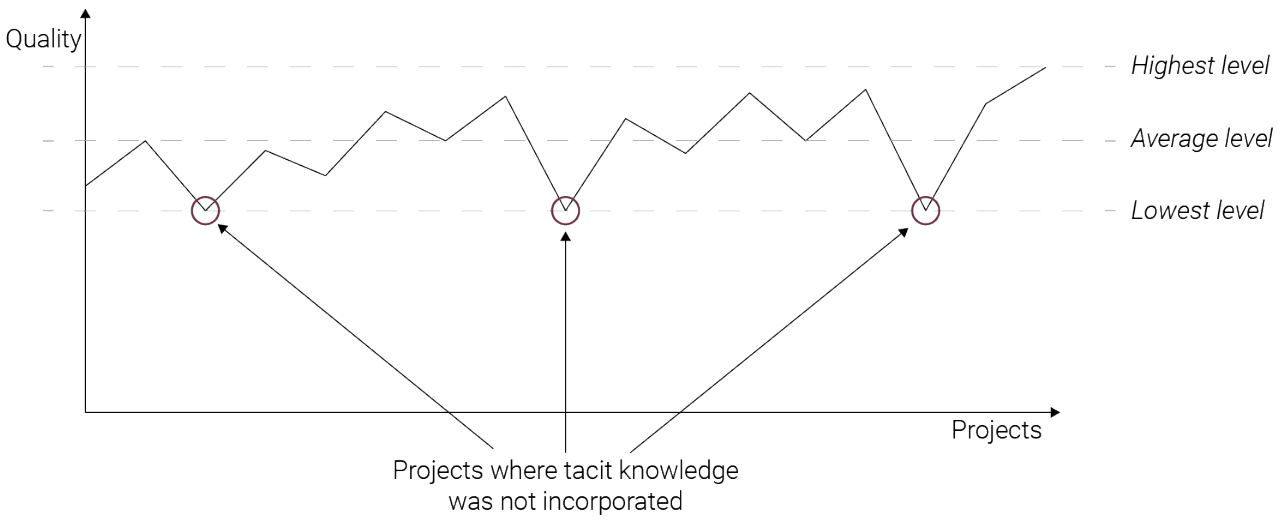


**Figure 6.5:** Illustrating the possibility of how projects not incorporating tacit knowledge lower the average quality of the organization project portfolio

A compromise to standardize the transfer of tacit knowledge could be to capture the implicit part of the it and making it explicit, an example of this is *engineering check sheet* (Bergsjö et al., 2018). The tool of the engineering check sheet is reflected in the WCM methodology as *design review checklist* (Yamashina, 2008). The interviewees confirm that IPAP is used as a similar tool. Looking closer at an example of IPAP (see Table 5.8) the description given is what is referred to as *"know-what"* by Stenholm et al. (2018) in ECS examples (see Table 3.1). The two other types of knowledge included in a ECS knowledge element, *"know-why"* and *"know-how"*, is not covered in the IPAP. Expanding the IPAP to include a complete knowledge element, as seen in ECS, could be deemed as positive if looking at the result of ECS implementation by (Stenholm et al., 2018). The added dimensions could enable a higher level of implicit knowledge transfer within the organizaiton, without substantially increasing the amount of standardization and thus risking people engagement. A suggested proposal to extend the current IPAP is presented in Table 6.1.

**Table 6.1:** A suggested example of extending the IPAP

| Know-what | Know-why | Know-how |
|---|---|---|
| Process FMEA | Identifying potential risks in process. Possibility to do early cost-efficient design changes. | Using the template and instructions found on EEM home page. |

### 6.2.2 Repository for EEM Knowledge and Projects

Tools such as EWO and HERCA are used when there has been an unplanned equipment breakdown, capturing and making the knowledge explicit based on reactive activities. These are stored in the maintenance system, which acts as a repository of explicit knowledge and experience. These are used in the projects as input for improvements, which is in line with the philosophy of EEM (Yamashina, 2008). The usage of this explicit knowledge and experiences in the projects will mitigate the weak points that has been historically resulting in failures. However, what if there are any improvements that could increase dependability that is not related to an equipment failure and hence cannot be captured in an EWO or HERCA? Studying the template of an EWO, there is a possibility for which it can be chosen that the specific EWO should be considered in future projects by stating the root cause as a design weakness. In contrast, two interviewees argues that it is in fact not possible to document any future ideas of improvements. Another interviewee even states they have been told to avoid stating the root cause as a design weakness. This implies that the awareness that the possibility actually exists, seems to be limited among some. However, one issue still remain, which is that an EWO is capturing the experience and knowledge of a reactive activity. If a person has an idea for improvement that does not relate to a specific equipment failure, there is no repository where this could be captured and stored. It is described by several authors (Bellgran and Säfsten, 2010; Axelsson et al., 2005; Yamashina, 2008; Gulati, 2013) the importance of identifying *potential future* root causes for future production disturbances. This relates to Yamashina (2008), who describes the goal of going from a reactive to a preventive and proactive approach. Handling issues related to experienced equipment failures is to use a reactive approach. Having a preventive and proactive approach would instead imply to capture and use knowledge that could prevent any potential equipment failures in future. Given also that interviewees experienced knowledge losses due to high employee turnover rate and that an equipment is in operation for at least a decade, it is of importance to systematically capture the equipment specific knowledge and experience. It could be concluded that the focus should not only be to mitigate current root causes for production losses, but to also capture and incorporate potential future improvements based on experience systematically captured over the lifetime of the equipment.

Further on, there are concerns raised at plant B regarding the level of knowledge in EEM. It is described that the low frequency of projects makes it difficult to accumulate and maintain knowledge about EEM. In addition, it is stated that it is difficult to know where to find competence when it is needed. It was also identified as organizational barriers in section 5.7. On the contrary, it is not mentioned as an issue among the other plants which raises two conclusions. Firstly, there are variations in knowledge among the plants. Secondly, there is no systematic method to capture and transfer knowledge in order increase the level of knowledge at each plant and decrease the variations among the plants. This could be achieved by a knowledge repository for projects, locally and globally, acting as a knowledge organization (see Figure 6.6). It could consist of people dedicated to EEM, with the goal of accumulating and transferring the knowledge between plants. A responsibility of knowledge retention would be given, meaning that the knowledge would be managed, updated and thereof also potentially increasing the knowledge reuse. This knowledge organization would be the source of knowledge and experience for all ongoing projects globally. This would increase the knowledge of EEM but also increase the inter-plant knowledge transfer.

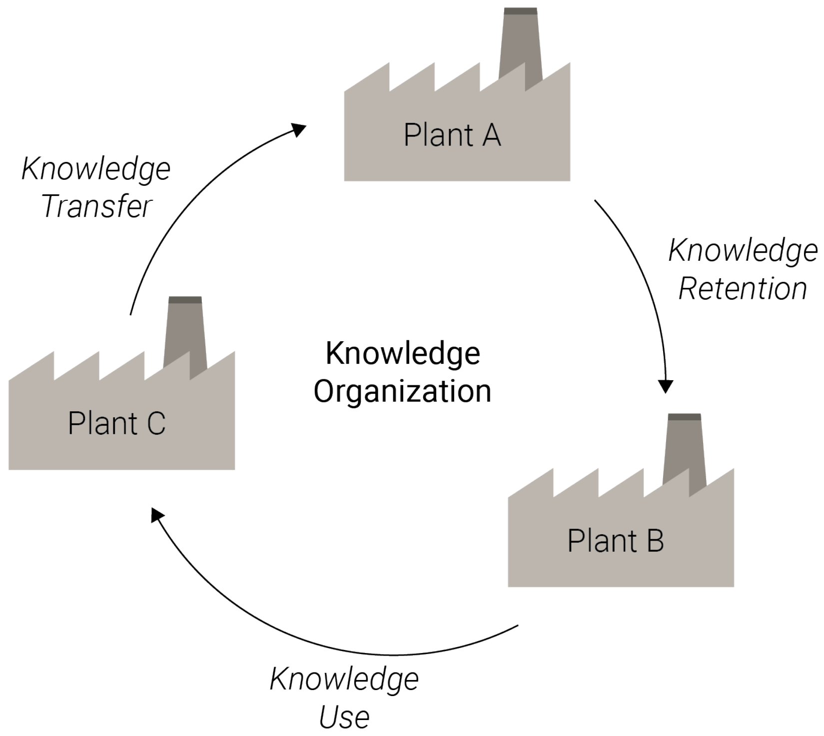


**Figure 6.6:** Illustrating the idea of a locally and globally knowledge repository

## 6.3 Supplier collaboration

Difficulties in the collaboration with supplier is described by the six of the interviewees. The difficulties described are the structure and content of the documentation that the case company requires from the supplier. Interviewee I12 even argues that "I definitely would like to share 3D-data on product, process and equipment in both directions... I would like them to work directly in our systems, with the documentation". Maintenance representative I2 exemplify a conflict when maintenance needed information and knowledge about a specific component in order to plan their professional maintenance plan, "I want to be able to repair this, I cannot just scrap it". The supplier did not want to share the knowledge and information about the specific component, since that was their know-how. It is evident that the information and knowledge sharing through documentation between the supplier and the case company is hindering the collaboration. This seem to affect the quality of maintenance's work in the project, in this case disturbing their work to plan an optimal professional maintenance plan, thus hindering the possibility to prevent future production disturbances. Not only does it seem to affect the prevention of future production disturbances, but purchasing representative I5 even argues that is becoming harder to find suppliers due to the case company's requirements on documentation and maintenance requirements.

On the contrary, the collaboration and design of the production equipment is based on upon the requirements that are set, hence these are critical for the project's success (Axelsson et al., 2005). The level of supplier responsibility in projects is at the highest, relating to Petersen et al. (2005), where the design is purely based on the buyer's requirements. Therefore it is arguable to have the level of requirements on documentation and technical specifications in order to make sure that the equipment is meeting their needs, even with the interviewees experienced difficulties. Requiring a higher level of documentation and specifications from the supplier should increase the chances for the company to receive an equipment meeting all their needs. But this seem instead to affect the ease of collaboration and thus potentially also affect the end result negatively.

There seems therefor to be a trade-off between the level of requirements on documentation and specifications, and ease of collaboration. Therefor, it seems to be a need for an improved collaboration where exchange of information and knowledge through documentation is managed with more efficiently. This would disrupt the trade-off and enable a more efficient supplier-collaboration with higher level of details in the specifications and documentations, resulting in improved equipment.

# 7
# Conclusion

*In this chapter, the data and analysis are synthesized to answer the research questions. Secondly, the contribution to research and industry will be presented. Lastly, recommendations to the case company are presented.*

## 7.1 Synthesis

### 7.1.1 RQ1. Are there any differences and similarities between theory and how project members defines the procurement of production equipment process, if so, what are these?

The participants in the study defined EEM as a structured method of procuring equipment, with clear stages, gates and documents to pass. The process seems to be solid and well defined, similar what theory describes. However, it was seen that the holistic view of capturing and transferring knowledge in order to eliminate all potential root causes for future production disturbances, was not fully expressed. EEM was defined more as a stage-gate model, with high focus on tools, and front-loading seen from a project perspective instead from a life cycle perspective.

### 7.1.2 RQ2. How is knowledge transferred from maintenance into the process in order to prevent future production disturbances?

In the formal procurement process, several sources of captured knowledge from maintenance is used. Tacit and implicit knowledge were also transferred by including maintenance and operator representatives, visits to the supplier and other plants for benchmarking and building relationships. A high level of trust was seen among the interviewees during inter-plant knowledge transfer, with several activities based on their own initiatives.

### 7.1.3 RQ3. Does the supplier collaboration affect the knowledge transfer in the project and if so, how?

Overall, all interviewees describes their experiences as positive. However, difficulties in knowledge sharing through the required documentation is mentioned by several of the interviewees. A higher level of details in the requirements should result in improved equipment but is on contrary expressed as demanding for the supplier, affecting the knowledge transfer.

### 7.1.4 RQ4. What possible improvements can be identified to the knowledge capture and transfer in the procurement of production equipment process?

The main focus of this thesis have been to explore how knowledge is transferred from maintenance and production into the procurement of production equipment process. However, after analyzing the current state, some recommendations of possible improvements have also unfold, and will be presented here as recommended improvements for the case company.

**Increase the lean philosophy focus**
A stable process for the usage of tools related to EEM is found. However, it is seen in theory that a balance between the understanding for tools and philosophy is favourable.

**Make a clear distinction between PSM and EEM**
The interviewees were comfortable using the PSM process in isolation. However, when it was used together with EEM, people was noticeable confused about the differences and how they should complement each other. There is no problem with PSM found but it could be positive for the people trying to educate the organization in EEM to showcase how they complement each other in a clearer way.

**Broaden the view of EEM**
Similar to earlier mentioned recommendations, the time span of EEM is often mixed up with the one of PSM. A model for conducting projects have a time span of the project in mind, EEM is about the entire life cycle of the equipment procured. Clarifying that the total life cycle cost of the equipment is more important than the cost of the project could improve the outcome of EEM.

**Start to quantify the benefits of EEM**
In order to justify a holistic view of EEM, the benefits needs to be quantified. Quantifying potential benefits by analyzing the cost avoidance, could support increased resource investments in projects, resulting in reduced production losses in future. In addition, retroactive LCC calculations is recommended to be performed according to the current process. This would validate past estimations and support future estimations.

**Incorporate know-why and know-how into the IPAP**
Research has shown that knowledge can be transferred through the use of check sheets, which seems to become more effective if it not only consists of know-what but also know-why and

know-how. IPAP was found to be appreciated and used, where it today consists of know-what statements from earlier projects. Introducing know-why and know-how into a document that already is used could improve knowledge transfer with a lower grade of interference to the daily work, compared to a brand new routine.

**Introduce a central knowledge repository for EEM**
Capturing knowledge and experience from reactive activities are currently performed systematically. Following the philosophy of EEM, it is recommended to further focus on the preventive and proactive approach. There is however no current systematic method to capture these potential improvements during the lifetime of the equipment. In addition, the knowledge level of EEM was expressed as being low and decreasing. Therefor, a recommendation is to create a systematic method to capture and store knowledge that is related to specific equipment, but also to increase transfer of project related knowledge between plants.

**Improved management of documentation and requirements between the case company and supplier**
The end results from a procurement process depends on the requirements from that are defined towards the supplier. The supplier collaboration in the studied projects are expressed as positive but the management of documentation and requirements are described as problematic. It is thus recommended to further investigate how this could improved in order to improve the efficiency of future supplier collaborations.

## 7.2 Contribution to Research and Industry

The procurement process depends on knowledge capture and transfer in two dimensions; (1) capturing and transferring knowledge internally from maintenance to the procurement process and (2) transferring the knowledge to the supplier. Little research has been performed in the area of procuring production equipment and this thesis contributes to research in these two specific research gaps. It has shown that there is a well defined current process but it lacks the holistic view of how maintenance related knowledge capturing and transferring in the procurement process can prevent future production disturbances. The thesis highlights the importance of increased emphasis on the procurement process and the potential benefits it can yield for industry.

## 7.3 Sustainability

The main production disturbance is breakdowns. The breakdown itself will require corrective maintenance which involves scrapping the defect part of the equipment and replacing it with a new. This requires more equipment parts than originally planned, thus also requiring more resources. In addition, breakdowns can create scrap, which is defect parts, due to abnormalities in the production system. It can for example be production equipment that is dependent on a continuous flow in order to successfully produce parts according to specification. If there is a breakdown, the parts that are currently in the flow will need to be scrapped. In short, breakdowns causes inefficiency and scrap in production, having a negative impact from a sustainability perspective. Given that it is possible to eliminate breakdowns if the maintenance-related knowledge in the procurement process is managed properly, it can be argued that there is a correlation between maintenance and sustainability impact.

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# A

# Appendix 1 - Interview Guide

# Interview Guide

**General role**

- Tell me about your carrier up until today?
- Tell me about your position today?
- How does a typical work week look for you?

**EEM**

- What does EEM mean to you?
- Could you describe the objective with an EEM project?
  - How do you know if the project was a success?
- What are the biggest challenges?
- Could you describe the project from your perspective?
- Could you describe your role in the project?
- How did the project make sure that previous losses weren't transferred into the new equipment?
- Do you know how the equipment is performing today?

**Supplier**

- How was the collaboration between the project and the supplier?
  - How did the project collaborate with the supplier around maintenance?
  - What information would you like to share with the supplier?
- Could you describe the optimal supplier collaboration?
- What do you see as the biggest challenges to reach that collaboration?

**Knowledge**

- Could you give an example of when you faced a problem that could have been avoided if you would have had more information?
  - How did you solve that problem?
  - Would it have been possible to avoid?
- You have a lot of experience. Do you think it would be possible for someone new to do your task solely dependent on documented processes?

- ❑ Does “**Design Review**” ring a bell for you? it's a checklist that tries to make sure that nothing important is forgotten, what do you think about that ide?
- ❑ “**Project Office**” is a concept that in theory means that an organization has a function that only tries to catch knowledge from completed project and give it to new ones. What do you think about that?
- ❑ How to you use **“White Books”**?
- ❑ How is the success of the projects measured?

# B

# Appendix 2 - Emergency Work Order

English

# Emergency Work Order (EWO)

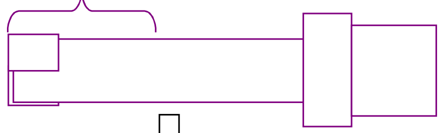
| Department and Line:: | issued by: | Work order nr: |
|---|---|---|
| 7115 A5 | Seppo Läppenen & Göran Harnesk | |
| Machine number and tuype | Date: | |
| 88114 Fischer | 2008-05-21 | 20080521 153336 |

**Problem beskrivning:**

The total lengt of the detail is too short 0,15 mm. The drill was burned out and squealed. Probably wry revolver.

Drawing/photo of problem

Burned out and damaged around the whole drill.



Spare parts used:

No machine parts, but a few drills.

**Problem definition:**

| Facts collection at problem site (5W & 1H) | |
|---|---|
| What | Countershaft, normal work. |
| When | Every detail. After cleaning. |
| Where | Drill burned- Right revolver. |
| Who | Several OP were there. Skilled Ops. |
| What trend: | Same problem on a few details. Stable. |
| How: | Burns drill, Every detail. |

| List possible fault reasons. | |
|---|---|
| 1 | Revolver wry? |
| 2 | Incorrect cutting data? |
| 3 | Wrong drill? |
| 4 | ???? problem? |
| 5 | No cooling? |
| Notes: | |

**Root reason analysis:**

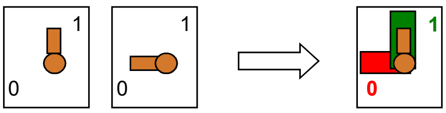
| | Test/verify possible reasons for faults: (Snabb Kaizen at machine) | NOT OK |
|---|---|---|
| 1 | Revolver measured and was straight. | OK |
| 2 | Same cutting data as always | OK |
| 3 | Same drill as always. | OK |
| 4 | No variations on other surfaces, central drill cuts well, and other cutting | OK |
| 5 | Cooling is missing, a mini handle on the ventilator that regulates globe valve for cooling on/av, was turned in wrong position. | NOT OK |

| Impairment / wear | | Increased stress | | Innsufficient solidity | |
|---|---|---|---|---|---|
| Basic state not maintained . | Failure to observe operating conditions | Abrasion not seen to or eliminated | Unsatisfactory knowledge | Construction difficulties | External influence |
| Failure to maintain/Lack of basic conditions | Failure to observe operating conditions | Failure to restore, eliminate deterioration | Insufficent operator or craftsman skills | Design weakness | External Influence |
| Polllution<br>Lubrication<br>Loose förband | Dissonance<br>Heat<br>Wrong pressure<br>Leakage | Wear<br>Aging<br>Worn | Operator<br>Maintenance<br>Professional | | Material fault<br>Media<br>Environment<br>Material |

**Countermeasure**

| Countermeasure | Who: | When |
|---|---|---|
| Mark the normal mode. | PH | No |
| Block the tap from involuntary influence. | PH | No |
| Create a "checklist before start" (OPL) | PH | Nu |

Skiss / Details of suggested countermeasure.



**Maintenance activities:**

| Addressering: | Who: | When |
|---|---|---|
| Revise AM-Schedule. | Per H. | ASAP |
| Create and spread single-point lesson | | |
| Revise PM-schedule/update Competence matrix | | |
| Give feedback on improvement to the suppplier. | | |

AM Calendar | One point lesson for machine status | PM Calendar | Single-point lesson for operator/ specialist | Competence matrix | Update Technical specifications | Report to dept/unit/ company concerned

| These s. | | | | | | |
|---|---|---|---|---|---|---|
| Start date: | 2008-05-21 | Completion da | 2008-05-21 | Waiting time: | 2 H | Downtime: 6 H |
| Start Time: | 14:00 | Completetion | 20:00 | Rep time: | 4 H | |

Comments

Blue test is filled in by Operator — Purple text filled in together by operator and Repairman.

Red text filled in by Technician. — Green text filled in together by Repairman and Maintenance engineer.

# C

# Appendix 3 - Human Error Root Cause Analysis

# HUMAN ERROR ROOT CAUSE ANALISYS - HERCA

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Stage of the process and shopfloor | | | | | | Date | | | HERCA N° | | |
| Made by | | | | | | RNC | | | BEQS N° | | |
| Task Frequence | New task | Daily | Weekly/Monthly | Ocasional | Experience of the employee in this work station | New work station | Less than one week | Less than one month | Many months | Many years | Reoccurrence ? | ( ) Yes. Herca n°__________ ( ) No |
| Problem Description | | | | | | | | | | | |

## STEP 1 TWTTP

| | | |
|---|---|---|
| **1. Does the Operator know how to do the work ?** | | |
| a) ( ) Yes | b) ( ) Not completely | c) ( ) No |
| **2. How does he/she know the work is correct ?** | | |
| a) ( ) Checking OPL / SOP / Visual Aids | b) ( ) Self Evaluation | c) ( ) Other |
| **3. How does he/she know it's free from defects ?** | | |
| a) ( ) Team Leader feedback | b) ( ) Self Evaluation | c) ( ) Other |
| **4. What does he/she do when has a problem ?** | | |
| a) ( ) Request Team Leader immediatly | b) ( ) If a staff is close I inform | c) ( ) Other |

After answer STEP1 follow to STEP2

**Lack of knowledge**
If mark any answer **b** and/or **c** training is mandatory

**Action plan for training - Lack of knowledge**

| Instructor | Description | Hours | Cost | B/C |
|---|---|---|---|---|
| | | | | |
| | | | | |
| | | | | |
| | | | | |

| 2° interview | | | | Notes: |
|---|---|---|---|---|
| 1- | a) ( ) | b) ( ) | c) ( ) | |
| 2- | a) ( ) | b) ( ) | c) ( ) | |
| 3- | a) ( ) | b) ( ) | c) ( ) | |
| 4- | a) ( ) | b) ( ) | c) ( ) | |

## STEP 2 Root Cause Analysis

| Question | Method | OC | S.O.P | O.P.L | P.Y | VA | K. | PI | W.P.O |
|---|---|---|---|---|---|---|---|---|---|
| Are there procedures and work instructions? | PROCESS WEAKNESS | | x | x | | x | | | |
| Visual aid is not clear, is missing or is not available in the rigth place? | PROCESS WEAKNESS | | | x | | x | | | x |
| Are there mistaken/obsolets/not updated procedures concerning modifications? | PROCESS WEAKNESS | | x | x | | | | | |
| Are there improper ergonomic conditions when perform operations? | PROCESS WEAKNESS | | | | | | x | | x |
| Are there very complex operations, or out of operator view? | PROCESS WEAKNESS | | | x | | x | x | | x |
| Operation requires a description clearer/easier? | PROCESS WEAKNESS | | x | x | | x | | | |
| Is there problems due to work overload? | ENVIRONMENT | | | | x | | x | | |
| The workplace is bad organized, not functional or leads to mistakes? | ENVIRONMENT | | | | | | x | | |
| Are there bad conditions in order to do the work? | ENVIRONMENT | | | | | | x | | |
| At workplace lighting is properly? | ENVIRONMENT | | | | | | x | | |
| Too much noise ? | ENVIRONMENT | | | | | | x | | |
| Is temperature properly? | ENVIRONMENT | | | | | | x | | |
| Is organization around workstation not properly? | ENVIRONMENT | | | | | | x | | |
| Non conformity was made due to lack of attention? | LACK OF ATTENTION & FORGETFULNESS | | | x | x | x | x | | |
| Is there any source of distraction for the operators? | LACK OF ATTENTION & FORGETFULNESS | | | x | x | | x | | |
| Is there poka yoke/error proof device that can avoid failures due to lack of Attention or forgetfulness | LACK OF ATTENTION & FORGETFULNESS | | | | x | x | x | | |
| Is there a lack of motivation? | ATTITUDE & BEHAVIOUR | | | | | | | x | |
| Employee has showed low motivation concerning his/her specific job? | ATTITUDE & BEHAVIOUR | | | | | | | x | |
| Is there conflit between employee and work team? | ATTITUDE & BEHAVIOUR | | | | | | | x | |
| Operation was wrong made voluntarily ? | ATTITUDE & BEHAVIOUR | | | | | | | x | |
| The employee has used on equipment/tools on the wrong way voluntaliry ? | ATTITUDE & BEHAVIOUR | | | | | | | x | |

## Action plan

| Type | Action Plan | Who | When | Kaizen/I9 | RNC closed? |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |

LEGEND:

| | | | | | |
|---|---|---|---|---|---|
| O.C | OCCURENCE | S.O.P | Std Op. Procedure | P.Y | Poka Yoke |
| | | O.P.L | One point Lesson | K. | Kaizen |
| | | VA | Visual aid | W.P.O | Work Place organization |
| | | | | PI | People involvement |

Teamleader:

Production Manager:

Valid from April 2010
Approved by QMM
Process manager: Luciana D´Assumpção