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*The division of Engineering Logistics*

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**Mechanical Engineering**

# Implementation of the Focused Improvement concept in outsourced production

- A study at Tetra Pak's suppliers of Distribution Equipment

**Author:** **Ola Bramstorp**

**Supervisors:** **Salvatore Todaro**  
Tetra Pak  
**Lennart Perborg**  
The division of Engineering Logistics

**Examiner:** **Andreas Norrman**  
The division of Engineering Logistics



## Preface

This master thesis has been performed at the department of Industrial Management and Logistics at Lund University Faculty of Engineering and Tetra Pak's department of Supply Chain Operations – Capital Equipment. The thesis constitutes 30 academic credits and concludes the author's Master of Science in Mechanical Engineering.

First of all I would like to thank my supervisor at Tetra Pak, Salvatore Todaro, for his support, time and effort. I would also like to thank Mastec Stålvall for taking the time support me during the visits and especially Jimmy Carlsson at Mastec Stålvall for assisting me during the many phone calls.

Finally, I would like to thank my supervisor Lennart Perborg at Lund University Faculty of Engineering for the helpful guidance throughout the thesis work and all others that have helped me along the way.

*Lund, July 2011*

*Ola Bramstorp*

## Abstract

- Title:** Implementation of the Focused Improvement concept in outsourced production – A study at Tetra Pak’s supplier of Distribution Equipment
- Author:** Ola Bramstorp
- Supervisors:** Salvatore Todaro, Supply Chain Engineer, Supply Chain Operations – Capital Equipment, Tetra Pak  
Lennart Perborg, Engineering Logistics, Lund University Faculty of Engineering, Lund
- Problem description:** Tetra Pak has started to develop their suppliers of Distribution Equipment in pursuit to regain control over quality and reducing lead-times. The next step in the development of suppliers has been identified as to spread Tetra Pak in-house capabilities in terms of World Class Manufacturing and the Focused Improvement pillar measures and procedures, which is focusing on systematically identify and eliminate target losses to enhance overall production efficiency.
- Purpose:** The purpose of this master thesis is to create an implementation plan for the FI pillar as a foundation for the continuing development of Tetra Pak’s suppliers of distribution equipment, with a focus on Mastec Stålvall.
- Method:** In this study a system approach has been used together with a qualitative approach. Data has been gathered through literature review, observation, interviews, and content analysis. Gap analysis was performed to identify and close the gaps for an implementation.
- Conclusion:** The analysis resulted in a recommended loss structure for the supplier together with a measure to capture efficiency both on a system level and on a sequence level for an initial implementation. Gaps that need to be closed before an implementation were presented together with an implementation plan for the next steps to be taken in the implementation of the Focused Improvement Pillar at Mastec Stålvall.
- Key words:** WCM, TPM, Focused Improvement, manual assembly system, supplier development, outsourcing, Tetra Pak, Distribution Equipment.

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# 1 Introduction

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*In this chapter the background of the study will be explained. This will lead to the problem discussion and later the problem question to be answered. The purpose of this study will be defined as well as the focus and target group. The chapter is closed with a description of the main disposition of the report to allow readers to easily follow the study.*

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## 1.1 Background

The manufacturing industry has experienced an unprecedented degree of change during the last three decades. Today, the highly dynamic and rapidly changing environment with the global competition amongst organizations has led to higher demands on manufacturing organizations. As a result, improvements of manufacturing performance and processes have become key factors for competitiveness in all industries. One of many new management methods that has arisen from this is World Class Manufacturing (WCM). WCM is a methodology that summarizes all experiences achieved within industrial improvement work in the last three decades. This includes well-known methods such as Lean production, Total Productive Maintenance (TPM), 6 Sigma.<sup>1</sup> The basic idea in WCM is to do something world-class, that is, to use the current best practice.<sup>2</sup>

In the year 2000 Tetra Pak announced the start of working with WCM and is using the TPM improvements methodology for continuous improvements. Tetra Pak delivers complete solutions for the processing, packaging and distribution of food products. Their products include packages, processing equipment, filling machines, distribution equipment and service products. Since it was founded in the early 1950s, it has become one of the world's leading manufacturers in their segment.

The production of distribution equipment at Tetra Pak is outsourced to 18 suppliers worldwide. Different suppliers produce different distribution equipment machines, such as cardboard packers, straw applicators, palletizers and conveyers. The distribution equipment machines are assembled and tested at the supplier site to later be shipped to the customer. An improvement project for the distribution equipment was started in 2009. The main objectives were to regain control over quality and improve speed in the “from order to performance” lead-time for the distribution equipment. Two major gaps were identified in the Order To Dispatch (OTD) lead-time. No available OTD data existed and there were no existing lead-time standards and procedures to control them. This resulted in the establishment of a data collection system for the OTD lead-time later that year. Figures were showing the need to start improving one of the distribution equipment machines, CBP 30 speed, to be aligned with other distribution equipment. Later that year a Takt system was implemented at several suppliers to better leveling the orders. Furthermore, a Standard Operating Procedures (SOP) sequence system was implemented as the first time standard to produce distribution equipment at some of their suppliers, among them Mastec Stålvall the supplier of CBP 30 speed.

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<sup>1</sup> Ahuja, I., & Khamba, J. (2001).

<sup>2</sup> Flynn, B. B., Schroeder, R. G., & Flynn, E. J. (1999).



The next step in the development of Mastec Stålvall has been identified as to spread Tetra Pak in-house capabilities in terms of WCM and the TPM methodology for continuous improvements. One of the first pillars to be implemented is the Focused Improvement (FI) pillar that is focusing on systematically identify and eliminate target losses to enhance the overall production efficiency.

## **1.2 Problem discussion**

Tetra Pak has identified several measures and procedures related to the FI pillar in-house that drive efficiency improvements. This study will investigate and describe how an implementation of the FI pillar measures and procedures could be designed at the suppliers of distribution equipment. However, an implementation of this kind would have some problems associated with it. For example, the suppliers not being an integrated part of Tetra Pak's organization raise questions such as commitment issues and willingness to change, both key factors in any implementation of new management methods. But still the relationship between the two organizations is not purely a customer-supplier relationship rather of a more partnership structure. This leads to some interesting aspects of how to handle the implementation.

Furthermore, the fact that the production of distribution equipment consist of mainly manual assembly activities result in a complex problem in terms of process measuring. The TPM methodology was founded upon a machine based production situation whereas measurement is a more natural part of the process. In manual assembly systems the measurements and collecting of data provide a far more challenging approach.

## **1.3 Question formulation**

The main question to be investigated in this study is.

- How can Tetra Pak take the next step and implement FI measures and procedures at the outsourced production of distribution equipment?

The questions stated above can be divided into separate sub questions.

- Is the foundation for an FI pillar implementation sufficient today at Mastec Stålvall?
- How would efficiency be measured at the outsourced production?
- What losses exist in the outsourced production?
- What are the gaps that need to be closed before the next step in a FI pillar implementation can be taken?

## **1.4 Purpose**

The purpose of this master thesis is to create an implementation plan for the FI pillar as a foundation for the continuing development of Tetra Pak's suppliers of distribution equipment, with a focus on Mastec Stålvall.

## **1.5 Delimitations and focus**

The master thesis will be a foundation for the work to implement the FI pillar within Tetra Pak's suppliers of distribution equipment. However, a study covering all aspects of the 18 suppliers would be an extensive study. The master thesis will therefore be focusing on Mastec Stålvall, to work as a pilot supplier for the implementation plan.

Tetra Pak has identified some basic features that make Mastec Stålvall suitable as the pilot supplier for this study.

- A standardized way of working is in place, thus the major part of the foundation in an FI pillar implementation has been created.
- Mastec Stålvall produces the CBP 30 cardboard packer, one of the machines within distribution equipment, which has the longest lead-time. Therefore a reduction of this lead-time is affecting the OTD for the entire supply chain the most.
- CBP 30 is one of the more complex machines to produce and therefore a substitution of the supplier is unwanted. Thus improving the customer-supplier relationship is the best alternative and to develop the supplier.

Due to the timeframe of the study the actual implementation of findings and later the follow up of the results will stand outside of the study.

## **1.6 Target group**

The primary target group of this master thesis is the department of Supply Chain Operations – Capital equipment (SCO-CE) at Tetra Pak who has initiated the development work with their suppliers.

Besides the SCO-CE department at Tetra Pak the study shall also be of interest to the faculty of Engineering and especially the department of Industrial Management and Logistics, people of certain interest in the field and younger students within the same area of focus.

## **1.7 Disposition**

### **Chapter 1, Introduction**

In this introductory chapter the problem background is presented together with the problem discussion and question, purpose, delimitations and disposition of the report.

### **Chapter 2, Methodology**

This chapter describes the methodology used in this study including the methods of collecting data and for the analysis.

### **Chapter 3, Theoretical Framework**

In this chapter the theoretical background is presented which provide a foundation for the underlying concepts and ideas in this study. It also helps the reader to understand the study at hand.

### **Chapter 4, Empirical Study**

The empirical data that has been collected is presented in this chapter. It provides the background of Tetra Pak's way of working with the outsourced production together with a description of Mastec Stålvall's production system.

### **Chapter 5, Analysis**

In this chapter the analysis of the study is presented. The analysis is based on the information gathered in the theoretical framework together with the empirical study.

## **Chapter 6, Results**

This chapter presents the key findings and results from this study.

*References*

*Appendices*

## 2 Methodology

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*The methodology chapter gives the reader an overview of some important methodology concepts and how these are connected to this thesis work. Furthermore, the choices of methodology is clarified and discussed throughout this chapter.*

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### 2.1 Scientific approaches

Establishing a methodological framework is crucial to ensure that no approach is taken for granted. Depending on a person's view of knowledge, different goals of the research can be pertained. According to Arbnor et al., this could be visualized with three different approaches. A compilation of their framework is shown in table 2.1.<sup>3</sup> The approaches will be further described in this section together with explorative, descriptive, explanative, and normative studies, resulting in a discussion of the approach used in this study.

**Table 2.1. Arbnor and Bjerke's framework<sup>4</sup>**

	Analytical approach	System approach	Actors approach
Theory type	Determining cause-effect relations. Explanations, predictions. Universal, time and value free laws	Models. Recommendations, normative aspects. Knowledge about concrete systems	Interpretations, understanding. Contextual knowledge
Preferred method	Quantitative (qualitative research only for validation)	Case studies (qualitative and quantitative)	Qualitative
Unit of analysis	Concepts and their relations	Systems: links, feedback mechanisms and boundaries	People – and their interaction
Data analysis	Description, hypothesis testing	Mapping, modeling	Interpretation
Position of the researcher	Outside	Preferably outside	Inside – as part of the process

#### 2.1.1 Analytical approach

The analytical approach is closely linked to the positivistic research tradition. From the analytical approach point of view there is an objective reality that can be understood and disclosed through research. It is important to not influence the research object whereas the researcher has to stay outside of the research. One of the central parts with using the analytical approach is the assumption that the world can be analytically decomposed into small "elements" which all can stand alone. The approach then follows with the transformation of these elements into concepts and finally tries to reveal cause-effect-relations by hypothesis testing. A method typically used in this approach is quantitative data analysis by the means of statistical procedures. However, qualitative methods are also used in the context of validating research.<sup>5</sup>

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<sup>3</sup> Arbnor, I., & Bjerke, B. (1994).

<sup>4</sup> Gammelgaard, B. (2004).

<sup>5</sup> Ibid.

### **2.1.2 System approach**

The system approach is based on the system theory, that is, the world must be understood in terms of mutually dependent components, as a system with parts, links, goals and feedback mechanisms. It is therefore pointless to analytically decompose reality into smaller elements, as in the analytical approach. In the system approach the researchers task is to create an understanding of a given part of the world in order to improve the system. Since the approach is pragmatic in its nature, the search for an absolute truth or the universal cause-effect-relationships is replaced by the search for a problem solution that works in practice. In classic system approach the researcher stands outside of the research object as in the analytical approach. However, according to Gammelgaard the researcher should be very close to the research object, if possible, also influence the research object since the primary purpose of system research is to improve the system in practice.<sup>6</sup>

### **2.1.3 Actors approach**

The actors approach is based on sociological meta-theories. From an actors approach perspective, in contrast to analytical- and system approach, reality is not an object, but rather the result of various social constructions. The researcher is involved and affects the system, and the creation depends on the researcher's interpretations. Ideally, the researcher should be a part of the research reality to understand and construct the future from within. Knowledge is seen as created through the understanding rather than explaining.<sup>7</sup>

### **2.1.4 Explorative, descriptive, explanative, and normative studies**

The amount of knowledge within a certain research area is often decisive for the choice of study structure. When conducting the study there are typically four different structures. The explorative is used when less knowledge is possessed within a study area and a pursuit for basic knowledge is desirable. The descriptive is used when there is a basic knowledge and understanding for a study area and the goal is to describe, but not explain, relations. The explanative is used when to both describe and explain relations in the pursuit for deeper knowledge and understanding. Finally, normative studies are used when there is some knowledge and understanding in place within a study area and the goal is to reach guidance and suggestion of actions.<sup>8</sup>

### **2.1.5 The scientific approach used in this study**

The system approach gives a holistic view, which is a key factor in many logistic researches. After reviewing the supply chain of distribution equipment at Tetra Pak this was identified as the main approach for this study. With the use of the system approach synergy effects could be taken into account and the search for a problem solution that works in practice rather than the absolute truth or universal cause-effect-relationships is in focus. This is crucial to allow the result to coincide with Tetra Pak's current way of working.

Since some amount of knowledge within the research area is in place and the goal is to reach guidance and suggestions of actions, the study can be considered normative to some extent. However, the author wants to seek deeper knowledge within the specific research area through describing and explaining relations. Therefore the study should be considered a combination of an explorative and a normative study.

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<sup>6</sup> Gammelgaard, B. (2004).

<sup>7</sup> Ibid.

<sup>8</sup> Björklund, M., & Paulsson, U. (2003), p 58.

## **2.2 Research methods and design**

Research methods are the technique for collecting data and the research design provides a framework for the collecting of and analysis of data.<sup>9</sup> In the following part of this section relevant research methods and strategies are presented leading up to the design and strategy of this study.

### **2.2.1 Qualitative and Quantitative Approach**

When it comes to the collection and analysis of data, methodology ranges from the two extremes, qualitative and quantitative. The qualitative research is seen as more objective and scientific, while the quantitative is more subjective, interpretative and constructive.<sup>10</sup>

The quantitative research can be seen, in a somewhat simplified way, as research that comprises information that can be measured or valued numerical. However, in many cases data is not possible to measure quantitative and a qualitative approach may be needed. A qualitative research is preferred if to create a deeper knowledge for a specific area, activity or situation. Although, the possibility to generalization is more restricted in contrast to quantitative research.<sup>11</sup> By that qualitative researches often believe that rich descriptions are valuable and they are more likely to confront constraints of every day life while quantitative researchers are less concerned with such details and they tend to abstract themselves from this world. The qualitative researcher also believes that they can get closer to the actor's perspective through detailed interviewing and observations while in the quantitative research the researcher strive for a role as an observer and observe the phenomenon from the outside.<sup>12</sup>

There is no need to strictly stay to only one approach. According to Holme et al. there is often a lot to gain by combining qualitative and quantitative methods and through that use their respective strengths. With the combining of approaches come several advantages. The validity of the method is most often crucial and if the results through different approaches are concluded to the same result, a high validity can be assured. Furthermore, the credibility to the analysis could be strengthened by showing that similar results are achieved in the analyze part through the use of different approaches.<sup>13</sup>

### **2.2.2 Data collection methods**

For a successful analysis it is crucial to obtain good reliable data. Data are often differentiated as either primary or secondary data. Primary data is consider to be data collected with the objective to be used in the current study e.g. interviews while secondary data is referred to as data collected for another objective than that of the current study e.g. literature reviews.<sup>14</sup> The eight most common methods of collecting data are surveys, interviews, observation, focus groups, case studies, experiments, literature reviews, and content analysis<sup>15</sup>. These will be further described in this section.

#### **2.2.2.1 Surveys**

Surveys consist of a number predetermined standardized questions and answering alternatives. The answers alternatives can be formed as yes/no questions but may also

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<sup>9</sup> Bryman, A., & Bell, E. (2003), p 32-33.

<sup>10</sup> Frankel, R., Näslund, D., & Bolumole, Y. (2005).

<sup>11</sup> Björklund, M., & Paulsson, U. (2003), p 63.

<sup>12</sup> Näslund, D. (2002).

<sup>13</sup> Holme, I. M., & Solvang, B. K. (1996), p 79-80.

<sup>14</sup> Björklund, M., & Paulsson, U. (2003), p 67-68

<sup>15</sup> Frankel, R., Näslund, D., & Bolumole, Y. (2005).

include a more open and descriptive answer possibilities. With surveys a large groundwork of primary data can be retrieved with a relatively small effort. However, visual information such as body language cannot be considered and the risk of misinterpretations is immediate since clarifications cannot be requested. There is also a risk of very brief answers and a low answering frequency.<sup>16</sup>

#### **2.2.2.2 Interviews<sup>17</sup>**

Interviews are covering all forms of questioning that can take place through personal interviews as well as over the phone, even contact via email can be considered to fall under the interview category. There are many different forms of interviews. Typically, they can either be structured, questions are asked in a specific order, or unstructured, similar to a normal conversation and questions are formed according as. There is also a combination of these whereas discussion areas are predetermined and questions are formed based on progress of the interview, this is called semi-structured interviews.

An important part of the interview is the awareness of using leading questions. In general, the use of leading questions should be reduced to its minimum. Interviews can be conducted with one person at a time or in groups of several individuals. Interviews provide primary data at its essence. Since the questions can be formed to the interview situation and adjusted after earlier stated questions, the data obtained often provides a more in-depth understanding. Interviews also allow interpretations of visual signals, such as body language. However, it is resource intensive and travelling is often needed.

#### **2.2.2.3 Observations**

Observations can be conducted in several ways. The observer can be involved in the research activity or observe it from the outside. Whom to be observed can be informed in advanced or not be aware of the observation at the time. Many tools can be used for the observation as well. A stopwatch can be used to provide data collection of a more objective characteristics or it can be based on more subjective estimations. Since this method can be formed in so many ways there are rarely any specific strengths and weaknesses that could be pointed out. However, it is most often a quite resource intensive method of collecting data and it usually provides more objective information.<sup>18</sup>

#### **2.2.2.4 Focus group**

Focus groups are performed by a trained moderator among a small group of respondents in an unstructured and natural manner. The main purpose of the focus group is to gain insights by listening to a group of people from an appropriate target group that is of interest to the researcher.<sup>19</sup>

#### **2.2.2.5 Case studies**

A case study is an ideal method when a holistic, in-depth study is needed. It is an empirical inquiry that investigates a contemporary phenomenon within its real-life context. The strength of case study approach is its ability to allow multiple sources of data and they are designed to bring out the details of the research from the participants' point of view. They also allow a multi-perspective analysis, which present the research with not only the perspective of the actors within the study but also the interaction between them.

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<sup>16</sup> Björklund, M., & Paulsson, U. (2003), p 68.

<sup>17</sup> Ibid.

<sup>18</sup> Ibid., p 69.

<sup>19</sup> Frankel, R., Näslund, D., & Bolumole, Y. (2005).

A case study can typically be conducted as a single case study or as multiple case studies.<sup>20</sup>

#### **2.2.2.6 Experiments**

Experiments are based on the use of an artificial “mini-reality” with given variables, which could be adjusted in a controlled environment. In the built-up phase of the “mini-reality” simplifications of the reality is often made, therefore it is appropriate to carefully describe and motivate these. The strengths of experimentations are the control over variables it provides and the possibility of reproduction in the experiment. However, it is most often resource intensive and often hard to fully describe a complex environment.<sup>21</sup>

#### **2.2.2.7 Literature review**

Literature review cover all written material, such as books, brochures and journals. The data obtained from literature reviews are secondary data and are therefore extra important to be aware of that the data may be bias or not fully covered. The strengths with literature review are that under a relative short period of time the access to a large extent of data can be obtained. It is therefore often used in the initial mapping of current knowledge of the research area and to construct the theoretical framework. There are also some weaknesses with literature review such as, the fact that it is secondary data. Source criticisms are therefore critical and the use of the material should always be questioned.<sup>22</sup>

#### **2.2.2.8 Content analysis**

Content analysis is often defined as a form of observation hence the similarities are striking. Its extensive use as a stand-alone data collection method has, however, justified it as a separate category. The content analysis of data sources can include published and unpublished documents such as, letters, reports, email messages, faxes, newspaper, articles, web pages etc. It provides a somewhat stable and repeated review process, and can often provide a broad coverage of data over an extended time span. The problems with content analysis are often that it provides difficulties in the retrieving of data and enhanced risk of researcher bias in source selection and reporting.<sup>23</sup>

### **2.2.3 Inductive, Deductive and Abductive**

During the progress of the research a movement between different abstraction's layers is conducted, constituted of two endpoints. On one side the more general is found that is theory, and on the other side the more concrete that is empiric.<sup>24</sup>

An inductive method starts from the collection of data and through that finding more general and theoretical conclusions. Often the data collection is to be considered fully impartial. Inductive methods have often been criticized within the theory of science since theory rarely contains anything except what is covered in the empirics. Furthermore, a theoretical standpoint is already taken when a selection is made and studies a certain phenomenon, thus to be fully impartial is therefore often impossible.<sup>25</sup>

In the deductive method the theory has a more central part compared to the inductive. A hypothesis is considered as a statement derived from the theory and is then to be proven

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<sup>20</sup> Frankel, R., Näslund, D., & Bolumole, Y. (2005).

<sup>21</sup> Björklund, M., & Paulsson, U. (2003), p 69.

<sup>22</sup> Ibid., p 67.

<sup>23</sup> Frankel, R., Näslund, D., & Bolumole, Y. (2005).

<sup>24</sup> Arbnor, I., & Bjerke, B. (1994), p 107.

<sup>25</sup> Wallen, G. (1996), p 47.



empirical.<sup>26</sup> Beginning with the theory, predictions are made about the empiric. These are then to be verified with the collected data and thus conclusions can be made about separate phenomenon based on the existing theory.<sup>27</sup> The relation between the inductive and deductive approach is depicted in figure 2.1.

An abductive approach arose from the insight that most great advances in sciences did not follow a strictly inductive or a strictly deductive approach, they were often a combination of these. This follows that by using the abductive approach a movement back and forth is continuously taking place between the abstractions' layers.<sup>28</sup>

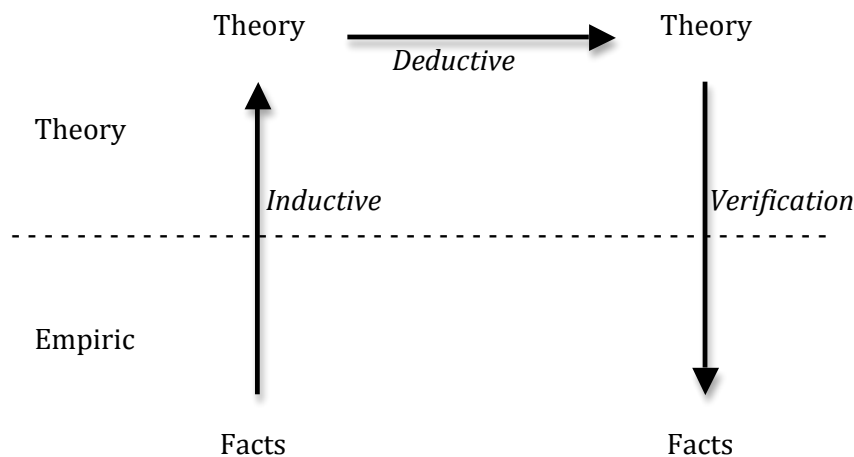


Figure 2.1. Illustration of inductive and deductive methods<sup>29</sup>

### 2.2.4 Gap analysis<sup>30</sup>

Gap analysis is a common term to identify, specify, and close the gap between an existing situation and a wanted one. The gap can be the differences between the company's existing competence and the competence needed to realize a chosen strategy. The analysis typically includes 6 steps.

1. Define the area of analysis.
2. Describe the existing situation.
3. Describe the wanted situation.
4. Analyze the gap between the wanted and existing situation.
5. Take decision to fulfill the gaps.
6. Follow up and if necessary makes changes to erase gaps.

A gap matrix can be used to identify what areas that are included in the analysis.

### 2.2.5 Research methods and design used in this study

The strategy of this study is depicted in figure 2.2. After initially building a project plan for the main outline of the study, a series of activities was conducted to reach the purpose of this study, which is to provide a FI implementation plan. A majority of the activities

<sup>26</sup> Wallen, G. (1996), p 48.

<sup>27</sup> Björklund, M., & Paulsson, U. (2003), p 62.

<sup>28</sup> Kovacs, G., & Spens, K. M. (2005).

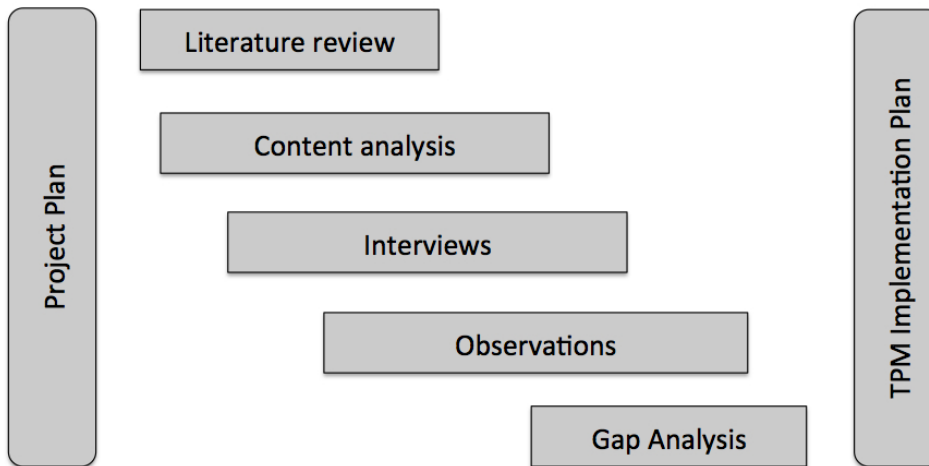
<sup>29</sup> Arbner, I., & Bjerke, B. (1994), p 107.

<sup>30</sup> Karlöf, B., & Lövingsson, F. (2007), p 133-134.

Figure 2.2. Research strategy in this study

runs parallel and there is also an interrelationship between these. E.g. interesting topics found in the content analysis were further studied in the literature review and vice versa.

The project plan was created in collaboration with Tetra Pak based on the main purpose of this study together with its delimitations and problem background. An initial understanding were required to achieve a result aligned with the expectations of the study, therefore an brief literature review and content analysis had to be in place before establishing the project plan.



### 2.2.5.1 Qualitative and Quantitative approach

Since the majority of this study has been conducted from the inside studying behaviors and actions the author has used a qualitative approach. By using the qualitative approach deeper knowledge about the activities has been created through qualitative methods such as interviews and observations.

### 2.2.5.2 Data collection methods

The collection of data has been conducted from both primary and secondary sources. As seen in figure 2.2 it has included literature review, content analysis, interviews, and observations.

#### Literature review

A review of literature was conducted as a first activity, closely linked to the content analysis, with an emphasize on supplier development and TPM, with a focus on the FI pillar to give a perspective of its concepts, tools and core values. Furthermore, to be able to reach the objectives of this study this has to be complemented with deeper understanding within process measuring, assembly system, and data collection.

#### Content analysis

Since Tetra Pak has many standard procedures documented, a good understanding for the supply chain and the overall relationship with suppliers could be established early on based on content analysis.

## Interviews

Unstructured interviews were conducted throughout the study. Initially with the purpose of understanding Tetra Pak's supply chain for distribution equipment and later to identify the facts needed in the analysis. Structured interviews were also conducted at Mastec Stålvall to identify key facts about the way of working and how an implementation could be constructed.

## Observations

Observations were critical for the success of this study. To be able to understand and later analyze the gaps, observations of Mastec Stålvall's production system was central. The collection of data through observations was conducted to create an understanding for the system and to analyze the gaps to be closed.

### 2.2.5.3 Methods of analysis

An inductive approach has been used in this study as the main analysis approach. This is strongly connected to the qualitative approach taken by the authors. However some influences of the deductive approach have been used as well during the construction the theoretical framework where some theory had to be proven empirically.

Besides the logical reasoning methods of induction and deduction, gap analysis was identified as the central part for reaching the objectives of the study. To be able to identify the gaps and close them to allow a FI pillar implementation are both key activities for the success of this study.

## 2.3 Credibility

In the scientific context credibility is crucial and should always be considered. There are three measurement related to credibility, namely validity, reliability and objectivity. Validity is concerned with to what extent the metrics are measuring what was intended while reliability is concerned with the question of whether the results of a study are repeatable. Objectivity of a study is concerned with the question of to what extent values (of the researcher) affect the study. A good objectiveness is secured through a clear presentation and motivation the choices made in the study. The ambition in any study should be to achieve as high validity, reliability and objectivity as possible.<sup>31</sup>

In figure 2.3 a schematic illustration of validity and reliability is depicted. In the left picture a study with low validity and reliability is shown. The study does not measure what it is set out to do and the result is not repeatable. In the center picture a study with high reliability but with low validity is shown. It does not measure what it is set out to do but the results are repeatable. Finally, the right picture is showing a study with both high validity and reliability.

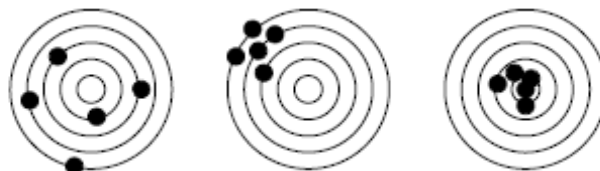


Figure 2.3. Schematic illustration of validity and reliability<sup>32</sup>

<sup>31</sup> Björklund & Paulsson, (2003), p 59-60.

<sup>32</sup> Björklund & Paulsson, (2003), p 59-60.

Validity and reliability can both be increased through triangulation. Triangulation means that through many different methods or perspectives investigate a single event. The result is a multi-perspective research result.

In this study, triangulation of different sources of information has been used, collecting information from both members in the supplier development initiative. Thus the validity is expected to be relatively high. The reliability of this study can be considered relatively low considering that the studied object is dynamic and constantly changing. However, with the purpose of creating an implementation plan it will be used as a background for such an implementation.

# 3 Theoretical Framework

*In this chapter the theoretical framework is presented, covering the underlying concepts and theory for this study. This chapter starts with an introduction to supply chain management, followed by a presentation of supplier development with its opportunities and issues. A brief introduction to WCM is then given, followed by a presentation of TPM and its role within WCM. The concepts of TPM and the implementation are then explored with a focus on continuous improvements, losses and the FI pillar. Other areas of interest for this study such as assembly systems, process measuring, efficiency measure, and data collection is also presented.*

## 3.1 Supply Chain Management

### 3.1.1 An introduction to Supply Chain Management

A supply chain is the physical network consisting of all activities performed from the raw material supplier to the consuming end customer, depicted in figure 3.1. The supply chain is a process that transforms material into products and delivers them to customers. In turn Supply Chain Management (SCM) is the integration of these activities to achieve a sustainable competitive advantage, through improved supply chain relationships.<sup>33</sup>

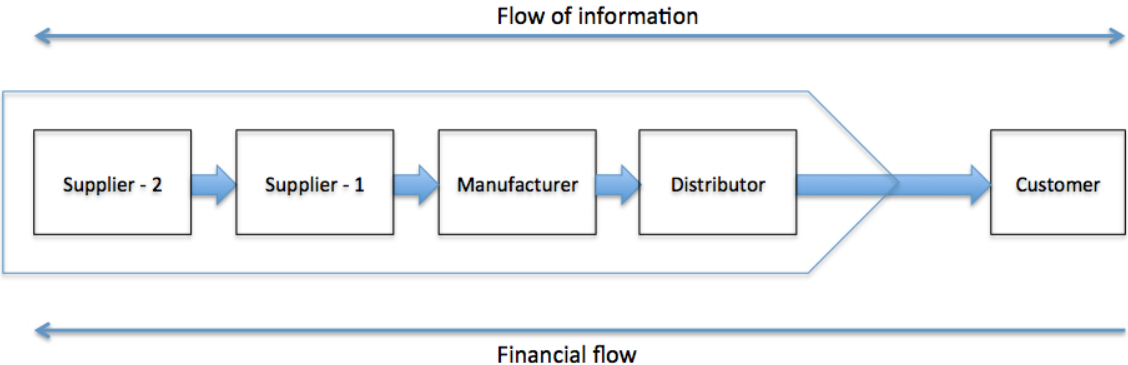


Figure 3.1. The concept of a supply chain

### 3.1.2 Partnership in Supply Chain

Relationship between organizations can range from an arm’s length relationship to vertical integration. Most of the times a relationship between two organizations are at an arm’s length, that is, two organizations conducting business with each other often over a long time. However, there is no sense of joint commitment or joint operations between the two organizations.<sup>34</sup>

A more integrated relationship is often referred to as a partnership. Partnership is often used to describe closely integrated, mutually beneficial relationships that enhance supply chain performance. Lambert argue that a partnership is most appropriately defined as “A partnership is a tailored business relationship based on mutual trust, openness, shared risk, and shared rewards that result in business performance greater than would be achieved by two firms working together in the absence of partnership”.<sup>35</sup>

<sup>33</sup> Handfield, R. B., & Nichols, E. L. (1999), p 5

<sup>34</sup> Lambert, D. M. (2008), p 257

<sup>35</sup> Lambert, D. M. (2008), p 257

The most common benefits of supply chain partnership are quality enhancement, time efficiency improvement, inventory reduction, and innovation<sup>36</sup>. Partnership achieves cost savings and reduces duplication of efforts. For suppliers, partnerships with industry leaders can enhance operations and provide stability in unstable markets. For buyers, partnership can reduce purchasing costs, improve profitability, and increase technical cooperation.<sup>37</sup>

### **3.1.3 Knowledge sharing in the supply chain**

Organizational learning has been identified as perhaps the key factor in achieving sustainable competitive advantages. Although organizational learning has been in focus on an individual firm level, there is increasing evidence that inter-organizational learning is more critical to competitive success.<sup>38</sup>

Dyer et al. argue that a network can be more effective than a firm at the generation, transfer, and recombination of knowledge. The primary reason is that there is a greater diversity of knowledge within a network than a firm. For a network to be effective at knowledge management, it must be able to create coordinating principles that support coordination among specialized firms. Toyota does this by creating and maintaining an “identity” for the network as well as an infrastructure that enables knowledge transfer among suppliers. One part of this is that production knowledge is viewed as the property of the network rather than the individual firm. Dyer et al. point out that Toyota’s ability to effectively create and manage network-level knowledge-sharing process partially explains the relative productivity advantages that Toyota and its suppliers possess.<sup>39</sup>

## **3.2 Supplier development**

### **3.2.1 What is supplier development?**

As companies outsource more to focus on their own core competencies, they increasingly expect their suppliers to deliver quality products on time at a competitive cost. When a supplier is incapable to meet these needs the buyer can approach this in three ways:<sup>40</sup>

- Vertical integration, i.e. the buyer bring the outsourced item in-house and produce it internally
- Switching supplier, i.e. change to more capable suppliers
- Supplier development, i.e. help to improve the supplier’s capabilities.

“Supplier development is a procedure undertaken by a company to help improve its suppliers’ capabilities. More specifically, it may be interpreted as a firms’ attempt to transfer (or replicate) some aspects of its in-house organizational capability across firm boundaries.”<sup>41</sup>

Supplier development is a powerful approach to enhance supply chain performance. It includes any activity initiated by the buying organization to improve the supplier’s performance such as assessing suppliers’ operations, providing incentives to improve

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<sup>36</sup> Qile, H., Gallear, D., & Ghobadian, A. (2011)

<sup>37</sup> Lambert, D. M. (2008), p 258

<sup>38</sup> Dyer, J. H., & Nobeoka, K. (2000).

<sup>39</sup> Ibid.

<sup>40</sup> Handfield, R. B., Krause, D. R., Scannell, T. V., & Monczka, R. M. (2006).

<sup>41</sup> Sako, M. (2004).

performance, instigating competition amongst suppliers, and working directly with suppliers through training and or other activities.<sup>42</sup>

Supplier development requires both firms to commit resources, in terms of financial, capital and personnel, to the work. It also requires to share timely and sensitive information and to create an effective means of measuring performance.<sup>43</sup> An example of the importance of measurement in supplier development can be taken from Nissan's Capability Enhancement Activities. The thinking here is that without concrete evaluation measures, Nissan cannot assist their suppliers in an effective way and the suppliers would not feel convinced that improvements needs to be made. Nissan has developed measures for suppliers such as financial performance, data on quality, evaluation of components, factories and companies. One important capability in supplier development is continuous improvement. It is inherently firm-specific in its application and results, which makes it an asset that has a central role in sustaining competitive advantage, thus also makes it difficult to replicate.<sup>44</sup>

### **3.2.2 Pitfalls in supplier development<sup>45</sup>**

Handfield et al. point out several pitfalls related to supplier development. Supplier specific pitfalls are most often related to the suppliers' lack of commitment or lack of technical or human resources (skills and knowledge). Lack of commitment from the suppliers often arise from the buyer's team have not clearly define potential reward for the supplier organization. To approach this it could be useful to show suppliers where they stand by showing areas needing improvements. It could also be to illustrate benefits first-hand through focused improvements designed to realize significantly results in a short time to a minimal cost. These types of continuous improvements initiatives are in the end an issue of how to share the profit arising from these. E.g. Honda never targets the supplier's profits as an area for cost reduction. Another supplier specific pitfall is often insufficient supplier resources in terms of engineering, equipment, information systems, employee skills, or training resources required to implementing improvement ideas. It could therefore be preferable to keep initial improvements simple by focusing on high-impact areas that could be improved quickly. This will minimize significant initial investments and still reveal large benefits for the suppliers. It could also be handled by offer personnel support to suppliers by sending competent employees to assist them in e.g. production development. In this way knowledge can be transferred from the buyer to the supplier that might not have access to the know-how.

Buyer specific pitfalls are primarily related to if there are no obvious potential benefits seen. This could be lack of immediately monetary benefits or too high expectations of the result. It is therefore important to keep a long-term focus i.e. look beyond the price and see suppliers impact on quality and technology and to not set too high goals.

There are also some potential pitfalls in the interface between the buyer and supplier such as lack of inter-organizational trust, poor alignment of organizational cultures, and insufficient inducements to the supplier. Lack of trust is one of the biggest challenges within supplier development. It could result in e.g. reluctance to share information and ineffective line of communication. Poor alignment of organizational cultures means that a

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<sup>42</sup> Handfield, R. B., Krause, D. R., Scannell, T. V., & Monczka, R. M. (2006).

<sup>43</sup> Ibid.

<sup>44</sup> Sako, M. (2004).

<sup>45</sup> Handfield, R. B., Krause, D. R., Scannell, T. V., & Monczka, R. M. (2006).

supplier development approach is not of a universal nature and need to be adapted to each supplier. To handle this, supplier development need to be adapted to local condition. Insufficient inducements to the suppliers are related to the buyer ineffectively communicating potential benefits for investing in supplier development. It may be necessary to offer things such as financial benefits or just a renewal of contract.

Initiating supplier performance improvement is not an easy task, with the objectives to transform suppliers so that continuous improvement becomes an integral part of their capabilities. Target project that are too complex most often result in poor follow-through, either due to lack of resources or lack of commitment. It is therefore important that the buyer commit sufficient resources to the supplier development performance improvement to convince the supplier top management. Another important aspect is to in an early stage of the supplier development determining which cost to bear and which to share.

### **3.3 World Class Manufacturing**

The term World Class Manufacturing (WCM) was first coined by Hayes and Wheelwright in 1984.<sup>46</sup> WCM is one of the broadest manufacturing philosophies and originally focused on primarily production. It includes, for example, JIT, TQM and TPM, and more structural changes such as new production technology.<sup>47</sup> Even though the concept of WCM was introduced in the early 1980's it has remained robust to the changes in the global manufacturing arena.<sup>48</sup>

Today, the term WCM is widely used in many different industries. There is no consistent definition of WCM.<sup>49</sup> However, the basic idea is to do something world-class, that is, to use the current best practice. Looking at the best practice today, Japanese production and management philosophies is still considered as the best. This means that Japanese production and management philosophies, such as, Lean manufacturing, JIT, and TPM, is having a central role in WCM.<sup>50</sup>

### **3.4 Total Productive Maintenance (TPM)**

#### **3.4.1 Introduction to TPM**

TPM is an innovative approach to maintenance that optimizes equipment effectiveness, eliminates breakdowns, and promotes autonomous maintenance by operators through daily activities involving the whole workforce.<sup>51</sup> Efficient maintenance practices are fundamentally to produce world-class manufactures that have machines and processes that are available whenever needed and produce products meeting the required quality level. These are the basic role of TPM in WCM.<sup>52</sup>

Nakajima, by many regarded as the father of TPM, suggested that the equipment should be operated at 100% capacity 100% of the time. This can be decomposed into the three ultimate goals of TPM; zero defects, zero accident, zero breakdowns. The benefits arising from TPM are a higher productivity, better quality, lower costs, reliable deliveries, enhanced safety, and improved morale of employees together with a motivating working

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<sup>46</sup> Flynn, B. B., Schroeder, R. G., & Flynn, E. J. (1999).

<sup>47</sup> Schonberger, R. J. (1986).

<sup>48</sup> Flynn, B. B., Schroeder, R. G., & Flynn, E. J. (1999).

<sup>49</sup> Maskell, B. H. (1991).

<sup>50</sup> Flynn, B. B., Schroeder, R. G., & Flynn, E. J. (1999).

<sup>51</sup> Bhadury, B. (2000).

<sup>52</sup> Ahuja, I., & Khamba, J. (2001).



environment. TPM is usually described as a manufacturing strategy comprising of the following steps:<sup>53</sup>

- TPM maximize equipment effectiveness by optimizing the equipment availability, performance, efficiency and product quality.
- TPM establish a preventive maintenance strategy for the equipment for the entire life cycle of the equipment.
- TPM cover all departments such as planning, user and maintenance departments and require participation from all these.
- TPM involves every employee from top managers to shop floor workers.
- TPM promotes and implement improved maintenance through small-group autonomous activities.

### **3.4.2 House of TPM**

The Japanese Institute of Plant Maintenance (JIPM) has suggested and promoted an eight pillar's implementation plan. These eight pillars are often referred to as the basic practices of TPM and are typically depicted as the house of TPM. The eight pillars are; Autonomous Maintenance, Focused Improvement, Planned Maintenance, Quality Maintenance, Education and Training, Safety, health and environment, Office TPM, and Development management.<sup>54</sup> The FI pillar coordinate with many of the other pillars such as Autonomous Maintenance and Planned Maintenance.<sup>55</sup> The Focused Improvement Pillar will be further discussed later in this chapter.

### **3.4.3 Losses in TPM**

#### **3.4.3.1 Overall Equipment Effectiveness (OEE)**

A key objective of TPM is to identify and eliminate or minimize all losses/wastes related to the production system. TPM initiatives focus on addressing the losses by affecting continuous and systematic evaluation of the production system. OEE is a time-based measure used within TPM. It is a quantitative metric that measures the performance of the productive system and is a good starting-point for relating efficiency to corporate strategy.<sup>56</sup> OEE measures on the bases of three aspects of performance; the time that it is available to operate, the speed of the equipment, and the quality of the product. The losses that reduce the OEE are typically summarized by six major losses, these are as followed:<sup>57</sup>

1. Failures
2. Set-up and adjustments
3. Idling and minor stoppages
4. Reduced speed
5. Defects
6. Reduced yield

These six major losses leads to three generic elements of OEE namely: availability, performance efficiency, and quality rate. Figure 3.2 is depicting the relations between the losses and the elements, and its calculations to reach OEE.<sup>58</sup>

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<sup>53</sup> Nakajima, S. (1992), p 10.

<sup>54</sup> Ahuja, I., & Khamba, J. (2001).

<sup>55</sup> Nord, Petersson, & Johansson, (1997), p 139-140.

<sup>56</sup> Ibid.

<sup>57</sup> Nakajima, S. (1992), p 22-25

<sup>58</sup> Bellgran, M., & Säfsten, K. (2010), p 263.

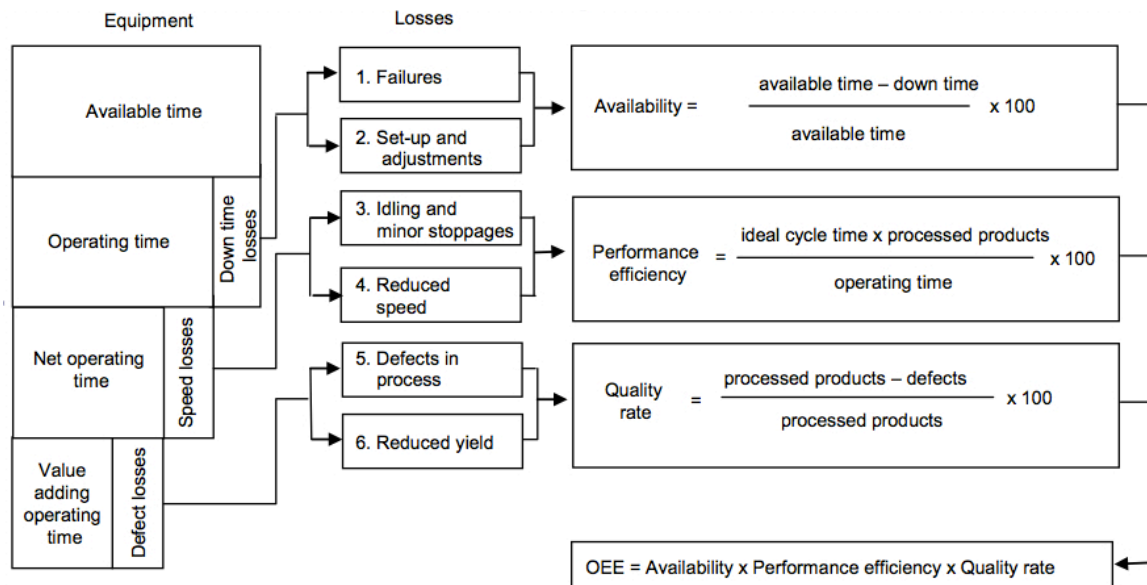


Figure 3.2. OEE calculations<sup>59</sup>

Figure 3.3 is depicting a scale of different production system in terms of automation. The OEE measure is only applicable in the upper region of this scale, since OEE does not consider the number of workers in the process and anticipate that there is a fixed ideal cycle time for each machine that restrict the processing time.<sup>60</sup>

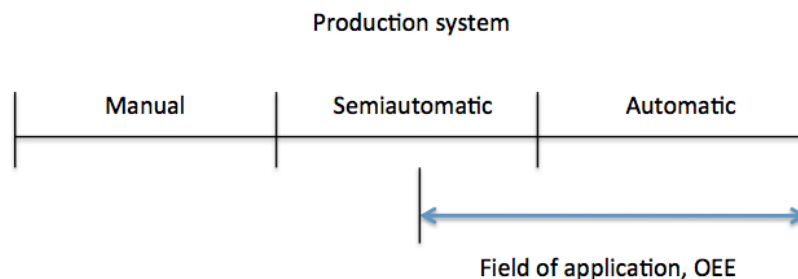


Figure 3.3. Field of application, OEE<sup>61</sup>

Pomoroski argue that the power of OEE lays within the linkage of OEE data to the identification of major equipment losses.<sup>62</sup> Furthermore, the most important role of OEE is not to get an optimum measure rather to get a simple measure that help the production personal to identify where to spend their improvement resources.<sup>63</sup>

OEE describes the efficiency of a flow or a single piece of equipment. There are many variants of calculating OEE and which losses to be included. Several variants includes eight losses that impede equipment efficiency i.e. breakdown, set-up and adjustment, reduced speed, idling and short stoppage, defect and rework, start-up, tool changeover, and planned shutdown. However, if it is possible to measure, there should be aspiration to move short stoppage from speed losses to not create a large loss group.<sup>64</sup>

<sup>59</sup> Bellgran & Säfsten, (2010), p 263.

<sup>60</sup> Petersson, P. (2000).

<sup>61</sup> Ibid.

<sup>62</sup> Pomoroski, T. (1997).

<sup>63</sup> Tangen, S. (2004).

<sup>64</sup> Nord, C., Petersson, B., & Johansson, B. (1997), p 105-113

Efficiency is measured on the basis such as.

- To give priority to continuous improvements
- To give an exact and fair illustration of the results from continuous improvements
- To be able to find out capacity, losses, possible investment needs etc. before planning.

If efficiency is not measured there is a risk that the issues are characterized by personal impact with wrong prioritizing as a result.<sup>65</sup>

### **3.4.3.2 The 16 losses**

The six or eight major losses included in OEE are mostly related to the equipment in the production. However, to achieve world-class performance, organizations have realized that losses related to other than equipment has to be accounted for. Shirose suggested that there is 16 losses impeding the manufacturing performance and efficiency, this includes equipment related losses as well as losses affecting human performance and energy/yield inefficiencies. The losses are typically divided into 4 categories and are summarized in table 3.1.<sup>66 67</sup>

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<sup>65</sup> Nord, C., Petersson, B., & Johansson, B. (1997), p 150.

<sup>66</sup> Ahuja, I., & Khamba, J. (2001).

<sup>67</sup> Shirose, (1996).

**Table 3.1. The 16 major losses impeding manufacturing performance<sup>68 69</sup>**

<i>Loss type</i>	<i>Description</i>
<i>Seven major losses that impede overall equipment efficiency</i>	
1 Breakdown/failure loss	Losses due to breakdowns. Includes both sporadic function-stopping failures and chronic function-reducing failures.
2 Set-up and adjustment loss	These losses arise from the shutdown of equipment during set-up and adjustment e.g. change of tools.
3 Reduced speed loss	Losses due to the actual operating speed falls below the designed optimal operating speed.
4 Idling and minor stoppage loss	Losses that occur when equipment is temporarily stopping or idling.
5 Defect and rework loss	Volume or time losses due to defect and rework, financial losses due to product downgrading, and time losses required repairing defective products.
6 Start-up loss	Time losses that occur when starting up production until production-processing conditions are stabilized.
7 Tool changeover loss	Stoppage loss caused by changing of tools due to breakage or reaching the service life.
<i>Losses that impede equipment loading time</i>	
8 Planned shutdown loss	Losses that arise from planned equipment stoppages at the production planning level.
<i>Five major losses that impede worker efficiency</i>	
9 Distribution/logistic loss	Losses due to inability to automate, even though an investment would be economical beneficial, which lead to manpower losses.
10 Line organization loss	Losses resulting from wrong number of operators are placed at each work cycle. This often results in waiting time losses for some operators or an excessive amount of work for others.
11 Measurement and adjustment loss	Work losses that occur due to excessive measurement and adjustment to avoid outflow of quality defects. Include monitoring, setting losses, and excessive accurateness.
12 Management loss	Losses related to management arise from for example poor planning that could lead to material shortage and can lead to waiting time for instructions or material.
13 Motion-related loss	These losses are related to lack in how a work task is conducted. It includes waiting losses from breakdowns and reduced performance, which often occur due to system losses. Motion losses are also related to unnecessary motions in the production e.g. losses that depend on differences in knowledge, wrong routines.
<i>Three major losses that impede efficient use of production resources</i>	
14 Yield loss	Material losses in production. The difference in weight of input material and output quality products.
15 Consumables (jig, tool, die) loss	Expenses that occur with production or repair of tools, dies etc. due to aging beyond service life or breakage.
16 Energy loss	Losses due to inefficient utilization of input energy (electricity, gas etc) in the process.

<sup>68</sup> Shirose, K. (1996).

<sup>69</sup> Ahuja, I., & Khamba, J. (2001).

### 3.4.4 TPM implementation

#### 3.4.4.1 TPM implementation process

There have been many approaches for implementing TPM in different organizations having varying environments for pulling together manufacturing competence to reach the organizational goals and objectives. Nakajima outlined a twelve-step TPM implementation methodology as a support to the basic developmental activities, which form the minimal requirements for the development of TPM. These are categorized into a four-phase TPM program.<sup>70</sup> The twelve-step TPM implementation methodology was further developed by Shirose and Suzuki and is depicted in table 3.2.<sup>71</sup>

Wireman argues that due to factors such as highly variable skills with the workforce under different situations, age differences in the workgroup, varied complexity of production systems, altogether with different organizations cultures and objectives, polices etc., there is no cookbook-style for a TPM implementation. Although there might not be a single right method for implementation of a TPM program, it is clear that a structured implementation process is a key element for TPM programs.<sup>72</sup> It is also important to be aware that TPM implementation is a long-term process, not a quick fix for the manufacturing problems today.<sup>73</sup>

With a too wide initial implementation of TPM on the shop floor there is a risk of lack in focus, which could lead to lack of available resources and management support. In an initial implementation phase it is therefore preferable to set up a pilot area to learn the working procedures and the practical implications of an implementation. It is advantageous if the pilot equipment has characteristics that allow replication to other machines, large improvement possibility, or includes many competence areas.<sup>74</sup>

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<sup>70</sup> Nakajima, S. (1992), p 57.

<sup>71</sup> Ahuja, I., & Khamba, J. (2001).

<sup>72</sup> Wireman, T. (2004), p 15.

<sup>73</sup> Ahuja, I., & Khamba, J. (2001).

<sup>74</sup> Nord, Petersson, & Johansson, (1997), p 85-86.

**Table 3.2. Twelve-step TPM implementation methodology** <sup>75</sup>

Phase	Stage	Activities
Preparation	1. Declaration by top management decision to introduce TPM.	Declare in TPM in-house seminar and published in organization magazine.
	2. Launch education and campaign to introduce TPM.	Managers: trained in seminar/camp at each level. General employees: seminar meetings using slides.
	3. Create a TPM promotion organization.	Steering committee and special sub-committees. TPM promotion office.
	4. Establish basic TPM policies and goals.	Set baselines and targets and forecast effects.
	5. Formulate master plan for TPM implementation.	Develop step-by-step TPM implementation plan. Framework of strategies to be adopted over time.
Preliminary Implementation	6. Hold TPM kick-off.	Invite suppliers, related companies, affiliated companies.
TPM implementation	7. Establishment of a system for improving the efficiency of production system.	Pursuit of improvement of efficiency in production department.
	7.1 Conduct focused improvements initiatives	Project team activities and workplace small group activities (SGA) at production centers.
	7.2 Develop an autonomous maintenance program.	Proceed step-by-step, with audits and qualification certification at each step.
	7.3 Implement planned maintenance program.	Improvement maintenance, periodic maintenance, predictive maintenance.
	7.4 Conduct training to improve operations and maintenance skills.	Group education of leaders and training members.
	8. Develop initial equipment management program level.	Development of easy to manufacture products and easy to operate production equipment.
	9. Establish quality maintenance organization.	Establish, maintain, and control conditions for zero defect.
	10. Establish system to improve efficiency of administration and other indirect departments.	Support for production, improving efficiency of related sectors. Improve and streamline administrative and office environments.
	11. Establish system to improve efficiency of administration and other indirect departments.	Creation of systems for zero accidents and zero pollution environments.
	Stabilization	12. Sustain TPM implementation and raise TPM levels

<sup>75</sup> Ahuja, I., & Khamba, J. (2001).

#### **3.4.4.2 Success factors for TPM implementation**

TPM is basically a result of the corporate focus on making better use of available resources. There are many key success factors to achieve a successful TPM implementation, thus realizing world-class manufacturing attributes in an organization. Through a literature study on implementation of TPM, Backlund et al. identified ten major categories that affect a successful TPM implementation:<sup>76</sup>

- Leadership support
- Training and education
- Information and communication
- Buying-in and empower
- Implementation planning
- Strategic planning
- Measuring and monitoring
- Rewards
- Teamwork
- Change culture

### **3.5 Focused Improvement (FI) pillar**

#### **3.5.1 The role of the FI pillar in TPM**

The FI pillar is one of the major activities in the TPM implementation. It is often the first pillar to be implemented, looking at the eight pillars in JIPM house of TPM, and begin simultaneous with the TPM kick-off.<sup>77</sup> Focused improvement is an improvement activity designed to minimize targeted losses that have been measured and evaluated. It involves the mapping and elimination of losses and it is the most demanding pillar to introduce and to successfully implement.<sup>78</sup> The word “focused” arises from the fact that it is an improvement focused on a particular loss. Cross-functional teams composed of people such as production engineers, maintenance personal, and operators perform the activity. It includes all activities that maximize the overall efficiency of equipment, processes, and plant by eliminating or minimize wastes and manufacturing losses, and improvement of performance.<sup>79</sup> Strategic FI initiatives must include all 16 losses discussed earlier in this chapter.<sup>80</sup>

There is a difference between the ordinary day-to-day continuous improvements and a focused improvement. Suzuki argues that an improvement carried out in the following procedure is a focused improvement.

- Select a topic
- Form a project group
- Register the topic
- Implement the improvement
- Evaluate the result

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<sup>76</sup> Backlund, F., & Hansson, J. (2002).

<sup>77</sup> Suzuki, TPM in process industries, (1994), p 45-46.

<sup>78</sup> Nord, Petersson, & Johansson, (1997), p 24.

<sup>79</sup> Suzuki, TPM in process industries, (1994), p 45-46.

<sup>80</sup> Ahuja & Khamba, (2001)

If the company is already making all possible improvements in the course of routine work and small-group activities, FI is unnecessary.<sup>81</sup>

With the FI pillar's aim to eliminate all kind of losses, the identification and quantification of these losses is the very foundation in this pillar. The traditional method is to identify losses, analyze result statistically to identify problems, and then searches back to find the causes.<sup>82</sup> To systematically eliminate or minimize the losses different methods and tools are required such as 5-whys, Failure Modes and Effects Analysis (FMEA), brainstorming, 7-QC tools etc.<sup>83</sup> Ljungberg argues that "If the magnitude and reasons for losses are not known, the activities will not be allocated towards solving the major losses in an optimal way".<sup>84</sup> Thus a measurement to guide improvement activities need to separate various types of losses.<sup>85</sup>

### 3.5.2 Implementation of the FI pillar

As mentioned in previous section, in the implementation of TPM the FI pillar is often one of the initial pillars to be implemented. During the initial implementation period of TPM there will most likely be doubt about the potential benefits of TPM, even though many other companies has successfully implemented it. Therefore, there should be a focus initially on the processes suffering with major losses, so that a clear result can be proven.<sup>86</sup>

Hartmann outlined a TPM implementation process that is based on Nakajima's 12 steps implementation plan discusses earlier in this chapter. It is a simplified process and its first phase, out of three, considers the implementation of the FI pillar.

Phase 1 - Improving equipment to its highest level of performance and availability:<sup>87</sup>

1. Determine existing equipment performance and availability, that is, its current OEE.
2. Determine equipment condition.
3. Determine current maintenance performed on equipment.
4. Analyze equipment losses.
5. Develop and rank equipment improvement needs and opportunities.
6. Develop setup and changeover improvement needs and opportunities.
7. Execute improvement opportunities as planned and scheduled activity.
8. Check results and continue with improvements as required.

## 3.6 The Assembly System

An assembly system is a manufacturing system, which in turn is a part of a production system. A manufacturing system is defined as: "the arrangement and operation of machines, tools, material, people and information to produce a value-added physical, informational or service product whose success and cost is characterized by the measureable parameters".<sup>88</sup> A production system includes all the elements to support the manufacturing system.<sup>89</sup>

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<sup>81</sup> Suzuki, TPM in process industries, (1994), p 45-46.

<sup>82</sup> Ahuja, I., & Khamba, J. (2001).

<sup>83</sup> Nord, Petersson, & Johansson, (1997), p 172-173.

<sup>84</sup> Ljungberg, Ö. (1998).

<sup>85</sup> Petersson, P. (2000).

<sup>86</sup> Nakajima, S. (1992), p 72-73.

<sup>87</sup> Ahuja & Khamba, (2001)

<sup>88</sup> Cochran, D. (1998), p 4.

<sup>89</sup> Petersson, P. (2000).



In the assembly system, components, building blocks and formless material such as lubricants are put together into final product or building block of higher complexity. In figure 3.4 the assembly system with its input and output is depicted. The assembly may also produce a secondary output in term of waste. The assembly system can be a combination of manual working stations and/or mechanical or automatic assembly stations depending on the task. These can be combined to a more or less automatic total system. The transport system between such stations is an important part of the total system.<sup>90</sup>

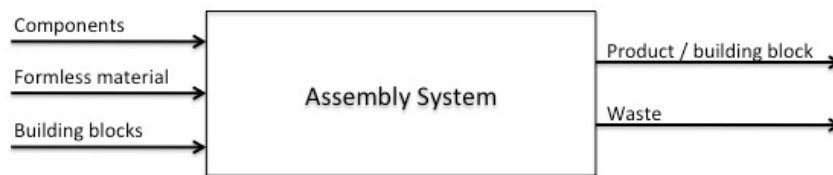


Figure 3.4. The assembly system with its outputs and inputs<sup>91</sup>

The assembly process is an important part of the assembly system with the obvious purpose of assembling products. Complex products are often assembled in several steps. The reasons for this is often to facilitate the treatment of product variants or in order to balance the needed capacity between various assembly stations. The assembly system interacts with other parts of the company such as purchasing, machining, and sales. Thus, if the assembly system is optimized in isolation, there is a risk that the total system is sub-optimized.<sup>92</sup>

## 3.7 Performance Measures in Production Systems

### 3.7.1 Introduction to performance measures

To be able to track performance of processes such as the assembly process, there need to be some kind of performance measurement established. Companies should select performance measures based on competitive priorities. Performance measure should be derived from the company's strategic objectives and clearly be defined at all management levels, in order to enable proper guiding of operating decisions. An effective measure should also lead to integration of operations and other functions so that they act as one coordinated value-adding system.<sup>93</sup>

Performance measurement includes two important questions that needs to be answered<sup>94</sup>:

- What will be measured?
- How will it be measured?

For a long time the main problem has been to know what to measure. However, in recent years this has been less of an issue and companies are having problems of having to many measurements in place. Säfsten et al. point out that: "To not drown in measures it is necessary to know what you want to achieve in your production system and moreover to

<sup>90</sup> Andreasen, M., Kähler, S., & Lund, T. (1983), p 47-49.

<sup>91</sup> Andreasen, Kähler, & Lund, (1983), p 48.

<sup>92</sup> Petersson, (2000).

<sup>93</sup> Ibid.

<sup>94</sup> Ibid.

make sure that measures are defined supporting these objectives”<sup>95</sup>. The second question in performance measurement relates to e.g. the measuring scale being used, the data source, and the location at which the measure is taken. The last aspect of measuring performance is that a particular measure is of little value itself. To be meaningful it has to be compared to some reference value. This could be comparison within an organization or with an external organization through benchmarking.<sup>96</sup> Within manufacturing the data to be measured usually have units such as quantity (e.g. number of products, workers, defects), time (e.g. lead time, process time), money (e.g. labor cost, manufacturing cost).<sup>97</sup> There are some advantages to use time when measuring productivity in a manual assembly process. Petersson mentioned these<sup>98</sup>:

- Time is easy to measure
- Time is easy for everyone to understand
- Time facilitate comparisons between assembly systems (independent of cost structure)
- Facilitate comparison between countries since time is independent of currency
- In manual assembly lines there is a approximately relationship between time and cost
- Time enables instant feedback to assemblers (cost implies some degree of inertia)

However, there are also a couple of disadvantages. Tangen mentioned these<sup>99</sup>:

- What can be considered as value adding might be subjective
- The definition supports activities with long processing time (without questioning whether it is the right processing).

Performance measures at various levels within an organization should be consistent with each other. Lower level performance measures are often created on the basis of improvement activities. Many of the measures used today are based on financial performance measures such as profit and return on investment. However, time is often easier for people to understand than money and this should contribute to building commitment in an organization. One example of measurement that focus on time rather than money that has been successful is ABB T50 project, where the purpose of the project was to reduce the throughput time of products with 50%. ABB reasoned that cost reduction would automatically follow by a throughput time reduction.<sup>100</sup>

### **3.7.2 The relationship between Productivity, Efficiency, and Effectiveness**

In the context of performance measurement in production systems, productivity and efficiency are the most common measures. This despite the fact that productivity does not necessarily implies high profitability. Productivity is an absolute measure and is defined as the relation between what is achieved in production and the efforts required achieving this. Productivity relates output to input at a certain point of time ( $P = \text{output}/\text{input}$ ).<sup>101</sup>

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<sup>95</sup> Bellgran & Säfsten, (2010), p 259-260

<sup>96</sup> Petersson, (2000).

<sup>97</sup> Tangen, (2004).

<sup>98</sup> Petersson, (2000).

<sup>99</sup> Tangen, (2004).

<sup>100</sup> Petersson, (2000).

<sup>101</sup> Bellgran & Säfsten, (2010), p 260-262.

There is often made a distinction between efficiency and effectiveness. Efficiency is about doing things right and effectiveness is about doing the right things.<sup>102</sup> In figure 3.5 the relationship between productivity, efficiency, and effectiveness is depicted.<sup>103</sup>

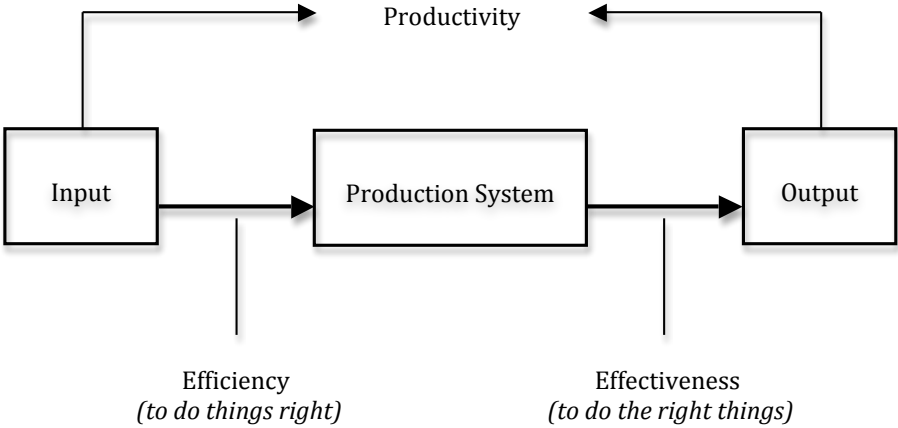


Figure 3.5. The relationship between productivity, efficiency, and effectiveness<sup>104</sup>

Figure 3.6 shows examples of measurable losses that can typically be found in manual assembly systems and how effectiveness and efficiency are affected in manual assembly systems. The efficiency of manual assembly processes is basically to what extent the total work time is actually spent on assembly operations. Losses related to effectiveness are mostly related to the assembly system design and the product design. E.g. adopting the thinking Design For Assembly (DFA) when developing the product can eliminate losses due to difficult operations.<sup>105</sup>

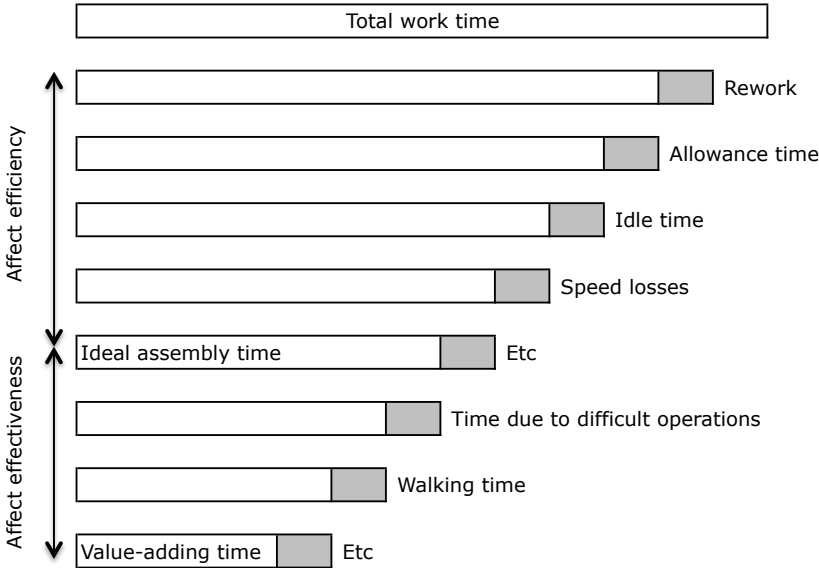


Figure 3.6. Measurable losses in manual assembly<sup>106</sup>

<sup>102</sup> Note that according to this definition, OEE is in fact measuring efficiency and not effectiveness. Throughout this study this definition of efficiency and effectiveness has been applied.

<sup>103</sup> Bellgran & Säfsten, (2010), p 260-262

<sup>104</sup> Bellgran & Säfsten, (2010), p 262.

<sup>105</sup> Petersson, (2000).

<sup>106</sup> Ibid.

### 3.7.3 Manual Assembly Efficiency<sup>107</sup>

Petersson has developed a performance measurement similar to OEE, called Manual Assembly Efficiency (MAE), to be used in the industry to track and improve the performance in processes. MAE focuses on capturing losses by measuring performance on the basis of manual assembly operations rather than automated assembly operations. Figure 3.7 is depicting the field of which MAE is applicable. One of the major differences between manual and automated operations is that the automatic assembly line has a relatively fixed pace, since the machines most often runs at a constant speed. The pace in a manual assembly line is, however, mostly dependent on the human performance related to the production system. This will result in a fluctuating pace, especially when different variants of the product are made in the same line.

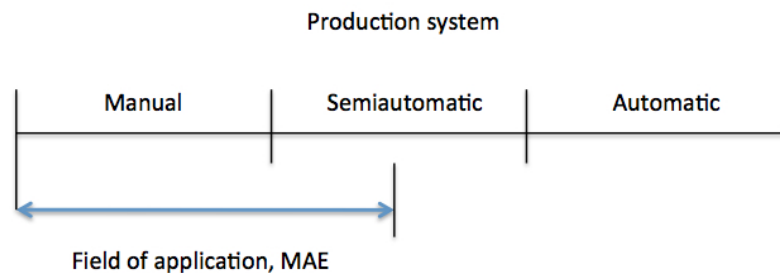


Figure 3.7. Field of application, MAE

To identify the greatest potential for improvement in the process efficiency, MAE has been divided into three components similar to those of OEE. The components of MAE are availability, utilization, and quality and their relation are depicted in figure 3.8.

The total time available is i.e. 24 hours a day and 365 days a year. Out of the total time, some time is spent on planned stop time e.g. unused shifts, meetings etc. In addition, the assembly time might be idle due to lack of orders, this is referred to as unused assembly time. The remaining time out of total time is the scheduled assembly time.

Availability is a measure of in what extent the scheduled assembly time is actually used. Due to losses, e.g. preparatory maintenance, breakdowns, waiting for material etc., the schedule assembly time may be reduced by unplanned stop time. Although preparatory maintenance should be reduced to its minimum to increase availability, therefore it should be handled properly to not affect the MAE in the long run.

Utilization is defined as to what extent the available assembly time is used for actual assembly activities. Actual assembly time means when the assemblers are actually working (doing something). The losses related to utilization is therefore related to speed losses e.g. over-employment, time smearing etc.

The last part of MAE is quality. In OEE the quality element is based on number of units but in MAE the quality measure is based on time. It is defined to what extent the actual assembly time is used to assemble non-defect units, i.e. rework time spent after the assembly process will reduce quality. In appendix A the calculations of MAE is provided.

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<sup>107</sup> Petersson, (2000).

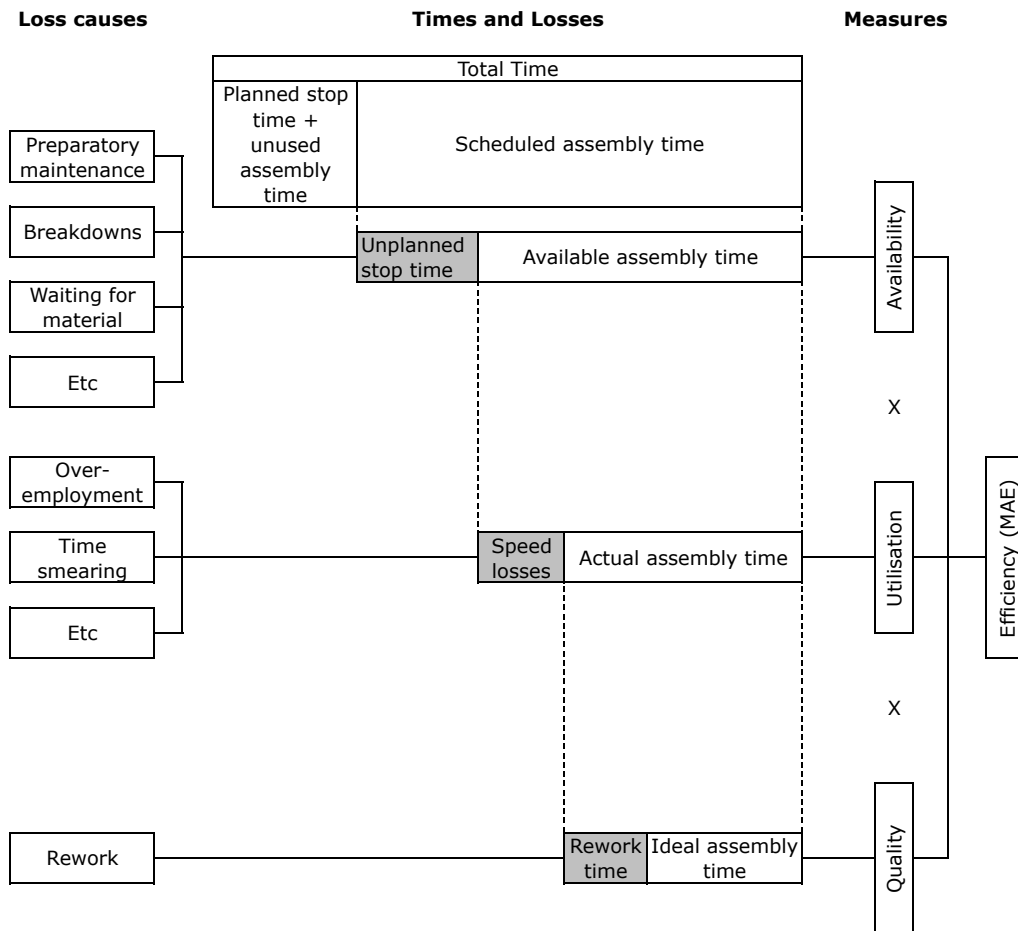


Figure 3.8. Components of MAE and their relationship

The main strength of MAE is that it can monitor processes in which many different ideal assembly times are made and by that the assemblers' performance is evaluated on the basis of how well they utilize the assembly system under given conditions. Another strength is that MAE describes how well a process is running when running, since unused assembly time due to lack of orders are subtracted from the scheduled assembly time. This means that MAE will favor work at full pace. However, it also has some limitations associated with it. To begin with, it does not distinguish between quality problems that can be related to the assembly process and the ones caused by external factors, such as purchased parts. The quality problems may not depend on the assembler, therefore it is important to specify the reasons of rework when given feedback to the assembler. Furthermore, if there is no waste in the process and the assembly workers work faster than the ideal assembly time the MAE can theoretically be greater than 100%. If this happens frequently, it should be a sign that the ideal assembly time should be reduced. There is a limit where the marginal cost of every small increase in MAE is so high that the improvement is not profitable. If this limit would be reached in an assembly system, the focus should be moved from increasing the MAE to increasing the effectiveness of the assembly process. That might result in e.g. improved product design for assembly, an improved assembly system design etc.

## 3.8 Data collection

### 3.8.1 Data collection in production

The data collection problem is not well covered in the literature. However, the collection of data is an important part of continuous improvement. “What has not been measured can not be improved”.<sup>108</sup> A lot of data need to be recorded on a regular basis to make it possible to measure. The operator can most often do the collection of data, but there are often some problems related to this. The form is often designed by someone that does not understand the complexity of production losses and the procedure of filling in are often not easy enough for the operator. Furthermore, it is of course important that the data compiled is analyzed, which is not always the case. If operators realize this, motivation to collect data will decrease considerable.<sup>109</sup> Jonsson et al. argue that since the nearness is an important part of continuous improvement, personnel that can affect the measured parameters should carry out the data collection.<sup>110</sup>

Another issue related to data collection is that there in many cases are a resistance to collect data among operators and foremen. Ljungberg suggest that one solution to this is a two-step model. In the first stage a simplified procedure of data collection is implemented where the operator is registering the number of disturbances from a certain kind. The data is compiled and every week and measures is taken to decrease the disturbance. In the second stage a full OEE model is implemented, that is, all different losses are quantified. Here the operator register all losses and specify the time for losses. The specification of the time spent on each loss is often an issue that is hard to solve. An alternative is to use a stopwatch to track the time loss. Furthermore, the measure of the actually cycle time is often also very complicated but need to be done if minor losses is to be calculated.<sup>111</sup>

To succeed with data collection it is critical to find a less time-consuming method that is also precise. This is important to overcome the resistance against data collection from operators and foremen that often exist. Different people in the organization often have completely different views of what of the patterns of disturbance. In some cases operators believe that some disturbance have a major impact on efficiency even though this is not the case when a measure is established.<sup>112</sup>

Ljungberg argues that it is of major importance that the data collection form is designed together with the operators responsible for filling out the form. He also suggests that the form should be tailor-made to suit the pattern of losses at each machine.<sup>113</sup>

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<sup>108</sup> Jonsson & Lesshammar, (1999).

<sup>109</sup> Ljungberg, (1998).

<sup>110</sup> Jonsson & Lesshammar, (1999).

<sup>111</sup> Ljungberg, (1998)

<sup>112</sup> Ljungberg, (1998)

<sup>113</sup> Ibid.

### 3.8.2 Measure and classification<sup>114</sup>

For a measure to be useful the losses taking a greater part of the production capacity should be focused and further divided into subgroups.

The way of classifying losses have been developed in relation to breakdown losses but these can also be used in other losses. The classification can usually been done in relation to cause, measure, technology area or time dependence. Table 3.3 shows different classification of losses.

**Table 3.3. Measure and classification of losses<sup>115</sup>**

Cause	Measure	Technology area	Time dependency
Operator	Maintenance mechanic	Mechanical	Time dependent
Hardware	Maintenance electric	Electronic	Non-time dependent
Software	Production	Electrical	Irregular stop
Adjustment	External	Hydraulic	Process failure
Design		Pneumatic	

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<sup>114</sup> Ljungberg, (1998)

<sup>115</sup> Ibid., (1998).

## 4. Empirical Study

*In this part the empirical data collected for this study will be presented. It begins with a more thorough presentation of Tetra Pak's way of working with the outsourced production. This will give the reader enough knowledge to understand the full context of this study and will also provide necessary data for the analysis. The empirical chapter will then focus on Mastec Stålvall's assembly system and how they are working with losses. The data is collected from internal documents at Tetra Pak together with interviews, observations, and workshops.*

### 4.1 Tetra Pak Supply Chain Operations – Capital Equipment

#### 4.1.1 SCO-CE Distribution Equipment

The department of SCO-CE at Tetra Pak is responsible for the manufacture and supply of filling machines and distribution equipment from receipt of order until performance is achieved at the customer site. This includes activities such as production of components, the assembly of the packaging equipment, and testing of the equipment. Tetra Pak provide the specifications for these outsourced activities and Tetra Pak's market companies' handles all activities after the delivery to customer. Tetra Pak's market companies are referred to as the customers for the department of SCO-CE.

SCO-CE Distribution Equipment is responsible for the outsourced production of distribution equipment at 18 suppliers worldwide (10 suppliers in Northern Europe, 4 suppliers in Southern Europe, 3 suppliers in Asia, and 1 supplier in North America). Distribution equipment includes different machines seen in figure 4.1. The packaging process line is module based which provide Tetra Pak with the possibility to meet each customer's specific requirements. At the outsourced production sites different suppliers are responsible for the assembly of different modules. They are tested at each site later to be delivered to customers. Tetra Pak is responsible for the shipping from the supplier to the customer. The contract of the outsourced production is today based on a fixed price for a standard production time for a machine, thus related to the business side of the relationship.

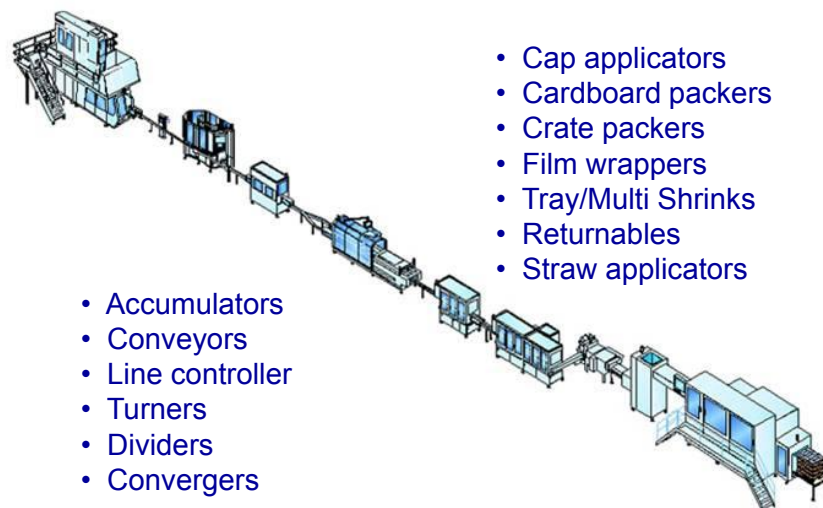


Figure 4.1. Distribution Equipment machines



In figure 4.2 the supply chain for distribution equipment is depicted. Throughout this study the outsourced production is referred to as the supplier and the outsourced production's suppliers will be referred to as sub supplier. In appendix B the KPI's for SCO-CE Distribution Equipment is presented.

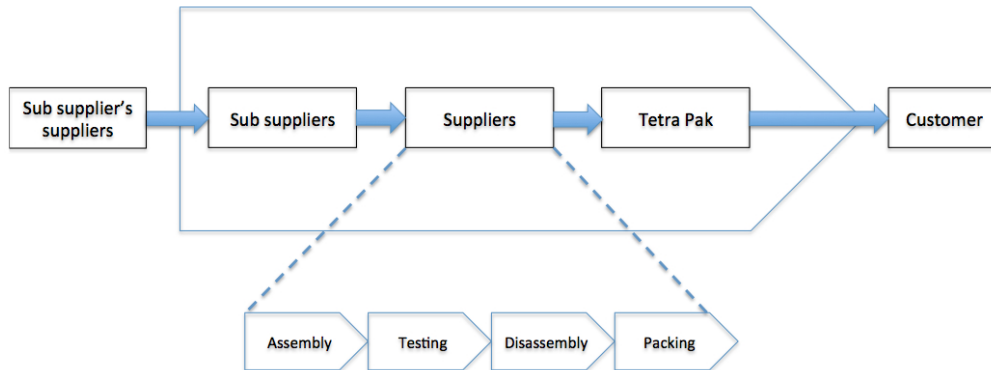
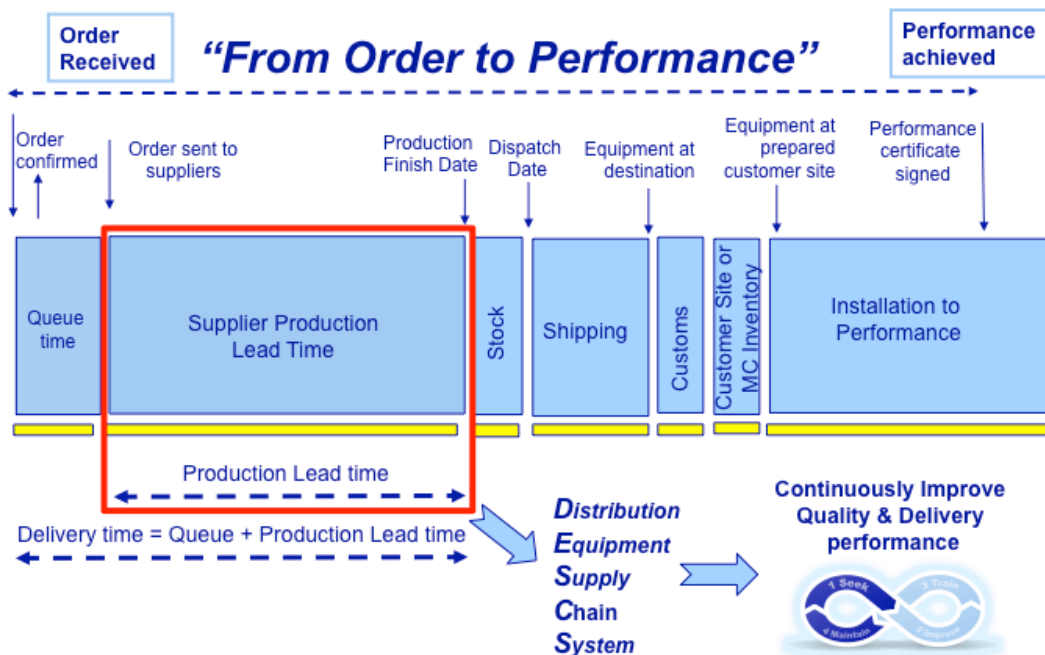


Figure 4.2. Supply chain of distribution equipment

#### 4.1.2 From order to performance of distribution equipment

Figure 4.3 is depicting “from order to performance” lead-time for distribution equipment. After the order has been received and confirmed the order is sent to the supplier sites where the distribution equipment is assembled and the final testing is conducted. The following steps consist of a time in the stock before the dispatch date (if there is problem with the delivery, e.g. missing documentation, the machine will remain in e.g. Malmö Harbor waiting to get shipped), when the distribution equipment is shipped to its destination. Before it reaches the customer it usually goes through the custom. At the customer site the distribution equipment is prepared and installed by Tetra Pak’s market company. From the time the order is received to the finish date of production, is defined as the distribution equipment supply chain system. The majority of this study will be conducted within this part of the “from order to performance”.



The delivery time seen in figure 4.3 is called the Order To Dispatch (OTD). It includes the queuing time, the supplier's production lead-time, and time in stock.

### **4.1.3 Mastec Stålvall**

The supplier production lead-time shown in figure 4.3 is related to any of the 18 suppliers and Mastec Stålvall is one of these suppliers located in Partille, Sweden. Mastec Stålvall is assembling the CBP 30, which is one of the more complex machines of the distribution equipment. Therefore it has a large impact on the overall lead-time of the delivered distribution equipment system, composed of different machines produced at different sites. Mastec Stålvall is producing around 100 CBP 30 per year for Tetra Pak. Mastec Stålvall is the pilot supplier for the purpose of this study and the majority of the empirics are collected on the basis for this. Mastec Stålvall's KPIs and OPIs are presented in appendix C.

## **4.2 Distribution Equipment's Supply Chain System**

### **4.2.1 Distribution Equipment's Supply Chain System daily operations**

Figure 4.4 is depicting the supply chain of distribution equipment and its overall daily flow of information and material. Red arrows is representing the flow of information and the blue arrows the flow of material. The distribution equipment supply chain system is a pull-system since it is initiated by the customer demand. It consists of a subsystem in terms of the supplier factory and support activities related to the department of SCO-CE. At the system boundaries there is an input in the form of distribution equipment specifications provided by the department of Design & Engineering (D&E) at Tetra Pak. The specifications include drawings and documents for the assembly and testing of the machines. The other input is the sourcing of so-called "other components", which involve components that are not Tetra Pak assigned sub suppliers. The output of the system is of course the produced distribution equipment machines that are dispatched to the customer.

Within the system boundaries the support activities from SCO-CE includes the daily management system, planning system, production order flow and Tetra Pak assigned components. The daily management system handles the information flow from the customers, daily report about the progress at the supplier factory, and information from the planning system. All this information is gathered at the SCO-CE department and is the backbone for the daily management. The planning system and its Takt-system enables control of the queue in order to better leveling orders. Today, the Takt-time (time that must pass between two successive unit completions in order to meet the demand) can be changed with a 20 calendar-days interval. The production orders can be placed to the supplier factory in an even flow and the production from different supplier factories can be synchronized to meet the customers demand. Finally, the last part in the system, besides the supplier factory, is Tetra Pak assigned components. Tetra Pak negotiate large-scale global agreements for components that exist in many different machines and systems. These are the sub suppliers of components that Tetra Pak's outsourced production is committed to buy from on the terms negotiated by Tetra Pak.

The subsystem, the supplier factory, is the actually outsourced production. It consists of the assembly of machines and final testing to meet the OTD time needed for the completion of the distribution equipment machine in question. The subsystem has its total sequence describing in which order the machine is to be assembled. Each sequence in the assembly system has its detailed sequence and there within its SOP and work instructions for each activity. There is also a daily meeting, controlling the current status at the

supplier factory. Based on the daily meetings, reports are made on a daily basis to Tetra Pak. This will be discussed later in this chapter.

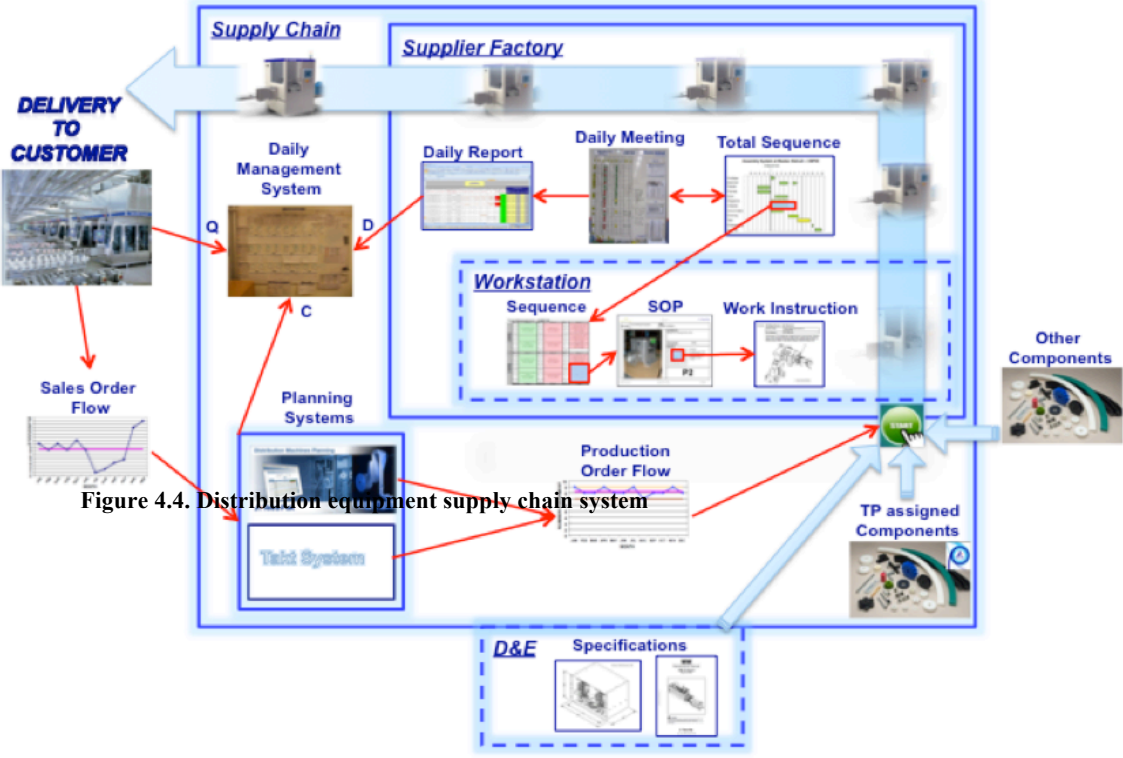


Figure 4.4. Distribution equipment supply chain system

The flow of information in figure 4.4 includes only the daily operation. In addition to this, reports on nonconformities (NC) from supplier factories are sent to Tetra Pak for managing quality.

**4.2.2 Tetra Pak’s data collection of nonconformity**

Tetra Pak’s definition of a nonconformity is: “A NC is a defect, a characteristics out of specification and/or from the Tetra Pak standard, detected during module assembling, machine assembling, final test or during quality control and can be detected on finished products or parts (manufactured part and commercial component)”. The work with NC detection is related to “create right from me principle”. Losses will be moved from customers downstream in the supply chain by detecting NCs thus creating a filter.

In figure 4.5 a description is presented of how the collection of nonconformity data at suppliers is performed and how it is reported back to Tetra Pak. All data is monitored daily and monthly on boards at the supplier and a selection of data is sent to Tetra Pak. The supplier detecting the NC makes the tracking and reporting.

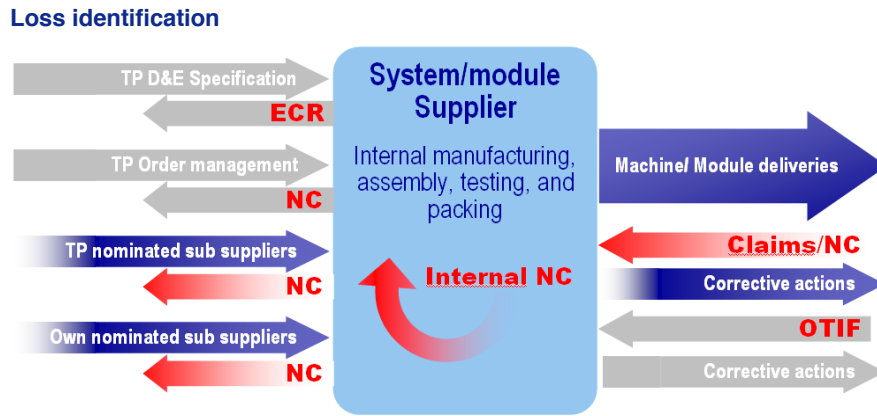


Figure 4.5. The collection of NC data in the distribution equipment supply chain system

Internal NC is a loss due to defect, a characteristic out of specification and/or from Tetra Pak standard caused by the module supplier production and detected there within. It is detected on finished products or parts during module assembling, machine assembling, final test, packaging or during quality control. There is a daily tracking and action standard in place where the module supplier should collect, track by coding (machine, process step, defect code etc), and log the internal NC. The loss should also be visualized on Daily Management System (DMS) board, take action, registering the action, and follow up the action. On a monthly basis, the KPI board should be updated with data from the daily log (number of NC), deployment should be made, and analyze and act to set countermeasure. A report should then be sent back to Tetra Pak.

Supplier's own nominated sub suppliers NC is defects detected during module assembling, machine assembling, final testing or quality control and can be detected on finished products or parts. The daily tracking and action standard is the same as for internal NC except that the action taken and registered of action is made by the sub suppliers. However, the supplier is responsible for driving the issues. The monthly tracking and actions are the same as for the Internal NC.

Tetra Pak nominated sub supplier NC is defects detected during module assembling, machine assembling, final testing or quality control and can be detected on finished products or parts. The daily tracking and action standard is the same as for internal NC except that the action taken and registered of action is made by the sub suppliers with support from Tetra Pak if needed. The supplier is also here responsible for driving the issues. The monthly tracking and actions are also the same as for the Internal NC.

Claims for the module suppliers are all NC detected during the installation and testing at customer site in terms of deviations in quality of delivered machines. When receiving the claim from Tetra Pak the supplier should log the claim and bring it to DMS to secure action. Supplier should both take remedial actions and perform a root cause analysis and propose corrective action to eradicate root cause and also visualize it on the DMS board. On a monthly basis, supplier should perform a deployment of Tetra Pak claims together with internal NC by defect modes, product and/or process. Then analyze and act to set countermeasure.

Engineering Change Request (ECR) is a deviation in specifications, drawings, documentations etc. from Tetra Pak. The daily tracking and action consist of collecting

data, visualizing the loss on DMS board, and take action by contacting Tetra Pak to finally register action and follow-up.

Tetra Pak Order Management NC is deviation of order coming from Tetra Pak and an Order Time In Full (OTIF) NC is a deviation of delivery according to plan and agreement.

#### **4.2.3 Introducing OTD data collection system**

In 2009 when the improvement work with the suppliers of distribution equipment was initiated, no data existed on the OTD and no production lead-times standards and procedures existed to control them. An OTD data collection system was established in 2009. Figures were showing that CBP 30 Speed had a lead-time of 80 calendar days and a target was set up to decrease the lead-time to 28 calendar-days to be aligned with other modules in distribution equipment. In the work with reducing the lead-time at Mastec Stålvall to 28 calendar days a Value Stream Mapping (VSM) was performed. Teams were created to work with different aspects of the future state and most of the development work is in place today, such as a new manufacturing layout and improved material flow. During the time this study was performed the new OTD lead-time of 28 days was implemented at Mastec Stålvall.

#### **4.2.4 Introduction of MTM at suppliers**

The official definition of Methods-time measurement (MTM) has been unchanged since it was first developed and is as follows<sup>116</sup>: “Methods-time measurement is a procedure which analyzes any manual operation or method into the basic motions required to perform it and assigns to each motion a predetermined time standard which is determined by the nature of motion and the conditions under which it is made.”

Method-Time Measurement (MTM) is an analyze technique that is used to analyze any manual operation or task in a unison way and on this basis visualize and evaluate improvement of the methods. As a byproduct it provides an objective determined standard cycle time in which the worker should complete that task without any use of a stopwatch or subjective assessment of performance. MTM is an international norm for performance related to manual work.<sup>117</sup>

Tetra Pak started to introduce MTM at individual suppliers during 2008. With good results a decision was made to implement MTM at several suppliers including those related to the outsourced production of distribution equipment. At the time this study is done an implementation of MTM at Mastec Stålvall has not been planned.

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<sup>116</sup> Karger, (1987)

<sup>117</sup> MTM-Föreningen i Norden

### 4.3 WCM at Tetra Pak SCO-CE

In figure 4.6 the pillar's in Tetra Pak's WCM is depicted. Several of the pillars are descended from the TPM methodology, such as the FI pillar.

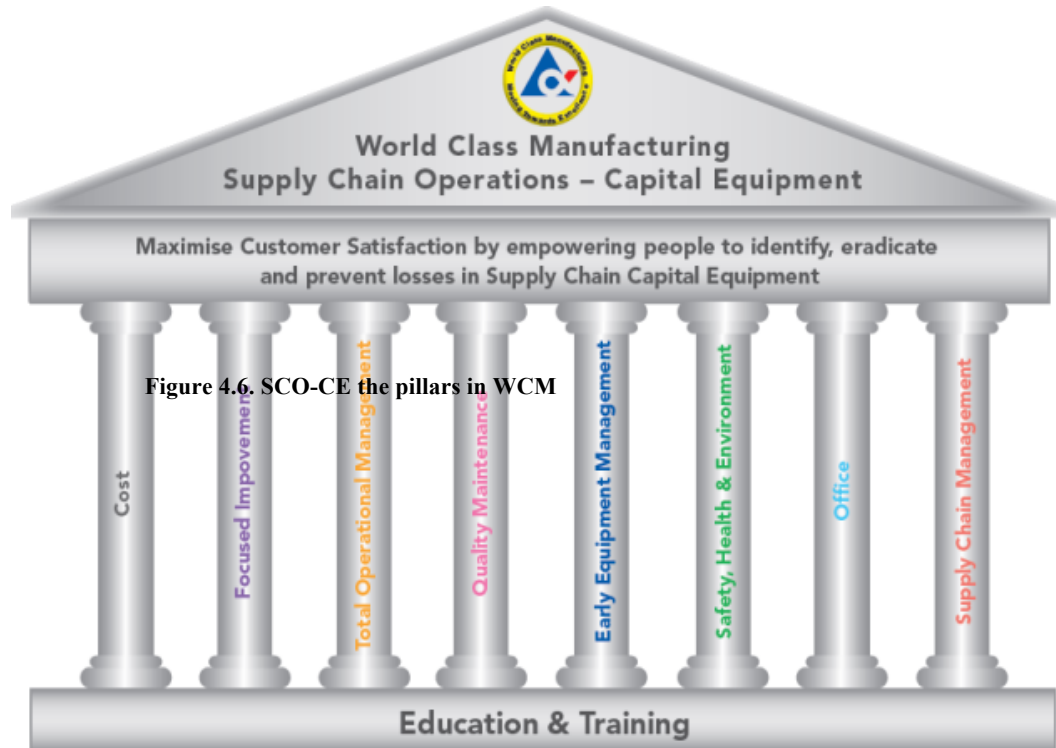


Figure 4.6. SCO-CE the pillars in WCM

### 4.4 FI pillar at Tetra Pak, Lund<sup>118 119</sup>

Tetra Pak has, on the filling machine side of SCO-CE, a FI pillar loss structure in place today that drives efficiency improvements. It is divided into the groups of availability losses, quality losses, and performance losses. Besides the different groups the loss has a classification associated with it describing the effect of the loss. These are defect, lack of resources, unplanned activities, breakdowns, set-up, speed losses, and short stop. In turn, different types of losses (loss codes) belong to each class.

Looking at the collection of losses at the shop floor, it has a system called EPM in place today, which is Tetra Pak's production monitoring system. It is a system in which the production workers are logging the losses that are detected during the final assembling and testing of the filling machines in-house at Tetra Pak. The basic outline for this system is that when a loss is detected a loss registration is opened. From this time until the loss is closed is defined as duration time (the lead-time for the loss). Within this time there are time periods when the production workers are working on solving the loss, e.g. tracking the loss, put in countermeasure etc. These time periods are logged in man-hours and registered in the system. Figure 4.7 is showing a schematic picture of how man-hours can

<sup>118</sup> Sorensen, 15 April 2011.

<sup>119</sup> Visit Tetra Pak A3/Flex production site, 15 April 2011, Lund.

be registered during a loss duration time. The number of man-hours is the related time loss caused by the issue, thus the amount of time spent on activities such as tracking the loss and solving the loss.

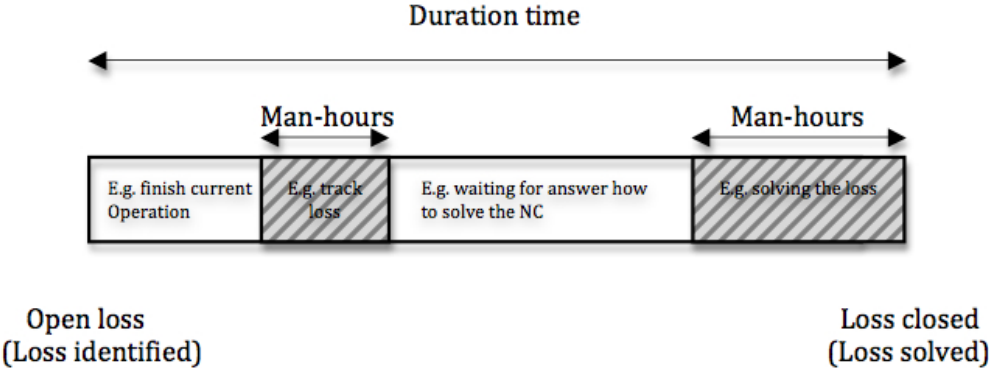


Figure 4.7. Tetra Pak collecting of losses in man-hours

Losses are connected to each machine and sequence where it was detected. In the loss reporting a loss family is chosen (Internal NC, Customer, D&E, Supplier, Tools & Manuals, Utilities, and Waiting for). Within each family a loss type can be chosen consisting of a loss code. Based on the loss code, different losses can be summarized in the EMP system and focused improvements can be made to similar losses. Furthermore, in the loss reporting a description of the loss is also provided by the production workers together with the date the loss was identified, who identified it and if possible if any corrective actions were taken. It is also required that a photo should be taken if it is a NC that is detected and attached to the related machine. An email is automatically sent to the owner of the loss code and it is important with a good description of the problem since it could take several weeks to close the lost if e.g. it is related to a supplier NC. The owner of the loss code is responsible to put corrective actions in place, if it has not yet been done, and then to close the loss. The owner of the loss code is also responsible for certification of the loss, that is, to ensure that the problem will not occur again. It could be to get a NC report from the supplier if it is a supplier NC. The certification of the loss does not take place within the duration time.

The FI pillar also has two measures established today that measure the efficiency of operations, Overall Operator Efficiency (OOE) and Overall Efficiency (OE). These are depicted in figure 4.8. All losses that are collected in the EMP system should sum up to the difference in OOE. There is, however, typically a deviation that can be derived from production workers working at a higher pace. The value of OE and OOE has shown stability to changes in the production system. OE and OOE are defined as follows:

# OOE & OE DEFINITION

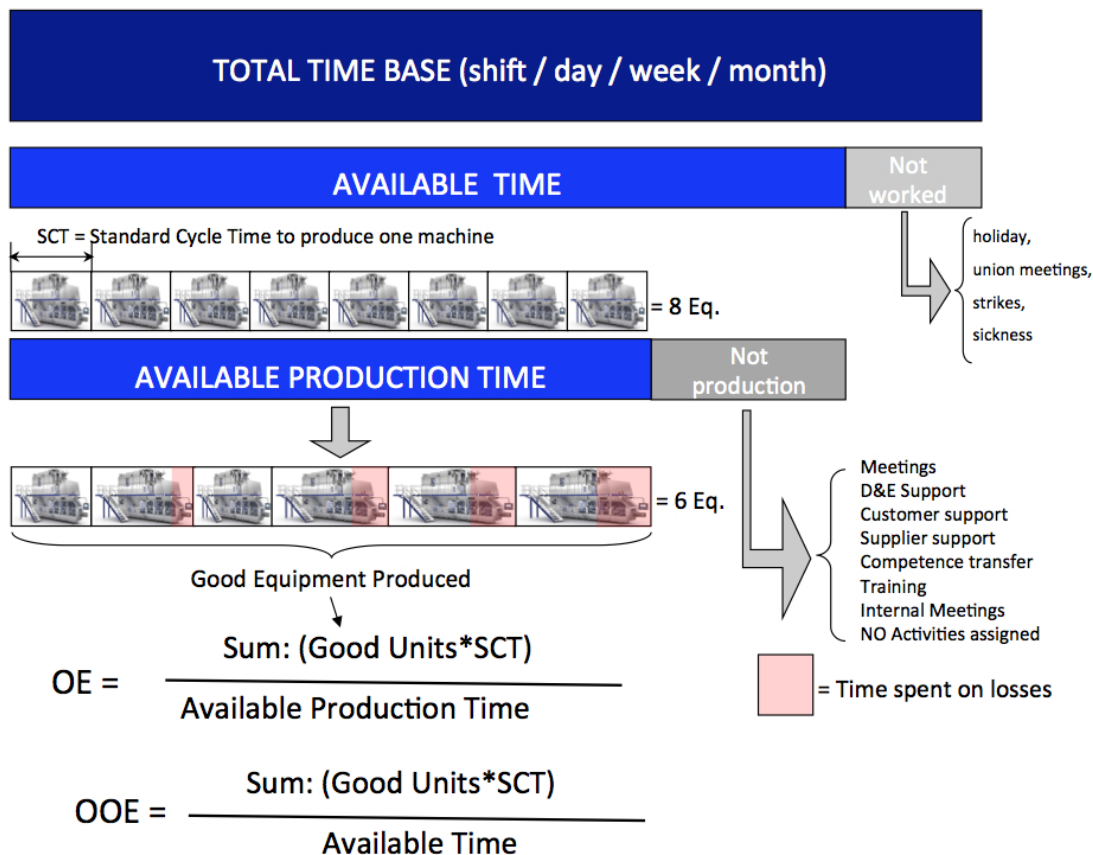


Figure 4.8. Tetra Pak's OE and OOE

## 4.5 Mastec Stålvall's production system

### 4.5.1 The assembly system

Mastec Stålvall's production system is a manual assembly system where different configurations of the cardboard packer CBP 30 are assembled, tested, and packed for shipping. In figure 4.9 a schematic overview of the production layout is depicted with the workstations and production flow (note that the correct flow between sequences are shown in figure 4.11). The electrical installation for the base sequence and the electrical installation for electrical cabinet is a "floating" workstation moved between these sequences. Most operations in the system are performed manually. However, some equipment is used in the assembly operations such as cordless screwdrivers. Furthermore, overhead cranes is used e.g. in the docking sequence of the different modules and in the testing sequence two machines (Helix) is used to provide the CBP 30 with dummy-packages when the final testing is performed.

In figure 4.10 the total sequence of CBP 30 is described. It can be seen that the CBP 30 requires 410 man-hours in total from the start of assembly (including the external assembly that is a part of Mastec Stålvall) to the finished machine is ready for shipment. The man-hours required for the internal assembly system is 369 man-hours. The required man-hours depend on what the configuration of CBP 30 is (e.g. what different arc size of the cardboards that the CBP 30 should facilitate). According to the production leader it can differ around 10-20 man-hours between the configuration extremities. Today, the



assemblers log the man-hours spent on different machines manually, which capture the scheduled assembly time per machine. If it deviates from the average standard cycle time of hours, it is followed-up by looking at what the machine configuration it was and the amount of internal tags related to that machine. The internal tags are disturbance out of ordinary procedures and will be discussed in section 4.5.4.2. Depending on the Takt time set by Tetra Pak, the assembly system needs a certain amount of assemblers. The assembly system would require e.g. 25-26 assemblers if the Takt-time is set to two days.

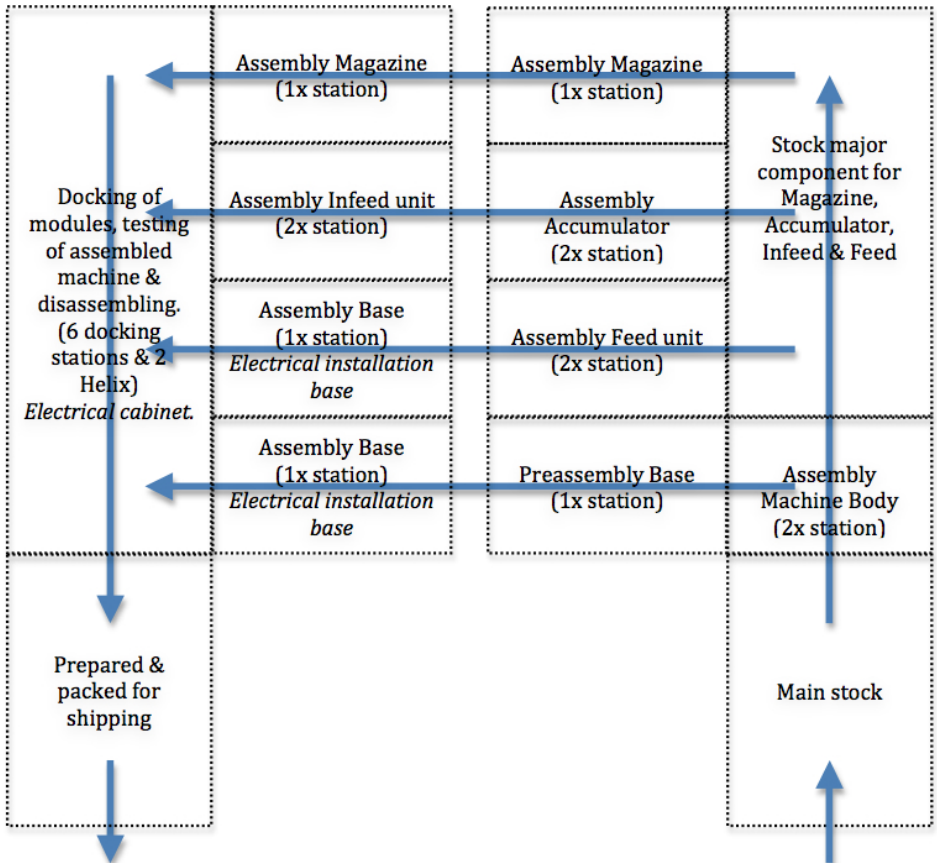


Figure 4.9. Schematic overview of the production layout at Mastec Stålvall

Week	Order arrival												Man-hour sequence			
	-3	-2	-1	1	2	3	4	5	6	7	8	9		10	11	12
Machine Body																24
Feeder																23
Pre Base																16.25
Base																48.25
Electrical Installation Base																15
Magazine																56
Infeeder																44
Ackumulator																23
Docking																35
Electrical Cabinet																7
Testing																42
Disassembly																6
Packing																29
Sum internal assembly																368.5
<i>External assembly</i>																
Wrap unit																20.95
El-kit																20.5
Sum of man-hours needed to finish one CBP30 at Mastec Stålvall																410

Figure 4.10. Total sequence of CBP 30

The machine body and feed unit are assembled before the order has been received to be able to meet the lead-time of 12 calendar-days according to figure 4.10. The electrical kit

and the wrap unit are assembled externally at Mastec Stålvall in Lidköping. Besides the machine body, feed unit, electrical kits, and the wrap unit, the production system at Mastec Stålvall is a make-to-order system. After receiving an order in the production, the production leader manual put in the specification in terms of customer configurations in their order system and makes the sales order. If an order has been received with an old machine model not currently in Tetra Pak’s product portfolio today, a request has to be sent to Tetra Pak for the required drawing and the sales order is placed when receiving these (this is referred to a order management NC discussed in section 4.2.2). A production plan with the total sequence of assembly is constructed by the production leader and is sent to the operative purchaser as a production order, thus creating a pull system. At this stage the production leader is also creating a specification for the testing staff. This is a more detailed specification than the total sequence, with information such as software, documentation, and customer deviation. It happens quite frequently that Tetra Pak’s market companies changes the order while the machines are assembled. Depending on how far the machine is in the total sequence the changes could be met by adjusting it to the new order. It has also occurred that Tetra Pak’s market companies visit the suppliers for e.g. test-runs of the machine, which would cause disturbance out of the ordinary procedures.

**4.5.2 Workstations at Mastec Stålvall**

In figure 4.11 a flow chart of the total sequences is shown. Preassembling of accumulators that are used in the assembly sequences of the base and the infeed unit is done at the accumulator sequence. The sequences from preassembling until docking there are input of parts and electrical kits from sub suppliers. There are also larger modules (e.g. electrical cabinet and the wrap unit) that are preassembled external and assembled at the sequences. There is an aspiration to have the assemblers assigned to a certain sequence over the day. However, depending on the order levels assemblers is moved frequently by the production leader to enable high flexibility in the manufacturing system. During low Takt-time the balancing of sequences can be done several times during the day. The development of the SOP sequence system has made it possible to move assemblers between the sequences without causing too much disturbance. In table 4.12 the amount of assemblers required at each sequence in the SOP sequence system is listed.

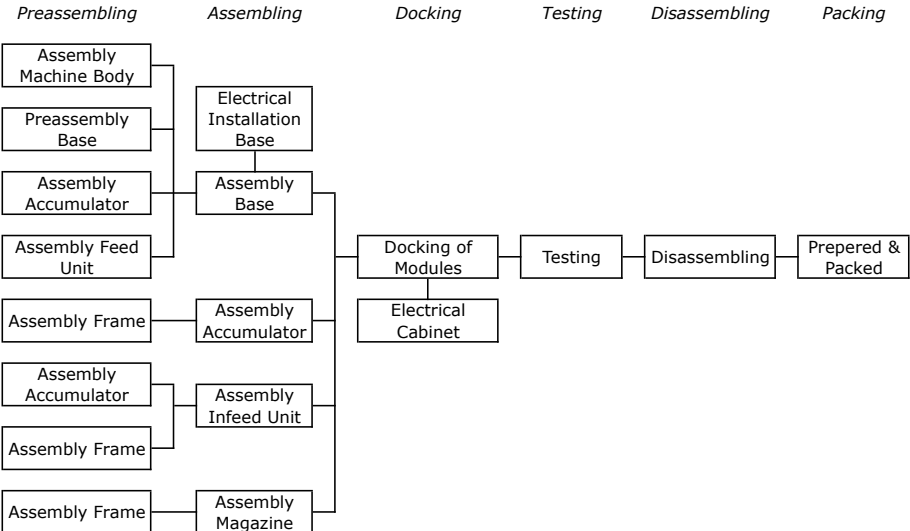


Figure 4.11. The flow between sequences at Mastec Stålvall

**Table 4.12. Number of assemblers at each sequence and the man-hours per sequence**

<i>Sequence</i>	<i>Number of assemblers at each sequence</i>	<i>Man-hours at each sequence</i>
Machine Body	1	24
Feeder	1	23
Pre Base	2	16.25
Base	2	48.25
Electrical Installation Base	1	15
Magazine	2	56
Infeeder	2	44
Accumulator	1	23
Docking	2	35
Electrical Cabinet	1	7
Testing	2	42
Disassembly	2	6
Packing	2	29

The standardization work in place today at Mastec Stålvall consists of standardized picking stations, the start of working with standardized workstations, development of detailed sequences in workstations, its related SOP and work instructions. Mastec Stålvall has further developed the SOP sequence system for assembly since the one implemented from Tetra Pak is not detailed enough to be able to meet the required quality level, from Mastec Stålvall's point of view.

The standardized picking stations are based on that each workstation has a material carrier with only the components needed in that sequence, the carrier is depicted in figure 4.13. The assemblers at each workstation specifying their material needs on a daily basis to be replenished the following day from the stock. Larger components for accumulator, feed, infeed, and magazine are placed in the stock for major components. The assemblers are picking these components themselves. Some larger components are directly put out on the shop floor at each station without being placed in stock.



**Figure 4.13. Material carrier at workstations**

In figure 4.14 a workstation is shown with its 5S environment and in figure 4.15 its related SOP sequence system. Only the tools and material used at the workstation are present. Experiences assemblers together with the production leader have outlined the detailed sequences for each workstation. At the time this study is performed there are only

detailed sequences for the most complex ones but they are working on outlining detailed sequences for the preassembly as well.



Figure 4.14. Standardized workstation

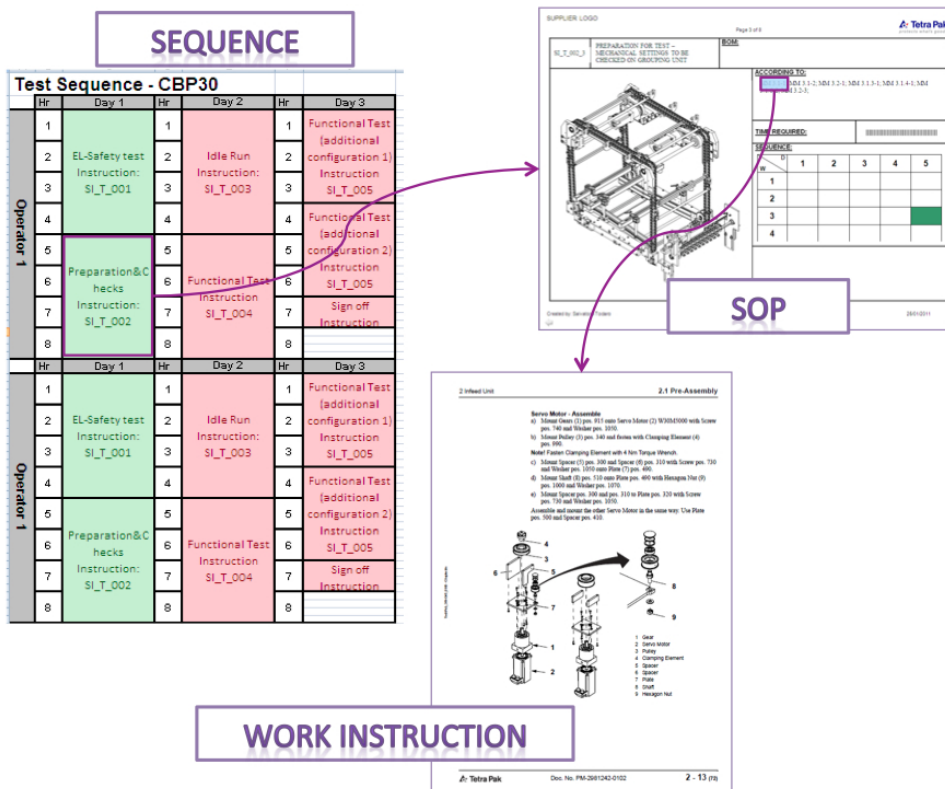


Figure 4.15. SOP sequence system at each workstation

To effectively handle the production, the production leader has developed support tools. One example of this is a competence list for the personal resources in the production to allow an optimal staffing of sequences based on their competences and knowledge.

### **4.5.3 Daily management system**

To handle the daily management in the workshop the production leader holds a daily meeting in the workshop that takes about 15 minutes. The agenda for the meeting covers safety, personal resources, material status (held by the operative purchaser), production status, orderliness at the workstations, internal tags, and others (e.g. informing about changes in the production speed the following weeks). The daily management board is updated with the material status and the current status in the production with either delivery on time, probable delay, or highly probable delay. It is then reported back to SCO-CE on a daily basis as discussed in the distribution equipment supply chain system.

### **4.5.4 Handling of NC and other losses at Mastec Stålvall**

#### **4.5.4.1 Claims**

The routines for handling NC's in terms of claims have its foundation in the daily quality meeting. The daily quality meeting takes place at 8 am every day and the activity is owned by one of the employees, working fulltime with handling NCs together with one other in the staff. The goal of the meeting is to check NCs in terms of claims to make everyone aware of the issues. Attending the meeting is the employee owning the activity, production manager, production leader, and operative purchaser. The basic outline of the meeting is to go out on the shop floor and look at the claims. Each NC has a report associated with it and an assembler is responsible for presenting each NC. These should then be tracked with the use of 5-whys before 12:00 that same day. The 5-whys analysis is presented to the production leader and 24 hours later a solution should be implemented. Finally, the solution is followed up to see that it has been standardized. NCs that can be traced back to suppliers are not handle within this timeframe. The goal here is to have an answer within 14 days from the time it has been traced to the supplier. Claims are registered on the basis such as administrative cost, adjustment cost, working cost with its related working time. The number of claims received is directly connected to one of their KPIs and production OPIs related to quality.

#### **4.5.4.2 The AM system (Internal NC, supplier NC and other losses)**

Mastec Stålvall has implemented a tagging system during 2010, called AM system. The AM system is a production improvement system to handle losses detected in the assembly system. It handles all internal NCs, sub supplier NCs (Tetra Pak nominated and supplier nominated) and other losses that are detected in the assembly system. Internal NCs and sub supplier NCs, that is requested by Tetra Pak to be collected, and other losses such as missing material are handle inseparably in the tagging system and are called internal tags. The internal NCs and sub supplier NCs according to Tetra Pak's definition is compiled and sent back to Tetra Pak.

When an issue is identified, assemblers tag it as an internal tag at either one of the four computer stations located on the shop floor. In the final testing phase the tags are logged initially on a paper form to later be logged in the AM system after shipping. This is the procedure to minimize time losses from logging the issues at this phase and to ensure that no issues are disregarded.

The assembler that identified the issue add to the AM system information such as in what sequence of production it was detected, what sequence it can be traced back to, group of tags (quality, documentation, lack of material, material handling, production equipment, n/a), estimation of time spent on loss, choice of action, if there were no action the

assembler can suggest course of action, description of the problem, and to which function it is to be sent. Under each tag group there is also a possibility to specify further the type of issue in a predetermined list. This is, however, not specified most of the time. The production leader is receiving the tags most of the time (more than 90%), otherwise it is sent directly to the function responsible for the activity (e.g. purchasing, material handling). If possible, the production leader immediately adjusts the tag.

The AM system receives between 200 and 300 tags monthly, see appendix D. To handle the large amount of tags they are gone through by the production leader on a monthly basis, grouped together on the basis of similarity or sequence in the production where they occurred, and prioritized on the basis of how critical they are. This in turn is based on either the number of tags in that group or the amount of time spent to adjust the tag group. The time spent on the tag is derived from the AM system where the assembler can estimate the time spent on the loss. The production leader then controls if the time loss reported is reasonable otherwise it is adjusted. On the most critical groups of tags the production leader conducts a 5-whys together with one or two of the assemblers. The production leader is also analyzing them and looks for trends where and why the tags occurs. The most recent tags, solutions to previous tags, and new standards in place are discussed on the daily management meeting in the workshop. The purpose of this discussion is only to lift up the awareness of the tags, not to solve any of these at that time.

Looking at the different sequences and where the tags have occurred, the production leader has seen a clear correlation between a high number of tags and a high turnover in personal or the amount of components assembled in a sequence. The production leader has identified the assembly sequence of the magazine as one of the most critical ones in terms of amount of tags. He has also seen that changes in the product specification from Tetra Pak D&E result in a higher number of tags. Other observation from Mastec Stålvall is that some of the assemblers feel that the collecting of losses in the AM system is too complicated.

Key findings from analyzing internal tags in the AM:

- Similar problems are added under different types of issues within a group. E.g. missing part in the material carrier (lack of material) are placed under “shortage”, “wrong number of components”, “cannot find” etc.
- An issue that frequently occurs is estimated on the time it has caused in total and is tagged only ones.
- Very rough estimations of time (typically 0.5 hours intervals).
- Lack of material is one of the most tagged issues.

In appendix E a list of different types of tags that the author has identified is presented.

#### **4.5.4.3 ECR**

ECRs are partly handled outside of the AM system. However, ECRs according to Tetra Paks’s definition of NC is tagged in the AM system, such as deviations in specifications, drawings etc. from D&E. The other part of ECRs that are related to improvement of the product design to enhance assembly performance has been observed being tagged in the AM system. These are otherwise mostly handled outside of the AM system.

#### 4.5.4.4 Summary of the handling of NC

In figure 4.16 a summary of the collection of NC at Mastec Stålvall is shown. The NC that relates to Tetra Pak order management and OTIF are logged manually.

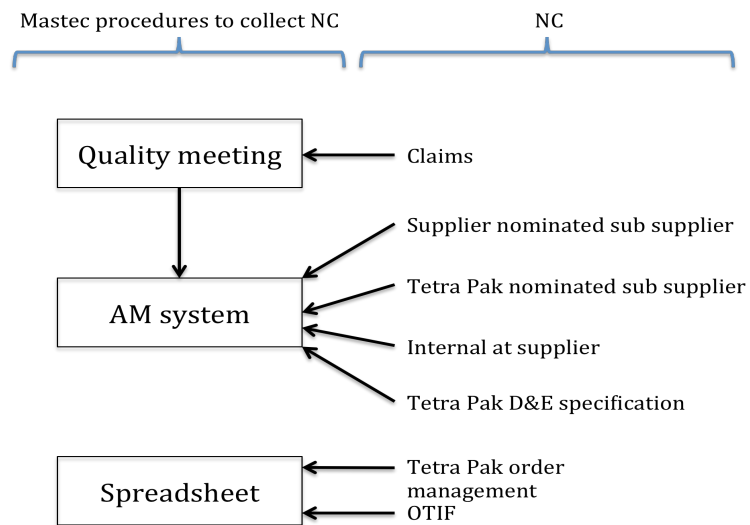


Figure 4.16. Mastec Stålvall's procedures to collect NC

## 5 Analysis

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*In this chapter the analysis is presented of how the next step could be taken in the development of Mastec Stålvall by implementing the FI pillar methodology. The analysis is based on the information presented in the theoretical framework together with the data gathered in the empirical framework.*

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### 5.1 Foundation for implementing the FI pillar

#### 5.1.1 FI pillar methodology in manual assembly system

The scope of this thesis is the implementation of the FI pillar in Tetra Pak's WCM methodology that uses TPM's FI pillar methodology for continuous improvements. There is, however, a relationship between the FI pillar and the other pillars in the methodologies but this falls outside the scope of this thesis. Although it is important to highlight the fact that this relationship exists and a FI pillar implementation will affect the other pillars, if implemented. The FI pillar fulfills the same purpose in Tetra Pak's WCM as in TPM and is typically the initial pillar to be implemented to support an implementation of the remaining pillars.

The FI pillar's main purpose is to systematically identify and eliminate the 16 losses with the goal to achieve improved system efficiency, where OEE has a central part for driving this improvement. The FI pillar include all activities that maximize the overall efficiency of equipment, processes, and plant by eliminating or minimize losses, and to improve performance. Looking at this very foundation of the FI pillar concept it is also applicable in the context of a manual assembly system. However, the losses that exist in a manual assembly environment are of a different kind from those in an automatic assembly environment and the efficiency measure OEE that is typically used is mainly related to equipment.

#### 5.1.2 The need to measure at suppliers

To be able to drive efficiency improvements the very foundation is to quantify losses and therefore to measure these. OEE has a structure that enables guidance of improvements through grouping and classification of the losses related to different aspects of equipment losses. It is important to point out that OEE is not measuring on the basis of all 16 losses related to the TPM methodology, but only focusing on the 8 losses impeding overall equipment efficiency. Therefore, it does in fact not capture all losses in the system. In a manual assembly system there are often more people than workstations and the assemblers have the correspondent role as the equipment in an automatic assembly system, the people working in the system control the pace. Therefore losses will first and foremost depend on the assemblers. It would certainly be valuable to have a measure of similar characteristics as OEE in place in a manual assembly system to drive the efficiency improvement and help the production personnel to identify where to spend their improvement resources.

Tetra Pak is today measuring several aspects of their suppliers. The OTD system in place captures the lead-time at the suppliers and the quality improvement system with the collection of NC captures some of the losses impeding the efficiency of the outsourced production. The losses are measured on the amount of NC detected in the distribution equipment supply chain system. To use this data to guide efficiency improvements at the



suppliers has its limitations. Hence to quantify the data with using a time-based measure would be preferable. Several of the advantages to use time when measuring productivity are favorable for the use of an efficiency measure in this context. Since the measure's main purpose is to drive internal efficiency improvements as an operational performance indicator, it is important that the metric is easy for everyone to understand and can give instant feedback to the assembler, which time can facilitate. Furthermore, time also enables comparison between assembly systems (independent of cost structure) and comparison between countries (independent of currency) that could make it favorable for the purpose of this measure. The reasons for this will be discussed later in section 5.7.

In figure 5.1 the major components of continuous improvement loop related to the FI pillar is depicted. Data is systematically collected on losses in the assembly system to form the basis of a measure that will enable guidance of the improvements efforts so that target losses can be eliminated or minimized.

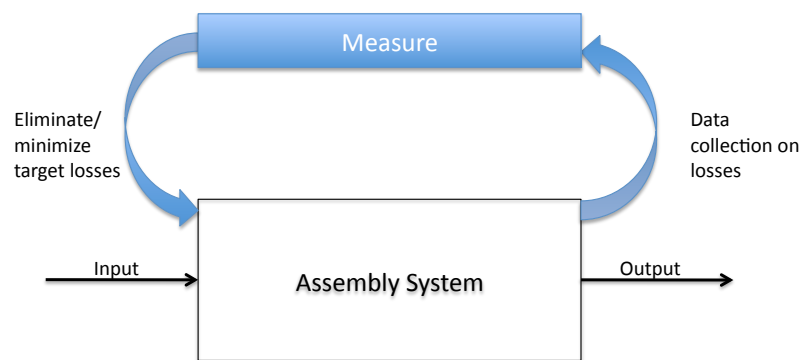


Figure 5.1. FI pillar efficiency measure

### 5.1.3 The foundation for implementing the FI pillar at Mastec Stålvall

Tetra Pak's development of Mastec Stålvall's production system so far has laid the foundation for the possibility to implement the FI pillar. The development of a SOP sequence system has enabled tracking of losses internally and created a standardized way of working, which is crucial to be able to systematically identify losses in a structured way. Mastec Stålvall's work with standardizing workstations and material handling would also facilitate this. The standardization work together with the implementation of a Takt-system has created a relatively stable production environment.

The resistance to collection of data is often an issue that is challenging to overcome. Tetra Pak's quality improvement system for collecting NCs has started to create a culture of collecting data at the suppliers which could ease this initial resistance to the data collection. Mastec Stålvall has also started to collect other losses such as missing material at workstations, which could be seen as an indication of a willingness to further develop the collection of losses. There have also been clear indications of commitment to handle the efficiency losses in a more effective way by management, e.g. production leader has requested estimations of time spent on losses from the assemblers. Hence the commitment on a management level seems to exist. Thus the author believes that there is a good foundation to implement the FI pillar and an efficiency measure at Mastec Stålvall.

## 5.2 Measuring efficiency at Mastec Stålvall

### 5.2.1 Efficiency at an assembly system level and the groups of losses

The measure proposed by the author is a time-based efficiency measure based on Tetra Pak’s OOE. It has been modified to fit the specific requirements for this study and is referred to as Assembly System Efficiency (ASE), to not be confused with OOE. The overall calculation of ASE is the same as Tetra Pak’s OOE. The main difference lies in the handling of speed losses, which are collected in Tetra Pak’s in-house production. This has been made to simplify the measure for an initial implementation.

Losses in terms of NC and some other issues are collected at Mastec Stålvall today. However, it is difficult to identify to what extent they are in fact collected. By establishing an overall measure based on the predetermined standard cycle time the risk of not capturing all losses impeding the overall efficiency of the assembly system is minimized. Losses that are not collected will be captured in speed losses, thus the author believes that this will create an inducement for the supplier and the assemblers in the assembly system to in fact collect all losses. To be able to calculate the efficiency and track losses at Mastec Stålvall the time elements shown in figure 5.2 need to be collected. Total time is here the total time that assemblers are registered for work in the assembly system. Each component should be collected in man-hours.

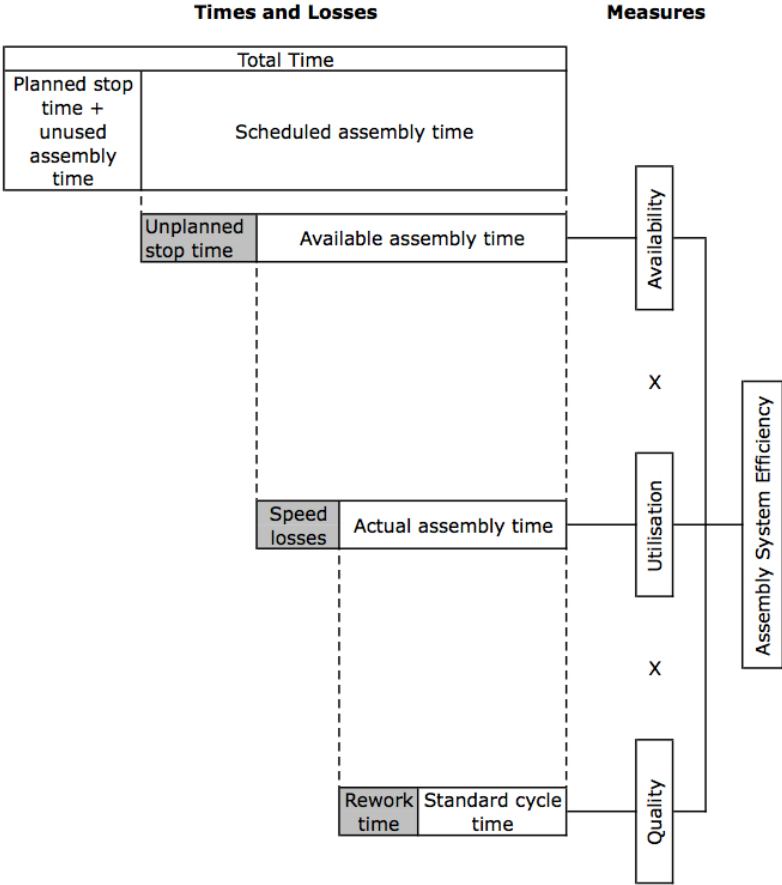


Figure 4.2. Time element is ASE

The calculation of ASE:

$$ASE \text{ (modified OOE)} = \frac{\sum_i^N t_{STi}}{t_{SAT}} \cdot 100$$

Input parameters

- $t_{SAT}$  = Scheduled assembly time (man-hours)
- $N$  = Number of assembled machines (units)
- $t_{STi}$  = Standard cycle time for machine  $i$  (man-hours/unit)

### **Number of assembly units**

Number of assembly units is referred to the number of machines assembled in the system during the measured time interval.

### **Scheduled assembly time**

At Mastec Stålvall the scheduled assembly time per machine is collected manually today. This would provide the ASE with the scheduled assembly time during the measured time interval in the assembly system.

However, a further development of collecting planned stop time and unused assembly time due to lack of orders would be valuable to reveal the overall efficiency of the system, that is Tetra Pak's OE measure. This could for example be established by extracting the total time registered for assembly from Mastec Stålvall's system for logging working hours in the assembly system. This would provide the time available for assembly where unused shifts, absence due to sickness etc. is excluded. The collection of planned stop time and unused assembly time due to lack of orders would then have to be established. This would include time spent on e.g. the daily meeting in the workshop, training of assemblers, and working with focused improvements etc. The collection of this data would have to be established at Mastec Stålvall if this would be introduced.

### **Standard cycle time**

The standard cycle time is the time from the start of assembly until the finished machine is ready for shipment. But the external assembly of the wrap unit and the electrical kit is not seen as a part of the system and are handled as a sub supplier. The standard cycle time should be chosen carefully since the efficiency is calculated directly on the basis of this. To determine the right standard cycle time is very challenging in a supplier development environment since this would most likely be related to the business side of the relationship. Thus a separation of the standard cycle time from the business side of the relationship would be needed, to be able to establish a correct assembly time. This fall outside of the scope of this study. However, there should be a possibility to adjust the standard cycle time without affecting the business side of the relationship. For example Tetra Pak should never target the suppliers profit area thus the possibility to adjust the standard cycle time would be possible. This is also related to that there is a risk that suppliers feel threatened by Tetra Pak that they use the results from the measure as leverage in the business relationship. It is first and foremost an OPI that is used to guide improvements. By using it as leverage in the contract negotiation could result in false collection of data, thus loose it purpose.

There ought to be a willingness from the supplier as well to establish a standard cycle time that are accurate since this would allow a more correct guidance of improvement

work. The actual standard cycle time of CBP 30 need to be established and separated from the business side of the relationship before the implementation of the FI pillar could be initiated.

Another aspect that needs to be discussed is however there should be an average standard cycle time or a standard cycle time for different configurations. CBP 30 has a standard cycle time of 369 man-hours today. There are differences between the assembly time of different configurations of CBP 30 but these are relatively small, the production leader estimates it to be 10-20 hours in assembly between the two configuration extremities. However, the author believes that to not affect the efficiency measure it would be preferable to not have an average standard cycle time. This would allow an evaluation of the assemblers' performance on the basis of how well they utilize the assembly system under given conditions. Thus also enhance the trust in the measure from the assemblers. Figure 5.3 show the problem with having an average standard cycle time and not be able to separate losses and the differences in standard cycle time.

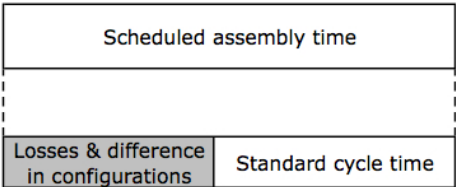


Figure 5.3. The problem with having an average standard cycle time

**Reduced availability – Total unplanned stop time**

Total unplanned stop time includes all man-hours related to losses that do not depend on the assembler such as missing material, breakdown of equipment etc. To enable a good loss deployment it is important to collect all man-hours related to losses that influence the amount of available assembly time. These are otherwise captured in speed losses due to the formation of this calculation and would therefore aggravate the possibility to find the root cause for these losses. Unplanned stop time will be further discussed in section 5.2.2.

**Reduced utilization – Speed losses**

At Tetra Pak's in-house production speed losses are in fact collected. In ASE the calculation will instead capture to what extent there exists speed losses in the assembly system, this to simplify the data collection procedures. Speed losses will include losses such as assemblers not working at full pace, minor stoppages, learning losses and over employment. This will be discussed in section 5.2.2.

**Reduced quality – Rework time**

Rework time would include time spent on quality issues detected within the assembly system that can be derived from internal activities, sub supplier, Tetra Pak D&E or Tetra Pak market company. The collection of data related to quality issues is today done to some extent at Mastec Stålvall. This will be further discussed in section 5.2.2.

## 5.2.2 Classification of losses and its related loss types

Similar to OEE a classification of losses can be formed to support the guidance of improvements. To enable the possibility to reach synergy effects with Tetra Pak's in-house production the classes are kept as similar as possible. In figure 5.4 classes of losses suggested by the author are depicted with their relation to loss groups.

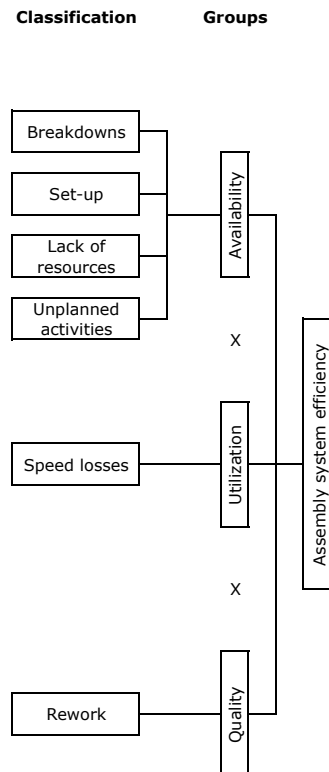


Figure 5.4. Classification of losses in ASE

The loss types that are described below have been identified as the internal and external factors that impede the efficiency of the assembly system. In appendix F a more detailed description of the loss types are provided. One of the reasons that the losses are of a more generic nature is that it would be preferable in the initial data collection to minimize the risk of relating the losses to wrong loss types. Although, there is of course a tradeoff between how detailed the loss types needs to be and the efficiency of loss deployment. The losses are collected on the basis of the assembly sequence it is related to, i.e. where it was detected or can be derived from. This means that each loss type exist as:

- Machine Body
- Preassembly base
- Base
- Electrical installation base
- Feed unit
- Accumulator
- Magazine
- Infeed unit
- Electrical cabinet
- Docking
- Testing
- Disassembly
- Packing

### **Breakdowns**

This class is related to equipment breakdowns that are beyond human control. A separation is made between the tools belonging to the standardized workstation and the equipment used in the overall assembly system. The class is separated into these types of losses:

- Equipment failure (overhead crane, Helix test machine etc.)
- Broken tools (tools designated to the standardized workstation)

### **Lack of resources**

Lack of resources are referred to as production hours wasted due to lack of necessary resources, as in lack of material or lack of personnel. A separation is made between lack of parts/components that can be derived from the internal material handling and sub supplier due to the difference in source. It also includes sequence-balancing issues such as waiting for other sequences and personnel. The class is separated into these types of losses:

- Lack of equipment (equipment not related to standardized workstation)
- Lack of parts/components – internal material handling
- Lack of parts/components – not delivered from sub supplier
- Waiting on other sequence (loss due to preceding/succeeding sequence)
- Lack of assembler (to perform assembly operation when more than one assembler is needed)

Today, a major part of the internal tags made at Mastec Stålvall is lack of parts/components in the assembly. It can be questioned if the loss deployment is sufficient here and further expansion of this loss type might have been preferable. But the author believes that to ease the initial implementation as a first step it could be divided into these two types and be further developed later on.

### **Set up**

These are time losses related to preparatory maintenance of the standardized workstation. It could be argued if this should be considered as a loss since it can then be ignored in an attempt to improve the efficiency. Although this would most likely result in reduced efficiency in the long run. So there is a tradeoff between minimizing the time spent on preparatory maintenance and the efficiency in the long run. It is related to the standardized workstations and is separated into these types of losses:

- Missing tools at workstation (tools designated to the standardized workstation)
- Missing documentation at standardized workstation (drawing, detailed sequence, shortage list on material carrier etc.)
- Preparing workstation (not fulfilling workstation standard for orderliness)

### **Unplanned activities**

Unplanned activities include activities that are requested by Tetra Pak Market Company and are out of the ordinary activities, such as a test run of the finished equipment.

### **Speed losses**

Speed losses are calculated through the efficiency measure, thus it is essential to have the right standard cycle time to reveal the true speed loss. It captures speed losses on a system level thus it cannot be traced to each sequence. Speed losses covers all losses that are related to the assembler not fulfilling required working pace in the assembly system and include time smearing, minor stoppages, minor assembly mistakes, learning losses, and

over employment. These types of losses are often hard to measure but it would of course be preferable to break out these from this large loss group. The author believes that in an initial implementation phase the data collection should be kept as simple as possible although still enabling a fair loss deployment.

There is, however, some issues with including speed losses in the efficiency measure. E.g. speed losses will capture learning losses that would occur when changes are made in the product design or from inexperience assemblers. It is important to be aware of this initial loss when using the efficiency measure since the value of efficiency will certainly be affected. This is one of the issues with using this measure in a short-term perspective. However, it would also highlight the actual cost of introducing changes in the machine design or hiring new personnel and thereby highlight the need to take preventive measures to handle this change, such as training.

Furthermore, depending on the standard cycle time the speed loss could actually be a “speed gain”. If assemblers are working at a higher pace than the predetermined standard cycle time the speed loss could take a positive value. However, if this frequently occurs it should indicate that the standard cycle time is too low and needs to be adjusted. This is closely related to the discussion about separating the standard cycle time from the business side of the relationship to be able to adjust it.

### **Rework/Defect**

These are losses that depend on quality problems detected within the assembly system that can be derived from internal activities, sub supplier, deviations in D&E specification or changes from customer. A separation is made between wrong mechanical setting and wrong electrical setting due to the difference in competence for these assembly operations. When using the measure as feedback to the assemblers it is of course important to separate rework created by the assembler and those depending on external factors. It includes these types of losses:

- Wrong mechanical setting (internally)
- Wrong electrical setting (internally)
- Wrong part/component assembled (internally)
- Defect on part (created internally)
- Deviation in specification (internally)
- Defect on part (sub supplier)
- Deviation in specification (D&E)
- Rework due to changes in configurations (Tetra Pak Market Company)

To get the rework loss types related to each sequence can be quite challenging. There should be an aspiration to link reworks losses to the right sequence if possible. Each sequence should carry the rework losses that are related to the part/components they assembled. So when receiving a module from previous sequence with quality issues it should be linked to that previous sequence. If this would not be done the right picture of where losses occur would not be possible to be established. The author believes that this would be needed to enable a satisfying loss deployment. Also to be able to separate if losses depend on internal or external factors, this tracking has to be made anyhow.

### 5.2.3 Measuring efficiency on a sequence level

The proposed efficiency measure has so far been discussed on an assembly system level as depicted in figure 5.5. It is of course preferable to measure the entire assembly system to capture all losses and not risking any sub optimization by focusing on only one assembly sequence. The overall lead-time of the assembly system should be superordinate each individual sequence lead-time to improve the system as whole. Also by measuring the entire assembly system instead of only a sequence the risk of creating an attitude of “we-against-them” among the assemblers would be avoided. This could otherwise result in spending more time relating losses to the right sequence instead of solving the issues in a constructive way.

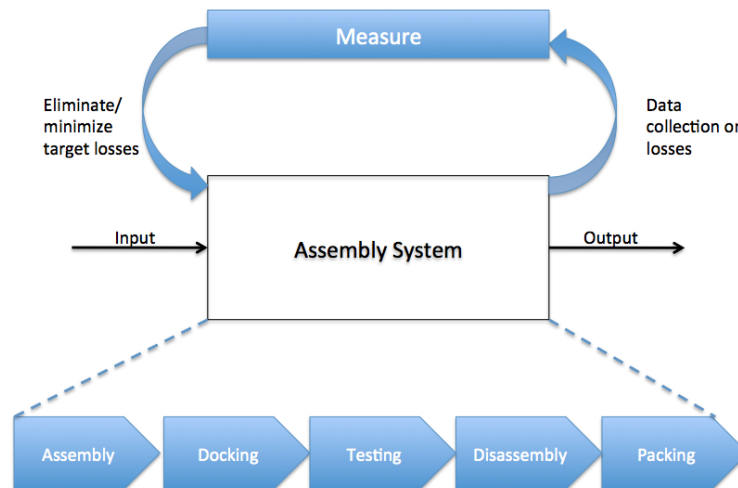


Figure 5.5. Measuring efficiency in the entire assembly system

There are, however, some benefits of measuring on a sequence level. Speed losses could be traced back to each sequence, thus it would ease the possibility to find the root cause for speed loss. Also an initial implementation of an efficiency measure on a system level would most likely result in failure due to its complexity. So in an initial implementation it would be preferable to start with one assembly sequence to set procedures of data collection and identify problems that might occur in an implementation phase. This could later be replicated to other sequences to finally embrace the whole assembly system. An initial implementation at one sequence with efficiency issues would also prove the necessity of measuring and hopefully create an awareness of issues and a commitment from the assemblers to move on to a full implementation. Countermeasures that have been identified could also be replicated to similar sequences i.e. within the assembly sequences due to their similarity.

To get the true efficiency of a sequence the calculation would be as depicted in figure 5.6. Rework within the measured sequence caused by modules from previous sequences are lifted out of the calculation, these are denoted system losses. Quality issues created at the measured sequence and detected in succeeding sequences are lifted into the calculation of efficiency to form the quality group. Thus the ideal assembly time is assembly time spent on assembling non-defect units. This means that loss types related to quality would exist both in rework within sequence and rework after sequence. OEE is based on the three aspects of performance; the time that it is available to operate, the speed of equipment, and the quality of the product. Similar, the true sequence efficiency measure would also be based on these three aspects of performance; time that is available to assembly, the



speed related to the assemblers, and the quality of the products. The calculation of the true efficiency and its related time elements are presented in appendix G.

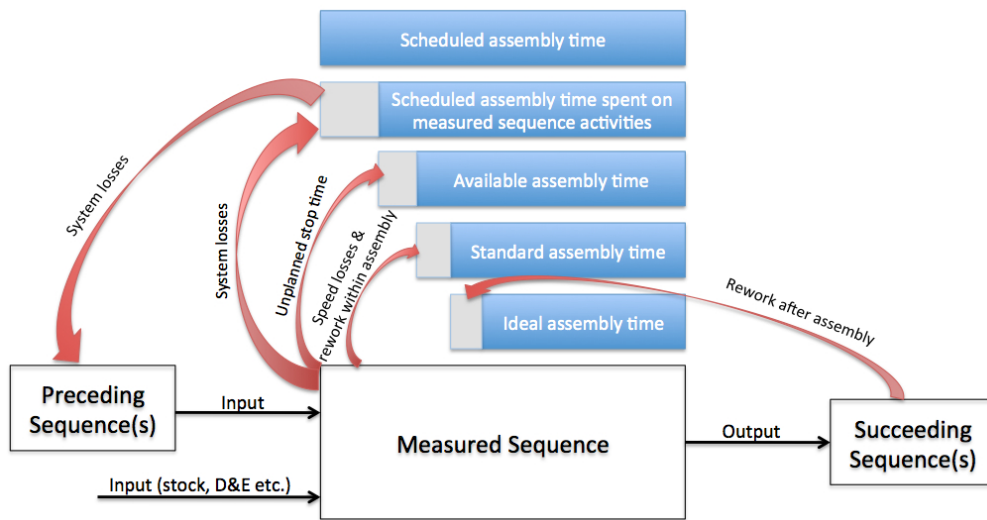


Figure 5.6. True efficiency in a sequence

The true efficiency would certainly be valuable to follow and could be a good complement to measure efficiency on a system level. However, for an initial implementation with the purpose of taking the initial step before embracing the whole assembly system it would be sufficient to start collecting losses affecting the standard assembly time. The time elements that need to be collected are shown in figure 5.7. One issue with this formation is the fact that the quality issues originating from the measured sequence is not captured in this sequence measure. The quality output rate is what cause most disturbances in the assembly system and would of course be valuable to follow on a sequence level as well.

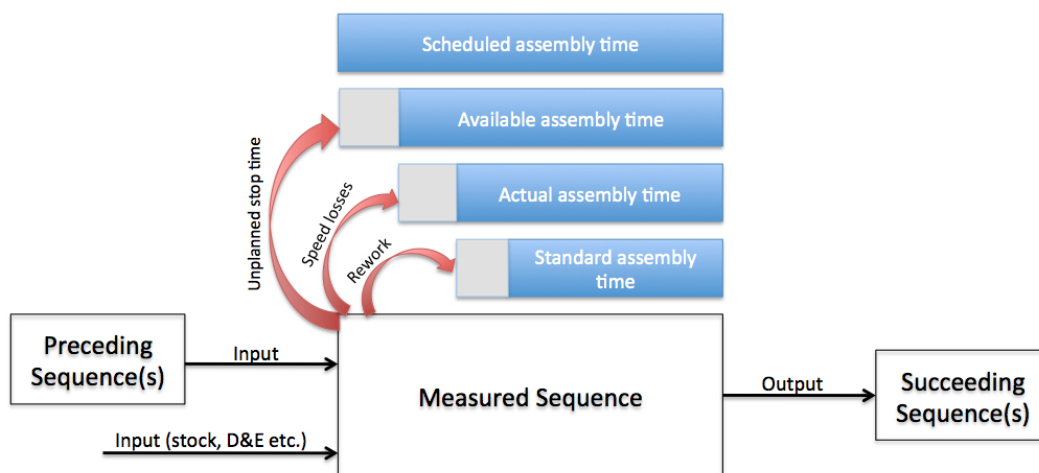
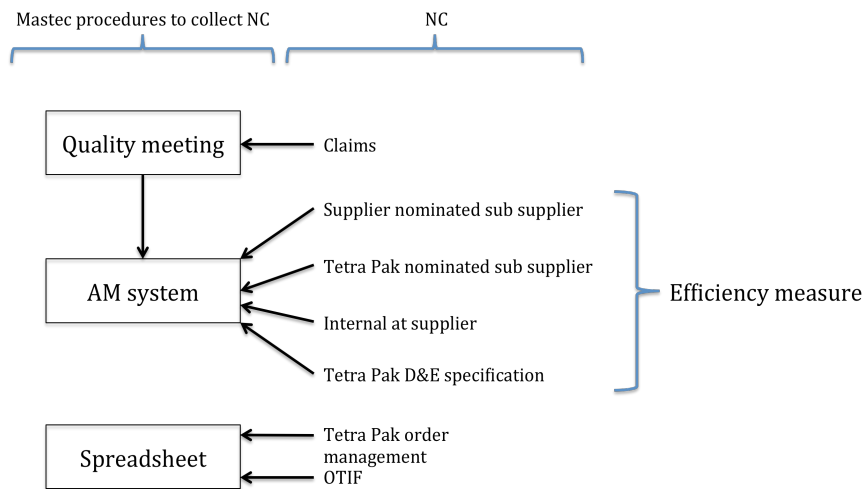


Figure 5.7. Time element of efficiency in a sequence

The loss types to be collected in the sequence efficiency measure are the same as on a system level. This would foster good data collection procedures with the assemblers and standard procedures for collecting losses could be further refined before a full implementation.

## 5.2.4 Family of losses

The relationship between the NC data collection in place today at Mastec Stålvall and the suggested efficiency measure are depicted in figure 5.8.



**Figure 5.8. Relationship between NC and the measure of efficiency**

The author suggests that a separation between the different types of losses need to be made on the basis of this relation between NC and the efficiency in the assembly system. This to support the quality improvement system that Tetra Pak has established, hence integrate the collection of losses with the already established data collection methods at suppliers. The family of losses would be as follows:

- Sub supplier NC (Tetra Pak nominated)
- Sub supplier NC (Supplier nominated)
- Internal NC
- Internal (not a Tetra Pak defined NC)
- Tetra Pak D&E
- Customer (Tetra Pak Market Company)

## 5.2.5 Compilation of the loss structure

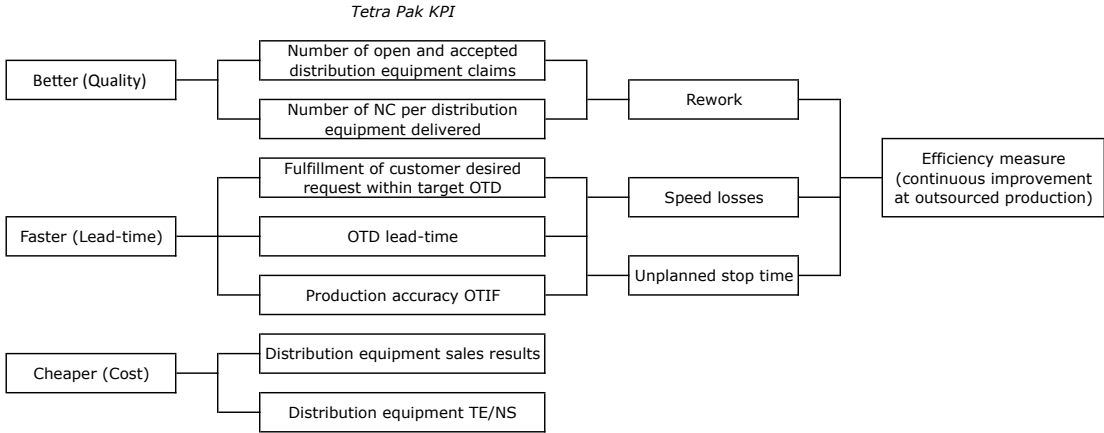
In table 5.1 the link between groups, classes, types, and families of losses are summarized.

**Table 5.1. The loss structure**

<i>Group</i>	<i>Class</i>	<i>Type</i>	<i>Family</i>	
Availability	Breakdowns	Equipment failure	Internal	
		Broken tools	Internal	
	Lack of resources	Lack of equipment	Internal	
		Lack of parts/components – material handling	Internal	
		Lack of parts/components – not delivered from sub supplier	Internal	
		Waiting for other sequence	Internal	
		Lack of assembler to perform assembly activity	Internal	
		Set-up	Missing tools at workstation	Internal
	Missing documentation		Internal	
	Preparing workstation		Internal	
	Unplanned activities	Unplanned activity from customer	Tetra Pak Market	
	Utilization	Speed losses	Speed losses	Internal
	Quality	Rework/Defect	Wrong mechanical setting	Internal NC
Wrong electrical setting			Internal NC	
Wrong part/component assembled			Internal NC	
Defect on part (internally)			Internal NC	
Deviation in specification (internally)			Internal NC	
Defect on part (sub supplier)			Sub supplier (TP nominated)	
Defect on part (sub supplier)			Sub supplier (Supplier nominated)	
Deviation in specification (D&E)			Tetra Pak D&E	
	Rework due to changes in configurations	Tetra Pak Market		

**5.2.6 The efficiency measure in the supplier-buyer environment**

When introducing a new measure several aspects need to be taken in consideration. First and foremost, a performance measure should be based on competitive priorities and be consistent with other performance measurements at all levels. So in a supplier development environment the measure has to be aligned with and support Tetra Pak’s KPIs for distribution equipment but also the suppliers. Referring to the KPIs presented in appendix B, an efficiency measure will support several of these. Figure 5.9 shows the linkage between the efficiency measure and Tetra Pak’s KPIs for distribution equipment.



**Figure 5.9. The efficiency measure’s relationship with SCO-CE Distribution Equipment KPIs**

By establishing the actually cost in terms of time losses of rework and defects the quality awareness could be considered to be increased at the outsourced production. Similar, speed losses and unplanned stop time would have a positive effect on the lead-time. In figure 5.9 it can also be seen that no linkage is established between the costs dependent KPIs and the efficiency measure. However, the author believes these should be affected as well in terms of reduction of expenses in the long-term. This is related to the issue of sharing the costs and profits in a supplier development initiative as this one made by Tetra Pak. This will be discussed in section 5.7.

It is also crucial that the efficiency measure is aligned with the supplier’s competitive priorities and consistent with their measurements at all levels. Looking at Mastec Stålvall’s KPIs and OPIs there are no visible conflicts. There exist an OPI that is based on planned working hours divided with actually working hours, which is measuring the efficiency. It is also important to point out that the assembly system interacts with other parts of the company thus optimizing the assembly system alone could result in a risk of sub optimization. When implementing this measure much focus will of course be placed in the measured system, which could result in neglecting other parts of the production system. For example improving the efficiency in the assembly system by increasing the stock levels might not improve the overall efficiency at the supplier. So before an implementation is initiated there should be a discussion with the supplier about how it could affect their business and an alignment of there performance measurement system needs to be done.

## **5.3 The data collection problem**

### **5.3.1 The data to be collected on losses**

To be able to establish the efficiency measure and evaluate the losses for guiding improvements efforts certain data about the losses needs to be collected. The data collection should also support Tetra Pak's quality improvement system in place today. The minimum requirement of data that needs to be collected about the losses is as follows:

- Loss type
  - If a loss type is “defect on part” – specify part number (to separate Tetra Pak nominated sub supplier and supplier nominated sub supplier for Tetra Pak's quality improvement system).
- Machine serial number (track NC per machine and standard cycle times for different machine configuration).
- Identified at sequence (traceability).
- Time spent on loss by assemblers in man-hours for tracking and solving the loss.
- Sequence that the rework is related to (traceability).
- Description of loss (provide enough information for focused improvement on loss type and to put in counter measures).

### **5.3.2 Data collected at Mastec Stålvall**

Today, the data collecting procedures at Mastec Stålvall require information about the machine serial number, at which sequence the loss was identified, the part number on defect parts/components, and a description of the loss that is collected. Four major gaps were found in the collection of data that needs to be closed.

- The sequence that the losses are related to is collected to some extent and is in the implementation phase.
- The loss types existing today do not capture all losses impeding the efficiency of the assembly system and does not enable a sufficient loss deployment. Several of the loss types proposed by the author are tagged in the AM system. However, it is difficult to establish to what extent the losses are in fact collected.
- The time spent on losses is estimated by the assemblers and are not accurate enough to enable a satisfying guidance of improvements.
- There is also a major gap in the understanding from the assemblers about what should be collected as a loss. E.g. losses that are in fact suggestions of improvements on the standardized procedures are collected in the AM system. These should of course be encouraged to be collected but separately.

### 5.3.3 Suggestion of initial data collection at a pilot sequence

As discussed earlier, an initial implementation of a measure at a system level would most likely result in failure due to its complexity. Also an instant integration of data collection in the AM system would not be feasible according to the author. For this study an initial data collection procedure will be described for measuring efficiency on a sequence level as a first step to set data collection procedures and identification of losses. The time elements needed to be collected for the measure are shown in figure 5.10. Speed losses are not collected but calculated through the collection of the other time elements.

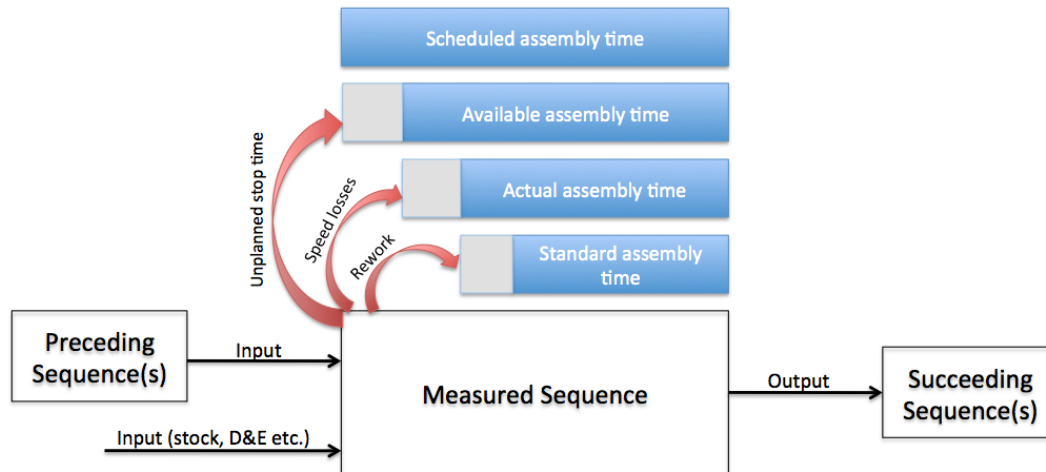


Figure 5.10. Time elements to be collected at an initial implementation

The proposed sequence for an initial implementation is the magazine sequence depicted in figure 5.11. It has several features that making it suitable as a pilot sequence.

- It is an assembly sequence, which would enable more possibilities to replicate loss elimination to other sequences since the majority of the time spent in the assembly system is in assembly sequences. This would later also enable a replication of the data collection procedures to other assembly sequences due to their similarity.
- It is a sequence with one of the longer assembly times, which makes it more stable in terms of movement of assemblers.
- The magazine has been identified as the sequence with most issues related to it hence it has large improvement possibility. An implementation at this sequence would create an awareness of issues and a commitment from the assemblers to move on to a full implementation.
- It only has one preceding sequence, the machine body. This is a less complex sequence therefore the amount of rework originating from this sequence would be minimized.

The author suggests that the initial data collection is done manually on a paper form and that time is measured with a clock at the pilot sequence. The following part of this section describes how this initial data collection procedure could be performed manually as a first step in the implementation of the FI pillar. However, it is important to point out that involvement from experience assemblers in the design of the collection form and the data collection station would be preferable. It would most likely increase the commitment to collect loss data and make the data collection more suitable for them.

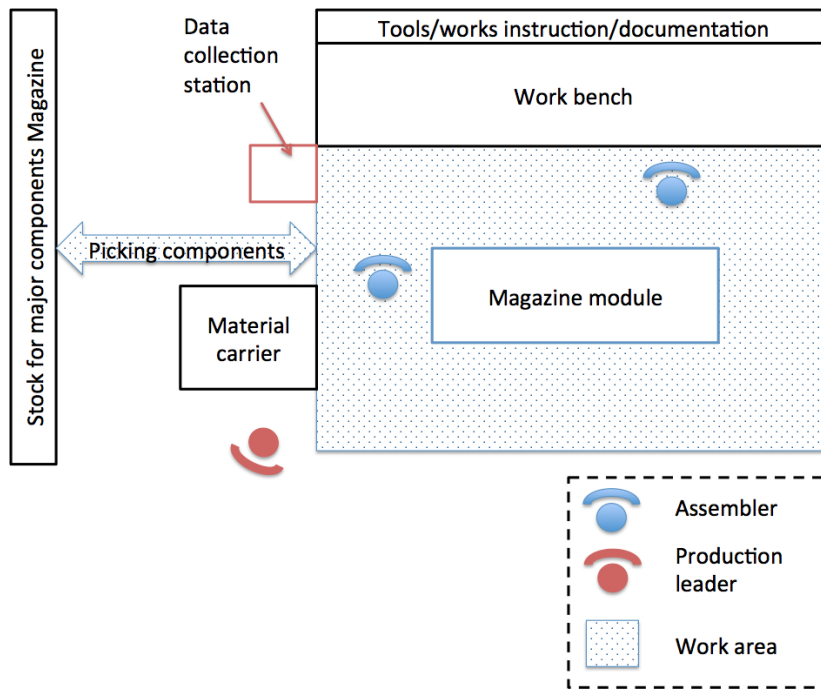


Figure 5.11. Initial data collection at the standardized workstation for the Magazine sequence

The data collection station shown in figure 5.11 consists of paper forms to collect scheduled assembly time and losses. It also holds start-and-stop timers to keep track of time spent on losses and a regular clock to be able to log the scheduled assembly time. This will be further described below. Visualizations of the results and progress from the data collection and the efficiency of the sequence should be done in connection to the data collection station to give feedback to the assembler and hopefully show the improvement over time.

### Data collection within sequence

#### *Scheduled assembly time*

One of the issues with measuring efficiency on a sequence is that the assemblers are not always assigned to a specific sequence at Mastec Stålvall, this to support high flexibility during a low Takt environment. Referring to section 5.2.3, scheduled assembly time at a sequence level needs to be collected. The author suggests that the assemblers working in the sequence initially collect this manually on a paper form at the data collection station. This would make it preferable to minimize the transfer of assemblers by the production leader at this sequence during the day. An example of a paper form to be filled out by the assemblers is shown in figure 5.12. The column for scheduled assembly time is for compilation at the end of the day by the production leader. Having an assembler at the measured sequence that is the owner of the data collection could be responsible for the right data is collected.

Assembler	Logging in at sequence	Logging out at sequence	Time spent on planned stop time	Scheduled assembly time

Figure 5.12. Paper form for collection of scheduled assembly time

### Collection of losses

The data to be collected are the loss types described in section 5.2.5 and it is of course essential that the assemblers collecting the losses have a good understanding about the loss types and how to collect them. In appendix H an example of a simple paper form for the assembler to collect losses on is presented. Losses such as unplanned activities would not exist in the magazine sequence and could be excluded to make the data collection easier for the assemblers.

A loss is an activity outside of the standard procedure and should be registered as soon as the assembler start working on the loss. One of the major challenges is of course the collection of time spent on losses. Most losses would be tracked and solved within the same time period, as depicted in figure 5.13. In the SOP sequence system the point when the loss is detected (start working on the loss) and when it is closed are the same.

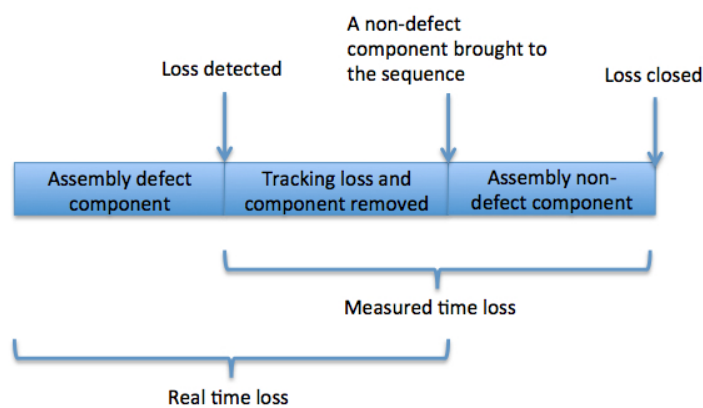


Figure 5.13. The collection of time when a loss is solved within the same time period

However, some losses might not be solved within the same time period. For example one scenario to illustrate this would be the assembly of a defect component where no components for substitution exist in-house but the assembler can continue in the sequence anyway, as depicted in figure 5.14.

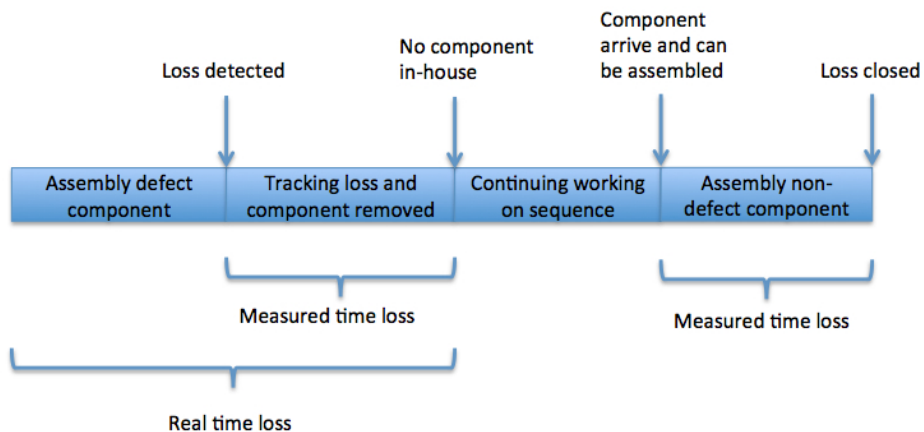


Figure 5.14. The collection of time when a loss is not solved within the same time period

To facilitate this issue, losses that are opened need to be distinguished from closed ones. For example losses that are closed are put away separately. These kinds of issues exist with many of the losses that depend on external factors and need to be handled efficient to enable a good data collection.



Another dimension to this problem, which would make it even more complex, is if a loss is detected in one sequence and the assembled module has to be moved to the next sequence before it is possible to close the loss. A solution to this would be to e.g. send the loss collection form to the next sequence with the module and it is solved there.

Another issue that needs to be solved is how much time the assembler should spend on tracking the loss. For example, a defect part in a module from preceding sequence is detected and needs to be solved to proceed, as depicted in figure 5.15. Should the assembler try to find the cause for this problem to decide if it is a supplier NC or a defect created internally. The author believes that e.g. the production leader has an important role here to support the assemblers in the tracking of losses, this to minimize the time loss in the sequences. Procedures for handling this needs to be developed in the initial implementation phase and having a support organization for handling the more time-consuming tracking would have to be established.

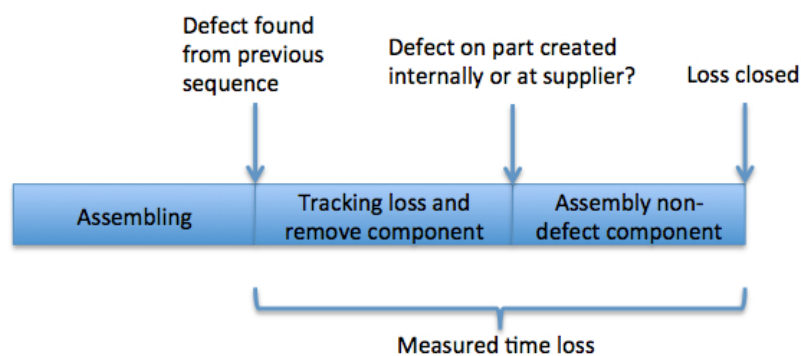


Figure 5.15. The problem with tracking loss types

The following procedure captures the basic outline of collecting a loss under regular circumstances.

1. Loss detected and need to be solved to proceed.
2. When starting to work on the loss, the start-and-stop timer is started to initiate the collection of time spent on the loss.
3. Track what kind of loss type it is.
  - a. The assembler should do the tracking of loss type if it is possible within a reasonable time frame.
  - b. If the loss belongs to a preceding sequence someone outside of the measured sequence should perform the tracking to minimize the time loss and the disturbance in the lead-time.
4. Solve the issue to the point in the SOP sequence system where it was detected.
5. Fill out the loss form and lastly the time spent on the loss.
6. Loss closed and the assembler proceeds with the assembling.

If a loss cannot be solved within the same time period the loss should stay open and additional time for assembling should be added before closing the loss.

### Data collection in succeeding sequences

When introducing these new data collection procedures at the magazine sequence the author believes it is important to keep track of the quality output from that sequence to assure that it is not affected. Therefore, in the initial implementation phase it would be valuable to keep an extra eye on the tags made in succeeding sequences to ensure that it does not result in increased quality issues.

### **Standard assembly time**

The same problems as discussed in section 5.2.1 around the standard cycle time would be related to the establishment of a standard assembly time.

### **5.3.4 Future development of data collection procedures**

One of the biggest challenges is to design the data collection so that it is less time-consuming but still provide the FI pillar with enough data for a good loss deployment. There is a trade-off between the gains of collection detailed data about the losses and the time loss the data collection in itself cause. This is first and foremost an initial issue that could cause disbelief from the assemblers to collect data. This is why the author suggests that a minimum of information about the losses is gathered to still provide enough information to facilitate good loss deployment but also enough information to support the tracking of NC.

The data collection in a paper form is very much an initial data collection procedure. A development of a less time-consuming but still accurate data collection system is crucial for a long-term effective implementation. The collection of losses is done today at either one of the four computer stations. This requires unnecessary motion losses by the assemblers. A data collection system at each sequence would be a better solution and would also enhance the possibility to register smaller time losses in the future. However, it is important to point out that an investment of this size would not be feasible unless there is a satisfying data collection procedure established on a sequence level.

The tracking of time is something the author believes is the main issue to be solved. Using a start-and-stop timer or similar is a solution that is most suitable during the initial implementation phase. To facilitate the different aspect of capturing time spent on losses as discussed section 5.3.3 would require a more complex tracking system to allow an long-term effective implementation of the FI pillar.

## **5.4 Eliminating or minimizing target losses**

Mastec Stålvall is today working with focused improvements in some aspects of the identified losses, applying tools such as 5-whys on their most critical groups of losses in terms of numbers of tags or estimated time spent on these tags. There also exist some resistance to the data collection at Mastec Stålvall in its current design. To further develop the data collection as proposed in this study would most likely increase that resistance. Therefore the author believes that it is crucial for the success in the implementation phase that the work with eliminating or minimizing target losses is undertaken immediately and strongly so results can be proven quickly. Otherwise there is a risk that the implementation loses its momentum and disbelief in using the measure with its collection of detailed loss data start to spread among personnel. Hence an organization for the FI initiatives need to be established early on together with well proven working procedures. Similar procedures and priorities as for the handling of claims discussed in chapter 4 could for example be established for working with target losses. The author sees this as partly Tetra Pak's side of the bargain in the supplier development.

A major part of this supplier development initiative is to transfer Tetra Pak in-house capabilities. Tetra Pak's in-house know-how and experience on how to organize for the FI pillar, effective tools and methods, and working with reducing target losses should be transferred to supplier. This means that Tetra Pak has to put in necessary resources in competence development at the supplier to set good working procedures before an implementation.

## 5.5 Obstacles to overcome with the measurement of efficiency

It is important to point out that the measure proposed in this thesis will only capture efficiency losses and not losses related to effectiveness. To improve the productivity of the assembly system, the effectiveness has to be improved as well, since productivity is a function of both efficiency and effectiveness. So if the efficiency is high and the effectiveness is low, it is important to realize that the improvement potential is greater within the losses related to effectiveness. The Value Stream Mapping that was conducted at Mastec Stålvall captured several of these losses such as the assembly system layout.

Another issue related to efficiency and effectiveness that the author could see is a lack of understanding with the assemblers what is actually measured. It is important that there is established an understanding of the measure with the personnel that are evaluated. The measure would only capture efficiency losses thus losses due to assembly system design and most of all due to the product design is not captured. The last part is especially important since this falls within Tetra Pak's area of responsibility. If the assemblers believe that the design of the machines, in terms of DFA, will affect their performance captured in the measure it will most likely result in disbelief in using the measure. So it is important to e.g. distinguish between ECR in terms of deviation in specifications from D&E and the possibility to improve the design to enhance assembly performance. However, DFA is an important part to increase the productivity in manual assembly systems, thus Tetra Pak should encourage supplier to collect these separately as well.

Furthermore, the robustness and stability of the measure to act as an indicator of achieved continuous improvements can be questioned. For example high turnover in personnel will result in learning losses that could affect the efficiency. But as discussed in section 5.2.2 it should work as an indication that these losses have to be dealt with. Changes in order will also affect the efficiency since over employment in the assembly system punishes the efficiency in the group of utilization. This is related to the flexibility of the assembly system. With the Takt system in place today the fluctuation of orders would be held relatively even during longer periods of time. Thus the possibility to adjust the number of assemblers in the assembly system would be possible. In-house at Tetra Pak, OOE has proven to have a certain level of robustness. However, the implementation of WCM in the in-house assembly system makes it, by far, a more stable system.

As discussed in section 5.2.2, including speed losses in efficiency could give some unwanted results. If assemblers were working at a higher pace than the standard cycle time, there would in fact be a "speed gain" instead of a speed loss. Also if rework losses and unplanned stop time are small and the assemblers are working at a higher pace than the standards cycle time, the value of the efficiency measures could take a higher value than 100%. This should, however, indicate that the established standard cycle time is too low and need to be adjusted. Hence, the importance of establishing a correct standard cycle time is central to be able to use the efficiency measure in an effective way.

It can also be discussed whether claims (quality issues after deliver) should be included in an efficiency calculation. It is, in fact, a part of the assembly system efficiency since the assembling of defect units should be considered as a loss. However, the efficiency improvement at the suppliers should be seen as a complement to Tetra Pak's quality improvement system and as discussed in section 5.2.6 it supports several of these aspects.

The resistance among the assemblers to implement this kind of data collection procedures could be a major obstacle to overcome. It has been observed at Mastec Stålvall that there exists a resistance to collect data among assemblers. This is something that Mastec Stålvall has to handle and is a key success factor for a successful implementation. The author has proposed several aspects such as to involve the assemblers in the design of the data collection procedures to raise the commitment. However, a further possibility would be to create a financial inducement for the assemblers in terms of an “improvement bonus” to raise the commitment. This should of course only be done at a system level.

Finally, the proposed measure only captures what the losses cause in terms of assembly hours. A further development of costs that are related to the loss in terms other resources such as indirect man-hours, energy usage etc. would be valuable to follow. Especially if a support organization for tracking the losses is created.

### 5.6 The implementation phases of the FI pillar

It is important to point out that the implementation of the FI pillar is a process and not a project. To have a clear implementation plan is a key factor for a successful implementation but changes will have to be made during the course of the implementation. Figure 5.17 show the phases of an implementation.

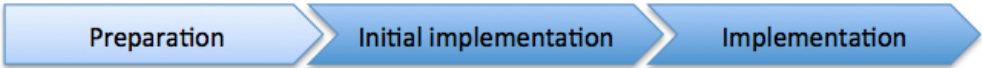


Figure 5.17. Implementation of the FI pillar

#### Preparation phase

Since the start of the implementation of the AM system in the beginning of 2010, Mastec Stålvall has been working with continuous improvements in a somewhat structured way. Hence, the culture change needed at the supplier to start work with the FI pillar methodology has in a way already started. However, the FI pillar is the most demanding pillar to introduce and successfully implement. To do this in a supplier development environment would most likely not be an easy step to take since to spread this kind of continuous improvements capabilities are very challenging. Thus, to create a steering committee at the supplier with Tetra Pak involvement for the implementation process would be preferable to ensure a long-term focus and a successful implementation.

When introducing the proposed measure for the assembly system, much focus is placed on reducing the losses impeding the efficiency in this part of the production system. Therefore, there is a risk of neglecting other parts of the production system e.g. increasing stock levels to improve the efficiency in the assembly system. This is something that the supplier needs to be aware of. An alignment of the efficiency measure with the supplier’s performance measurement system is therefore important at this initial stage to avoid sub optimization.

Furthermore, as discussed earlier, Mastec Stålvall is working with continuous improvement on the collected losses today. However, to implement data collection procedures as discussed in this chapter would require more of the assemblers and the existing resistance to data collection among the assemblers would most likely be increased. Thus it is essential that the work with reducing target losses according to the FI pillar be done initial so that the assemblers sees that it is more than just collecting the losses. Therefore, before the initial implementation, Tetra Pak together with the supplier has to ensure that a sufficient level of knowledge exist to work efficiently with focused

improvements and to compose efficient cross-functional FI teams. By starting to transfer this knowledge before the initial implementation also show the supplier that there is a commitment from Tetra Pak to put in resources for this implementation. This would most likely increase the commitment on a management level at the suppliers to implement the FI pillar.

The gap in knowledge about how to collect losses among the assemblers would also need to be closed before the initial implementation. Assemblers need to have a sufficient level of knowledge about the suggested loss structure to assure a correct collection of data. At this stage it would be preferable to also involve the assemblers in the shaping of data collection procedures to raise the commitment on the shop floor.

The overall calculation of ASE (OOE) needs to be established to visualize the true potential of improvement at the supplier, hence show the supplier where they stand in terms of efficiency. This would require that a standard cycle time is established and that the scheduled time for assembly is collected to get the efficiency, as discussed in section 5.2.1. To be able to follow the overall efficiency when taking the next step with an initial implementation on a sequence level is important as well. This to ensure that not all focus is placed on that sequence, hence neglecting the overall efficiency of the system.

#### **Initial implementation phase**

1. Run a pilot sequence by introducing the efficiency measure at the magazine sequence and start to collect losses according to the suggested procedures by the author in section 5.3.3.
2. Evaluate the pilot sequence and run additional pilot sequences if needed in other parts of the assembly system to identify problems that might not be found in the magazine sequence. The author believes that the testing sequence has a different loss picture compared to the assembly sequences and it would be valuable to run a second pilot there.
3. With the learning from the pilot sequences and if there is a top-down commitment at the supplier, a development of a less time-consuming but still accurate data collection system should be initiated. As discussed earlier the author believes that neither the data collection on a paper form nor the data collection system at Mastec Stålvall in its current design would facilitate these requirements.

#### **Implementation at a system level**

The last step would be to implement the data collection on a system level to capture the efficiency in the entire system and thereby in fact collect all losses impeding the overall system efficiency. This will create a focus on reducing the overall lead-time and the overall efficiency. A further development of the loss structure would be possible support a more efficient loss deployment. Also to further develop the system efficiency measure to include the tracking of planned stop time would be valuable to be able to follow time spent on these activities.

## 5.7 Standardized measure on a supplier level

As mentioned in section 5.2.2, it could be argued that the types of losses should be more detailed to allow a better loss deployment in the work with eliminating or minimizing target losses. However, besides having the initial generic loss structure to facilitate an easier collection of the right losses, it would also enable comparison between different suppliers through a standardized measure, depicted in figure 5.18. As mentioned earlier a time measure would enable comparison between different assembly systems (independent of cost structure) and also between different countries (independent of currency), which could make it possible to benchmark. Although, it could be questioned if the similarity of being a manual assembly system with the assembly, testing, disassembly, and packing activities are enough to perform benchmarking.

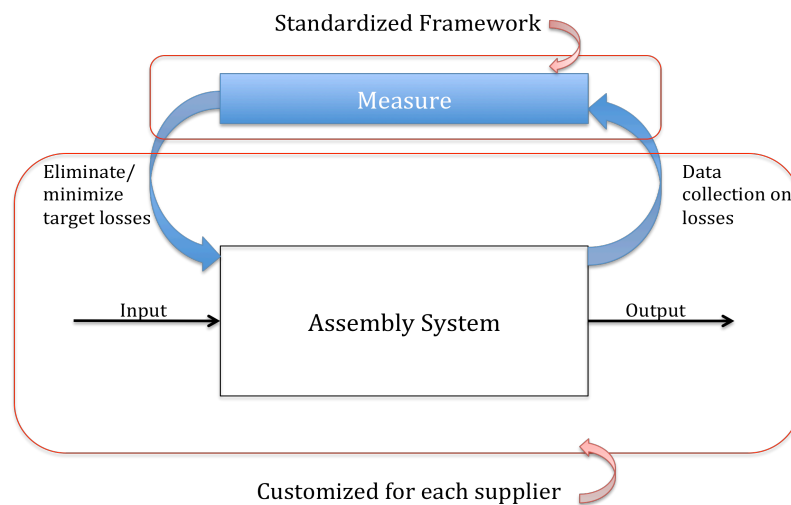


Figure 5.18. Standardized measure on a supplier level

However, the measure could ideally be used as a benchmarking tool to improve knowledge-sharing capabilities. By identifying suppliers that are top performer in certain aspects of the measure during longer time periods, the knowledge could be identified and transferred between suppliers. Thus using different suppliers as a source of improvement possibilities. Having this in mind when further developing the loss structure would be recommended. The other components of the efficiency measure shown in figure 5.18 need to be customized to each supplier. The data collection problem and how to work with the FI pillar methodology needs to be aligned with current data collection procedures and organizational structure at each supplier.

## 5.8 Supplier development aspects

As discussed throughout this chapter, the author suggest that the development of suppliers require resources both from the supplier and Tetra Pak. Referring to section 5.2.6, the author believes that there should be a connection between Tetra Pak's cost related KPIs and the development initiatives of the supplier. This falls outside of the scope for this study. However, it is important to highlight the fact that depending on the strategic purpose of this relationship there should be established a mechanism for sharing the costs and profits arising from this joint commitment. This is also closely related to the aspect of which member in the supply chain should carry the cost of losses collected at the outsourced production. Some of the losses are originating from Tetra Pak's operations and some of them from the suppliers. This is a complex problem in relationship management that has to be solved to enable a long-term effective implementation.

# 6 Result

*This chapter summarizes the key findings and results from this study in terms of how Tetra Pak could take the next step and implement the FI pillar's measures and procedures at the outsourced production of distribution equipment.*

## 6.1 Measuring efficiency at the outsourced production

The foundation for a FI pillar implementation at Mastec Stålvall has been identified to be sufficient. Several aspects of the supplier development initiated by Tetra Pak have created an assembly environment where losses could be systematically identified and eliminated. The tracking of NCs has created a culture of collecting losses, which would ease the initial implementation. Also indications of commitment to further develop the collecting of losses on a management level have also been observed at Mastec Stålvall, which is a key success factor for initiating such an implementation.

To measure efficiency in a satisfying way an overall time-based efficiency measure based on a predetermined standard cycle time would be preferable to establish. This would minimize the risk of not collecting all losses impeding the overall efficiency of the assembly system, thus create an inducement for the supplier and the assemblers within the assembly system to in fact collect all losses.

The author has proposed two measures that would drive efficiency improvements at the outsourced production. First, the ASE based on Tetra Pak's in-house efficiency measure OOE but has been modified to suit the requirements for the outsourced production and an initial implementation. It is intended to be applied on a system level, depicted in figure 6.1, and capture all losses that impede the overall efficiency of the assembly system.

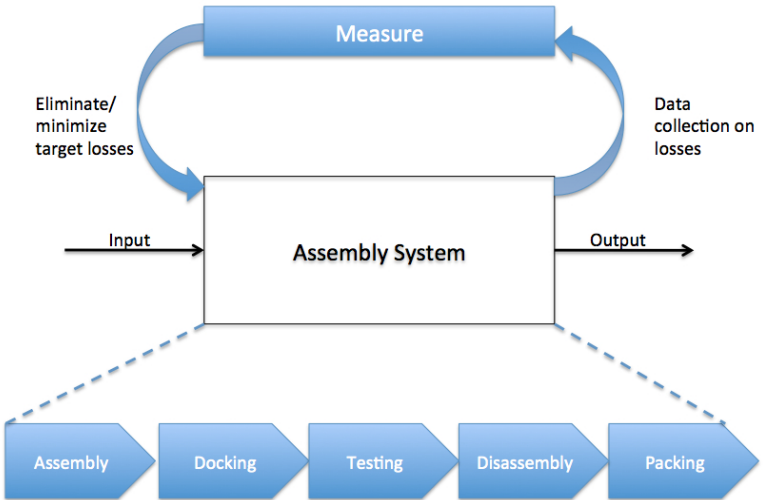


Figure 6.1. Efficiency measure on a system level

The loss structure related to the efficiency measure and the FI pillar are listed in table 6.1. The groups are related to different losses impeding the efficiency in terms of reduced availability, utilization or quality. Each group consists of a set of classes and its related loss types. The families of losses are constructed to support the quality improvement system already established at the outsourced production by Tetra Pak and differentiate

between losses created by different parts of the supply chain system. Speed losses are calculated through the collected time elements and are therefore not collected. There is of course a tradeoff between how detailed the loss structure should be and the efficiency of the loss deployment. However, the author believes that in an initial implementation the loss structure should be kept as simple as possible but still enables a fair loss deployment.

**Table 6.1. The suggested loss structure**

<i>Group</i>	<i>Class</i>	<i>Type</i>	<i>Family</i>
Availability	Breakdowns	Equipment failure	Internal
		Broken tools	Internal
	Lack of resources	Lack of equipment	Internal
		Lack of parts/components – material handling	Internal
		Lack of parts/components – not delivered from sub supplier	Internal
		Waiting for other sequence	Internal
		Lack of assembler to perform assembly activity	Internal
	Set-up	Missing tools at workstation	Internal
		Missing documentation	Internal
		Preparing workstation	Internal
	Unplanned activities	Unplanned activity from customer	Tetra Pak Market
Utilization	Speed losses	Speed losses	Internally
Quality	Rework	Wrong mechanical setting	Internal NC
		Wrong electrical setting	Internal NC
		Wrong part/component assembled	Internal NC
		Defect on part (internally)	Internal NC
		Deviation in specification (Internally)	Internal NC
		Defect on part (sub supplier)	Sub supplier (TP nominated)
		Defect on part (sub supplier)	Sub supplier (Supplier nominated)
		Deviation in specification (D&E)	Tetra Pak D&E
	Rework due to changes in configurations	Tetra Pak Market	

The second measure proposed by the author is measuring on a sequence level in Tetra Pak's defined SOP sequence system. It is first and foremost used to meet the requirements for an initial implementation at a sequence level but would also facilitate the tracking of speed losses on a sequence level. However, it is important to point out that there are some issues with using this measure. There is a risk of creating a "we-against-them" attitude



between the assemblers at different sequences and a risk of sub optimization. The sequence measure and the time element that needs to be collected are depicted in figure 6.2.

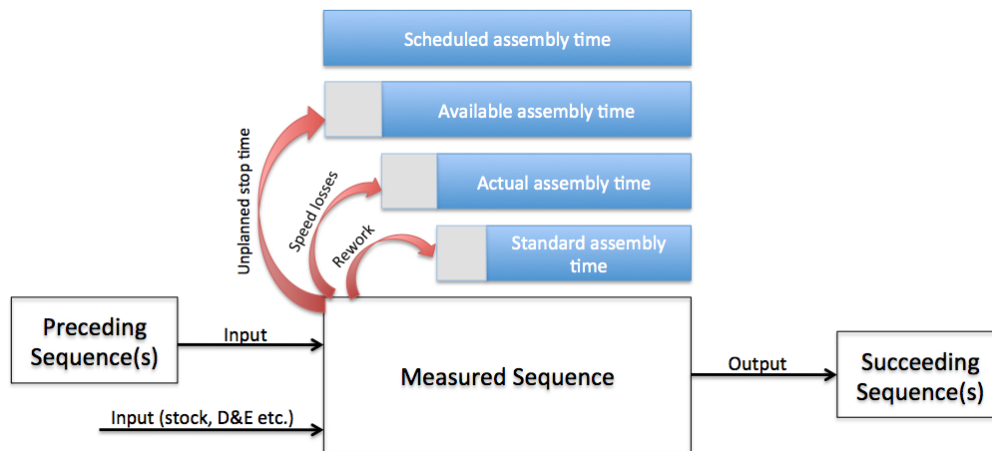


Figure 6.2. Efficiency on a sequence level

To be able to implement the FI pillar's measure and procedures and still support the quality improvement system already established at the outsourced production the following minimum requirement of data needs to be collected.

- Loss type
- Machine serial number
- Identified at sequence
- Time spent on loss in man-hours
- Sequence that the quality issues can be derived from
- Description of the loss.

The data collection has been identified as the biggest challenge in an implementation phase of the FI pillar. Four major gaps were found at Mastec Stålvall that needs to be closed to measure efficiency at Mastec Stålvall.

- The loss types existing today do not capture all losses impeding the efficiency and does not enable a sufficient loss deployment.
- The measuring of time spent on losses is not accurate enough to enable satisfying guidance of improvements based on these time values.
- What sequence the loss was related to is not yet fully implemented but are in the implementation phase.
- The knowledge among the assemblers about collecting losses is inadequate.

## 6.2 Implementation plan for the FI pillar at Mastec Stålvall

The implementation of the FI pillar at the supplier has been divided into three separate phases shown in 6.3.

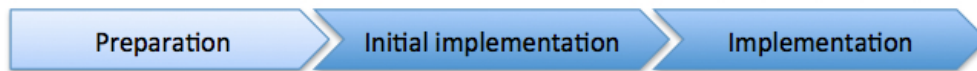


Figure 6.3. Implementation of the FI pillar

### Preparation phase

To ensure a successful implementation of the FI pillar several aspects need to be taken in consideration before an implementation. The following activities have been identified to be included in the preparation phase before an initial implementation can be initiated.

- Create a steering committee at the supplier with Tetra Pak involvement to ensure a long-term focus for the implementation process.
- Alignment of the efficiency measure with the suppliers performance measurement system due to the fact that a great deal of focus will be placed on the measured system when implemented.
- Establish the right standard cycle time for the outsourced production. This means that the standard cycle time also needs to be separated from the business side of the supplier-buyer relationship to allow adjustment. Hence create the possibility to reveal the true efficiency at the supplier and in fact capture all losses.
- Tetra Pak together with the supplier has to ensure that a sufficient level of knowledge exist to work efficiently with focused improvements and to compose efficient cross-functional FI teams at Mastec Stålvall. The work with eliminating or minimizing target losses has to be undertaken immediately and strongly to handle the resistance to detailed data collection on the shop floor. The author sees this as partly Tetra Pak's side of the bargain, to transfer their in-house know-how and knowledge on how to organize for the FI pillar, its effective tools and methods, and how to work with reducing target losses to the supplier before an implementation.
- The gap in knowledge among the assemblers in the current data collection of losses at Mastec Stålvall needs to be closed before the initial implementation. Thus the supplier needs to ensure that a sufficient level of knowledge is established among the assemblers to collect losses.
- Introduce the overall efficiency measure to visualize the true potential of improvement at the supplier, hence show the supplier where they stand in terms of efficiency. To be able to follow the efficiency on a system level is also essential when later introducing the data collection on the pilot sequence due to the risk of placing too much focus there initially.

### Initial implementation phase

Due to the complexity of a FI pillar implementation on a system level the author suggested the next step should be to run a pilot sequence. This phase is an initial implementation phase to set data collection procedures, refine procedures of how to work with the FI pillar, and to identify problems that might occur in the implementation. A secondary purpose would be to hopefully show the gains that an implementation on a system level could result in to raise the commitment on shop floor, thus the importance of establish an FI pillar organization before the implementation. The following steps have been identified as the most suitable course of actions in this phase.

1. The magazine sequence has been identified to have several features that make it suitable to act as a pilot. The author proposed an initial manual data collection in chapter 5 with the use of paper forms and start-and-stop timers. Having the same loss structure as on a system level would foster good data collection procedures with the assemblers. The standard procedures for collecting losses and procedures of how to work with losses could be further refined before a full implementation.
2. The next step would be to evaluate the pilot sequence and run additional pilot sequences if needed in other parts of the assembly system. This to identify problems that might not be found in the magazine sequence. The author believes that the testing sequence has a different loss picture compared to the assembly sequences and would therefore recommend a second pilot in that sequence.
3. If there exist a top-down commitment at the supplier, a development of a less time-consuming but still accurate data collection system should be initiated on the basis of the learning gained from the pilot sequences. The author believes that neither the data collection on a paper form nor the data collection system at Mastec Stålvall in its current design would facilitate these requirements. The author has provided what data that would have to be collected to form the proposed measure and still facilitate Tetra Pak's quality improvement system in place today. However, the data collection problem is a major issue that has to be solved to be able to proceed with a full implementation without spending unnecessary amount of time on collecting data.

### **Implementation at a system level**

The final step would be to implement the data collection system and capture the efficiency on a system level and thereby in fact collect all losses impeding the overall system efficiency. This will create a focus on reducing the overall lead-time and improve overall efficiency. A further development of the loss structure would be possible to meet the requirement of a more efficient loss deployment. Also to further develop the system efficiency measure to include the tracking of planned stop time, similar to Tetra Pak's in-house measures, would be valuable to be able to follow the time spent on these activities.

### **6.3 Concluding remarks**

The possibility to use the measure as a benchmarking tool in Tetra Pak's work with the outsourced production could be advantageous, as Tetra Pak has identified as well. With an adequate similarity between the different suppliers, the true supremacy of having a supplier base could be revealed through measuring efficiency on similar basis. As Dyer et al. point out a network can be more effective than a firm at the generation, transfer, and recombination of knowledge<sup>120</sup>. Having this in mind when further developing the measure and the loss structure would be recommended.

A supplier initiative to spread in-house capabilities in terms of continuous improvements is not an easy task since it is inherently firm-specific in its application and results<sup>121</sup>. This together with the fact that the FI pillar is the most demanding pillar to introduce and successfully implement makes this a certainly challenged supplier development initiatives. To achieve results comparable to Tetra Pak's in-house production would require a major commitment from both members in the supplier development initiative and a long-term focus. The author sees an even closer relationship as a part of reaching a successful implementation.

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<sup>120</sup> Dyer & Nobeoka, (2000)

<sup>121</sup> Sako, (2004)

## **6.4 Discussion and general reflections**

The author is confident that the chosen research strategy for this study has ensured a valuable result. To further perform a workshop at Mastec Stålvall would certainly have made the results more valuable in terms of closing the last gaps for the initial implementation phase. However, due to the holistic approach taken by the author and the time frame of this study this step was not possible to take.

The triangulation of different sources of information has been used, collecting information from both members in the supplier development initiative. Thus the validity is expected to be relatively high. The reliability of this study can be considered relatively low considering that the studied object is dynamic and constantly changing. Several times during the course of the study changes have been made at the studied object affecting the results of this study. However, with the purpose of creating an implementation plan, it will be used as a background for such an implementation.

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## **Main observations**

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## **Interviews**

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Jimmy Carlsson, *Production leader*, Mastec Stålvall AB, Partille, several occasions.

Hans Söberg, *Production Manager*, Mastec Stålvall AB, Partille, several occasions.

Niclas Wiking, *Purchaser*, Mastec Stålvall AB, Partille, 22 March 2011.

Mikael Hammar, *External Supply Manager*, Tetra Pak SCO CE CV Distribution Equipment, Lund, several occasions.

Salvatore Todaro, *Supply Chain Engineer*, Tetra Pak SCO CE CV Distribution Equipment, Modena, several occasions.

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## Appendices

### Appendix A - Calculation of Petersson's MAE

MAE = Manual assembly efficiency [%]

A = Availability [%]

U = Utilization [%]

Quality = Quality [%]

$t_{TOT}$  = All available time (i.e. one year = 365 days, one day = 24 hours etc) [time]

$t_{PS}$  = Total planned stop time [time]

$t_{UN}$  = Total unused assembly time due to lack of orders [time]

$t_{US}$  = total unplanned stop time [time]

N = Number of assembled units [units]

$t_{IAi}$  = Ideal assembly time for unit i [time/unit]

$N_A$  = Number of assemblers that are registered for work [number]

$t_{Ri}$  = Rework time for unit i after the assembly process [time/unit]

$$MAE = A \cdot U \cdot Q$$

$$A = \frac{t_{TOT} - t_{PS} - t_{UN} - t_{US}}{t_{TOT} - t_{PS} - t_{UN}} \cdot 100$$

$$U = \frac{\sum_{i=1}^N t_{IAi}}{N_A \cdot (t_{TOT} - t_{PS} - t_{UN} - t_{US})} \cdot 100$$

$$Q = \frac{\sum_{i=1}^N (t_{IAi} - t_{Ri})}{\sum_{i=1}^N t_{IAi}} \cdot 100$$



## Appendix B - Tetra Pak SCO-CE Distribution Equipment KPIs

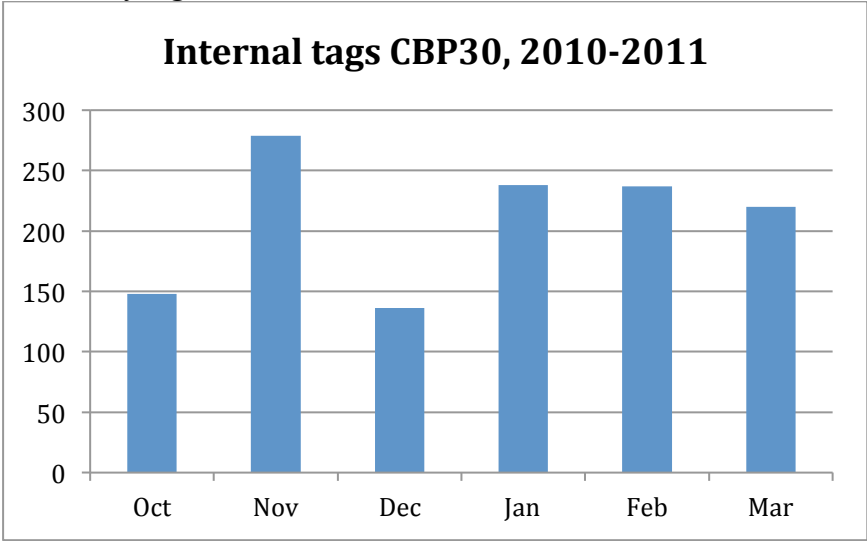
<i>KPI</i>	<i>Description</i>
Distribution machines delivered	Number of machines expected to be delivered.
Finished distribution machines stock in core company	Amount of machines is stock between system supplier and customer (due to issues such as cancel of order, insufficient shipping order).
Energy consumption	Environmental aspects.
Number of open and accepted claims distribution equipment claims	Total number of claims from customers that are accepted by Tetra Pak.
Countermeasure in place for distribution equipment claims	If the issue of the claim falls within Tetra Pak's responsibility. The amount of time Tetra Pak has put on countermeasure to solve these claims.
Number of NC per distribution equipment delivered	NC solved by Tetra Pak before the distribution equipment reach the customers. Measure how well Tetra Pak filter NC.
ECR resolution	Number of problems closed by D&E by changing construction.
EDCS equipment with issues	Relates to customer satisfaction based on a survey sent out after delivery.
Supplier development result	Based on an audit performed by Tetra Pak on the development of their suppliers.
OTD lead-time	Number of days (calendar days)
Fulfillment of customer desired request within target OTD	Fulfillment of orders on time measuring the whole supply chain.
Takt capacity utilization	The fulfillment of capacity at Tetra Pak's outsourced production.
Production accuracy OTIF	How many machines on time out of the total, measure the suppliers.
Perfect orders	The customer is placing orders with configuration and it could be meet.
Distribution equipment sales result	Sales result is equal to total revenue minus total expenses.
Distribution equipment – Total Expenses/Net Sales	Measuring the total expenses versus the net sales.

## Appendix C - Mastec Stålvall's KPIs and OPIs

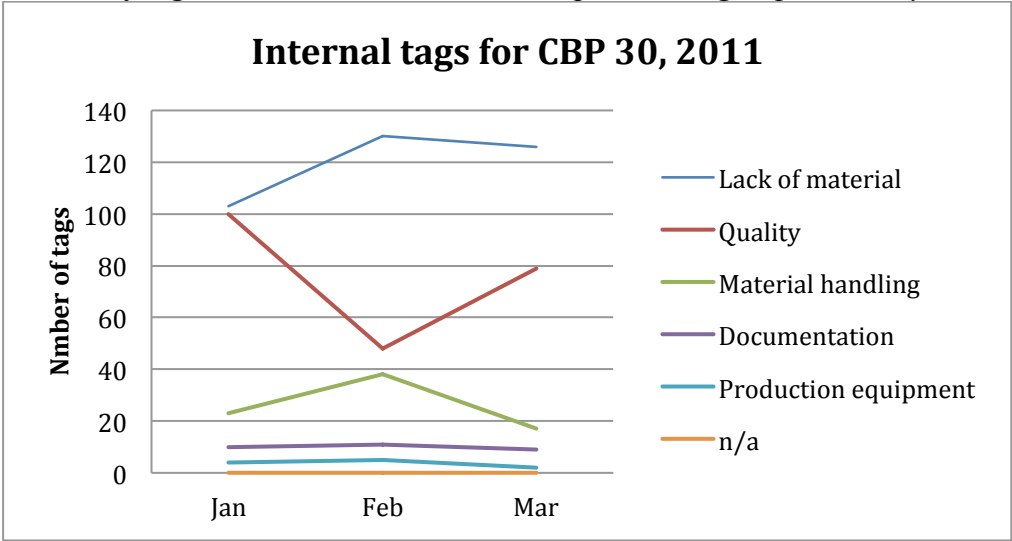
<i>KPI</i>	<i>Description</i>
Q	Based on the amount of Claims.
L	Order time in full.
E	Related to cost.
P	Overtime.
<hr/>	
<i>OPI production</i>	<i>Description</i>
Q	Connected to the KPI Q. Amount of claims.
L	Planned lead-time versus actually lead-time.
E	Planned working hours versus actually working hours. Efficiency measure.
P	Overtime in production (direct and indirect).
<hr/>	
<i>OPI purchasing</i>	<i>Description</i>
Q	Claims against sub suppliers.
L	Delivery time sub suppliers.
E	Turnover in stock.
P	Overtime.

### Appendix D – Internal tags at Mastec Stålvall

Number of tags created at Mastec Stålvall, October 2010-March 2011.



Number of tags created at Mastec Stålvall separated in groups, January-March 2011.



## Appendix E – Different internal tags made at Mastec Stålvall.

*An overview of tagged issues in the AM system at Mastec Stålvall, 2010-12-21 to 2011-02-24. Compiled by the author.*

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Wrong mechanical setting done internally (loose screws and parts, wrong setting etc.)

Wrong electrical setting done internally

Wrong part/component assembled internally

Defect on part sub supplier (defect, missing feature, mechanical setting, electrical setting etc.)

Defect on component assembled by sub supplier/external assembly (wrap unit, electrical cabinet, electrical kits etc.)

Defect on part created internally (part damaged during assembly)

Not fulfilling orderliness standard

Wrong mechanical setting sub supplier/external assembly (wrap unit, electrical cabinet, electrical kits etc.)

Wrong electrical setting sub supplier/external assembly (wrap unit, electrical cabinet, electrical kits etc.)

Wrong internal documentation (shortage list material carrier, machine documentation, picking list etc.)

Missing tools related to workstation

Broken tools related to workstation

Production equipment breakdown

Stock major components not replenished

Inadequate material handling

Wrong number of parts picked (+/-)

Wrong part picked

Parts not picked (shortage list not updated, material handling missed to pick part etc.)

Assembler cannot find material (in the wrong place of the material carrier, searching in the wrong place)

Parts/components not delivered from sub supplier

Deviation in drawing/specification Tetra Pak D&E (detected at supplier, wrong in sub supplier part due to D&E drawing)

Wrong mechanical design Tetra Pak D&E

Software issues Tetra Pak D&E

Suggestions of improvements on a general problem

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## Appendix F – Detailed description of loss types

<i>Loss Type</i>	<i>Description</i>
Equipment failure	All time losses caused by failure of equipment not part of the standardized workstation. Includes Helix, forklifts, overhead cranes etc.
Broken tools	All time losses caused by broken tools that is a part of the standardized workstation.
Lack of equipment	All time losses caused by equipment not part of the standardized workstation that is not being available to perform assembly activity.
Lack of parts/components – material handling	All time losses caused by missing material at the sequence due to deviation of standardized material handling. Depend on internal material handling.
Lack of parts/components – not delivered from sub supplier	All time losses caused by missing material at the sequences due to sub suppliers' deliveries.
Waiting for other sequence	All time losses caused by preceding or succeeding sequence. Line balancing losses, either no available assembly space or no available module to assembly.
Lack of assembler to perform assembly activity	All time losses caused by assembler's inability to perform assembly activity due to the requirement of additional assembler to perform assembly activity.
Missing tools at workstation	All time losses caused by missing tools at standardized workstation.
Missing documentation	All time losses caused by missing documentation that is part of the standardized workstation.
Preparing workstation	All time losses caused by preparing workstation to fulfill the standard that should be persevered.
Unplanned activities	All time losses due to unplanned activities from Tetra Pak Market.
Speed losses	All time losses related to the assemblers not fulfilling the predetermined standard cycle time due to time smearing, minor assembly mistakes etc.
Wrong mechanical setting	All time losses caused by adjusting wrong mechanical settings according to work instructions, created internally.
Wrong electrical setting	All time losses caused by adjusting wrong electrical settings according to work instructions, created internally.
Wrong component assembled	All time losses caused by wrong component assembled according to work instruction, assembled internally.
Defect on part (internally)	All time losses caused by a defect on a part created internally.
Deviation in specification (Internally)	All time losses caused by a deviation in specification created internally. Machine specifications, work instruction etc.
Defect on part (TP nominated sub supplier)	All time losses caused by a NC on a sub supplier (TP nominated) part or component. Includes external assembled components as well.
Defect on part (Supplier nominated sub supplier)	All time losses caused by a NC on a sub supplier (Supplier nominated) part or component. Includes external assembled components as well.
Deviation in specification (D&E)	All time losses caused by deviation in specification from D&E.
Rework due to changes in configurations	All time losses caused by Tetra Pak market company requesting changes in order after the start of assembling order.

# Appendix G – Calculation of true efficiency in a sequence

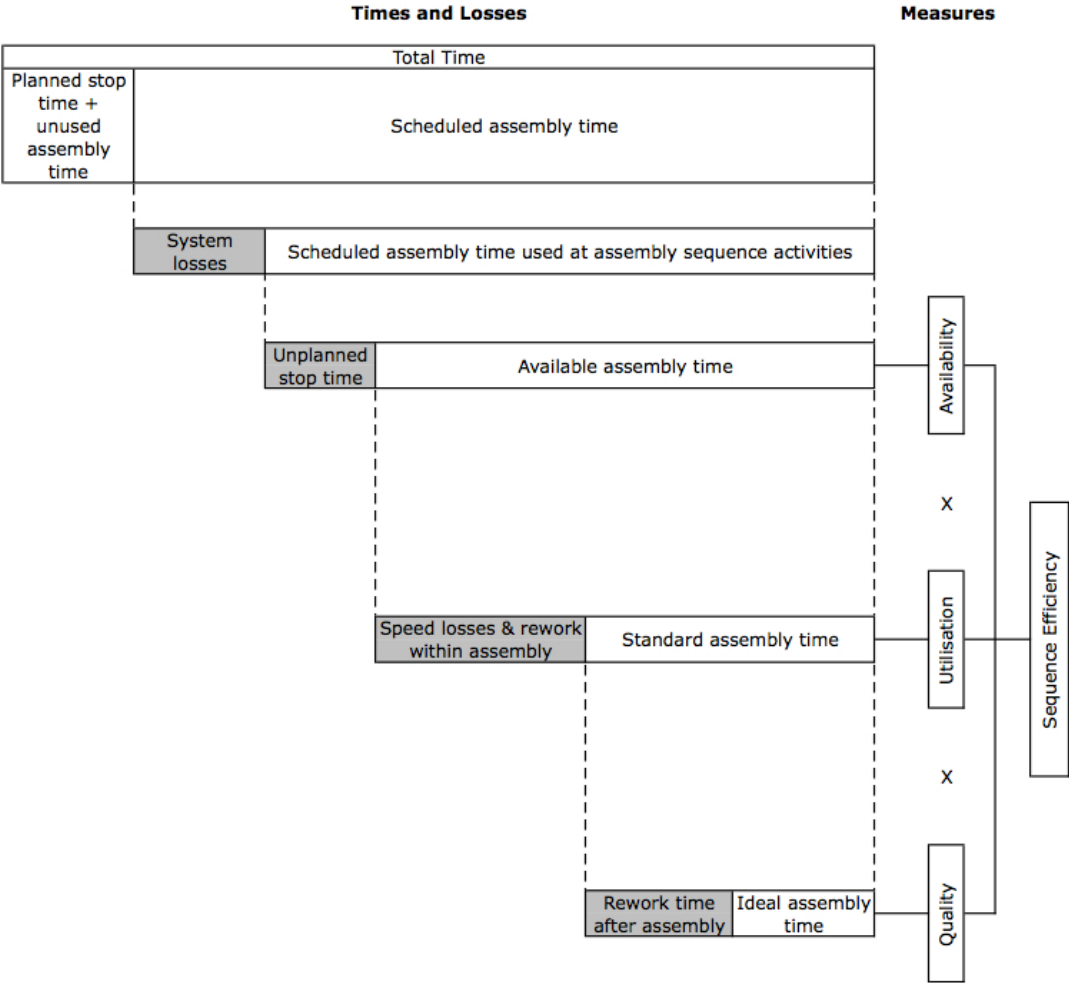


Figure 1. Time element of efficiency in a sequence

## Availability

The calculation of availability is as follows:

$$Availability = \frac{t_{SAT} - t_{UST} - t_{SL}}{t_{SAT} - t_{SL}} \cdot 100$$

Input parameters:

- $t_{UST}$  = Total unplanned stop time (man-hours)
- $t_{SAT}$  = Scheduled assembly time (man-hours)
- $t_{SL}$  = System losses from preceding assembly sequences (man-hours)

The scheduled assembly time is on a sequence level i.e. the time assemblers are registered for work at the measured sequence.

System losses are the time assemblers assigned to the measured sequence is spending on rework due to preceding assembly operations to be able to perform their assembly activities. It would include all types of rework losses discussed in this study.

## Utilization

Utilization is calculated as follows:

$$Utilization = \frac{\sum_i^N (t_{ST_i})}{t_{SAT} - t_{UST} - t_{SL}} \cdot 100$$

Input parameters:

- N = Number of assembled machines (units)
- $t_{ST_i}$  = Standard assembly time for machine i (man-hours/unit)
- $t_{UST}$  = Total unplanned stop time (man-hours)
- $t_{SAT}$  = Scheduled assembly time (man-hours)
- $t_{SL}$  = System losses from preceding sequence (man-hours)

Standard assembly time is the assembly time at the measured sequence. Due to the formation of this calculation it is important to establish correct standard assembly time to reveal the true efficiency and in fact capture all losses impeding the efficiency.

The calculation of utilization will capture both speed losses and rework time within the assembly sequence. Rework time within the assembly sequence includes all types of losses discussed earlier that is detected and solved within the assembly sequence. Rework should be separated from speed losses to get the true speed losses related to the sequence.

## Quality

Quality is calculated as follows:

$$Quality = \frac{\sum_i^N t_{ST_i}}{\sum_i^N (t_{ST_i} + t_{R_i})} \cdot 100$$

Input parameters:

- N = Number of assembled machines (units)
- $t_{ST_i}$  = Standard assembly time for machine i (man-hours/unit)
- $t_{R_i}$  = Rework time for unit i after assembly sequence (man-hours/unit)

The quality term is describing the quality level of the output from the measured sequence similar to Petersson's MAE and OEE. This in contrast to the quality group in ASE that describes the quality issues detected within the measured system. Rework time after assembly is the time spent on solving quality issues in later sequences of the assembly system that has been created at the measured sequence and includes the quality losses discussed in previous section. The separation in the calculation is made due to the fact that quality issues detected in succeeding sequences should be given a higher priority since these are causing most disturbances in the assembly system.

# Appendix H – Loss collection form

**Magazine losses** Machine ID: xxxxx/xxxxx

**Loss created at sequence:**

Magazine  
 Machine body

**Loss type:**

**Reduced availability**

- Equipment failure
- Utility issues
- Broken tools
- Lack of equipment
- Lack of parts/components – material handling
- Lack of parts/components – not delivered from sub supplier
- Waiting for other sequence
- Lack of assembler to perform assembly activity
- Missing tools at workstation
- Missing documentation
- Preparing workstation

**Reduced quality**

- Wrong mechanical setting
- Wrong electrical setting
- Wrong component assembled
- Defect on part (internally)
- Deviation in specification (Internally)
- Defect on part (sub supplier)
- Deviation in specification (D&E)
- Rework due to changes in configurations

**Time spent on loss:**

**Description:**

**Loss closed:**

Predefined machine ID

Man-hours spent on loss

Description of loss. Should also include e.g. part number, drawing number etc.