A case study in consolidating the loss structure of different manufacturing sectors under lean context

By Hua Tong & Thi Minh Trang Dao
Supervised by: Professor Peter Berling
Logistics and Supply Chain Management
Lund University
Master Thesis Spring 2020

Acknowledgement

We want to express our gratitude to Tetra Pak especially the department of Global WCM Management for trusting and awarding us this project as a golden chance to apply skills and to gain in-depth knowledge with hands-on experience in the manufacturing industry. We would like to thank our supervisor Sachin Jonnalwar for guiding us from the very first day of the project, and for generously giving us a lot of information sources including database and insight experts. Special thanks also to Amey Supnekar for a lot of ad-hoc Q&A online meetings with us, despite the time zone difference. Last but not least, we would like to express our deepest appreciation to our supervisor, Peter Berling, for his constructive comments and warm encouragement during the whole project.

Abstract

In the light of lean methodology, World Class Manufacturing requires continuous improvement in analyzing the losses to eliminate the wasteful resources and to boost the overall productivity. However, the standardized loss structure should be well-balanced to be general enough to cover the whole manufacturing procedure while being specific enough to point out the real issues happening for further improvement. The master thesis attempts to investigate how a typical manufacturing company can build up a loss structure and information system for recording inefficiencies according to the specific need of its daily operations in the lean context.

In order to make the most out of the loss analysis, a suggestion for restructuring loss library and consolidating loss deployment systems in different manufacturing sectors was proposed by performing a number of qualitative cause-effect analysis combined with quantitative ABC analysis. Another attempt is to find out the additional parameters that can be implemented in the loss system as a way to reduce misunderstanding, thereby minimizing the inefficiency caused by human error.

The proposed loss structure outperforms the critical overall equipment efficiency (OEE) and loss deployment model. It gives the results of a great improvement in reducing duplication and ambiguity as well as increasing the consolidated manner for the loss categories used in different sectors. The approach is expected to perform well in the manufacturing-based company with different final products and working procedures. Since the framework was highly customized, in depth validation is recommended before implementation or application in any other specific scenarios.

List of Abbreviation

WCM	World Class Manufacturing
EPM	Equipment Production Monitoring
KPI	Key Performance Indicators
OEE	Overall Equipment Efficiency
SMED	Single Minute Exchange of Dies
TPM	Total Productive Maintenance
RCPS	Root Cause Problem Solving
PQCDSM	A Loss deployment model, which was named after 6 key TPM elements (Productive, Quality, Cost, Delivery, Safety and Morale)
4M	Man, Machine, Method, Material
QA/QC	Quality Assurance/Quality Control

Contents

List of Figures

List of Tables

1. Introduction

In this section, the background of the theory and the degree project will first be introduced, followed by a more detailed description of the problem, the purpose of the project and the focus area on research questions, together with the limitation of the research. Finally, some potential contribution to the knowledge will also be discussed.

1.1. Background

Lean production movement has become one of the dominant trends in the global manufacturing industry over the last two decades. It first caught the world's attention in the 1980s as the concept behind Toyota Production System that was first proposed by Toyota, an auto manufacturer. To be a lean manufacturer with a perfect business process requires constant improvement and innovation to avoid obsolescence by eliminating wasted time and resources as well as building quality into workplace systems (Liker, 2004).

Most manufacturing companies have joined the global movement to "think lean" and have learnt that the isolated application of lean techniques cannot contribute to continuous improvement for the development of product and process (Liker and Morgan, 2006; Liker, 2004). Tetra Pak, as an industrial leader in providing the best possible processing and packaging solution for food, also has progressed continuously on a change journey through World Class Manufacturing (WCM) and Global Production Strategy.

Tetra Pak has an extensive global network of internal and external factories. Part of this network consists of the Processing Solutions & Equipment organization delivering Processing and Filling lines. The two main manufacturing systems used in this part of the network are the systems of Processing and Packaging. Currently, even though both manufacturing systems follow Lean Manufacturing with records of all losses, they are managed by different departments under different systems. Because of that, the way that losses are categorized and named is different due to the nature of each manufacturing system, resulting in a major obstacle in standardization and further performance improvement.

- The system for reporting losses used in the Processing Section is a web-based tool called "Loss Bank". The losses are categorized into 3 levels. Most loss codes have more than 1 sub-category and the operator needs to select depending upon the situation. Four main loss categories in Loss Bank are Production, Engineering, Supplier and Customer. Standardization of Loss Bank will be the main focus of this paper.
- The system used in the Packaging Section is called Equipment Production Monitoring (EPM). It has a consolidated structure already for reporting losses occurring in the production during packaging. Another main task of this project is to make the two tools structure loss categories and record losses in the most similar way to improve the standardization of the entire manufacturing system.

Currently the company has more than 1000 loss codes in Loss Bank and many of them are repetitive with similar meaning. Some of the descriptions for loss code are missing and the master data have not been converted into the interface available in different languages, making the detailed analysis of losses in Lean Manufacturing complicated and ineffective. Structuring the loss categories and titles in a more standardized way may allow the management board to have a mutual language and system on loss analysis and management.

1.2. Problem description

At Tetra Pak, productive working hours is one of the main key performance indicators (KPI) in manufacturing lines. The working hour can be productive only when the station/machine is working, the input information and material are available, and the operator is available to work. In case one of those four elements is not available, a loss record has to be input in the system, with clear date and time with a specific category of loss.

Starting with WCM in 2015 in Process Technology, Tetra Pak's first data collection in losses was started in 2016 as a pilot trial. From 2016 until now, the system recording all losses was implemented globally in all factories in both processing and packaging. The dictionary of losses, therefore, was developed from time to time based on real situations. From the current loss dictionary, the consolidation of categories in both sectors would be the next step in the development plan of WCM implementation (Figure 1).

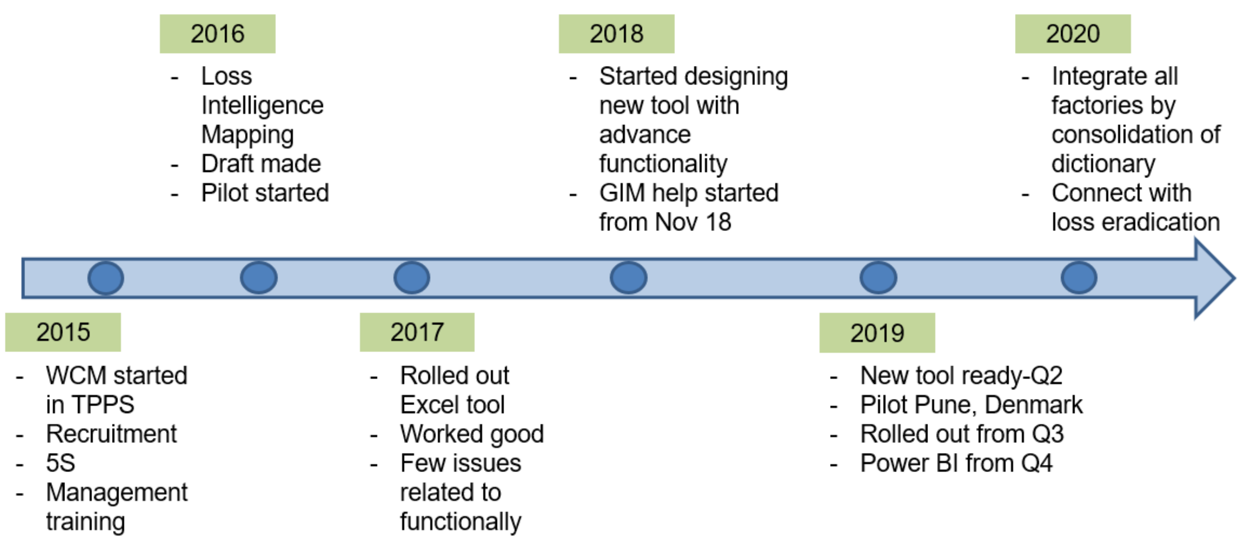

Figure 1. Timeline for WCM implementation in Tetra Pak

Tetra Pak is one of the three subsidiaries of multinational holding company Tetra Laval. It is an international food packaging and processing company with business represented in more than 160 countries with net sales in 2019 of €11.5 billion. The company provides integrated processing, packaging and distribution solutions for food manufacturing, covering alternative packaging machines and complete processing equipment for dairy, cheese, ice cream, beverages and prepared food.

With the database of all loss records in both Processing and Packaging in the last two years, the loss categories would be analyzed to match the duplication and reduce the number of categories for better analysis and more user-friendly for the operators to input the information. In the Processing sector, all the losses that happened in the blue-collar worker section are recorded in the Loss Bank system. Meanwhile in the Packaging sector, the EPM system is used to record the losses. Both systems are web-based and can be accessed from internal computers. In case the operators are not provided with the computers, a paper-form will be used to record the losses. Data will be manually input to the system by administrators later on.

While the loss category structure used in Packaging System has been used more than ten years, and has been developed to be a standard system, the loss category structure used in Processing systems is under development. The Loss category system was structured in three levels: level 1, level 2 and level 3. The level 1 categories mainly follow Lean Manufacturing major losses in production, one of the well-known loss deployment models. Each level 1 category is broken into different loss level 2 for more details. Since not all level 2 has level 3 under it, almost all level 2 have [Blank] level 3 for systematic purpose, which may mislead the interpretation in Power BI report. However, there is an exception of “Design” loss level 2 which is mentioned under two different loss level 1. Since the loss library in the Processing system is under development, new level 2 or 3 will be added in case of need.

Another problem of under-development situation is that the database is not recorded properly in all factories. The reasons for that partially due to the continuously developing IT supporting as well as reporting systems. Moreover, Tetra Pak Processing is currently on the way of spreading the systems to the rest of factories in the world (Germany has recently entered, the Jakarta site was closed). A big difference in loss distribution from country to country is also observed from the database taken from the Loss Bank system. Especially in the non-English speaking countries, each country had some specific common loss categories registered by the operators. Based on their notes, irrelevant or wrongly categorized loss events were found a lot as part of the human mistakes or human habit.

1.3. Purpose

This thesis is conducted as one of the last parts in the Loss Analysis process, as a transition from Loss Analysis to Loss Eradication in order to standardize loss categories and consolidate loss records in a systematic method. The purpose of this thesis is to observe current production systems, analyze different loss titles and map them together, reduce duplication and prepare a proposal with a consolidated manner.

1.4. Research Questions

The research questions of the thesis were tackled as follows:

- RQ 1: AS-IS. How can the current situation of Loss Bank be improved based on the loss database from both systems in 2019 collected by all Tetra Pak factories?
- RQ 2: TO-BE. How to restructure and combine the loss categories in both manufacturing systems to cover all the losses in a more systematic way?
- RQ 3: IMPROVEMENT. What else can be provided as additional parameters in the loss bank as a way to reduce misunderstanding while recording the losses?

1.5. Focus and Delimitation

Due to the time framework the scope of this thesis was limited to two specific manufacturing systems within Tetra Pak, which are Processing system and Packaging system. The loss code in the Packaging system had already been standardized separately and would be used as a Benchmark and reference for the consolidation into the Loss Bank system. Therefore, the goal of the research is to propose a consolidated loss structure covering all loss categories in the Processing sector especially shared losses together with the Packaging. In the scope of this project, the losses which only happen in the Packaging sector were not considered. The losses were more focused on the aspects of man-hours related to manufacturing lines, excluding the white-collar losses.

2. Methodology

In this section, the methods used in this study will be presented, together with the project plan.

2.1. Research Approach

Major research approaches can be categorized into inductive, deductive and abductive, depending on the research questions as determined by the focus of the proposed study. These approaches observe different aspects of the same reality.

The inductive path highlights the opportunities of first-hand experiences each day from the informant's perspective (Golicic et al, 2005) and aims to understand and describe the phenomenon in its own terms (Hirshman, 1986). One of the major risks of inductive study is generality of the conclusion emerging from the data. It can be hard to draw a universal conclusion under a specific context when trying to build up a general theory for similar cases. Thus the theory within the discipline is suggested adding deductive foundations to be tested to be reliable once the data analysis has been completed (Suddaby, 2006). In a deductive path, the goal changes into the verification of formal theory by testing the relationships among proposed variables that have been pre-defined in the hypotheses. A deductive research typically discusses how the findings confirm or revise an existing theory through hypotheses tests (Woiceshyn and Daellenbach, 2018). The third choice is a balance of method that can be achieved in an abductive approach where the research path tracks back and forth between inductive and deductive approaches. Abductive research possesses a strong ability to distinguish general rules and particular circumstances and thus becomes very suitable for deriving hypotheses and propositions which can later be tested in a deductive phase of research (Kovács and Spens, 2005) .

The main body of this research can be considered as an abductive approach with the path more inclined to deductive-based methods. The research started with reviewing well-known theoretical concepts, models and tools that were defined and developed in the existing theory. Grounded in the previous research, formal theory and field data was combined to frame an understanding for the phenomenon. The generalizable conclusions were derived mixed with deductive aspects where the data was collected to perform the analysis.

2.2. Qualitative and Quantitative Methods

Research techniques for collecting empirical data may typically differ based on different research methods. There are basically two methods: qualitative methods and quantitative methods, and usually the two are used in combination. Qualitative research pays more attention to the contextual understanding with verbal data gathering from interviews and event observations. Quantitative research focuses more on explaining phenomena by collecting numerical data which will later be analyzed by mathematical models (Cavaye, 1996). When choosing the method of a research, there are several trade-offs that reflect validity in control, realism and generalizability (McGrath, 1982). Qualitative research strategy can optimize internal validity through realism, while quantitative research strategy can maximize the external validity by balancing control and generalizability.

As Golicic et al (2005) argued, with the increasing complexity of logistics and supply chains in the business environment, instead of using only quantitative methods, more qualitative methods should be used to improve the accuracy of describing, understanding and explaining these complex phenomena. However, Golicic et al (2005) also recommend to see both views to avoid delimiting the scope of the research and thus result in a limited contribution to the body of knowledge. When combining two methods within a study, qualitative and quantitative data can be collected at the same time from sites, or one type after another from the same sites, or one type after another from different sites (Cavaye, 1996).

In this research both quantitative and qualitative data was empirically collected at the same time from the same site for further analysis. Given the fact that the results and suggestions were generally proposed within a qualitative manner, the research therefore focused on examining and improving the efficiencies of re-structured procedures and techniques mainly from a qualitative perspective. Certainly, some simple but systematic quantitative calculations and analysis were used to support the final conclusion as well.

2.3. Literature Review

A thorough literature review has been conducted in order to achieve the purpose of this research. In the process of obtaining relevant knowledge through literature reading, most of the literatures on wastes and losses in lean production were found either to focus more on how to establish a conceptual model to measure the theoretical aspects of leanness, or to pay more attention to how to reduce losses to maximize the company's economic benefits. Since the project is a specific case of Tetra Pak, the key player in the carton food industry, the limitation of academic articles solving a closely related problem can be expected. Therefore, the root-cause analysis brings great direction to breakdown the research questions. Keywords such as “lean manufacturing”, “WCM”, “wastes”, “loss structure/categories” and “loss deployment” have been used for the theoretical framework building on various databases such as LUBsearch, Google Scholar, Ebsco and Science Direct, etc.

2.4. Case Study

Case study was conducted from a particular sample by field observations and systematic interviews. The methods and tools that are used can be both quantitative and qualitative approaches (Meredith, 1998). According to Stuart et al (2002), the purpose of a case study consists of three main aspects:

- Discovery/Description
- Mapping/Relationship building
- Theory Validation/Extension/Refinement

Based on the problem description in the first section, this article contributed progress mainly on mapping and building relationships where critical variables and linkages between them were identified and described to get an in-depth causal understanding. Moreover, the research also considered the possibility to expand the map of the theory in light of the observed results under a pre-described situation.

With the clear purpose of the research, a contextual case-study-based method was chosen to deliver the research. The nature of this research is a single case study with the organization as the unit of analysis. According to Voss et al (2002), taking one single longitudinal case into analysis brings about good depth as well as the comprehensiveness of the analysis. Even though only one single case barriers the risk of low generalizability, the longitudinal case could show a complete situation with full complexity, allowing the researcher to collaborate with different perspectives in the analysis.

In general, the process of conducting case research can be broken down into 5 steps (Stuart et al, 2002), as shown in Figure 2. Initially a researcher builds their framework and constructs the questions with the consideration of which kind of variables to be included. Then, once the instruments and sites for conducting the study have been chosen, the empirical data are gathered through the interviews, meetings, documents from the company and self-observations from researchers, followed by an in-depth analysis. Finally, researchers prepare to deal with the criticism with a proper planning and executing of research paper.

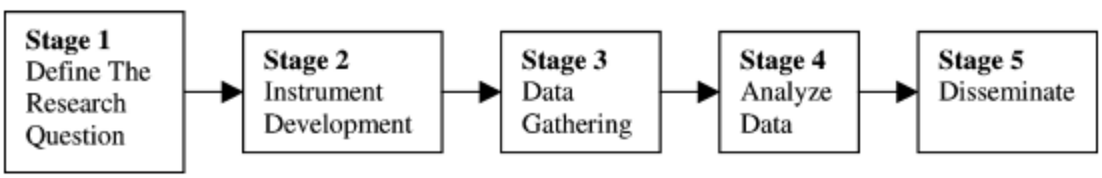

Figure 2. The five-stage research process model (Source: Stuart et al, 2002)

2.5. Data Gathering

Regarding the Figure 2 above which mentioned the Research process model, Step 3 - Data Gathering includes the data type selection and data collection as well. For the purpose of understanding the current situation, both quantitative and qualitative data was necessary to get the full picture, not only about the losses happening, but also about how the database was built and recorded in different factories.

The qualitative information and data should be taken from the trusted source of information regarding the implementation and development plan of WCM. Besides the internal documents given by the supervisor at the company, meetings with responsible people in the WCM implementation project at the company were also necessary to get the side information which may help building the big picture of the current situation. Moreover, attending meetings with local factories related to Q&A regarding issues of implementing the Loss Deployment system was also very beneficial to have a better understanding from the viewpoint of end users.

The database in the Loss Bank system is the mixture of quantitative data and categorical data. The quantitative part of the data includes numerical data of date and duration of loss (the amount of time it took to recover from the loss); while the categorical part of the data includes the loss categories or the reason causing the loss (in terms of different loss levels). As to the nature of the categorical data, miscategorization of data and synonymous categories would be analyzed as a part of data analysis. Moreover, data cleaning with awareness of some typical data errors related to data entry, measurement, distillation and data integration was effective to evaluate the quality of the large database (Hellerstein, 2008).

As suggested and agreed by the WCM teams, the range of databases was limited to the recorded entries in 8 countries in 2019, especially the last quarter can be used for detailed analysis. The main reason for the data limitation was about the stability of the data entry in different factories, and the supportiveness of the information systems used in the data gathering. Since all the data was input into the systems by the operators or administrators, human mistakes cannot be avoided completely. Therefore, understanding about the sources of errors in data, the differences in the methods of categorizing the losses and inputting the entries would be beneficial for data cleaning and data analysis.

Last but not least, progress meetings with the WCM team at the company were used as qualitative data not only to keep track of the project, but also be used as open discussions for feedback from internal people about the data analysis and suggestions for solutions. With the opinions from the end users, in both managing and operating sides, the data analysis and proposals for improvements can get closer to the reality and be more efficient for the future phases of the project.

2.6. Quality Assurance

This case-based research enhances its reliability and validity following the guidelines outlined by Yin (1989). Four logical tests are concerned, including construct validity, internal validity, external validity and reliability. Construct validity can be improved by a clear explanation of how data are to be collected and to be transformed for the studied concept. Internal validity shows the extent to which research framework based on the existing theory can be developed. It can be improved by establishing causal relationships and matching patterns between empirical data and previous proposals. External validity refers to what extent the findings and conclusions can be generalized from each case to a more common circumstance. Reliability explains to what extent repeated research operations can achieve the same results. Using a case protocol and maintaining a study database can provide a repeatable analysis process with raw data that can be retrieved from the beginning, which greatly improves the reliability (Stuart et al, 2002).

As discussed in section 2.5, procedures of collecting data through multiple sources and forms in this research were explained in detail. To validate that, all of the files related to data analysis and meeting notes were summarized in documents and were saved in cloud-based systems such as Teams and personal drive. In Teams, all the essential files from the focal company will be uploaded for correction and validation by the insight experts while in the shared personal drive between the two authors, later retrieval and analysis could be done. Field verification through flexible factory visits was also conducted. Furthermore, followed by a thorough literature review and detailed data analysis supported by and discussed with the responsible managers who are closely working with the project from the focal company, the causal relationships between loss categories and the proposed loss structure can be ensured to the greatest extent in accordance with the theory and practice. During this process, data analysis was conducted with pre-stated boundaries, such as limited exploration on level 3 of the losses, thus this research can focus on dealing with the border that have already been clarified and with the external generalizability. Finally, a starting point of proving reliability was the statement of clear definition of the phenomena and the unit of analysis, which have been already outlined in previous sections. Questions and discussions during the meeting also followed a commonly used format with broad questions coming first and more specific questions coming last.

2.7. Project Plan

Following the research questions and the proposed methodology, the project was carried out in three major phases:

In the beginning phase of the project, most of the effort was spent on the literature review and problem analysis. The loss record in both manufacturing systems in the previous year was used as the master data for analysis. Moreover, observation and interviews with operators have been done during site visits for better understanding about the real meaning of the loss categories. At the end of the first phase, an analysis of loss categories for each single manufacturing system was delivered, together with a comparison between that of the two manufacturing systems.

In the second phase, suggestions for reducing the number of loss categories were proposed. Restructuring inactive loss categories which are uncommon or infrequently mentioned in the database while keeping the same loss coverage can be quite obvious. Matching similar loss categories was proposed in case of need. The mapping between loss categories in the two manufacturing systems was also considered with the support from internal employees.

Last but not least, the comparison between the theories from academic articles and the practices in reality at the company. The scalability of the proposed loss categories standardization, to different internal branches of Tetra Pak and external companies in the industry, was considered for the transferability characteristic of a case-based research.

The Gantt Chart below for theory exploration and company work (Figure 3) illustrates the degree project schedule as a whole, showing relationships between major activities and giving insights for scheduled status.

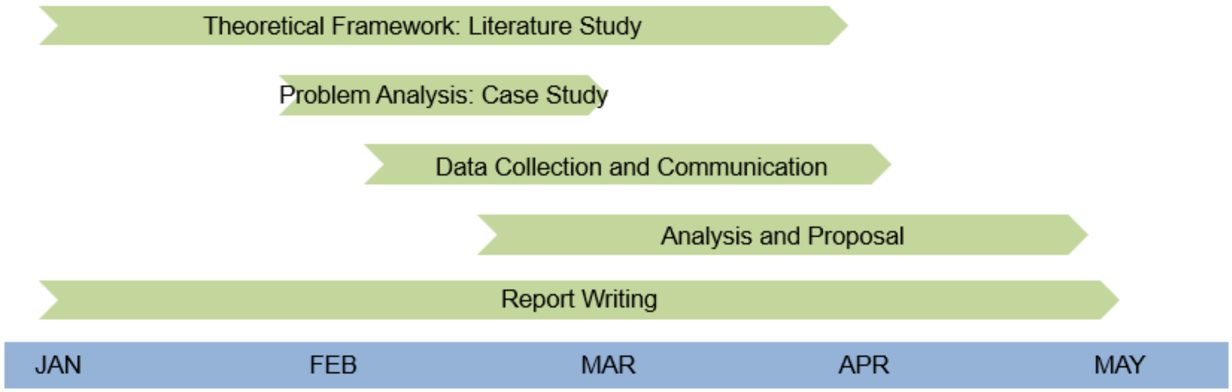

Figure 3. Timeline for theory exploration and company project

3. Theory

In this part of theoretical background, there are two main areas: the Lean concept and the Loss deployment. In the first part of the Lean concept, the main idea of Lean Manufacturing structures and benefits are discussed. This part of theory provides the general foundation about WCM - the current path that Tetra Pak factories are following to optimize their working productivity. Theoretical background about Overall Equipment Efficiency (OEE) and some quantitative or qualitative analysis tools are beneficial to backbone the loss in efficiency or productivity. Under the umbrella of Lean theory, the loss deployment would be dug further in the second part. Different approaches in categorizing the losses in Lean Manufacturing are necessary for further empirical data analysis and future suggestions or discussion.

3.1. Lean Concept and common tools

Lean concept provides a big picture of the manufacturing method which all Tetra Pak factories are following. Thus, all research activities in this topic follow the Lean concept. Moreover, the global manufacturing development department in Tetra Pak is structured to be the same as WCM pillars. Therefore, in the first part of Lean concept, basic ideas of Lean Manufacturing model as well as the WCM houses and pillars are mentioned as the backbone for the term of inefficiency and loss deployment.

3.1.1. Lean manufacturing and lean production

Lean Manufacturing is a production method which was initiated by Toyota's manufacturing model in the 1930s. The concept of Lean Manufacturing is to identify the value and generate the flow of value to customers, while eliminating the losses or wastes during the manufacturing process. The losses and wastes in Lean manufacturing cover also the unnecessary lead time, rework, inventory levels in order to save more money. In Lean manufacturing, there are 7 types of wastes which is widely known as MUDA: Overproduction, Waiting time, Transportation, Inventory, Overprocessing, Motion, and Defects, as shown in Figure 4 (Melton, 2005).

Lean methodology is not a one-time set up, but it requires a long term and continuous improvement in the implementation phase. This concept can be reached by applying several techniques such as Kanban system, 5S, Poka yoke, single minute exchange of dies (SMED). The main ideas of those techniques are to increase the overall productivity by reducing non-value-added wastes, by avoiding human mistakes and by reducing changeover time (Karim and Arif-Uz-Zaman, 2013)

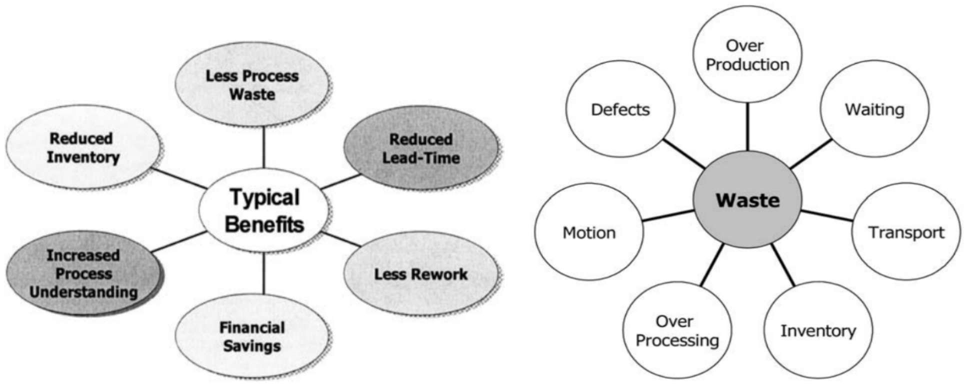

Figure 4. Lean Manufacturing benefits and major losses (Source: Melton, 2005)

3.1.2. World Class Manufacturing

Under the roof of Lean Manufacturing, WCM is a manufacturing concept initiated by Hayes and Wheelwright in 1984, with the focus on 6 main aspects: Workforce skills and capabilities, Management technical competence, Competing through quality, Workforce participation, Rebuilding manufacturing engineering and Incremental improvement approaches (Hayes and Wheelwright, 1984; Flynn et al, 1999). In order to implement WCM, ten main pillars are used as the KPIs for the manufacturing activities to measure the quality of implementation: Safety and Health, Cost Deployment, Focused Improvement, Autonomous Maintenance, Professional Maintenance, Early Equipment Management, People Development, Product Quality, Customer Service and Environmental, and Social Responsibility (Figure 5). Among ten pillars, the term of Total Productive Maintenance (TPM) is mentioned in the fifth and sixth pillars, in order to reach zero wastes in breakdowns, defects and accidents at work (Gajdzik, 2013).

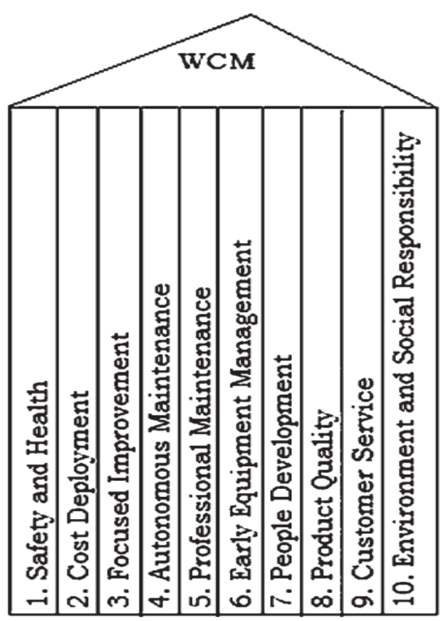

Figure 5. WCM Pillars (Source: Gajdzik, 2013)

In terms of TPM, the functions of different groups are put in consideration with the outcome of product quality. The necessity of maintenance in minimizing the defects or improving the product quality were highlighted in Figure 6. Not only the equipment maintenance, TPM also focuses on the quality maintenance and worker development for overall comprehensive maintenance. Therefore, differentiating between the TPM which is value-added activities and the waiting time for breakdowns which are nonvalue-added activities is also part of the loss analysis in manufacturing (Chan et al, 2005).

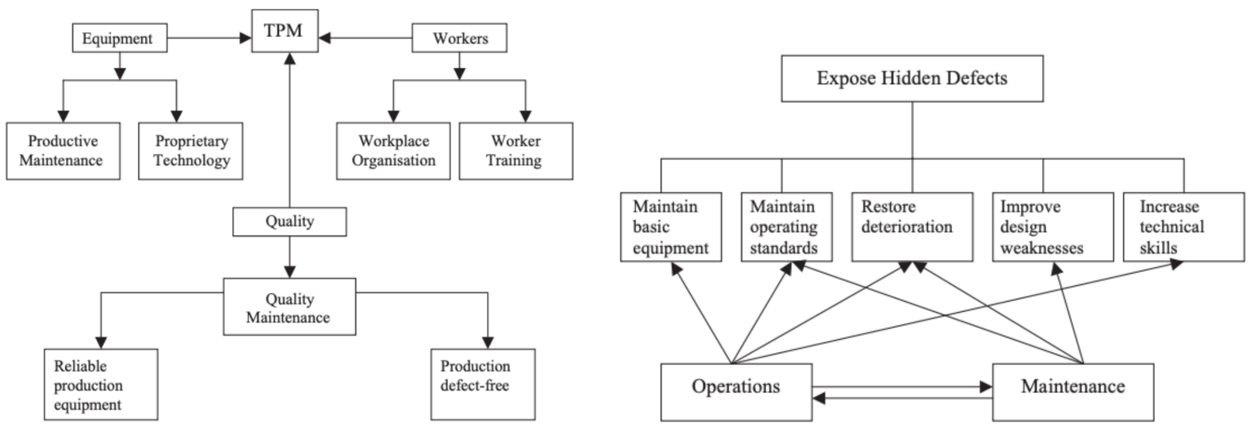

Figure 6. Key supporting elements and relationships of maintenance (Source: Chan et al, 2005)

3.1.3. Inefficiencies in Production

With the proper implementation of TPM, the equipment effectiveness could be correctly analyzed with the term of OEE, in which productivity of each single equipment in the factory can be measured in a quantitative way with the parameters depicted in Figure 7.

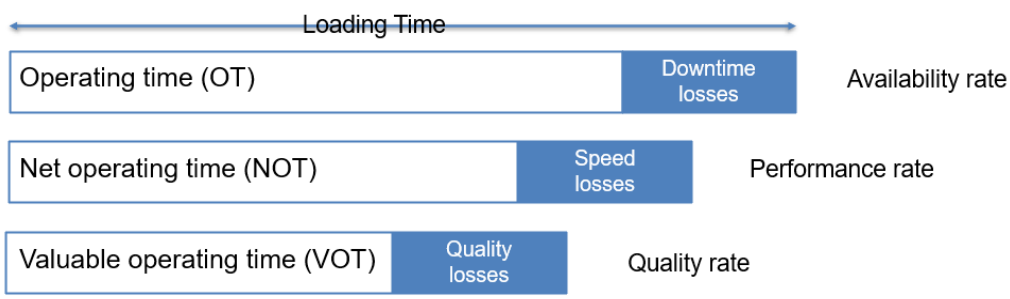

Figure 7. Time breakdown for OEE formulation (Source: Ahuja and Khamba, 2008)

As proposed by Nakajima (1988), the six big losses that can quantify the losses existing during equipment operation and quantify the wastes in between the planned production time are classified into three major factors: availability (indicating the breakdowns and setup time), performance (indicating minor stoppages and reduced speed) and quality (indicating yield losses and defects), as depicted in Figure 7. Another common way to classify OEE losses is proposed by Jeong and Philips (2001). The authors further subdivided the availability factor and considered more losses that originally cannot be quantified through the traditional calculation approach of OEE, such as scheduled maintenance, which is typically excluded from OEE due to its unavoidable nature during the production (Perumal et al, 2019). Table 1 shows the comparison of classification of OEE losses.

Table 1. Comparison of classification of OEE losses (Source: Perumal et al, 2019)

OEE Facor	Nakajima (1988)	Jeong and Philips (2001)
Availability	Breakdown losses Set-up and adjustment	Unscheduled maintenance Set-up and adjustment Non-scheduled time Scheduled maintenance R&D time Engineering usage time WIP starvation time Idle without operator
Performance	Idling and minor stoppages Reduced speed	Speed losses
Quality	Defects and rework Yield losses	Quality losses

In addition to being a good performance metric to quantify production losses, OEE can also be used as an excellent tool to improve and identify the scope of improvement from a visual loss perspective. Perumal et al (2019) proposes a loss distribution map (as shown in figure 8) including all the possible inefficiencies that OEE covered and not covered in its philosophy, in a better visualization. Planned downtime can be categorized into shutdown losses because it is assumed that the equipment should be shut down due to planned maintenance for better performance and effectiveness. Along with breakdown and setup & adjustment, losses like tool changeover, logistics, motion and measurement & adjustment can further deplete the available time for production (Puvanasvaran et al, 2016). Another component that prevents operating time from being fully utilized is speed loss. Some weaknesses from management and line organization may cause people and machines to wait and therefore slow down production (Ahuja and Khamba, 2008). Moreover, when the machine produces defect products that need reworks, quality loss occurs and will further reduce valuable operating time (Perumal et al, 2019).

The improved OEE is actually equivalent to the meaning of Overall Plant Efficiency, with the purpose of not only measuring the effectiveness of planned equipment performance but also caring about how well the organization’s assets are used in every single minute of the total calendar time (Ahuja and Khamba, 2008). They are the metrics that can guide the current production towards world-class production.

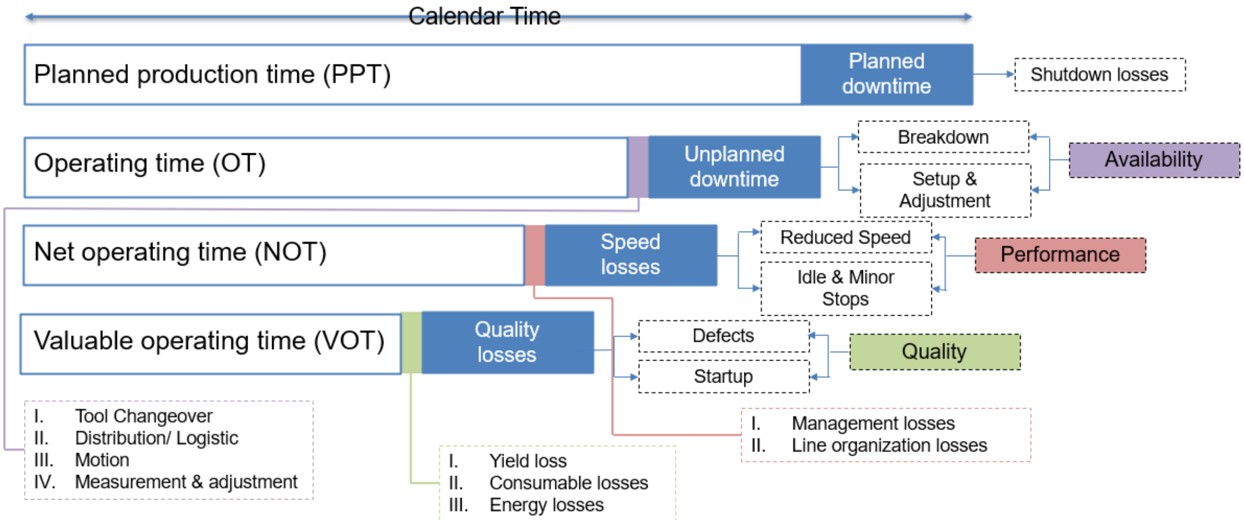

Figure 8. An improved loss distribution map in the context of OEE (Source: Perumal et al, 2019)

3.1.4. Lean tools for analysis

In order to improve OEE, both value added loss (Planned maintenance time) and non-value added losses (Unplanned downtime, Speed losses, and Quality losses) should be optimized. To eliminate losses, however, the potential root causes of the problem should be recognized in order to solve that problem in a more structured way (Murugaiah et al, 2010). In this regard, Root Cause Problem Solving (RCPS) is considered as a systematic solution that uses simple standardized tools to identify and solve critical problems, especially quality problems, encountered in manufacturing operation. The use of this method is believed to have a positive impact on the factory, such as increased efficiency, improved quality and lower scrap losses (Murugaiah et al, 2010). One of the common RCPS analysis tools is cause-effect diagram, also called the fishbone diagram or the Ishikawa diagram. The cause-effect diagram has been proved to be very useful for providing a systematic way of representing the causes and effects and their relationship between each other (Karim and Rahman, 2012; Amrina and Lubis, 2017). Moreover, it has been found that the cause-effect diagram and Pareto analysis (also known as the “80-20” rule) work as an excellent partner to distinguish the majority of the quality losses in many case studies (Hekmatpanah, 2011; Karim and Rahman, 2012; Vinodh et al, 2011).

From a broader perspective, ABC analysis is another well-known classification tool developed based on Pareto principle and is most extensively used in the field of inventory management. The familiar classification approach is to divide the items into A, B and C level according to the annual consumption value. Though there is no exact percentage to classify each category, a general rule for ABC analysis has often been used in practice, as shown in Table 2 (Nallusamy et al, 2017). According to the principle, Class A products will typically account for only about 10-20% of all goods to reach 70-80% of the annual consumption value. As one of the common classification methods, ABC analysis can be used in lots of fields as well to give different levels of significance according to the relative importance of the item or item group (Flores and Whybark, 1986). The item mentioned here can be interpreted as inventory items, customers, events, activities, sales territories and so on, as needed. Similarly, A-item occupies a large proportion of the overall value but a small proportion of the quantity. When applied to quality as a lean tool, it indicates that a low percentage of quality defects always constitute a high percentage of the overall quality losses (Karim and Rahman, 2012). Introducing ABC analysis as a lean approach can help to provide valuable information to analyze each process from a lean manufacturing perspective.

Table 2. General rules for ABC analysis (Source: Nallusamy et al, 2017)

Category	Percentage of items	Percentage of overall value
Class A - items	10-20%	70-80%
Class B - items	30%	15-25%
Class C - items	50%	5%

Furthermore, based on the classical ABC analysis, many authors discuss extensions to take multiple criteria into account when facing more than one important dimension of a problem. Most of the extension is to introduce several alternatives to the cost-volume related criteria that are commonly associated with inventory management, including lead times, substitutability, criticality, commonality and obsolescence (Flores and Whybark, 1986). More generality can be situation dependent in the joint criteria matrix, providing practical utility for ranking the importance of items from various perspectives. The most commonly used two-criteria ABC matrix is illustrated in Figure 9. If all items fall into the diagonal cells (corresponding to AA, BB and CC), a re-classification can be considered, though this is rarely happening in practice (Flores and Whybark, 1986). The off-diagonal items could also be reclassified according to a predefined mechanical procedure. Of course, the more criteria considered, the more complex the overall classification will be.

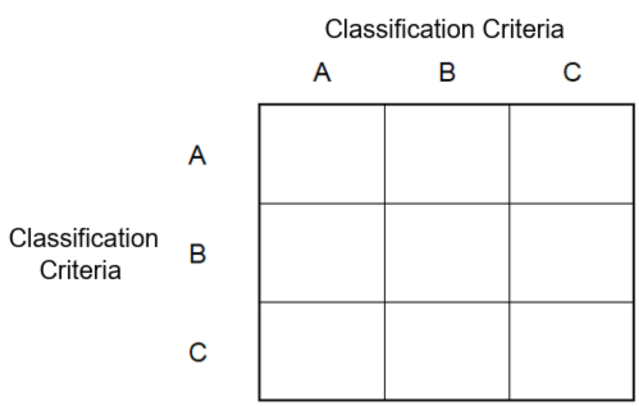

Figure 9. A typical joint criteria matrix for ABC analysis

3.2. Loss Deployment

Instead of emphasizing a single packaging line or a product, loss deployment focuses initially on the factory as a whole. For this project, several approaches for loss deployment have been considered, which can provide guidance in different aspects for the construction of loss structure. Major categorized systems discussed include (7+1) wastes, major losses in production and PQCDSM system as these categorizations are the structured systems that have been studied and reviewed by many researchers.

3.2.1. Different Structure System for loss categories

(7+1) wastes

Removing wastes within an operation is the core principle in lean concept (Liker, 2004). In lean manufacturing, waste is defined as any expense or effort that is expended but which does not transform into value to the product or service from a customer perspective (Tohidi and Khedri Liraviasl, 2012). When optimizing the process and eliminating the wastes, only value-added activities should be carried out at each phase of production. Ohno (1988), the founder of the Toyota production system, defined seven major types of non-value-adding wastes combating productivity in production, as described in Table 3 below.

Table 3. Seven major types of non-value-adding wastes in manufacturing process (Source: Liker, 2004)

Type of Waste	Description
Overproduction	Producing items for which there are no orders, which generates such wastes as overstaffing and storage and transportation costs because of excess inventory.
Waiting (time on hand)	Workers merely serving to watch an automated machine or having to stand around waiting for the next processing step, tool, supply, part, etc., or just plain having no work because of stockouts, lot processing delays, equipment downtime, and capacity bottlenecks.
Uncessary transport or conveyance	Carrying work in process (WIP) long distances, creating inefficient transport, or moving materials, parts, or finished goods into or out of storage or between processes.
Overprocessing or incorrect processing	Taking unneeded steps to process the parts. Inefficiently processing due to poor tool and product design, causing unnecessary motion and producing defects. Waste is generated when providing higher-quality products than is necessary.
Excess inventory	Excess raw material, WIP, or finished goods causing longer lead times, obsolescence, damaged goods, transportation and storage costs, and delay. Also, extra inventory hides problems such as production imbalances, late deliveries from suppliers, defects, equipment downtime, and long setup times.
Uncessary movement	Any wasted motion employees have to perform during the course of their work, such as looking for, reaching for, or stacking parts, tools, etc. Also, walking is waste.
Defects	Production of defective parts or correction. Repair or rework, scrap, replacement production, and inspection mean wasteful handling, time, and effort.

Besides the seven production-process-oriented types of wastes conceived originally, an additional source of waste that relates more to the management ability has been identified when the lean concept was introduced to the Western World. Non-utilized talent, the eighth waste, occurs when the senior management fails to ensure that all employee creativity is being utilized at a high level. This waste encourages the organization to involve the development of staff more into the lean system and to pay more attention to efficient communication, improving overall operational effectiveness.

Elimination of wastes could become increasingly easier when the production process becomes more visible. With the mind mapping tools such as fishbone diagram, a detailed analysis of related losses in the production could be really helpful in this case.

Major losses in production

Traditionally only about 6-8 major equipment losses would be considered in an initial TPM approach. However, in order to better track inefficiencies existing in the production process, it is recommended to list all potential losses, such as management losses, to form a loss mindmap. With the additional loss categories added into the recording system, normally 4 sub-groups can be presented to categorize the losses, which includes losses that reduce equipment effectiveness, losses that impede machine reliability, losses that impede man efficiency and losses that impede the effective use of production resources. Ahuja and Khamba (2008) elaborates on sixteen big losses which impede the manufacturing performance and efficiency based on these four categories, as briefly described in Table 4.

The “six major equipment losses” elaborated in OEE, as derived by Nakajima (1988), is a central thrust of TPM (Kumar et al, 2014) and a starting point for developing quantitative variables for the plant performance benchmarking process (Ahuja and Khamba, 2008). While the “sixteen big losses” are used in a much wider calculation of overall equipment effectiveness, covering various aspects and members involved in the context of manufacturing organization. These kinds of core set of loss-based KPIs and the corresponding common measures could contribute a lot during the continuous improvement process. In addition to the traditional index calculation in OEE and the wider coverage in “sixteen big losses”, Kumar et al (2014) observes that TPM deployment plays an essential role in improving the manufacturing process in the field regarding productivity, quality, cost effectiveness, delivery and morale. It has also been recommended to arrange and report these related losses or their equivalent KPIs via a “PQCDSM” structure which includes six key TPM elements used widely in the manufacturing industry (Kumar et al, 2014).

Table 4. Sixteen major losses impeding manufacturing performance and efficiency (Source: Ahuja and Khamba, 2008)

Seven major losses that impede overall equipment efficiency		
1	Breakdown/failure loss	Losses due to failure. Types of failure include sporadic function-stopping failures and function-reducing failures in which the function of the equipment drops below normal levels
2	Set-up and adjustment loss	Stoppage losses that accompany set-up changeovers. These losses are caused by changes in operating condition. Equipment changeovers require a period of shutdown so that the tools can be exchanged
3	Reduced speed loss	Losses due to actual operating speed falling below the designed speed of the equipment
4	Idling and minor stoppage loss	Losses that occur when the equipment temporarily stops or idles due to sensor actuation or jamming of the work. The equipment will operate normally through simple measures (removal of work and resetting)
5	Defect and rework loss	Volume/time losses due to defect and rework (disposal defects), financial losses due to product downgrading, and time losses required to repair defective products to turn them into excellent products
6	Start-up loss	When starting production, the losses that arise until equipment start-up, running-in and production-processing conditions stabilize
7	Tool changeover loss	Stoppage losses caused by changing the cutting blades due to breakage or caused by changing the cutting blades when the service life of the grinding stone, cutter or bite has been reached
Losses that impede equipment loading time		
8	Planned shutdown loss	Losses that arise from planned equipment stoppages at the production planning level in order to perform periodic inspection and statutory inspection
Five major losses that impede worker efficiency		
9	Distribution/logistic loss	Losses occurring due to inability to automate, e.g. automated loading/unloading leading to manpower reduction not implemented
10	Line organization loss	These are waiting time losses involving multi-process and multi-stand operators and line-balance losses in conveyor work
11	Measurement and adjustment loss	Work losses from frequent measurement and adjustment in order to prevent the occurrence and outflow of quality defects
12	Management loss	Waiting losses that are caused by management, such as waiting for materials, waiting for tools, waiting for instructions, waiting for repair of breakdowns, etc
13	Motion-related loss	Losses due to violation of motion economy, losses that occur as a result of skill differences and walking losses attributable to an inefficient layout
Three major losses that impede efficient use of production resources		
14	Yield loss	Material losses due to differences in the weight of the input materials and the weight of the quality products
15	Consumables (jig, tool, die) loss	Financial losses (expenses incurred in production, regrinding, renitriding, etc.) which occur with production or repairs of dies, jigs and tools due to aging beyond service life or breakage
16	Energy loss	Losses due to ineffective utilization of input energy (electricity, gas, fuel oil, etc.) in processing

PQCDSM System

To become a competitive WCM company, it is quite necessary to set clear indicators in order to track manufacturing performance and keep shareholders involved. PQCDSM has been introduced as the abbreviation of six key TPM performance indicators which highlight the improvements of operational efficiency, namely Productive (P), Quality (Q), Cost (C), Delivery (D), Safety (S) and Morale (M), as depicted in Figure 10. These are the losses and bottlenecks that have a great chance to heavily affect the plant performance (Sharma, 2016).

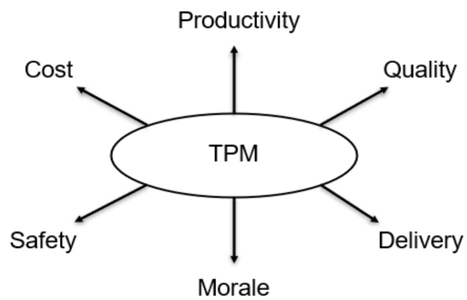

Figure 10. PQCDSM: Six key TPM performance indicators (Source: Johansson and Nord, 1996, cited by Kumar et al, 2014)

Nakajima (1988) proposes that input variables consist of labor, material and machines, while output comprises "PQCDSM". The objective of manufacturing improvement is to increase productivity by maximizing output while minimizing input. It also means to improve goods quality, reduce various costs and meet demand at perfect time but not at the expense of morale, safety and health conditions (Khairnar, 2016). All the indicators discussed above have a great significance on TPM implementation (Sharma, 2016) and should be measured periodically to measure the overall effectiveness and keep the organization's operation on track. The meaning and impact of TPM on each indicator are explained as shown in Table 5.

Table 5. The meaning and impact of TPM on each indicator in PQCDSM (Source: Sharma, 2016)

KPI in PQCDSM	Meaning	Impact of TPM on each indicator
Productivity (P)	Lost production output due to material productivity, manpower productivity, and tools productivity.	5S implementation in offices and shop floor has also play a significant role in improcing the manpower productivity.
Quality (Q)	To reach zero customer complaints. This can be done by eliminating rejection/ rework, by avoiding mistakes in the preperation of bill and invoices. It also means by meeting customer expections so that there should be no return of customer.	One of the most promising parameters for making the brand image. Customer complaints were reduced siginificantly after the implementation of TPM initiatives. Refine the processes from the beginning so that no defective items were manufactured.
Cost (C)	Reduce manufacturing cost by reducing operational and maintenance cost, inventory carrying cost and cost of communication, etc.	TPM could result in reduction in operating expenses and losses etc, and improvements in financial output in terms of market share and profits.
Delivery (D)	To deliver 100% goods on time to customer. It can be achieved by minimizing the delay in logistics losses, delay in delivery to any of the support functions.	Delay or inaccurate deliveries will have an adverse impact on customer satisfaction and brand image. Contributors to delay will ultimatey cause the delay in logistics.
Safety (S)	To create zero accident-free zone area by ensuring safety while working on machines, safety in material handling, safety in packaging, etc.	To succeed in safety, health and environment, the most important element needed to take care is human in the workplace. Ensuring equipment reliability, maintainability, preventing human and eliminating accidents and pollution are the fundamental principle of TPM.
Morale (M)	To boost up the employees of the organization by making them participate in contributing a number of kaizens. It also includes the establishment of autonomous maintenance teams for a better communication and teamwork.	For encouragement and maintaining the enthusiasm with positive focus over the period, motivation is an important TPM indicator.

PQCDSM system contributes to the improvement of performance and efficiency through pushing the employee to achieve the predefined target in limited time. It also increases the involvement of senior management (Khairnar, 2016), which, according to Liker (2004), is essential in the part of lean.

4. Empirical Case

In this section, an overview of the focal company and its current status will be provided to get the readers some insights of the loss deployment systems used in Tetra Pak. Moreover, this section will describe in detail the relevant data obtained from the field, as well as their scope and limitations, which can be used by later researchers to evaluate the relevance of research direction and case data for different situations.

4.1. Company Description

As mentioned before, there are two main sectors of Processing and Packaging in Tetra Pak. In the financial year of 2019, there were 358 Filling machines (Packaging) and 2404 Processing units (Processing) delivered to the customers. The current loss catalogues of Processing and Packaging systems are recorded in two different information systems with different ways of classification and naming. The number of categories in Processing is quite high in comparison to Packaging, making the detailed analysis of losses in Lean Manufacturing complicated and ineffective.

There are differences in the final product, the main function as well as the nature of working procedure between Packaging and Processing. Regarding the final product, the Processing is focusing on producing the machines used in different dairy processing factories which can be used in different technology areas such as blending, dosing, mixing, etc, or can be specifically designed for a single product family such as ice cream or cheese. Therefore, the main function of Processing is to design and manufacture different machines with different technical specifications to fit customers' requirements. As a result, the working procedure in the Processing sector mainly focuses on Engineering-related activities, including design and design reworking, manufacturing and quality assurance. The cycle time in Processing, therefore, depends on the machine type and the complicatedness of the customers' requirements. The Tetra Pak Processing sector is spreading all over the world with factories in China, Denmark, France, Germany, India, Poland, Sweden, USA and UK.

On the other hand, the final product in the Packaging is the automated or semi automated filling machines or other downstream equipment. The filling machines usually consist of different modules provided by different suppliers. Since most of the packaging machines are standardized equipment, the main function of the Packaging sector is to connect different machine parts to make an automated or semi-automated manufacturing line. Therefore, the working procedure in the Packaging sector is quite different from the Processing. In general, it takes them 2 days for assembly and disassembly of the machine parts provided by different suppliers, and 19 days to test the whole system before shipping the package to the customers. There are only 2 Packaging factories, which are located in Lund, Sweden and Modena, Italy, who are using the EPM loss deployment system.

4.2. Loss Deployment systems

There are two different and separated loss deployment systems inside Tetra Pak, initiated and developed by Processing and Packaging sectors. The loss deployment system used in the Packaging sector - EPM - was first developed about fifteen years ago with a quite standardized library of about a hundred of loss categories. The loss deployment system used in the Processing sector - Loss Bank - has been in the developing path since 2018, with a huge number of loss categories of more than a thousand of loss categories in the lowest level.

In this research, the Loss Bank would be analyzed in detail, from the viewpoint of loss structure, supporting information systems as well as implementation and improvement methods. The same approach from EPM is used as the reference for the proposals to optimize the Loss Bank and for the purpose of consolidating the two systems together.

4.2.1. Loss library - Loss structures

The loss structures in Loss Bank consists of the loss categories, the area of happening and the responsible functions for the losses. There are more than one thousand loss categories, being structured in three loss levels: level 1, level 2 and level 3. The first loss level in Loss Bank - level 1 - follows the major losses in production (Chapter 3.2.1) with 16 loss categories. Each level 1 category is divided into different loss level 2. Each loss level 2 is encoded with a separated loss code family, including different loss codes representing for belonging loss categories level 3. The areas of loss happening representing the production areas or product steps where the losses happen, or the machine which is involved in the loss. The responsible functions for the losses mainly separated into four main functions: Customer, Engineering, Production and Supplier. Moreover, 4M categories (Man, Machine, Method, and Material) are also considered in the loss deployment database. However, at the moment, this field of data hasn’t been used or analyzed by the company due to insufficient data. The loss library used in the Loss Bank and EPM system are mentioned in Appendix A and Appendix B for reference.

4.2.2 The supporting information system

Both supporting information systems for Loss Bank and EPM are web-based systems. The operators have their accounts to log the production losses they faced into the systems, using the computer provided or the paper template in case the computers are not available.

When a loss happens, the operator will log into his own account in the system and submit a loss entry or fill in a specific form for loss record at the factory. Each loss entry requires different fields of information related to the site, date and time, the loss category and the amount of wasting time. The most basic site-related information in each loss-entry contains information about the country where the factory is located, the specific site that the loss is happening, the affected machine or production area as well as the related product. The information related to the losses includes the loss levels from level 1 to level 2 (in “Engineering related losses”, loss level 3 is required as well) with specific loss code, the remarks (if any) for more details about the loss happened, and the amount of time it takes to recover from the loss. In case there is no information about level 3 inputted into the system, the loss entry will have [Blank] loss level 3 by default. The information related to drawing numbers are encouraged (but not required) to be filled in case the losses happening related to the design of the product. Last but not least, other information related to the responsible functions (Customer, Engineering, Production, and Supplier) and the 4M categories can be filled in by the operators, but those fields of data are not compulsory to submit the loss entry into the system.

From the database in the Loss Deployment system which was input by the operators, the report would be automatically generated in the platform of Power BI, and can be accessed by the managers. The current report in Power BI mainly focuses on the top 10 losses categories level 2 in duration. In depth details about those top 10 losses can be broken down into different loss level 3 under them, different countries and factory sites, as well as different time periods.

Regarding the access to the systems, it is not uniformly applied in different factories. In some factories, the operators are provided with computers with installed systems. While in the others, the paper format is applied to collect the data and there are other responsible people in charge of inputting data into the system. In the higher level, the systems are managed by the global WCM managers, who own the Admin rights in those systems.

4.2.3 The implementation of the method/system

The implementation of the Loss Bank was firstly initiated in Sweden - the Head quarter and the main Processing factory of Tetra Pak. From time to time, the system was built and developed based on the actual production situation. More and more factories have been involved in the Loss Bank system as well. In the year of 2019, there are 8 countries which have been using the Loss Bank on a stable daily basis: China, Denmark, France, India, Poland, Sweden, UK, and the USA. Currently in the year of 2020, Germany has been newly involved into the system.

Since all the factories are now familiar with the system, the development path of the system is now coming to the final stage before moving to the next step of Loss Eradication. Therefore, the consolidation between the two systems of Loss Bank and EPM can be considered the transitional steps between the two phases: Loss Analysis and Loss Eradication.

4.3. Current Status

Based on the database of the Loss Bank in the year of 2019, all the loss entries recorded in the factories in 8 countries were put into the analysis, in order to understand the current status of the losses in the Processing area, and the usage of the Loss Bank system in different countries.

In the database, the information fields related to the loss categories and loss structure, as well as the duration of each loss entry are the main focus of the analysis for this empirical case in the quantitative approach. In order to form the qualitative approach, additional information from the meetings with responsible people would be beneficial for the conclusions and further analysis.

4.3.1. Quantitative approach

From the quantitative approach, the frequency of loss incidents, the duration of loss time and the average time per loss entry are the three main aspects that are taken to understand the current situation of the loss usage. In each aspect, only loss level 1 and 2 would be used as the unit for analysis since the data of loss level 3 is not mandatory while submitting the loss entry into the system. Among the three aforementioned aspects, the analysis of duration is also available in the company's Power BI reporting system with the similar contents analyzed and interested by the global WCM Managers.

Regarding the loss category structure which was used in Loss Bank, there are 18 loss categories level 1 following the major losses in production such as “Breakdown loss”, “Consumable loss”, “Defect & Rework loss”, “Engineering related loss”, etc. Each loss category level 1 is broken down into different loss level 2. In the whole Loss Bank system, there are currently 94 loss categories level 2. Going to the next level of loss level 3, there are more than a thousand of loss categories in the deepest scale.

Regarding the company's current report of the loss deployment, the top 10 loss categories level 2 are analyzed in detail, using the Power BI platform. There are reports regarding top 10 losses in loss duration, during a chosen period of time (which was explained later in section 4.4). Those top 10 losses would be also broken down into top 10 registered loss level 3 as well as into all the countries which have claimed those losses. Both data breakdown methods were applied in the Tetra Pak’s Loss deployment reporting system in numerical and percentage data.

<u>Frequency</u>

The top 10 loss categories level 2 which were registered the most during the year of 2019 were broken down in the Figure 11 for the contribution of each country. Each single loss event was considered as a loss entry with an identical loss ID, with claimed date of event in 2019. In total, the frequency of all top 10 loss categories level 2 accounted for 59% of all 94 loss categories level 2. It can obviously be seen from the figure that not all countries were facing the same problem in manufacturing loss. There was a big gap in the distribution of the countries in some loss categories, especially “No_order_from_customer” and “Time_taken_to_change_from_one_order_to_another”.

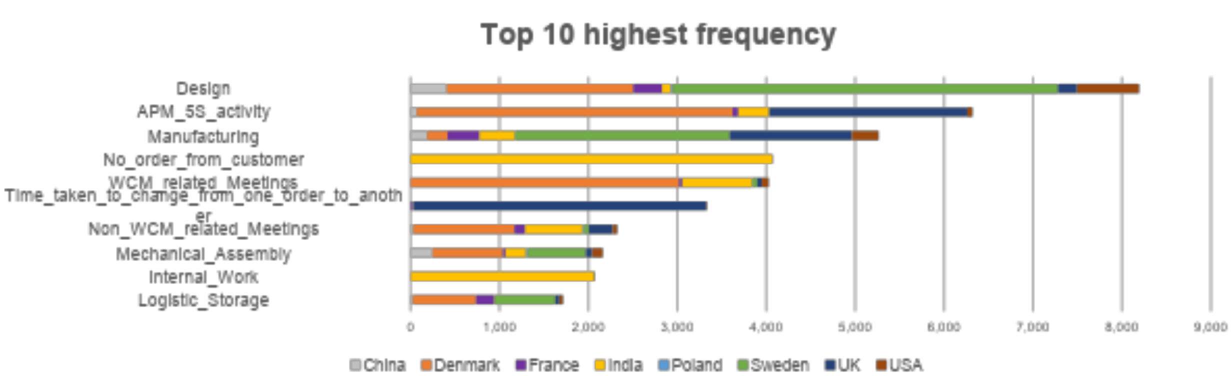

Figure 11. Breakdown of top 10 highest frequency loss level 2 categories

Duration
The top 10 loss categories level 2 which were claimed to be longest during the year of 2019 were broken down in the Figure 12 for the contribution of each country. The unit of loss duration was converted from *minute* in the data entry user interface to *hour* in the report. In total, the duration of all top 10 loss categories level 2 accounted for 77% of all 94 loss categories level 2. It can obviously be seen from the figure that there is a big gap between the top loss of "Non_WCM_related_Meetings" and the second loss of "Searching". Not all countries are facing all those top 10 losses. The contribution of different countries in the same loss category also varies a lot, especially in "Non_WCM_related_meetings", "Searching", and "No_order_from_customer".

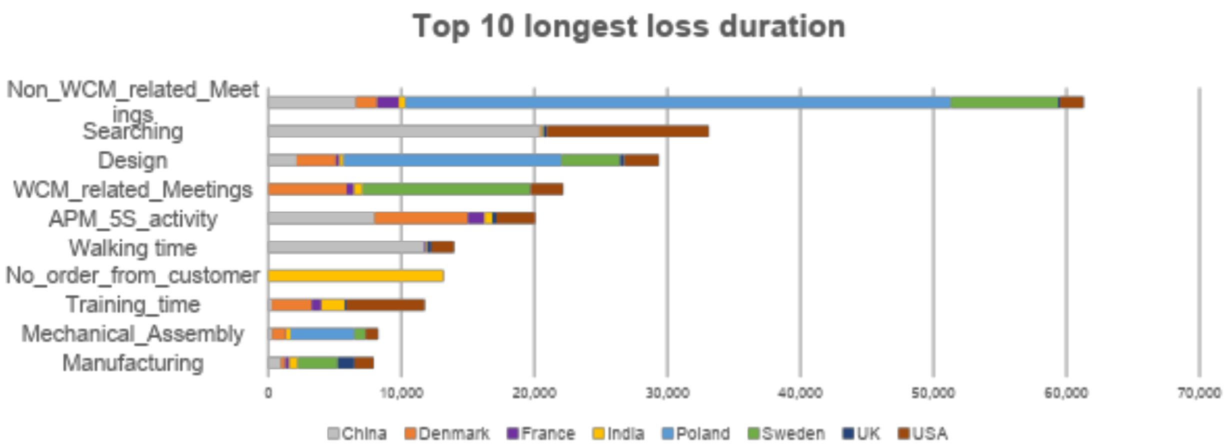

Figure 12. Breakdown of top 10 longest duration loss level 2 categories

There is also a big gap between the loss duration between different factories in the world, ranging from 3% to 22% of annual global loss duration (Table 6). The relationship between overall loss duration in each factory or country and their capacity or the nature of functionality would be analyzed further on.

Table 6. The percentage of loss duration consumed by different countries

China	20%
Denmark	10%
France	5%
India	9%
Poland	22%
Sweden	13%
UK	3%
USA	18%

Average Time
Since there is unstable data in loss duration and loss frequency, the average time per loss event was put into consideration. Table 7 below presents 10 loss categories level 2 with highest average

loss duration per loss event in different countries and worldwide. The cells marked in yellow are the one with longer than 100 hours per loss event on average. By looking at the data table, a significant difference in the way of inputting loss events into the Loss Bank system for each single type of loss category. Having an average of more than 400 hours in China spent on each walking time might need more explanation to get it. The meeting with an average duration of more than 2700 hours in Poland also needs some further notice as well.

Table 7. Top 10 highest average loss time per event

	China	Denmark	France	India	Poland	Sweden	UK	USA	Average
Waiting for material from earlier cells	61.07	1.42	-	1.19	-	-	0.97	-	8.86
Waiting for material from supplier	-	1.09	8.00	2.53	-	1.71	1.81	81.32	10.34
Walking_time	405.19	-	4.48	0.29	0.03	-	0.37	32.10	10.57
Utility_related_ Breakdown_failure	-	-	0.60	-	-	0.98	0.47	65.86	10.80
Records_data_reporting	96.07	0.94	10.54	2.12	-	-	2.78	38.65	16.35
Measurement_time_related_to_Quality	-	1.69	-	0.25	0.25	-	0.10	46.57	23.60
Searching	232.07	0.89	-	0.52	0.05	1.04	0.34	94.41	24.71
Non_WCM_related_Meetings	219.59	1.41	13.52	0.78	2,732.52	144.02	0.57	34.78	26.38
Other_Messurement_Adjustment_loss	-	0.17	91.30	0.88	0.11	-	-	1.06	28.65
Extra_operation	135.93	-	-	12.86	0.08	-	-	28.76	34.11

Uncommon loss categories

With the high concentration of loss frequency and duration in only top 10 loss categories, analyzing the uncommon loss categories should be done in order to understand the situation with the bottom categories.

Through discussion with the supervisor at the company, below 100 hours/year in loss duration and less than 100 times per year in global scale could be considered a benchmark for uncommon losses. All loss categories level 2 which met both criteria are considered uncommon loss categories. Among 94 loss categories level 2, there are 35 categories falling under this group of uncommon categories, accounted for 37%. In terms of loss duration and frequency, this group only consumed 0.2% of global annual loss time and 0.9% of global annual frequency. Therefore, 37% of loss categories level 2 truly consumed a really small impact in loss time. Table 8 below shows the annual global frequency of all uncommon loss categories level 2 grouped by loss level 1.

Table 8. Annual global frequency of uncommon loss categories.

	China	Denmark	France	India	Poland	Sweden	UK	USA
Breakdown Loss	-	50	36	26	-	-	18	-
Consumable (tool, jigs) loss	2	3	-	-	2	-	-	-
Energy Environment loss	-	-	-	-	-	-	2	-
Engineering related loss				24	2		20	-
Line organization loss	-	-	-	2	2	-	3	-
Management loss	-	3	3	5	-	-	2	-
Measurement and Adjustment loss	-	9	1	-	-	-	-	-
Stoppage loss	-	-	-	73	1	-	6	-
Operating motion loss	-	-	-	1	1	-	56	-
Planned Maintenance Shutdown loss	-	-	-	11	-	-	1	-
Startup loss	-	52	-	6	-	-	-	-
Tool change loss	-	-	-	1	-	23	1	1
Waiting time	-	11	-	15	-	1	108	1
Yield loss	-	36	4	-	-	-	-	-

4.3.2. Qualitative approach

Apart from the quantitative database downloaded from the Loss Bank system, the qualitative data used to be analyzed in this thesis includes the information obtained from internal documents as well as the Q&A meeting session with the responsible people in the company. The contents of the qualitative database is mainly related to the implementation path of the systems, as well as about the real meaning of loss categories and the workflow of the operators. Moreover, the information from the other perspectives or systems can also be used as qualitative reference.

Regarding the implementation path of the Loss Bank system, there were several versions of the Loss Deployment information infrastructure which was upgraded from time to time. Different factories in the world were gradually getting involved into the Loss Bank, starting from the training sessions and continuing with the Q&A sessions for any issues they would meet along the way. Moreover, from the higher level view of the WCM development, people understand the importance of the loss structure consolidation, but it's still mentioned in the meetings that they do not want to make the change in their own systems due to long procedure afterward related to the training for the operators.

Regarding the referencing systems from other departments of the company, the long-term developed EPM systems used in the Packaging sector would be the main reference for consolidation. Moreover, another system for a sub-sector of Filling machines can also be used for reference for the final proposals and suggestions. Besides the loss category structures, other smaller details such as information system user interface or the training documents and implementation procedure can also be used for the reference in the proposals.

4.4. Data Collection

The intercepted quantitative data and categorical data were 12 months (January to December) of the data extracted through the web-based database in the Loss Bank system from 8 countries (China, Denmark, France, India, Poland, Sweden, UK and USA) in the past 2019. The reason for only tracing the data of the past year is that after observing the data before 2019, it was found that the proportion of missing data in Loss Bank was too large to be trustable for further analysis. According to the discussion with the company supervisor during the open seminar, the situation happened mainly because some factories have only begun to use Loss Bank in recent years and the previous data records have been directly imported into the Loss Bank, or there is no required electronic equipment to record in the system at any time so the historical data need to be entered by personnel uniformly afterwards. In this process, some data may be lost or inaccurate. To make the analysis of the two systems align with each other, the data used in the Packaging system will also be scoped during year 2019 within the factories located in Lund, Sweden, and Modena, Italy, which are the only two factories using EPM system while handling packaging business. In addition, when analyzing the records of the loss categories and proposing the structure of loss catalog in the Processing system, the breakdown and reorganization were focused with a scope on loss level 1 and level 2 with higher attention.

5. Analysis

This section presents the analysis of the thesis. This is done by connecting what has been observed from the field with that the literature review has provided, in order to analyze the current state of the company. The topics are generated referring to the research questions raised in Chapter 1 in order to make it easier for readers to follow through the structure of the report. The section will start with a cause-effect analysis to breakdown the problem for a general root-cause analysis from a qualitative angle, followed by an ABC analysis of loss categories in the two systems for a further understanding of the current situation from a quantitative angle. The results are expected to assist with the identification of critical root causes which lead to the system losses. After that, a gap analysis between the two systems will be performed and the analysis and discussion of the loss structure will be carried out. The final proposal along with the guidelines for improvement will be presented in Chapter 6.

5.1. Cause-effect Analysis

According to the current status, it was found that there is a big gap in the distribution of loss categories among different countries. Some countries face extreme cases where only one factory there consumed a large portion to make a certain loss category into the list of top 10. This then led to the conjecture that the losses were recorded and interpreted in different ways among these countries. In order to identify which causes create or contribute to the quality problem, a fishbone diagram was performed to breakdown the problem and understand different angles of the current situation as a general root-cause grouping analysis. The goal is to identify where quantitative data and qualitative information should be collected for further study.

The approach has four major steps. It starts with identifying the problem, followed by a discussion on the major factors involved which might influence the effects. Then the possible causes can be determined, which will finally lead to a cause-effect diagram (Hekmatpanah, 2011). This process was determined from the use of brainstorming. Several following discussion sessions with experts were held to ensure its sufficiency, comprehensive coverage and reliability.

Identifying the root cause of the quality problem is grouped into 6 categories of WCM Managers, Loss Categories, Continuous Development, Operators, IT Supporting System and Database. These categories are defined in terms of the current inefficiencies that occur in the operation of the system. They do not exist independently but affect each other. The analysis of these categories is based on direct observations in the field factory, data analysis within the system and discussion sessions with supervisors, executives and other responsible people. Figure 13 below demonstrates all the involved parties in the Loss Deployment as well as potential causes which are resulting in the nonoptimal loss structure and database. The upper part of the Fishbone diagram is more related to management level, which is usually discussed in the Global WCM management office. The lower part is more related to the implementation process, according to the strategy from the managing office.

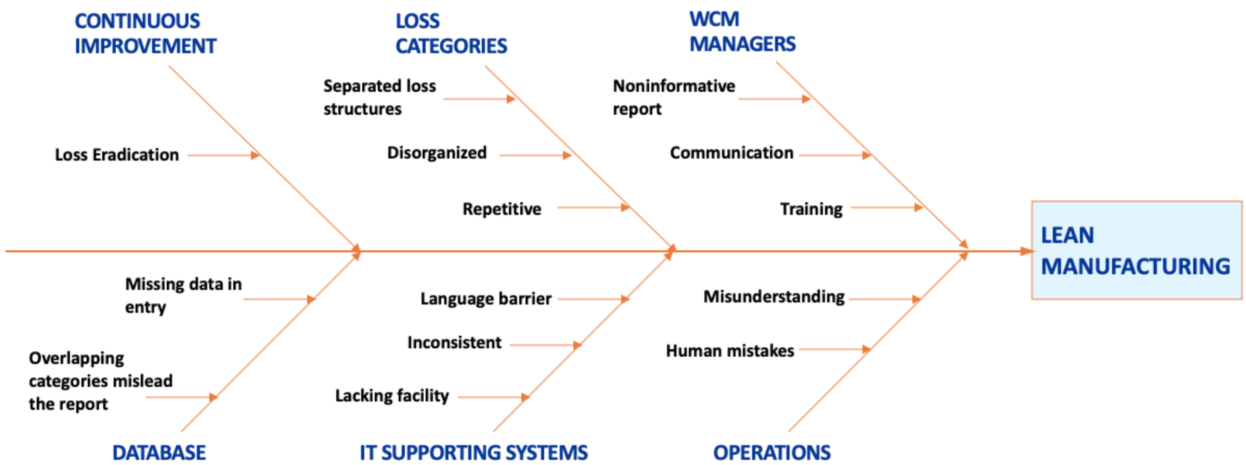

Figure 13. Root-cause analysis with a fishbone diagram

As illustrated in Figure 13, structure of loss categories, strategy of continuous development and management of WCM are recognized as three main causes for the upper level. The problem related to the loss categories is one of the main focuses frequently mentioned in this study. As discussed in previous chapters, the loss categories will be analyzed to match the duplication and reduce the number of categories for better analysis and more user-friendly for the operators to input the information. Another cause is relevant to the needs for continuous improvement. Anvari et al (2010) put forward eleven key success factors for an effective implementation of lean strategy, one of which is continuous improvement. Although achieving leanness in production is itself a continuous improvement technique (Karim and Arif-Uz-Zaman, 2013), loss eradication on a continuous basis according to the improved conditions can help to standardize loss categories and consolidate loss records in a systematic way. Besides, the inefficiencies can be caused by inadequate training of the managers, insufficient communication and non-informative reports. As discussed earlier, with the bulky loss structure and diverse interpretation by the operators, the recorded data would be quite fragmented. As a consequence, the analysis platform could not perform in the best way to support managers with problem detection. Therefore, loss structure consolidation with standardized user guide should be an essential step to gather highest quality data for further analysis.

When it comes to the implementation process, one important cause is applicable to the database due to the missing data in entry and the misleading reports generated with overlapping loss categories. The missing data is largely related to the IT supporting system: blanks and incorrect form filling caused by insufficient language instruction, lack of facilities and equipment to report loss records in time in some factories, etc. Another sub-cause under IT support is relevant to the inconsistency which can be partly caused by the overlapping categories occurring in the loss structure. Inconsistency also exists in the Loss Bank database for requiring loss level 3 or not. Last but not least, the accuracy of operators' tasks also plays an important role. In the actual operation process, misunderstandings caused by language barriers and unclear loss structures will waste more time and effort. In order to reduce waste and unnecessary steps of each process (such as correcting data), it is necessary to ensure that each operator can perform their tasks with fewer errors. Otherwise, the additional rework for whatever reason will cause the previous production to become a loss with no added value.

The main sub-causes are summarized as follows, because these sub-causes are more influential than the others shown in the fishbone diagram (Figure 13).

- Loss categories: repetitive, disorganized, separated loss structure
- Continuous development: loss eradication
- Operators: misunderstanding
- IT support system: language barrier, inconsistent
- Database: overlapping categories mislead the report

We therefore put more focus on these sub-causes and investigate the effects when making changes. Other issues will be discussed and some guidelines for improvement will be suggested in later sections.

5.2. ABC analysis for loss categories in EPM and Loss Bank

An ABC analysis regarding the frequency and duration of usage is performed for all losses categories used for production in the Processing system as one of the fundamental analysis for further structure proposal. It can help to distinguish the top losses from the uncommon ones in each of the two systems and to prioritize the action and process changes that should be focused on.

5.2.1. Frequency and duration

In this part, the loss database of both Processing and Packaging sectors was put into the analysis. The loss database in the year of 2019 would be considered the best to represent the normal manufacturing activities, without any effect of the COVID-19 pandemic or the training session of newly involving factories into the systems.

The ABC analysis would be done separately regarding the duration and the frequency, in order to obtain the classification for each viewpoint. Later on, the classification would be merged together to get the overall combined class for each single loss category. The database would be taken for all the factories in each sector during the whole year. The frequency of the loss events and the total duration of loss time in each single loss category would be analyzed. The analyzed loss category unit in the Processing sector is loss level 2. There are 94 loss level 2 under 18 loss level 1, which was claimed in the whole year of 2019. With the aforementioned ratio by Nallusamy et al (2017), the number of loss categories in each class as well as their relative proportion in loss duration and frequency was summarized in Table 9.

Figures 14 and Figure 15 below represent the detailed analysis of loss deployment database in both logarithmic data and cumulative percentage. The figures show visually how the loss categories are classified into different classification based on their proportion in the overall loss frequency and time duration.

Table 9. ABC classification summary for duration and frequency separately

Class	Duration			Frequency		
	Segmentation	# of categories	Percentage	Segmentation	# of categories	Percentage
A	11.7%	11	79.10%	20.0%	18	77%
B	30.0%	28	18.26%	27.7%	26	20%
C	58.3%	55	2.64%	53.2%	50	3%

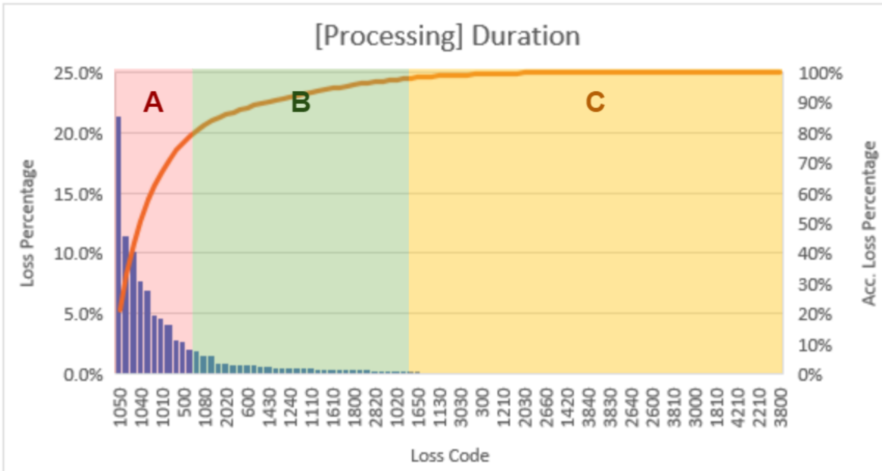

Figure 14. ABC classification of Processing losses based on Duration

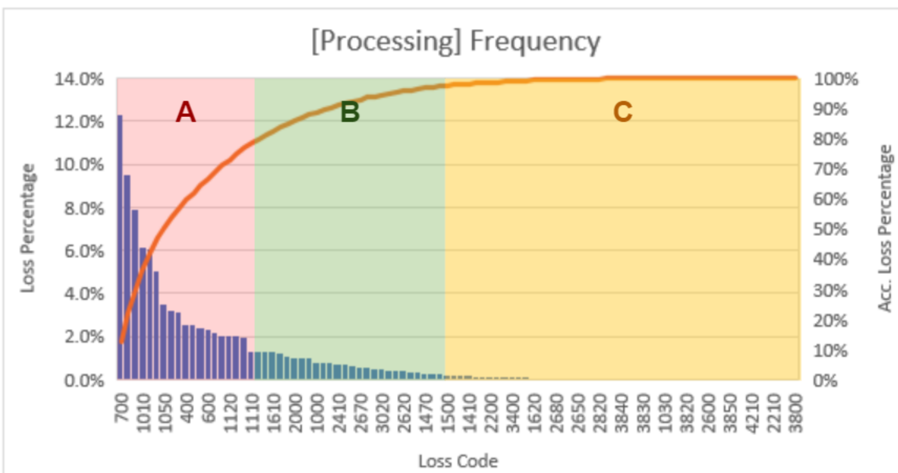

Figure 15. ABC classification of Processing losses based on Frequency

In the next level of analysis, the classification of each viewpoint was merged together, to obtain the overall classification for each single loss category level 2. Based on the combined overall classification, all the loss categories can be grouped into top losses (Table 10) or minor losses (Table 11) for further analysis and future suggestions. The full version of the ABC analysis for Processing is mentioned in the Appendix C.

Table 10. Top losses in Processing

Loss code	Titles	Duration %	Duration Class.	Frequency %	Freq. Class.	Combination
700	Design	10.22%	A	12.33%	A	AA
2400	APM_5S_activity	6.99%	A	9.51%	A	AA
500	Manufacturing	2.76%	A	7.92%	A	AA
1010	No_order_from_customer	4.59%	A	6.13%	A	AA
1040	WCM_related_Meetings	7.72%	A	6.06%	A	AA
1050	Non_WCM_related_Meetings	21.34%	A	3.50%	A	AA
200	Mechanical_Assembly	2.88%	A	3.25%	A	AA
1090	Training_time	4.10%	A	2.57%	A	AA
1060	Searching	11.53%	A	2.02%	A	AA
1600	Walking_time	4.87%	A	1.99%	A	AA
2010	Material_handling_between_differnt_processes	2.11%	A	1.08%	B	AB
2800	Time_taken_to_change_from_one_order_to_anoth	1.51%	B	5.02%	A	BA
1150	Internal_Work	1.92%	B	3.12%	A	BA
400	Logistic_Storage	0.41%	B	2.58%	A	BA
1630	Assistance_needed	0.76%	B	2.41%	A	BA
600	Welding	0.76%	B	2.33%	A	BA
100	Electrical_Automation	0.55%	B	2.16%	A	BA
1430	Waiting for other resources	0.61%	B	2.06%	A	BA
1120	Missing	0.66%	B	2.05%	A	BA

Table 11. Uncommon losses in Processing

Loss code	Titles	Duration %	Duration Class.	Frequency %	Freq. Class.	Combination
2630	Other_type_of_machine_Breakdown_failure	0.11%	C	0.25%	C	CC
1500	Waiting_for_inspection	0.11%	C	0.23%	C	CC
1210	Product_Document	0.11%	C	0.20%	C	CC
2810	Time_taken_on_machine_to_change_order_produ	0.11%	C	0.17%	C	CC
1650	Applying PPE	0.11%	C	0.17%	C	CC
3220	Other_changes_in_machine_or_assy	0.11%	C	0.14%	C	CC
2420	Building_Maintenance	0.11%	C	0.12%	C	CC
3400	Other_Stoppage_loss	0.11%	C	0.12%	C	CC
2660	Leakage	0.11%	C	0.11%	C	CC
1460	Waiting_for_plan	0.11%	C	0.11%	C	CC
1620	Collect_measuring_tools	0.11%	C	0.09%	C	CC
3010	Programme_error	0.11%	C	0.08%	C	CC
2030	Wrong_delivery_point	0.11%	C	0.07%	C	CC
2680	Power failure	0.11%	C	0.06%	C	CC
1220	Over_Engineering	0.11%	C	0.06%	C	CC
2650	Utility_related_ Breakdown_failure	0.11%	C	0.05%	C	CC
1420	Waiting for drawing	0.11%	C	0.05%	C	CC
3210	Fetching_Tools	0.11%	C	0.04%	C	CC
1440	Waiting for instructions SOP	0.11%	C	0.03%	C	CC
#N/A	(Blank)	0.11%	C	0.03%	C	CC
3840	Loss_raw_material	0.11%	C	0.03%	C	CC
2640	Transportation_material_failure	0.11%	C	0.02%	C	CC
2430	Other_Maintenance	0.11%	C	0.02%	C	CC
3830	Surface_damage	0.11%	C	0.02%	C	CC
1450	Waiting_for_instructions_OPL	0.11%	C	0.02%	C	CC
2230	Calibration	0.11%	C	0.01%	C	CC
1030	No_or_unclear_despatch_documentation	0.11%	C	0.01%	C	CC
4000	Other_Consumable_loss	0.11%	C	0.01%	C	CC
1810	Wrong_layout	0.11%	C	0.01%	C	CC
3820	Loss_in_other_materials_in_Euro	0.11%	C	0.01%	C	CC
1100	Order_to_late_to_pick_from_stock	0.11%	C	0.01%	C	CC
3000	Material_loss	0.11%	C	0.01%	C	CC
2600	Hydraulic_related_machine_failure	0.11%	C	0.00%	C	CC
3810	Loss_in_sheet_in_Euro	0.11%	C	0.00%	C	CC
1480	Waiting_for_stock_goods	0.11%	C	0.00%	C	CC
3850	Loss_WIP	0.11%	C	0.00%	C	CC
2240	Equipment_capability	0.11%	C	0.00%	C	CC
4220	Electricity_cost	0.11%	C	0.00%	C	CC
4210	Water_cost	0.11%	C	0.00%	C	CC
4200	Gas_cost	0.11%	C	0.00%	C	CC
1230	Product_breakdown	0.11%	C	0.00%	C	CC
2210	Measurement_time_related_to_non_Quality	0.11%	C	0.00%	C	CC
1510	Waiting_for_BOM	0.11%	C	0.00%	C	CC
1490	Waiting_for_packing_nextcell	0.11%	C	0.00%	C	CC
3800	Loss_in_Pipe_in_Euro	0.11%	C	0.00%	C	CC

In the Packaging sector, the loss analyzed category unit is the loss category with registered identical loss code in the loss deployment system. There are 92 loss categories which were put under ABC analysis. With the aforementioned ratio, the number of loss categories in each class as well as their relative proportion in loss duration and frequency was summarized in Table 12.

Table 12. ABC classification summary for duration and frequency separately

Class	Segmentation	# of categories	Duration	Frequency
A	20%	18	77.17%	72.20%
B	30%	28	18.99%	22.28%
C	50%	46	3.84%	5.52%

Figures 16 and Figure 17 below represent the detailed analysis of loss deployment database in both logarithmic data and cumulative percentage. The figures show visually how the loss categories are classified into different classification based on their proportion in the overall loss frequency and time duration.

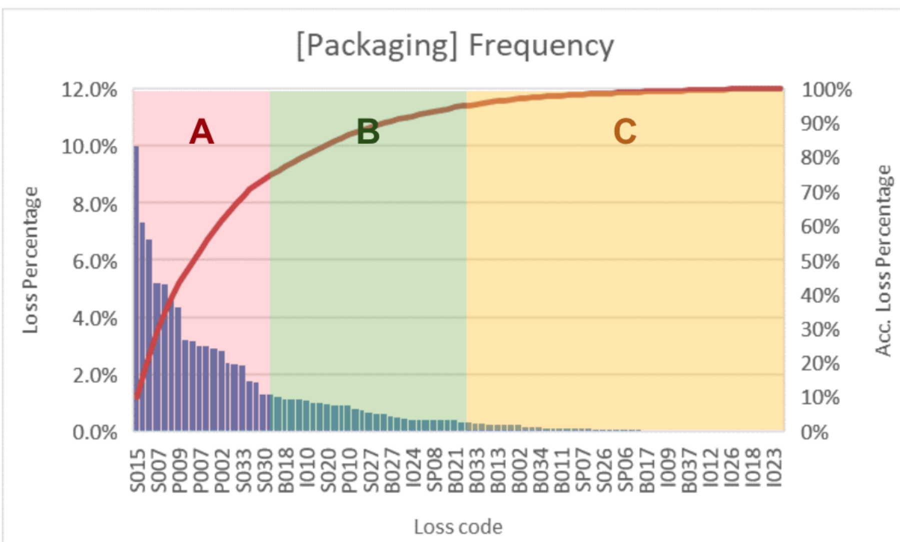

Figure 16. ABC classification of Packaging losses based on Frequency

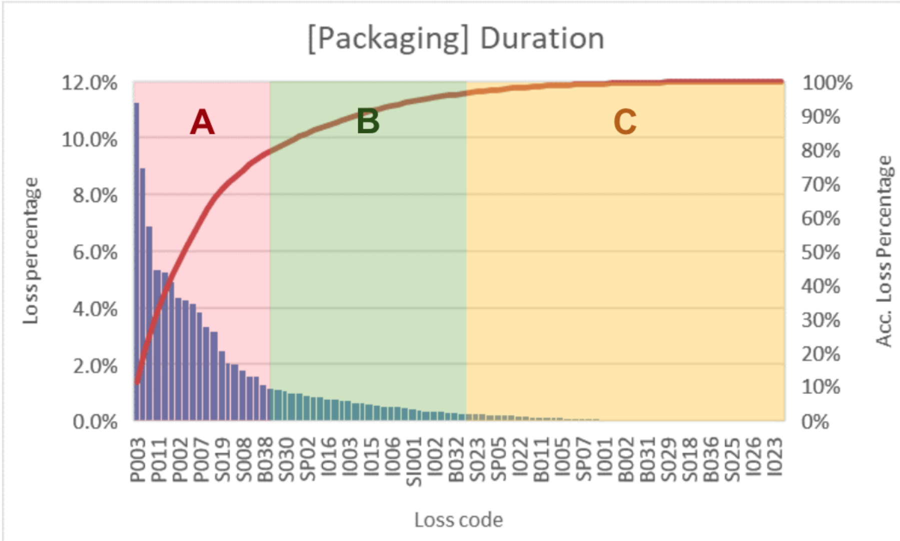

Figure 17. ABC classification of Packaging losses based on Duration

In the next level of analysis, the classification of each viewpoint was merged together, to obtain the overall classification for each single loss category in the Packaging sector. Based on the combined overall classification, all the loss categories can be grouped into top losses (Table 13) or minor losses (Table 14) for further analysis and future suggestions. The full version of the ABC analysis for Packaging was mentioned in the Appendix D.

Table 13. Top losses in Packaging

Loss code	Loss title	Frequency %	Freq. Class.	Duration %	Duration Class	Combination
P003	Mechanical design fault	7.34%	A	11.25%	A	AA
S015	Supplier NC - Superstructure	10.01%	A	8.95%	A	AA
P009	Software error	4.37%	A	6.88%	A	AA
S007	Supplier NC - Electrical Cabinet	5.20%	A	5.28%	A	AA
S022	Supplier NC - Lid Forming Unit	3.00%	A	4.92%	A	AA
P002	Automation design fault	2.82%	A	4.34%	A	AA
B016	D&E test not planned	1.75%	A	4.29%	A	AA
S021	Supplier NC - Package Section	5.17%	A	4.14%	A	AA
P007	Mechanical mandatory kit installation	3.00%	A	3.83%	A	AA
S006	Supplier NC - Machine Body	4.57%	A	3.33%	A	AA
P006	Automation mandatory kit (SW or HW) installation	6.74%	A	3.16%	A	AA
S019	Supplier NC - Carton Section	2.91%	A	2.46%	A	AA
S012	Supplier NC - ASU	3.18%	A	2.04%	A	AA
S008	Supplier NC - Service Unit	2.38%	A	1.79%	A	AA
A012	Lack of technical information / instructions	3.24%	A	1.57%	A	AA
P011	Package Forming Issue	1.04%	B	5.34%	A	AB
B018	FM test run for customer visit or training	1.16%	B	1.58%	A	AB
B038	Missing part due to cannibalization	1.78%	A	1.28%	B	BA
SP01	Test line conveyor stopped	2.41%	A	0.96%	B	BA
S033	Supplier NC - Assembly/Disassembly/Cleaning/Packing	2.35%	A	0.83%	B	BA

Table 14. Minor losses in Packaging

Loss code	Loss title	Frequency %	Freq. Class.	Duration %	Duration Class	Combination
S023	Supplier NC - Openings and Closures	0.06%	C	0.24%	C	CC
B033	Waiting support for standard phase activity	0.30%	C	0.23%	C	CC
SP05	Air pressure supply problem	0.30%	C	0.20%	C	CC
S028	Supplier NC - Machine Body Upper [TR]	0.15%	C	0.20%	C	CC
B013	Electrical setting tools missing	0.24%	C	0.19%	C	CC
I022	Internal NC - Machine Body Upper [TR]	0.06%	C	0.17%	C	CC
B017	D&E test longer than planned	0.06%	C	0.16%	C	CC
T001	B-group damaged during transportation	0.24%	C	0.13%	C	CC
B011	Mechanical setting tools missing	0.15%	C	0.13%	C	CC
SP10	Granulate Supply Problem	0.06%	C	0.12%	C	CC
I005	Internal NC - Railing and Platform	0.18%	C	0.10%	C	CC
B034	Waiting outfeed conveyor installation	0.18%	C	0.09%	C	CC
SP07	Utility connection tools missing	0.12%	C	0.09%	C	CC
S009	Supplier NC - Railing & Platform	0.27%	C	0.07%	C	CC
S026	Supplier NC - Filling system [TR]	0.09%	C	0.07%	C	CC
I001	Internal NC - Final Folder	0.15%	C	0.06%	C	CC
I021	Internal NC - Machine Body Lower [TR]	0.12%	C	0.06%	C	CC
I020	Internal NC - Filling system	0.06%	C	0.06%	C	CC
B002	Waiting slot assignement	0.24%	C	0.05%	C	CC
SP09	Cap Supply Problem	0.06%	C	0.05%	C	CC
I025	Internal NC - Electrical Cabinet PT	0.03%	C	0.04%	C	CC
B031	Packing list error	0.12%	C	0.04%	C	CC
B014	Packaging material defective	0.09%	C	0.03%	C	CC
I004	Internal NC - Service Unit	0.09%	C	0.03%	C	CC
S029	Supplier NC - Magazine [TR]	0.09%	C	0.03%	C	CC
I009	Internal NC - DIMC	0.06%	C	0.03%	C	CC
SP06	Utility connection tools damaged	0.09%	C	0.03%	C	CC
S018	Supplier NC - kit ICU	0.09%	C	0.02%	C	CC
B037	Unpredictable/Unfortunate events (flod, earthquake ...)	0.06%	C	0.02%	C	CC
S032	Supplier NC - Electrical Cabinet DIMC	0.06%	C	0.02%	C	CC
B036	Waiting overhead crane (Organization)	0.03%	C	0.02%	C	CC
I018	Internal NC - Bottom Sealing Unit [TR]	0.03%	C	0.02%	C	CC
I012	Internal NC - kit ICU	0.06%	C	0.02%	C	CC
S025	Supplier NC - Cleaning System [TR]	0.06%	C	0.02%	C	CC
S017	Supplier NC - kit HVA	0.03%	C	0.01%	C	CC
S016	Supplier NC - Strip Applicator	0.06%	C	0.01%	C	CC
I026	Internal NC - Electrical Cabinet DIMC	0.06%	C	0.01%	C	CC
B010	Mechanical setting tools broken	0.03%	C	0.01%	C	CC
I008	Internal NC - PullTab	0.03%	C	0.01%	C	CC
I023	Internal NC - Magazine [TR]	0.03%	C	0.01%	C	CC
B035	Waiting overhead crane (Breakdown)	0.09%	C	0.00%	C	CC

5.2.2. Major and minor losses

Based on the overall combined classification from the aforementioned ABC analysis, the major and minor losses in both Processing and Packaging sectors were marked with a similar ratio as the percentile using in ABC analysis (Table 15).

Table 15. Major and minor losses based on ABC analysis.

Overall classification	Processing	Pakaging	
AA	10	15	Major losses
AB-BA	9	5	
AC-CA	-	1	Middle range
BB	15	21	
BC-CB	15	9	
CC	45	41	Minor losses

Getting a deeper analysis into the percentage proportion of loss frequency and time duration, there are similarities between analysis in both Processing and Packaging sectors (Table 16). With the high impact of the top losses in both duration and frequency, any action which helps improve the identification or understanding of the categories would make a relatively high impact. Further analysis of those top losses would also gain high impact in the later phase of loss eradication to increase the productivity or efficiency of the manufacturing line.

Table 16. Consumption of different loss ranges in duration and frequency

	% Categories	% Duration	% Frequency	
Major losses	20.21%	86.27%	78.08%	**Processing**
Middle range	31.91%	12.52%	19.55%	
Minor losses	47.87%	1.21%	2.37%	

	% Categories	% Duration	% Frequency	
Major losses	21.74%	78.23%	74.40%	**Packaging**
Middle range	33.70%	18.89%	21.27%	
Minor losses	44.57%	2.88%	4.33%	

On the other hand, almost half of the loss categories fall into the minor losses group. Thus, further actions could be done to reduce the number of minor losses for simplifying the loss structure in both systems. Smaller number of loss categories may help the end users or the operators to better locate the loss events into the best fit loss category.

5.3. Gap analysis between EPM and Loss Bank

Different system structures will lead to differences in the content and the scope of their respective coverage. A gap analysis can make better use of EPM as a benchmark to build Loss Bank and can consolidate two systems from a more comprehensive perspective.

5.3.1. Viewpoint of building loss structures in two systems

Unlike Loss Bank, EPM has been developed into a standardized system after years of usage. There are slightly less than a hundred losses that are classified according to eight loss families: D&E, Supplier NC, Internal NC, Utilities, Tools & Manual, Customers, Simulator and Waiting for. Each loss will also be traced to the Loss Source: whether it is internal or external. The system also focused on recording information about losses as per machine type. According to the data report in Power BI, it can be seen that the machine types which cause losses under some of the loss families are quite overlapping. In addition, since the operation in the Packaging system is mostly composed of automated or semi-automated filling machines containing various modules, the losses are recorded as per module as well, such as Superstructure, Machine body, Electrical Cabinet, Service Unit, Assembly/Disassembly/Cleaning/Packing, Jaw system, Final folder, Railing & Platform and Packaging material defective. Although some data records are found to be incomplete in EPM's database, overall, the structure of EPM is clearer, more interrelated and more standardized than the one used in Loss Bank. Part of the reason can be attributed to the very different workflows of the two systems. From the perspective of automation degree and operation complexity, EPM can be considered to be easier to standardize than Loss Bank.

As introduced in section 4.2, the loss category system in Loss Bank was structured in three levels: loss level 1 as the major losses and loss level 2 and 3 as the breakdown of loss level 1 with more detailed loss description. Meanwhile the losses are classified into four categories including Customer issues, Engineering issues, Production issues and Supplier issues. It is a broader classification compared to EPM. Unlike EPM recording losses as per module, Loss Bank details the losses to each department: Assemble, Bending, Common Area, Grinding, Machine area, Manufacturing, Packing, Standard line, Warehouse, WCM Admin and Welding. Again, the different ideas for building up systems are due to the different working procedures involved.

Since the Processing sector attaches more importance to the engineering-related activities and quality control, machine type should have been an essential data recorded in the database. However, in the current Loss Bank interface, the machine type exists as an optional item, resulting in a large amount of missing data in this field. Another difference from the Packaging sector is that the machines used in Processing vary a lot from different departments, which makes it harder to track down the machines that caused the losses.

5.3.2. Coverage of the loss categories in both loss structures

As discussed above in the structure of both loss deployment systems, different viewpoints will result in different coverage. Analysis in the coverage of the loss categories, therefore, is very important in studying the difference in the two loss structures.

One of the biggest differences in loss category coverage is about the Engineering-related activities due to the nature of main function and working procedure in Processing and Packaging sectors. In Processing, since there are different machines with customized technical specifications that are manufactured as the main products, there are quite a lot of losses related to the machine design or specification information. However, in the Packaging sector, as its nature of functioning the existing different types of filling machine, there are limited design-related problems happening. The design in Packaging sector is the automation design of the manufacturing line, not the design of the final products.

Regarding the scheduled maintenance, which is one of the compulsory activities in manufacturing, there are differences in viewpoints from the two sectors. The scheduled maintenance in the

Processing covers all the planned maintenance activities aligning with the theory. However, in the Packaging sector where testing is the main activity, scheduled maintenance is not part of the working basis.

Additionally, regarding the testing as well as other Quality Control or Quality Assurance activities, the differences in main working procedure in the two sectors lead to the differences in their viewpoint about the time spent for them. In the Packaging sector, there is standardized typical time duration spent for each Filling Machine package (2 days for assembly/disassembly activities and 19 days for testing), all the testing activities which take longer than expected will be considered in the loss deployment system. However, in the Processing sector, testing is one of the mandatory tasks that they have to finish before sending out the products to the customer, as a part of Quality Assurance and Quality Control. Therefore, testing is not considered as a loss in time.

Last but not least, in the Processing sector, there's always “Other losses” in loss level 2 and level 3 to cover the rest of the losses which has not been mentioned yet in other specific categories. However, those “other” loss categories can be somehow misleading for the operators. Some operators with language barriers can just choose this type all the time because it’s always correct. However, in the Packaging sector, there’s no “other losses” anywhere, which means the loss structure already has pretty good coverage of all probability, and the meaning of loss titles are clear enough for the operators to allocate their losses.

Those loss titles with unclear meanings could be considered as the main reason for the wrong categories allocation by the operators. There were a lot of notes mentioning “Power failure” under the “Minor Stoppage loss”. There were also a lot of notes mentioning the “Internet crashed” or “Server down” under different loss levels 1 of “Defects and Reworks” or “Engineering related losses”. “Jig making” should belong to the consumable losses, but some operators made them happen in “Tool change”. Some logistics related losses were also mentioned under the “Line Organization loss”. Those aforementioned examples are just some of the typical wrong categories allocation done by the operators with relatively high frequency. Therefore, having clear and non-overlapping loss titles is very important to maintain the high quality of the input data.

Regarding the repetitives and other potential misleading loss categories in the Processing loss deployment system, there are some specific examples which can be found from the loss library. Under Breakdown loss level 1, there are two loss levels 2 called “Power failure” and “Utilities_related_breakdown_failure”. The operators can be misled somehow because “Power failure” could also be covered under “Utilities_related_breakdown_failure”. There are also some similarities between the two loss levels 1 of “Defect and rework loss” and “Engineering related loss”: there is “Design” and “Product document/documentation” loss levels 2 under both of them. These repetitives can be misleading and confusing to the end users - operators.

5.4. Structure analysis

Based on the previous analysis along with the combined theory, different possibilities of constructing the loss dictionary are analyzed and discussed to indicate the path for the final proposal.

5.4.1. Loss structures regarding common loss deployment models

After sufficiently understanding and comprehensively analyzing the situation and facing problems, in turn, from the perspective of the currently used loss dictionary, the well-known loss deployment models introduced in Chapter 3 will be analyzed from the actual production demand. This discussion could help to make the newly constructed loss dictionary more suitable for the actual needs in the production process.

(7+1) Wastes

In practice, the two systems, especially Packaging (as shown in Table 17), do not really follow the (7+1) Wastes model. Processing seems to have a high degree of coverage, but in fact the agreement between what the two deployment methods concern is not impressive. That is to say, although the loss titles can be found and classified into corresponding classification in the (7+1) Wastes model, most of the theoretical big loss categories are not the ones obtaining great attention in practice.

Table 17. Application of the (7+1) Wastes model in two systems

(7+1) wastes	Processing	Packaging
Overproduction	☐	☐
Waiting	☑	☑
Uncessary transport or conveyance	☑	☑
Overprocessing or incorrect processing	☑	☐
Excess inventory	☐	☐
Uncessary movement	☑	☐
Defects	☑	☑
Non-utilized talent	☑	☑

The “Overproduction” and “Excess inventory” in Tetra Pak are out of scope since everything is made-to-order. Although there are some losses caused by insufficient inventory, such as waiting for material or waiting for stock goods. Similarly,the overprocessing related loss regarding the working procedure is not found to be recorded, but there is a loss category related to the quality of design drawings called “Over_engineering” in case of having unnecessary details or parts. The design problem occurring in the Processing sector can be considered as incorrect processing issues. In the packaging sector, as mentioned above, the main activity is testing. Their design faults are more about the automated systems instead of about each single machine inside.

Both systems have a big loss level for the waiting time, covering waiting time for necessary tools and equipment, or planning and instructions. However, waiting time caused by equipment downtime is considered in different Loss families or Loss level 1 in Packaging and Processing respectively. Especially in the Processing sector, where the daily operation is closely related to the manufacturing, the losses caused by equipment downtime are divided into various categories in detail, including breakdown, stoppage, less speed, tool change, startup loss, etc.

“Transportation or logistics loss” as loss level 1 in Processing represents the losses due to unnecessary transportation or conveyance. There is no big loss family related in Packaging, though one loss under “Supplier NC” called “B-group damage during transportation” can be considered as inefficiency during the transportation. As for unnecessary movement, it can be interpreted as “Operating motion loss” in Processing. “Searching” as one of the top-class loss level 2 under “Management loss” covers losses caused when looking for materials and tools which can be categorized into unnecessary movement as well according to the definition, but it also covers searching for instruction which is not in the same topic of this waste.

Both systems have quality-related problems that cause defects and rework. Processing department has their final products as machines, therefore people pay more attention to the quality issues. Actually “Defects and rework” is one of the biggest focused losses in Processing. Regarding the inspection issues, both of the sectors have one loss code for “Waiting_for_inspection” or “Waiting_for_support_in_troubleshooting”. The difference in practice is that they only care about the waiting time for the inspection activity, but do not count the inspection or troubleshooting time as a loss.

For the eighth wastes, the non-utilized talent, it is basically the management issue when failing to ensure the manpower productivity to improve the overall operational effectiveness. Since Processing is under the implementation process of WCM, there are a lot of internal losses related to meetings and training to get all related people involved into the systems. Moreover, “No_order_from_customers” is also a big loss in Indian factories. Packaging sector also has losses caused by machine downtime due to meetings.

Major losses in production

Judging from the overall coverage of the main losses, the Processing system fits the theory very well in practice, as indicated in Table 18. This is mainly because the main function of the Processing sector is producing or manufacturing the machines used in the dairy industry. Therefore, as a typical manufacturing factory, all of the major losses would fit into the daily working basis. However, since the final products, i.e. machines, are made-to-order, which need to be customized based on customer requirements, the engineering activities play an important part in the whole working procedure. This can be seen as the reason why “Engineering related loss” as one of the only two losses that does not appear in the theory (the other one is “Waiting for”), but in practice exists as a big group of losses, which contains one of the top losses called “Design” happening in reality. In addition, changeover losses are separated into “Tool change loss” and “Setup and adjustment loss”, both of which contain a few Loss level 2 with average low overall combined class, giving possibility and rationality to the option of merging.

Table 18. Application of the Major losses model in two systems

Major Losses in Production	Processing	Packaging
Equipment failure and breakdown	☑	☑
Changerovers	☑	☑
Start-up losses	☑	☐
Minor stoppages	☑	☐
Speed losses	☑	☐
Quality defects & rework	☑	☑
Shut down losses	☑	☑
Management losses	☑	☑
Operation Motion	☑	☐
Line Organization	☑	☐
Logistics	☑	☑
Measurement & Adjustment	☑	☑
Yield, Energy and Die-Jig losses	☑	☑

In the Packaging sector, on the other hand, since the structure of loss families are mainly focusing on the responsible departments (except for the Loss family for "Waiting time"), there is no big match between the Major losses and the loss families. Another reason is that due to the nature of main working activity of testing the automated filling machine lines, which is not manufacturing-related, structuring the losses following Major losses in production is not really suitable. The checklist here refers to the similar-meaning loss categories under Packaging.

PQCDSM System

Similar to the (7+1) Wastes model, a small part of the loss categories that are focused on in the PQCDSM model are not really covered in the actual production considerations. But the difference is that the PQCDSM model also has a high degree of attention to the big categories that are valued in the actual production process. Table 19 implies the compatibility of PQCDSM with the two systems.

Table 19. Application of the PQCDSM model in two systems

PQCDSM System	Processing	Packaging
Productive	☑	☑
Quality	☑	☑
Cost	☐	☐
Delivery	☑	☑
Safety	☐	☐
Morale	☑	☐

By definition, Productive refers to reducing unplanned stoppage and breakdown to improve equipment availability and productivity. Although there is no major category named Productive in the loss dictionary, multiple loss level 1 and loss family are related to losses that can cause productivity problems. In more detail, in the Processing system, breakdown loss, waiting time, operating motion loss and adjustment loss can all be classified as productive issues. Many loss level 2 belonging to these losses have obtained a high overall combined class in ABC analysis, which means that they are the main loss in the production process. In addition, some minor losses also fall into this category, including stoppage loss and tool change loss, etc. For Packaging, most losses belonging to the loss family of “Tools & Manuals” and “Waiting for” can be regarded as unplanned stoppage. A few losses such as “Waiting lifting unit head crane breakdown” under “Utilities” and test run for customer visit or training under “Customer” also stand in this column.

As has been discussed above, quality control is usually a category that is valued by both theory and practice, especially in the Processing system. Unlike the (7+1) Wastes model, Quality here not only aims to reduce defects and reworks in manufacturing, but more importantly, it is to satisfy the customers. Since “Customer" is one of the four major loss categories and one of the seven loss families in the Processing and Packaging system respectively, this seems to be more in line with the idea when constructing the two systems.

Delivery in the PQCDSM model refers to the efficiency of delivery, speed and reliability. Obviously, it corresponds to “Transportation or logistics loss” in Processing, with a prominent average overall combined class for loss level 2. “B-group damage during transportation” in Packaging can also be considered here since the theory also highlights the reliability.

Cost and Safety are not really covered in either of the two systems. In Processing, though the energy environment loss and yield loss are named after money-related titles, actually the information recorded in the database is in time. As for Morale, it exists in the system as a management-related loss in Processing. In Packaging, except for "Lack of technical information /instructions" under "Tools & Manuals", which can be regarded as management losses, there are few related losses recorded.

In summary, loss categories in Processing always covers theory better than the ones in Packaging. One reason can be referred to is that those theoretical deployment models are more suitable for the Processing system due to its manufacturing-based nature. Moreover, the complicatedness of the main working activities in Packaging is much simpler than the working procedure in Processing, which could also be the reason that the categories covered are different in quantity.

Only from reducing the loss time during production perspective, compared to (7+1) Wastes, which speaks more for the overproduction, overprocessing and excess inventory when coming to the manufacturing wastes, PQCDSM model put more attention on the productive issue that has a bigger coverage of the losses might occurring during the operation. Most loss level 1 classified into the Productive category are also a big focus in the Processing sector. Therefore, the revised structure for proposal will consider the remaining loss categories in the (7+1) Waste model, but it will be mainly based on the Major losses in production and PQCDSM models. Cost and Safety are still not within the scope of the discussion because Processing is concerned with the loss of time. As for the only two loss level 1 that are not taken care of by the Major losses model, namely the “Engineering related losses” and “Waiting time”, the other two theoretical deployment models could help to analyze and improve the coverage of loss structure in the Processing sector.

According to the impressions and suggestions given in the theoretical section, shutdown loss is discussed to be distinguished from other unplanned stoppage as mandatory scheduled maintenance for better performance and effectiveness of the machines. Quality section is also under discussion that it should exist independently as a big category rather than combined with other losses to better align with the benchmark with Packaging because both theory and practice in Processing value quality as a great focus. What needs to be realized here is that although the loss categories can be adjusted to the most suitable structure according to the theoretical and actual production conditions, the lack of measurement standards is not conducive to comparing the benefits and advantages brought about by these adjustments, nor is promising to identify further points for continuous improvement. In this regard, OEE can provide a general method of evaluation and guide the loss structure towards easier and clearer measurement in a quantitative way for both sectors.

5.4.2. Loss structures regarding overall working efficiency

In this part, the loss structure in both Processing and Packaging sectors would be analyzed from the viewpoint of overall working efficiency. Since the working procedure in both two sectors are not completely automated, so they include the participation of operators with potential human mistakes. Therefore, the losses which affect the overall working efficiency in the factories could be separated into two main parts: the losses in total operating time, and the losses happened while the operators and machines are well-functioned, but they have to do extra tasks or reworks.

In any business, the efficiency of the value-added system plays a highly important role in the overall benefits of the whole business. Thus, detailed analysis in the losses in working efficiency is very beneficial for the company to work on not only improving productivity and continuous development but also the measurement for loss eradication. Therefore, OEE calculation could be the best fit to analyze the loss in the real operating time they have out of the total working hours. This analysis/loss structure would to be done the same way for both Processing and Packaging. The coverage of the loss categories was summarized in Table 20 below, following the definition of OEE.

Due to the nature of the manufacturing at Tetra Pak, the manufacturing activities were not fully automated. That means the operators need to control and function the machine to get the job done. In this typical case, the working efficiency of the operators (or worker) also affects the machine or equipment efficiency. Therefore, all of the factors under both sectors of Equipment efficiency and Worker efficiency were considered in the below table to keep track of all the potential losses happening during the manufacturing activities.

Table 20. Loss structure coverage of Processing and Packaging sectors regarding OEE

	Theory of OEE	Processing	Packaging
Planned downtime	Shutdown losses	☑	☑
Availability	Breakdown	☑	☑
	Setup & Adjustment	☑	☐
	Tool changover	☑	☑
	Distribution / Logistics	☑	☑
	Motion	☑	☐
	Measurement & Adjustment	☑	☑
Performance	Reduced Speed	☑	☑
	Idle & Minor stops	☑	☐
	Management losses	☑	☑
	Line organization losses	☑	☐
Quality	Defects	☑	☑
	Startup	☑	☐
	Yield loss	☑	☑
	Consumable loss	☑	☑
	Energy loss	☑	☑

According to the definition of each different topic mentioned in the OEE theory, there are two main loss level 1 which are not covered by the checklist in Table 20: “Engineering related losses” and “Waiting time”, while all the rest of the current loss categories in used now were well covered and matched with the definition provided by the academical theory.

Regarding the Planned downtime, since the main functioning activities in Packaging is testing the automated or semi-automated Filling machines, there are no scheduled maintenance activities needed in Packaging. However, considering the “Mandatory kit installation", one of the loss categories in Packaging, it could be categorized into this category because it’s the mandatory activity for the machines.

Regarding the field of Availability, the losses mostly care about the loss in product working time. Therefore, there are some mutual situations that can happen in both sectors. However, due to the difference in nature of function working activities and final products, the Packaging sector is not likely to face all the main situations happening in a typical manufacturing factory like the Processing sector. The mutual loss types between the two sectors can be seen in the checklist: “Breakdown”, “Tool Changeover”, “Distribution/Logistics” and “Measurement & Adjustment”.

In the field of Performance, “Management” loss could be seen as the obvious category that Packaging is facing on a daily basis. Since the main functioning activities in Packaging is testing the automated/semi-automated Filling machines, when the tests take longer than expected to get it done, those kinds of loss in time can also be considered under the Speed loss section.

The most important area that any business would put them in the top priority is the Quality. Most losses under the Quality section show a great possibility to consolidate the mutual part between

Processing and Packaging because Quality is always the main concentration of the whole company. And there are some similarities between the functioning activities in both sectors regarding the Quality issue.

Due to the difference in the collaboration of the two sectors under each area, a cause-effect (fishbone) diagram was implemented for each area to analyze the loss events happening in both sectors during the year of 2019. In this analysis, together with the reference from the Packaging and the close supervision of the company's representative, the Loss Bank database for the whole year of 2019 was put under detailed analysis to get the close idea how the operators are categorizing the loss events based on their notes in the loss ticket, especially the with the loss tickets falling under "Other" loss categories. Different situations happened under the "Others" categories were considered and discussed to be categorized under a specific loss category. Human mistakes or wrongly categorized loss tickets were also studied to generate the suggestions to be avoided in the next part of this thesis.

In this analysis, there would be one fishbone for each area: Planned downtime, Availability, Performance, and Quality. Regarding the structure of each fishbone representing each area, the main contributors are inspired from Table 20, while the sub-causes were selected from the current Loss structure of Processing, considering the result of ABC analysis, the insights from company's supervisors and the notes from operators.

Quality

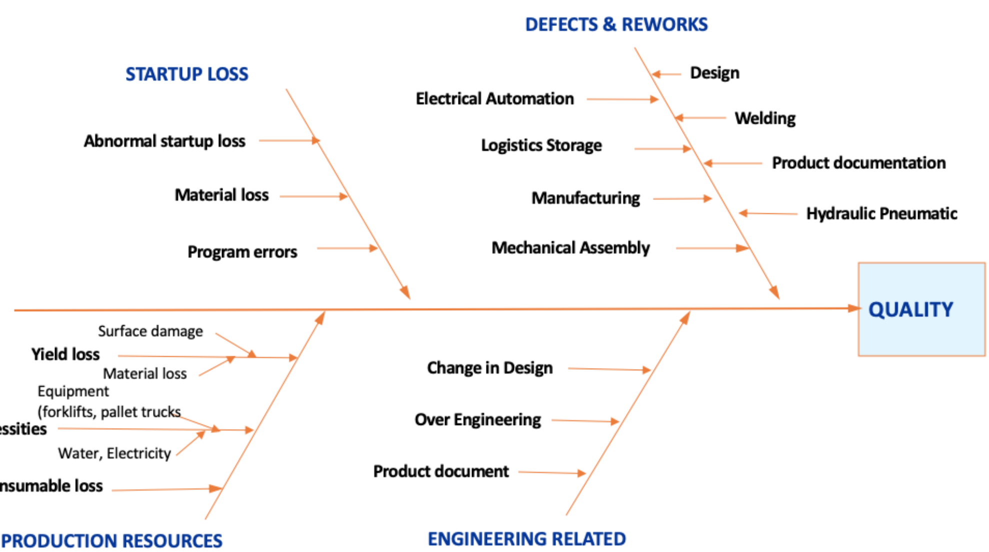

Figure 18. Cause-effect analysis in Quality area

According to the seminars and the message from the supervisors at Tetra Pak, Quality has been mentioned many times as the biggest focus in Processing. The main losses belong to the Quality aspect are: Defects & Rework, Startup loss, Production resources and Engineering related losses. Among all aforementioned loss categories, the "Defects and Rework loss", "Startup loss", "Yield loss", "Consumable loss" and "Energy loss" are collaborated with the loss level 1 under the same name in the Loss Bank deployment system. While the “Defects and Rework loss” and “Startup loss” are identical to be analyzed separately in the single branch. Since the “Yield loss”, “Consumable loss” and “Energy loss” together affect the efficiency use of the production resources, they are analyzed together in the same branch. Even though the “Engineering related losses” is not covered under the checklist according to the theory of OEE, they are closely related to the quality of working functions at the factories. Therefore, a new branch for “Engineering related losses” was added to analyze this section in detail (Figure 18).

Regarding the “Defect and rework losses” with 8 sub-causes, there was no changing in any loss currently used. Another reason for having those separated loss level 2 as sub-causes was that most of the loss level 2 here fell into the high impacting group categories in the ABC analysis.

Regarding the “Startup loss” which all recorded under the loss level 2 of “Other startup loss”, the notes from the operators were used to be analyzed and separated into different sub-causes of “Abnormal startup loss”, “Material loss”, and “Program errors”.

In the field of “Production resources” which originally consisted of “Yield loss”, “Necessities” and “Consumables loss”, there was a merging of Energy loss and the necessary equipment system to move things around in the factories. In this fishbone, the “Energy loss” was related to the energy supply problem, including the power failure. And the necessities of forklifts, pallet trucks are also considered in this part.

Regarding the newly added field of “Engineering related losses”, there are some differences between the current original loss structure and the fishbone structure. In the current loss structure, there is a top loss of “Design” with the same loss code with the “Design” under “Defects and Rework”. Therefore, those losses recorded under “Design” which were already considered under “Defects and Rework” would not be considered again in “Engineering related losses”. The loss category of “Product breakdown” is not considered as a specific category anymore. Refer to ABC analysis result, it’s one of the losses with lowest frequency and duration, and in fact, the final product here is the machines which would be machine put under strict tests for QA/QC. So if the machine doesn’t work, it comes to the “Defects and rework” category.

Performance

In the Performance section, there are Reduced speed, Idle & Minor stoppages, Motion loss and Measurement & Adjustment which collaborate with four loss level 1 under the same name. Moreover, there is one more newly added branch for Waiting time losses, which is only available in the current Loss Bank loss structure, but not the theoretical OEE checklist. The main reason why “Waiting time” is considered under the Performance section is, the root cause for any waiting time is the bad performance in some other parts of the entity (Figure 19).

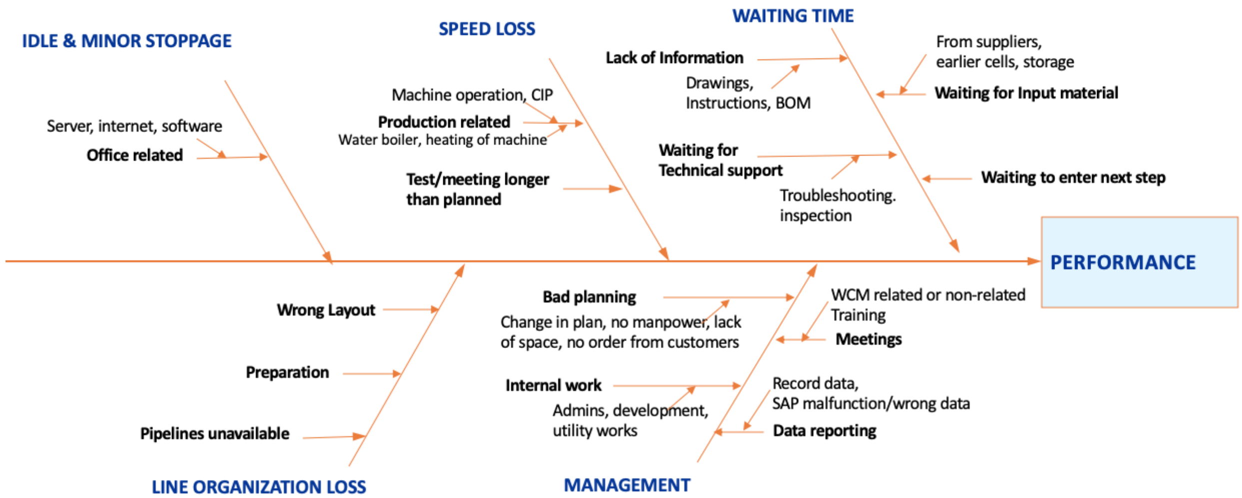

Figure 19. Cause-effect analysis in Performance area

Regarding the "Speed loss", all the production-related losses that lead to a lower performance and speed than expected are categorized into "Speed loss", for example some high frequency mentioned in the operator notes are the slow speed of water boiler, heating of machine, CIP cover problem, machine operation… Moreover, there is another sub-cause of the test or meeting taken longer than planned.

Regarding the "Idle and Minor stoppages", since there is only one loss level 2 of "Other stoppage loss", the meaning of the loss title is a bit misleading for the operators. Currently lots of the notes under "Other_stoppage_loss" are related to "No power" or "Power failure" which should be now located in "Production resources" (Quality). Moreover, there are also lots of the notes under "Other_stoppage_loss" are related to "Excel crash" and "Serve down" which can be generalized into "Office-related crash" such as serve system down, internet problem, software issues, etc.

In the field of Line organization loss, the loss level 2 of "Other_line_organization_loss" are divided into two specific categories: Preparation and Pipelines unavailable which are the two losses with high frequency, based on the notes of operators. However, those kinds of loss events do not really follow the definition of the "Line organization loss" according to the theory. Under the discussion on wrong layout, the operator's notes are quite diverse: collect documents from the printer or print several times due to personal lack of skill, etc. Those events should either be located under "Collect material or tools" or "Assistance needed" (Motion). Moreover, regarding the discussion on "pipelines unavailable" which is not clearly located under "Line organization loss" or "Waiting for material", the real definition of "Line organization loss" in theory could be used as the reference, it's little bit overlapping with the "Management loss" due to bad planning.

In the issues of "Waiting time", instead of having losses in really detail with low frequency (refer to ABC analysis), those losses can be divided into four big categories: waiting for the input material (physical tools, materials, from earlier steps, storage, ect), waiting to enter the next step, waiting for technical support (support of troubleshooting/inspection) and lack of information (drawings, instructions, BOM).

Regarding the management losses, similar to waiting time, the detailed losses are divided into four big categories: bad planning, internal work, data reporting and meeting. The other losses related to the tools, including "Tools missing" and "Searching for tools", are re-located under "Motion" for collecting tools and materials.

Availability

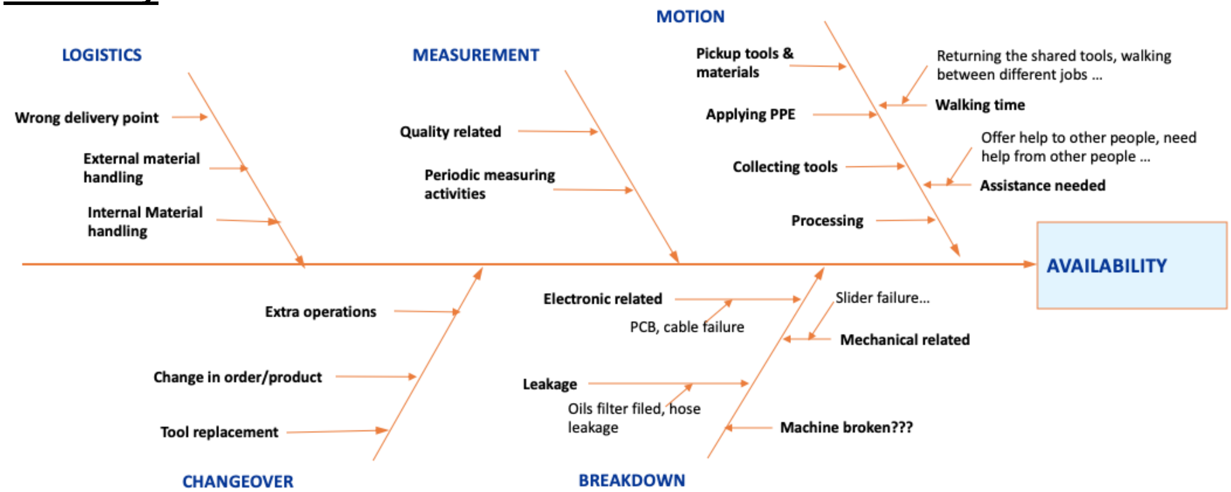

Figure 20. Cause-effect analysis in Availability area

Availability is the field of losses that mainly focuses on the loss in operating time of the machine, including Breakdown, Setup & Adjustment, Tool changeover, Distribution & Logistics, and Motion loss (Figure 20). Among those areas, the "Changeover" branch was used to cover both Setup & Adjustment and Tool changeover loss level 1. For the rest of the areas, details in each collaborated loss level 1 were analyzed in detail in each branch.

Regarding the Breakdown losses, there are three main groups representing three main causes for machine breakdown or failure which are Electronic related causes, Mechanical related causes, and hydraulic related causes or leakage. The main differences between "Machine broken" and other failure losses were hardly explained, even by the company supervisor. The losses under "Utility related breakdown failure" and "Power failure" are covered under the Production resources (Quality). And the losses related to the Transportation material failure are covered under the Logistics branch.

In the field of Changeover, the losses in time for Set up activities as well as Tool change whenever the tools were torn out are all considered in this branch. One of the highest frequency loss events mentioned under Tool change is changing the cutting wheel. Extra operations are also another sub-causes including set up after breakdown and change in orders or products, even though "Replacing tools back from repair" are currently considered as a breakdown. The causes related to Fetching tools or searching for tools are covered under the Motion loss (collect the tools or materials).

For the issues of Distribution and Logistics, wrong delivery information and defects during the movement are the obvious losses that can be expected. Wrong delivery point was mentioned under a separated loss level 2 in the current Loss Bank structure. The losses due to external material handling (collecting material from stores or inventory) includes the defects during the movement or picking errors. Additionally, the losses due to internal material handling (between processes) includes the defects during the movement, moving tower cranes, moving jobs around, moving barrels/chambers/scissor lift, etc. However, "Fetching materials from other cells" is covered under Motion loss (collect the tools or materials).

In the area of Motion loss, there are losses that refer to the unnecessary movement by the operators. Walking time is one of the biggest loss categories in terms of frequency and duration (due to the ABC analysis). However, regarding the notes from the operators, the reasons for walking time are so diverse: walking between different jobs, walking back and forth due to printing issues, finding and returning different types of tools, and even walking time to help or assist other colleagues. Therefore, in order to gain better insights and motivations for the motion loss, the walking time should be separated and merged with the reasons why operators need the walking time. "Assistance needed" together with "Less skill" includes the loss in time for providing assistance to others and requiring assistance from the others." Collect the materials and tools" was generalized from "Collect measuring tools" to cover all similar activities for different types of tools and materials. "Applying PPE" and "Processing" (including manual and automatic processing) are the two last sub-causes under this branch, mainly about the plastic coating or plastic remove and cooling process.

In the field of Measurement & Adjustment which was mentioned in the theory to be the periodic quality monitoring activities, amount of measurement time related to quality was used with high frequency and duration (AA - refer to ABC analysis). Thus, emerging Calibration (seldom used category) into it which has a similar meaning would be reasonable. The measuring activities can also be mentioned and under analysis in this branch. However, there are some activities noted with "collecting masking tape" by the operators which were moved to the Motion loss.

Planned downtime

In the section of Shutdown losses (Figure 21), the mandatory activities that need to be done to ensure the stable status for the machines like machine maintenance would be considered. Therefore, "Building maintenance" and "Machine maintenance" would for sure be under analysis in this category. Moreover, since "APM 5S activities" were applied to the factory on a daily working basis, the working time spent on it is also under consideration.

Regarding the "APM 5S activities", scheduled activities are done to ensure Sort, Set, Shine, Standardize and Sustain inside the factory area. Thus, cleaning activities to assure the 5S method under consideration are as follows (refer to the notes of operators): plastic found in the wrong place, cleaning area once tower work completed, end of day clean up, pack up, tidy up, sweep up, etc. "Tag management" or "Fill in the Loss Bank form" is also considered among "APM 5S activities".

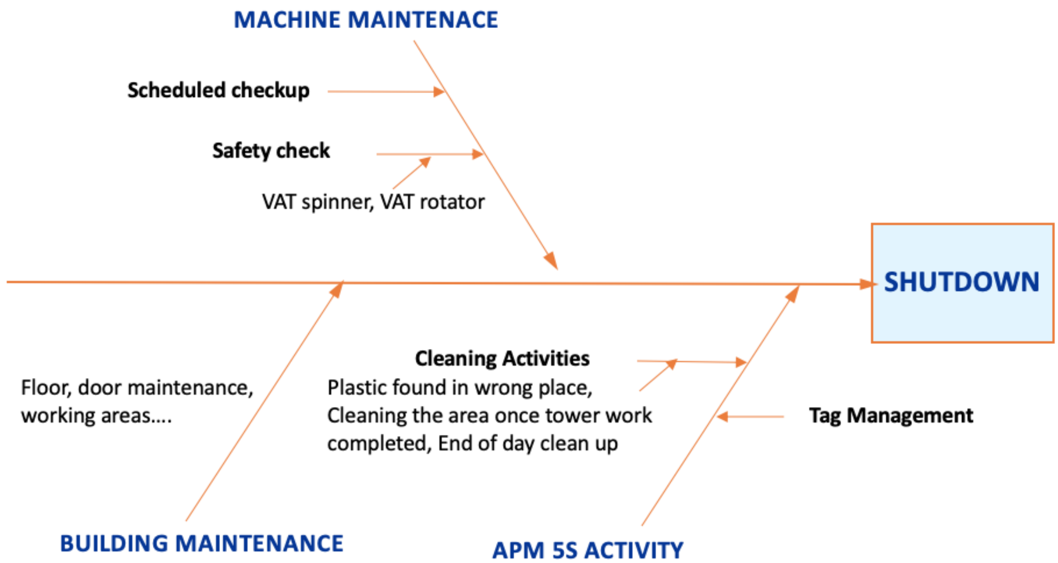

Figure 21. Cause-effect in Shutdown losses

Regarding the "Building maintenance", the activities which related to the factory area or building equipment were under this branch, especially the activities needed for the building such as lighting problem, roof leaking, broken door and floor, etc.

The last aspect in the area of "Shutdown losses" is "Machine maintenance". In this branch, the daily checkup or safety check activities such as VAT spinner, VAT rotator, etc are considered under consideration.

Lastly, as already discussed, the difference in the nature of working procedures and final products lead to a different viewpoint when dealing with the operation losses. Therefore, Therefore, it's hard to find truly matching pairs of loss categories in the two sectors. Take the test-based Packaging system for an example, two big groups of losses are recorded under "Supplier NC" and "Internal NC" regarding the inefficiency of various modules in the automated or semi-automated filling machines, which are not covered in the Processing. On the other hand, losses such as shutdown, motion and minor stoppage are only gaining attention in the manufacturing-based Processing system. However, there are some mutual topics that both of the sectors pay attention to, although the major part of the sub-causes classified under those Loss level 1 are only recorded in the Processing system, such as tool changeover, measurement & adjustment and management loss, etc.

6. Proposal & Discussion

In this section, the final proposal for loss structures in the Processing system and the consolidation will be presented. Moreover, this section will discuss to identify ways to remove other potential root causes analyzed in Chapter 5 by proposing creative recommendations. These improvement plans will be discussed with the responsible team in the focal company for an evaluation on a risk-benefit basis and the possibilities of implementation during the real operation process.

6.1. Establishing a Proposal for Loss Deployment

In this part, the proposal was made with the goal of building a similar structure for both loss deployment structure in Processing and Packaging, covering all loss categories in Processing and collaborating Packaging loss structure for the shared loss categories. In the proposed loss deployment structure, the prioritized similarities are concerning the data structure of the two systems and the coverage of the loss structure while keeping a relatively low number of loss categories.

Due to the limitation in the goal of this thesis, the proposal for the similarities in data structure between the two systems is presented in section 6.1.1, and the proposal for the consolidation in loss coverage is shown in detail in section 6.1.2.

6.1.1. Proposal for Processing System

As mentioned in Chapter 4, while there were 3 loss levels in Processing and the responsible department was considered an add-in parameter, there are only 2 loss levels in the Packaging system including the loss family which indicates the responsible department.

The newly proposed data structure has the same data structure as the currently used in the Processing system. The new system of loss level 1 and level 2 was rebuilt, with the full coverage of all the current loss categories in the Processing system. This newly introduced system of loss level 1 and level 2 will be used for both Processing and Packaging loss deployment systems. The loss categories that only happened in the Packaging systems (the categories that are not available in the Processing system) are not covered in the proposal.

In this proposal for the new loss structure, there are only 12 loss level 1, instead of 18 loss level 1 in the current Loss Bank Structure, with the same full coverage. Based on the cause-effect (fishbone) analysis in section 5.4.1, some of the current loss level 1 were combined together based on the result of ABC analysis (section 5.2.1) and the detailed notes from the operators. The rest of the loss level 1 were kept to be the same. The full loss structure of loss level 1 and level 2 was presented in Figure 22.

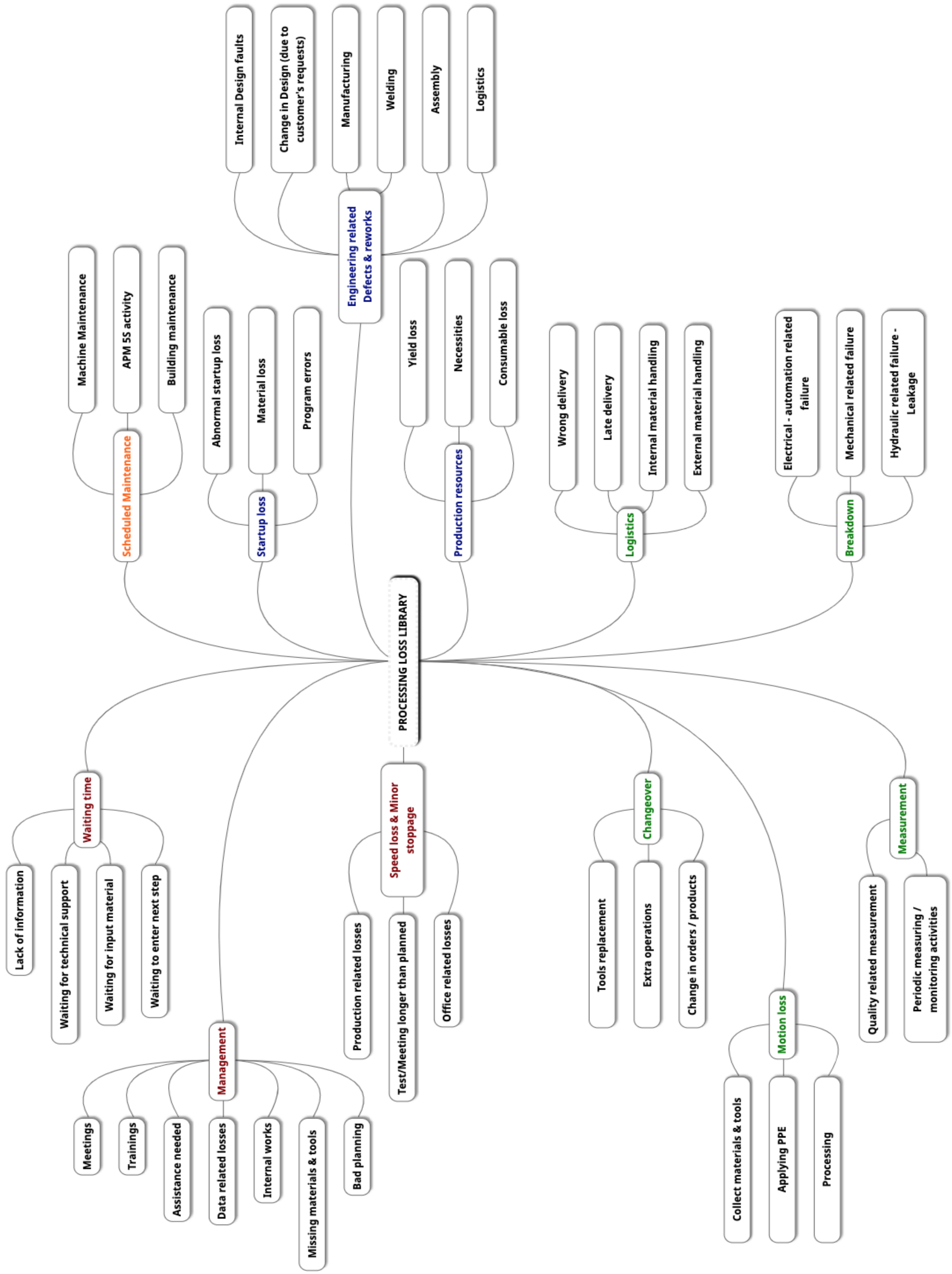

Figure 22. Mind map for the proposed loss structure in the Processing sector

AVAILABILITY: With low in frequency and duration of the relevant loss categories level 2, the two loss level 1 of “Setup and adjustment loss” and “Tool change loss” were merged together to make the “Changeover”. Detailed explanation was explained in section 5.4.2 in the section of Availability. The same structure representing the three main losses under “Changeover” of “Tool replacement”, “Extra Operations” and “Change in orders/products” is kept the same as the three loss level 2.

Under the “Breakdown” loss level 1, due to the unclear differences between “Machine broken” and other “Machine failure” confirmed by the company, “Machine broken” was taken out and separated due to the actual facing problem (Mechanical, Electrical or Hydraulic problems).

In the “Motion loss”, the whole category of “Walking time” was taken away and separated into different categories due to the reason why they need the walking time. Due to the notes from the operators, their main reasons were already mentioned in the other loss levels 2 (in different areas). “Assistance needed” was merged with “Less skill” under the “Management” loss level 1. “Collecting tools” and “Pick up the tools and materials” were also merged together due to the similarities in meaning. Therefore, there are only three remaining loss level 2 remaining in this topic: “Collecting materials & tools”, “Applying PPE” and “Processing”.

In the part of “Logistics”, due to the notes from the operators, there was an additional loss level 2 added to the list for the “Late delivery”. All other three main losses mentioned in the fishbone were kept the same. The loss level 2 under “Measurement” were also kept the same as they were in the fishbone (Figure 20).

QUALITY: With the similar meaning in a major proportion of the according loss level 2, the two loss level 1 of “Engineering related loss” and “Defects and rework” were merged together to make the “Engineering related Defects and reworks”. Since all of the relevant losses under the loss level 1 of “Defects and reworks” are also related to the engineering work, and since there were several similar loss level 2 under those two loss level 1 (as explained in Chapter 4), this action of merging is a reasonable move to not only reduce the number of loss level 1 but also to reduce the confusion for the operators. Due to the notes from the operators, the “Design”, “Over Engineering” and “Change in Design” losses were redistributed into the losses regarding internal faults or external (customer) requests for clearer meaning. “Logistics storage” was considered under the Logistics section. “Product Document” and “Product Documentation” were merged together due to the same meaning.

With the close meaning of the loss categories as explained in section 5.4.1, the loss level 1 of “Yield loss”, “Consumables loss” and “Energy & Environment loss” were merged into “Production resources” as explained in section 5.4.2 in the section of Quality. The loss due to necessary equipment such as forklift and pallet trucks were merged with the utilities to form the new categories of “Necessities”. Those three main points were considered as three loss level 2 under “Production Resources”. The section for “Startup loss” was also kept the same as they were in Figure 18.

PERFORMANCE: With the highly relevant in meaning of the operators' notes while recording the loss events and with the relatively low in frequency and duration of the loss categories levels 2 belong to them, the two loss levels 1 of "Speed loss" and "Minor stoppage" were merged together to make the "Speed loss and Minor stoppage". All the main topics under those two sections were kept the same to be in the loss level 2. This action of merging is a reasonable move to not only reduce the number of loss level 1 but also to reduce the confusion for the operators.

In the part of Management loss, the Training time was separated from the Meetings, merged together with the "Assistance needed" because they are both related to the improvement in skills of the operators. The "Missing" loss level 2 under "Management loss" was renamed to be "Missing materials and tools" in order to provide clearer definition for the operators.

Last but not least, as discussed in the cause-effect structure analysis in section 5.4.2, the loss events under "Line organization loss" recorded by the operators are quite diverse with various topics mentioned in the notes. Those loss events were not following the theoretical definition of the "Line organization loss" either. According to the ABC analysis in section 5.2.1, the loss level 2 under this loss level 1 was low in both frequency and loss duration. Therefore, splitting this category level 1 based on the meaning of major topics mentioned by the operators not only reduces the number of loss level 1 but also to reduce the confusion for the operators.

6.1.2. Suggestion for Consolidation

According to the reduced list of loss levels 1 after aforementioned merging actions, the list of loss levels 2 was followed to break down the loss level 1 into different aspects. The full structure of loss levels 1 and 2 proposed in this part will be used as the shared framework of loss structure between the two sectors of Processing and Packaging. The current system of loss categories in the Packaging systems is considered the loss level 3 under relative loss level 2. With this proposal, not many changes would be made in both systems, including the loss library and the information systems structure done by the IT department. The full proposal of the consolidation with relative loss level 3 in the Packaging system was mentioned in the Appendix E.

Moreover, with the shared systems of loss level 1 and level 2, together with high percentage of mutual losses, the synonyms of mutual losses or notes taking can be shared between the two systems as well. Having the same structure in a loss deployment library like proposed could also allow both sectors to use the same single information system for recording the loss events happening on the daily basis. Therefore, the loss deployment analysis could be done in a better efficiency and may lead to better effect on the next phase of the loss eradication.

With the same information systems used to record the loss events in both sectors, other value-added functions such as Poka Yoke user interface with directional questions can also be shared to avoid human mistakes in loss categorization and reduce the language barrier or confusion for the operator. Moreover, the user guidelines are definitely a mandatory document for the training (which is not available or not well-documented currently) to achieve the higher quality of the database. The standardized guidelines can help reduce the ambiguity in the actual record and thereby improve the concern of wrongly loss allocation mentioned in section 4.3.1.

6.2. Comparison to previous loss structure

The new loss structure in the Processing system provides a clear overall picture through matching the duplication and reducing the number of categories that are repetitive or seldom used. Numerically, the total number of loss level 2 can be dropped from the current 94 to the proposed 44, an overall decrease of about 53% as seen in the following Figure 23. It is expected to deliver a more user-friendly tool for operators to input the information as well as to offer a scientific structure for managers to measure the overall equipment and working efficiency.

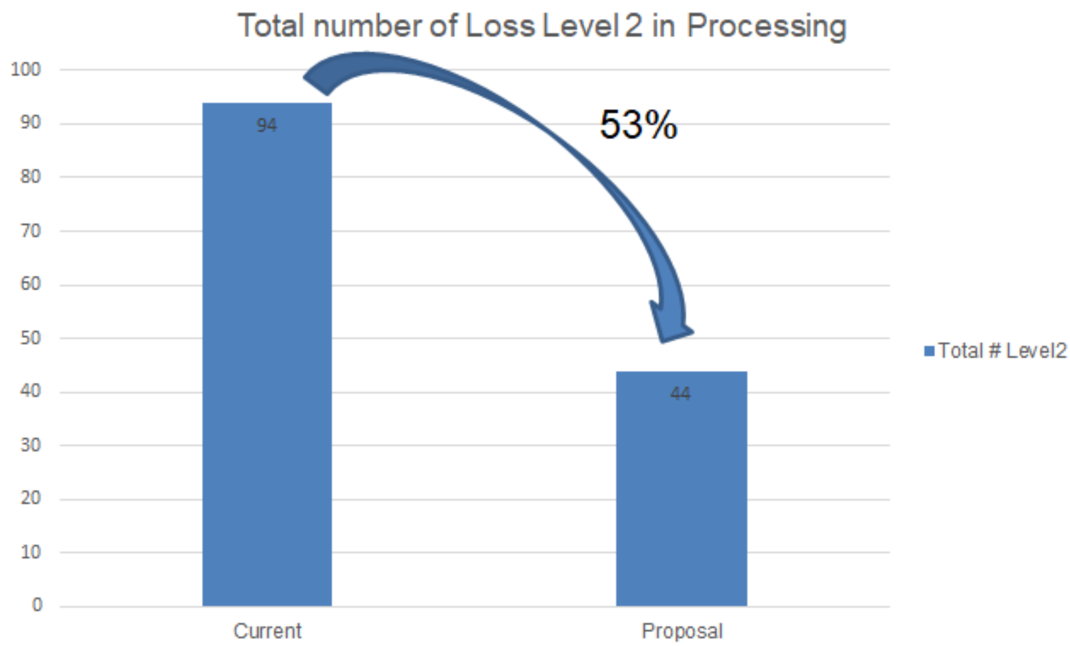

Figure 23. Comparison of the total number of Loss Level 2 for current structure and new proposal

On the other hand, for the consolidation part of discussion, if the current loss structures of the two systems are used, only two losses existing in the respective systems can be considered as a perfect match, accounting for 2.13% of the total in Processing. 19 are considered to have similar losses in Packaging, while the remaining 73 are considered completely different, accounting for 20.21% and 77.66% of the total losses recorded in Processing, respectively. The new proposal raised the number of exactly matched losses to 18, representing 40.91% of the 44 losses in total. In terms of percentage, the overall increase is about 39%, and the corresponding number of different losses decreases by about 19%, as illustrated in Figure 24. This result creates greater possibilities to build a common loss dictionary for both sectors using the same information system to input the data.

It should be mentioned that the total number used in the comparison of the percentage in calculation is the total number of Processing losses in the current structure or the ones in the new proposal. From the perspective of Packaging, the calculation results will be slightly diverse, but the general trend of the changes will not be much different.

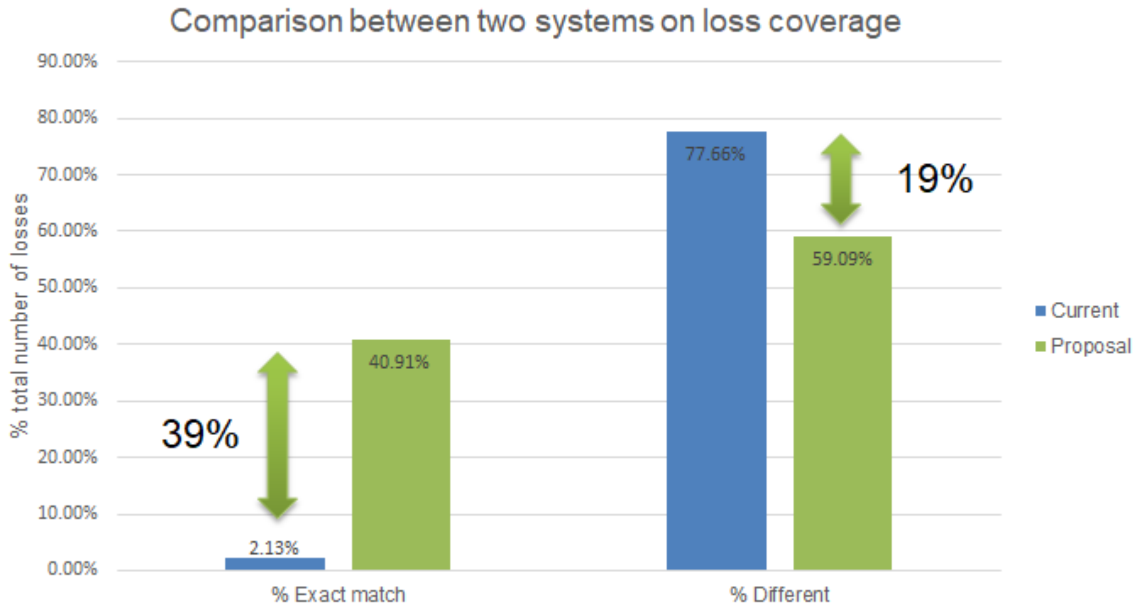

Figure 24. Comparison of loss coverage for current structure and new proposal

6.3. Discussion and Recommendation

From Figure 23 and Figure 24, it can be observed that both the Processing sector and its consolidated loss catalog integrated with the Packaging sector have significant improvement. In order to successfully put the improved loss framework into actual production, however, the participation of different personnel and the support of different departments plays essential roles as well. As mentioned in the section on describing the current status, some high-level managers expressed the idea of not wanting to change the current loss structure during the meeting, especially those in the Packaging department, due to the reality that their current structure is systematic enough to support their own daily operations and the extra invest of time and resource in the long procedure for the training afterwards. It must be recognized that only the high management personnel of both parties reach a consensus on the change of loss structure and the consolidation of the loss dictionary and, more importantly, are willing to participate in the change can make this transformation comprehensive and efficient. Otherwise the result may bring more serious process inefficiency and information inconsistency. In addition, the support of the IT department can focus on providing the best user-friendly interactive interface and systematic guidance scheme from the perspective of the operators. The biggest benefit from this regard is that it can further reduce the operators' error rate and meanwhile improve their work efficiency. The departments may also consider providing some training documents to maximize the smoothness of the process and some analysis framework to check the feasibility and quality of the proposal.

Speaking of the feasibility and efficiency of the proposal, even EPM is considered a standard loss structure, with only users from 2 factories, there is a lower chance to observe a diverse in user-behavior than there is in the Loss Bank system which is serving users from 9 different countries. Another shortcoming is that this consolidation aims to simplify the WCM analysis related to the losses happening in the factories, but there is no implementation data that proves the effectiveness of the consolidation to the next step of loss eradication. Once the departments have obtained the relevant data, further calculations can be carried out to clarify where the next stage needs to be monitored and improved. It is worth noting that although OEE is more considered as a loss distribution map that complements other theoretical deployment models in the study, it can actually be used as a quantitative tool for measuring the performance. This is also one of the advantages of constructing the loss dictionary based on the theory of OEE so that the overall efficiency can be more intuitively quantified and linked to each loss.

Regarding another big group of issues discussed in the fishbone diagram (Figure 13), providing synonymous clauses for various losses in the system, at least the losses allocated to high-frequency usage, can reduce overlapping or incorrect records caused by language barriers, misunderstanding and human mistakes. The efforts put in training as discussed before can contribute to a workflow with less missing data and operational errors. ABC analysis to identify the critical equipment could be an additional recommendation for leading the continuous improvement process.

7. Conclusion

The final section presents the conclusion obtained from the empirical case study. The contribution to both theoretical framework and empirical research together with the generalization possibilities and limitations will also be discussed. Finally, further research directions and application fields are proposed to researchers and managers who intend to continue with this topic in the future.

This study has been conducted in a target company in the selected manufacturing industry. The specific case deals with the underlying causes which result in the disorganized and repetitive loss structure and the separated loss systems in Processing and Packaging. All the research questions were gone through with in depth analysis and reflections to the theories in order to lead to the final proposal. The methodology has been properly selected and presented to explain how the research was conducted. Following the guidance methods, the loss structure has been scientifically designed by proper selection of defined concepts, lean tools and theoretical techniques. Suggestions for structuring the loss dictionary were proposed based on the thorough analysis elaborated through the cause-effect diagrams and the ABC analysis results. These results were fully discussed with the expertise in the focal company to ensure the efficiency and comprehensiveness of the proposal.

The degree project provided Tetra Pak with a better systematic way of categorizing losses and suggesting improvements. The newly proposed shared loss structure of level 1 and level 2 was introduced and proved to have a significant improvement from the current two separated systems. The proposal also allows the shared information system to be used in both systems which brings a great chance for better loss analysis for further loss eradication coming in the future. This proposal was also presented to the responsible people in the company, and received good feedback from not only the Global WCM Managing department in the Head Quarter in Lund, but also the branch factory in India - one of the core members involved in building the loss deployment system from the very first project phase of conceptualization. With proper efforts put into training, the inefficiencies in the WCM department's workflow can be further improved, especially those caused by human error. Quantifiable results, on the other hand, are expected to be committed to making the data reports more informative, which will in turn benefit continuous improvement.

The proposed framework in this thesis was built specifically for the two manufacturing systems in a single manufacturing organization with potential of shared information system infrastructure. For academia the practice will be reflected on the theory and be of assistance to propose a structured picture for lean manufacturing research. At large the results could give suggestions as a potential solution for similar situations in other companies. The potentiality of extending to other manufacturing organizations can be estimated after the successful implementation. Moreover, the proposed framework needs to be validated across different scenarios. Even though the framework should not be implemented to all types of industries due to the scale of production, the manufacturing theme and the nature of the offered products or services, this approach of how the framework was proposed based on different types of analysis and consideration can be used as a typical reference for the other practical lean management problems in reality.

With the limitation in the project duration and resources, only deep insight information in the Processing sector was investigated and analyzed. From the Packaging side, only the loss deployment database and the loss library were collected to use as reference for the consolidation purpose. The similar approach can also be done in the Packaging side with the loss families related to the Supplier NC and Internal NC for better chance of consolidating them into the shared loss structure.

List of References

Ahuja, I.P.S. and Khamba, J.S., 2008. Total productive maintenance: literature review and directions. *International journal of quality & reliability management*.

Amrina, E. and Lubis, A.A.A., 2017, April. Minimizing waste using lean manufacturing: A case in cement production. In *2017 4th International Conference on Industrial Engineering and Applications (ICIEA)* (pp. 71-75). IEEE.

Anvari, A.R., Norzima, Z., Rosnay, M.Y., Hojjati, M.S.H. and Ismail, Y., 2010. A comparative study on journey of lean manufacturing implementation. *AIJSTPME*, *3*(2), pp.77-85.

Cavaye, A.L., 1996. Case study research: a multi-faceted research approach for IS. *Information systems journal*, *6*(3), pp.227-242.

Chan, F.T.S., Lau, H.C.W., Ip, R.W.L., Chan, H.K. and Kong, S., 2005. Implementation of total productive maintenance: A case study. *International journal of production economics*, *95*(1), pp.71-94.

Flores, B.E. and Whybark, D.C., 1986. Multiple criteria ABC analysis. *International Journal of Operations & Production Management*.

Flynn, B.B., Schroeder, R.G. and Flynn, E.J., 1999. World class manufacturing: an investigation of Hayes and Wheelwright's foundation. *Journal of operations management*, *17*(3), pp.249-269.

Gajdzik, B., 2013. World Class Manufacturing in metallurgical enterprise. *Metalurgija*, *52*(1), pp.131-134.

Golicic, S.L., Davis, D.F. and McCarthy, T.M., 2005. A balanced approach to research in supply chain management. In *Research methodologies in supply chain management* (pp. 15-29). Physica-Verlag HD.

Hayes, R.H. and Wheelwright, S.C., 1984. Restoring our competitive edge: competing through manufacturing.

Hekmatpanah, M., 2011. The application of cause and effect diagram in the oil industry in Iran: The case of four liter oil canning process of Sepahan Oil Company. *African Journal of Business Management*, *5*(26), p.10900.

Hellerstein, J.M., 2008. Quantitative data cleaning for large databases. *United Nations Economic Commission for Europe (UNECE)*.

Hirschman, E.C., 1986. Humanistic inquiry in marketing research: philosophy, method, and criteria. *Journal of marketing Research*, *23*(3), pp.237-249.

Jeong, K.Y. and Phillips, D.T., 2001. Operational efficiency and effectiveness measurement. *International Journal of Operations & Production Management*.

Johansson, B. and Nord, C., 1996. *TPM-One Way to Increased Competitiveness: Examples from a Mediumsized Company*. IVF.

Karim, A. and Arif-Uz-Zaman, K., 2013. A methodology for effective implementation of lean strategies and its performance evaluation in manufacturing organizations. *Business Process Management Journal*.

Karim, R. and Rahman, C.M., 2012, July. Application of lean manufacturing tools for performance analysis: A case study. In *Proceedings of the International Conference on Industrial Engineering and Operations Management*.

Khairnar, D.T. (2016), "PQCDSM System- A Tool for Improving the Organizations Performance and the Efficiency with Reference to Mahindra CIE Automotive Ltd, Nashik". *International Journal of Pune and Applied Research in Engineering and Technology,* 5(4), 28-37.

van Hoek, R., Aronsson, H., Kovács, G. and Spens, K.M., 2005. Abductive reasoning in logistics research. *International journal of physical distribution & logistics management*.

Kumar, J., Soni, V.K. and Agnihotri, G., 2014. Impact of TPM implementation on Indian manufacturing industry. *International journal of productivity and performance management*.

Liker, J.K., 2004. The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer McGraw-Hill Education.

Liker, J.K. and Morgan, J.M., 2006. The Toyota way in services: the case of lean product development. *Academy of management perspectives*, *20*(2), pp.5-20.

McGrath, J.E., Martin, J.M. and Kulka, R.A., 1982. *Judgment calls in research* (Vol. 2). Sage Publications, Inc.

Melton, T., 2005. The benefits of lean manufacturing: what lean thinking has to offer the process industries. *Chemical engineering research and design*, *83*(6), pp.662-673.

Meredith, J., 1998. Building operations management theory through case and field research. *Journal of operations management*, *16*(4), pp.441-454.

Murugaiah, U., Benjamin, S.J., Marathamuthu, M.S. and Muthaiyah, S., 2010. Scrap loss reduction using the 5-whys analysis. *International Journal of Quality & Reliability Management*.

Nakajima, S., 1988. Introduction to TPM: total productive maintenance.(Translation). *Productivity Press, Inc., 1988,*, p.129.

Nallusamy, S., Balaji, R. and Sundar, S., 2017. Proposed model for inventory review policy through ABC analysis in an automotive manufacturing industry. In *International Journal of Engineering Research in Africa* (Vol. 29, pp. 165-174). Trans Tech Publications.

Ohno, T., 1988. *Toyota production system: beyond large-scale production*. crc Press.

Perumal P.A., Yoong S.S., Tay C.C., 2019). Classification of Losses in Overall Equipment Effectiveness Calculation*. International Journal of Recent Technology and Engineering*, 8(2), pp.7-11

Puvanasvaran, A., Perumal, I., Teruaki, T.Y.S. and Yoong, S.S., 2016. Examination of Overall Equipment Effectiveness (OEE) in Term of Maynard's Operation Sequence Technique (MOST). *American Journal of Applied Sciences*, *13*(11), pp.1214-1220.

Sharma, R., 2016. Some studies on total productive maintenance in flexible manufacturing environment.

Suddaby, R. (2006), “From the editors: what the grounded theory is not”, *Academy of Management Journal*, 49(4), pp.633-642.

Stuart, I., McCutcheon, D., Handfield, R., McLachlin, R. and Samson, D., 2002. Effective case research in operations management: a process perspective. *Journal of operations management*, *20*(5), pp.419-433.

Tohidi, H. and KhedriLiraviasl, K., 2012. Six sigma methodology and its relationship with lean manufacturing system. *Advances in Environmental Biology*, *6*(2), pp.895-906.

Vinodh, S., Gautham, S.G. and Ramiya R, A., 2011. Implementing lean sigma framework in an Indian automotive valves manufacturing organisation: a case study. *Production Planning & Control*, *22*(7), pp.708-722.

Voss, C., Tsikriktsis, N. and Frohlich, M., 2002. Case research in operations management. *International journal of operations & production management*.

Woiceshyn, J. and Daellenbach, U., 2018. Evaluating inductive vs deductive research in management studies. *Qualitative Research in Organizations and Management: An International Journal*.

Yin, R.K., 2003. Case study research design and methods third edition. *Applied social research methods series*, *5*.

Appendix

Appendix A: Loss structure in the Processing sector (Loss Bank)

Processing		
Level 1	Code	Level 2
Breakdown Loss	2670	Broken
	2610	Electronic_related_machine_failure
	2600	Hydraulic_related_machine_failure
	2660	Leakage
	2620	Mechanical_related_machine_failure
	2630	Other_type_of_machine_Breakdown_failure
	2680	Power failure
	2640	Transportation_material_failure
	2650	Utility_related_ Breakdown_failure
Stoppage loss	3400	Other_Stoppage_loss
Waiting time	1420	Waiting for drawing
	1440	Waiting for instructions SOP
	1410	Waiting for material from earlier cells
	1400	Waiting for material from supplier
	1430	Waiting for other resources
	1510	Waiting_for_BOM
	1500	Waiting_for_inspection
	1450	Waiting_for_instructions_OPL
	1490	Waiting_for_packing_nextcell
	1460	Waiting_for_plan
	1480	Waiting_for_stock_goods
	1470	Waiting_for_stocks_goods_to_order
Defect and Rework Loss	100	Electrical_Automation
	300	Hydraulic_Pneumatic
	400	Logistic_Storage
	500	Manufacturing
	200	Mechanical_Assembly
	800	Product_Documentation
	600	Welding
Engineering related loss	1240	Change_in_design
	700	Design
	1220	Over_Engineering
	1230	Product_breakdown
	1210	Product_Document
Operating motion loss	1650	Applying PPE
	1630	Assistance_needed
	1620	Collect_measuring_tools
	1610	Less_skill
	1640	Processing
	1600	Walking_time
Speed loss	3600	Other_Speed_loss
Transportation or logistic loss	2040	Fetching_material_from other_cell
	2010	Material_handling_between_differnt_processes
	2000	Material_handling_from_Warehouse_to_process
	2020	Other_type_of_material_handling
	2030	Wrong_delivery_point
Line organization loss	1800	Other_Line_Organiztion_loss
	1810	Wrong_layout

Processing		
Level 1	Code	Level 2
Management loss	1000	1000_No_manpower
	1150	Internal_Work
	1140	Lack_of_space
	1070	Machine_cleaning_before_shipment
	1120	Missing
	1030	No_or_unclear_despatch_documentation
	1010	No_order_from_customer
	1020	No_work instructions_available
	1050	Non_WCM_related_Meetings
	1100	Order_to_late_to_pick_from_stock
	1080	Records_data_reporting
	1110	Replanning_change_in_plan
	1060	Searching
	1130	System_malfunction_SAP
	1090	Training_time
	1040	WCM_related_Meetings
Measurement and Adjustment loss	2230	Calibration
	2240	Equipment_capability
	2210	Measurement_time_related_to_non_Quality
	2200	Measurement_time_related_to_Quality
	2220	Other_Messurement_Adjustment_loss
Planned Maintenance Shutdown loss	2400	APM_5S_activity
	2420	Building_Maintenance
	2410	Machine_Maintenance
	2430	Other_Maintenance
Setup and adjustment loss	2820	Extra_operation
	2810	Time_taken_on_machine_to_change_order_product
	2800	Time_taken_to_change_from_one_order_to_another
Startup loss	3020	Abnormal_Startup_loss
	3000	Material_loss
	3030	Other_Startup_loss
	3010	Programme_error
Tool change loss	3210	Fetching_Tools
	3220	Other_changes_in_machine_or_assy
	3200	Tool_Replacement
Energy Environment loss	4220	Electricity_cost
	4200	Gas_cost
	4210	Water_cost
Yield loss	3820	Loss_in_other_materials_in_Euro
	3800	Loss_in_Pipe_in_Euro
	3810	Loss_in_sheet_in_Euro
	3840	Loss_raw_material
	3850	Loss_WIP
	3830	Surface_damage
Consumable (tool, jigs) loss	4000	Other_Consumable_loss

Appendix B: Loss structure in the Packaging sector (EPM)

Packaging		
Loss Family	Code	Default Description
Customer	B018	FM test run for customer visit or training
Customer	B019	Rework due to configuration changes
Internal NC	I001	Internal NC - Final Folder
Internal NC	I002	Internal NC - Machine Body
Internal NC	I003	Internal NC - Electrical Cabinet
Internal NC	I004	Internal NC - Service Unit
Internal NC	I005	Internal NC - Railing & Platform
Internal NC	I006	Internal NC - Jaw System
Internal NC	I007	Internal NC - ASU
Internal NC	B031	Packing list error
Internal NC	B034	INC external conveyor
Internal NC	I008	Internal NC - PullTab
Internal NC	I009	Internal NC - DIMC
Internal NC	I010	Internal NC - Supertstructure
Internal NC	I011	Internal NC - kit HVA
Internal NC	I012	Internal NC - kit ICU
Internal NC	I025	Internal NC - Electrical Cabinet PT
Internal NC	I026	Internal NC - Electrical Cabinet DIMC
R&D	B016	R&D test not planned
R&D	B017	R&D test longer than planned
R&D	P002	Automation design fault
R&D	P003	Mechanical design fault
R&D	P006	Automation mandatory kit (SW or HW) installation
R&D	P007	Mechanical mandatory kit installation
R&D	P009	Software error
R&D	P010	Test due to new SW release
R&D	P011	Package forming issue
Supplier NC	B014	Packaging material defective
Supplier NC	S005	Supplier NC - Final folder
Supplier NC	S006	Supplier NC - Machine Body
Supplier NC	S007	Supplier NC - Electrical Cabinet
Supplier NC	S008	Supplier NC - Service Unit
Supplier NC	S009	Supplier NC - Railing & Platform
Supplier NC	S010	Supplier NC - Jaw system
Supplier NC	S012	Supplier NC - ASU
Supplier NC	S013	Supplier NC - Pulltab
Supplier NC	S014	Supplier NC - DIMC
Supplier NC	S015	Supplier NC - Superstructure
Supplier NC	S016	Supplier NC - Strip Applicator
Supplier NC	S017	Supplier NC - kit HVA
Supplier NC	S018	Supplier NC - kit ICU
Supplier NC	S031	Supplier NC - Electrical Cabinet PT
Supplier NC	S032	Supplier NC - Electrical Cabinet DIMC
Supplier NC	S033	Supplier NC - Assembly/Dismantling
Supplier NC	T001	B-group damaged during transportation

Packaging		
Loss Family	Code	Default Description
Tools & Manuals	A012	Lack of technical information / instructions
Tools & Manuals	B010	Mechanical setting tools broken
Tools & Manuals	B011	Mechanical setting tools missing
Tools & Manuals	B012	Electrical setting tools broken
Tools & Manuals	B013	Electrical setting tools missing
Utilities	B035	Waiting lifting unit headcrane (Breakdown)
Utilities	SP01	Test line conveyor stopped
Utilities	SP02	Water supply problem
Utilities	SP03	Electrical power supply problem
Utilities	SP05	Air pressure supply problem
Utilities	SP06	Utility connection tools damaged
Utilities	SP07	Utility connection tools missing
Waiting for	B020	Package collection request
Waiting for	B001	Waiting Test Engineer assignment
Waiting for	B002	Waiting slot assignement
Waiting for	B015	Waiting for packaging material
Waiting for	B032	Waiting support for troubleshooting
Waiting for	B033	Waiting support for standard phase activity
Waiting for	B021	Missing part due to supplier
Waiting for	B027	Waiting for B-Group
Waiting for	B036	Waiting lifting unit headcrane(Organization)
Waiting for	B037	Unpredictable/Unfortunate events (flood, earthquake ...)
Waiting for	B038	Missing part due to cannibalization
Waiting for	SP08	Machine stopped due to a plenary meeting

Appendix C: ABC classification of all loss categories level 2 in Processing sector

Loss code	Titles	Duration %	Duration Class.	Frequency %	Freq. Class.	Combination
700	Design	10.22%	A	12.33%	A	AA
2400	APM_5S_activity	6.99%	A	9.51%	A	AA
500	Manufacturing	2.76%	A	7.92%	A	AA
1010	No_order_from_customer	4.59%	A	6.13%	A	AA
1040	WCM_related_Meetings	7.72%	A	6.06%	A	AA
1050	Non_WCM_related_Meetings	21.34%	A	3.50%	A	AA
200	Mechanical_Assembly	2.88%	A	3.25%	A	AA
1090	Training_time	4.10%	A	2.57%	A	AA
1060	Searching	11.53%	A	2.02%	A	AA
1600	Walking_time	4.87%	A	1.99%	A	AA
2010	Material_handling_between_differnt_processes	2.11%	A	1.08%	B	AB
2800	Time_taken_to_change_from_one_order_to_another	1.51%	B	5.02%	A	BA
1150	Internal_Work	1.92%	B	3.12%	A	BA
400	Logistic_Storage	0.41%	B	2.58%	A	BA
1630	Assistance_needed	0.76%	B	2.41%	A	BA
600	Welding	0.76%	B	2.33%	A	BA
100	Electrical_Automation	0.55%	B	2.16%	A	BA
1430	Waiting for other resources	0.61%	B	2.06%	A	BA
1120	Missing	0.66%	B	2.05%	A	BA
1110	Replanning_change_in_plan	0.47%	B	1.34%	B	BB
2020	Other_type_of_material_handling	0.88%	B	1.34%	B	BB
1610	Less_skill	0.40%	B	1.32%	B	BB
2000	Material_handling_from_Warehouse_to_process	0.56%	B	1.04%	B	BB
1140	Lack_of_space	0.98%	B	1.04%	B	BB
1000	1000_No_manpower	0.47%	B	0.81%	B	BB
3600	Other_Speed_loss	0.26%	B	0.81%	B	BB
1240	Change_in_design	0.52%	B	0.81%	B	BB
2410	Machine_Maintenance	0.85%	B	0.75%	B	BB
1800	Other_Line_Organiztion_loss	0.36%	B	0.68%	B	BB
1080	Records_data_reporting	1.57%	B	0.42%	B	BB
1070	Machine_cleaning_before_shipment	0.35%	B	0.40%	B	BB
2620	Mechanical_related_machine_failure	0.30%	B	0.40%	B	BB
3200	Tool_Replacement	0.42%	B	0.39%	B	BB
1470	Waiting_for_stocks_goods_to_order	0.40%	B	0.32%	B	BB
1400	Waiting for material from supplier	0.48%	B	0.20%	C	BC
1410	Waiting for material from earlier cells	0.35%	B	0.17%	C	BC
2200	Measurement_time_related_to_Quality	0.78%	B	0.14%	C	BC
2220	Other_Messurement_Adjustment_loss	0.39%	B	0.06%	C	BC
2820	Extra_operation	0.30%	B	0.04%	C	BC
3030	Other_Startup_loss	0.11%	C	1.34%	B	CB
1130	System_malfunction_SAP	0.11%	C	1.25%	B	CB
1020	No_work instructions_available	0.11%	C	1.01%	B	CB
2040	Fetching_material_from other_cell	0.11%	C	0.69%	B	CB
2670	Broken	0.11%	C	0.59%	B	CB
1640	Processing	0.11%	C	0.57%	B	CB
300	Hydraulic_Pneumatic	0.11%	C	0.49%	B	CB
3020	Abnormal_Startup_loss	0.11%	C	0.49%	B	CB

Loss code	Titles	Duration %	Duration Class.	Frequency %	Freq. Class.	Combination
800	Product_Documentation	0.11%	C	0.34%	B	CB
2610	Electronic_related_machine_failure	0.11%	C	0.31%	B	CB
2630	Other_type_of_machine_Breakdown_failure	0.11%	C	0.25%	C	CC
1500	Waiting_for_inspection	0.11%	C	0.23%	C	CC
1210	Product_Document	0.11%	C	0.20%	C	CC
2810	Time_taken_on_machine_to_change_order_product	0.11%	C	0.17%	C	CC
1650	Applying PPE	0.11%	C	0.17%	C	CC
3220	Other_changes_in_machine_or_assy	0.11%	C	0.14%	C	CC
2420	Building_Maintenance	0.11%	C	0.12%	C	CC
3400	Other_Stoppage_loss	0.11%	C	0.12%	C	CC
2660	Leakage	0.11%	C	0.11%	C	CC
1460	Waiting_for_plan	0.11%	C	0.11%	C	CC
1620	Collect_measuring_tools	0.11%	C	0.09%	C	CC
3010	Programme_error	0.11%	C	0.08%	C	CC
2030	Wrong_delivery_point	0.11%	C	0.07%	C	CC
2680	Power failure	0.11%	C	0.06%	C	CC
1220	Over_Engineering	0.11%	C	0.06%	C	CC
2650	Utility_related_ Breakdown_failure	0.11%	C	0.05%	C	CC
1420	Waiting for drawing	0.11%	C	0.05%	C	CC
3210	Fetching_Tools	0.11%	C	0.04%	C	CC
1440	Waiting for instructions SOP	0.11%	C	0.03%	C	CC
#N/A	(Blank)	0.11%	C	0.03%	C	CC
3840	Loss_raw_material	0.11%	C	0.03%	C	CC
2640	Transportation_material_failure	0.11%	C	0.02%	C	CC
2430	Other_Maintenance	0.11%	C	0.02%	C	CC
3830	Surface_damage	0.11%	C	0.02%	C	CC
1450	Waiting_for_instructions_OPL	0.11%	C	0.02%	C	CC
2230	Calibration	0.11%	C	0.01%	C	CC
1030	No_or_unclear_despatch_documentation	0.11%	C	0.01%	C	CC
4000	Other_Consumable_loss	0.11%	C	0.01%	C	CC
1810	Wrong_layout	0.11%	C	0.01%	C	CC
3820	Loss_in_other_materials_in_Euro	0.11%	C	0.01%	C	CC
1100	Order_to_late_to_pick_from_stock	0.11%	C	0.01%	C	CC
3000	Material_loss	0.11%	C	0.01%	C	CC
2600	Hydraulic_related_machine_failure	0.11%	C	0.00%	C	CC
3810	Loss_in_sheet_in_Euro	0.11%	C	0.00%	C	CC
1480	Waiting_for_stock_goods	0.11%	C	0.00%	C	CC
3850	Loss_WIP	0.11%	C	0.00%	C	CC
2240	Equipment_capability	0.11%	C	0.00%	C	CC
4220	Electricity_cost	0.11%	C	0.00%	C	CC
4210	Water_cost	0.11%	C	0.00%	C	CC
4200	Gas_cost	0.11%	C	0.00%	C	CC
1230	Product_breakdown	0.11%	C	0.00%	C	CC
2210	Measurement_time_related_to_non_Quality	0.11%	C	0.00%	C	CC
1510	Waiting_for_BOM	0.11%	C	0.00%	C	CC
1490	Waiting_for_packing_nextcell	0.11%	C	0.00%	C	CC
3800	Loss_in_Pipe_in_Euro	0.11%	C	0.00%	C	CC

Appendix D: ABC classification of all loss categories in Packaging sector

Loss code	Loss title	Frequency %	Freq. Class.	Duration %	Duration Class.	Combination
P003	Mechanical design fault	7.34%	A	11.25%	A	AA
S015	Supplier NC - Superstructure	10.01%	A	8.95%	A	AA
P009	Software error	4.37%	A	6.88%	A	AA
S007	Supplier NC - Electrical Cabinet	5.20%	A	5.28%	A	AA
S022	Supplier NC - Lid Forming Unit	3.00%	A	4.92%	A	AA
P002	Automation design fault	2.82%	A	4.34%	A	AA
B016	D&E test not planned	1.75%	A	4.29%	A	AA
S021	Supplier NC - Package Section	5.17%	A	4.14%	A	AA
P007	Mechanical mandatory kit installation	3.00%	A	3.83%	A	AA
S006	Supplier NC - Machine Body	4.57%	A	3.33%	A	AA
P006	Automation mandatory kit (SW or HW) installation	6.74%	A	3.16%	A	AA
S019	Supplier NC - Carton Section	2.91%	A	2.46%	A	AA
S012	Supplier NC - ASU	3.18%	A	2.04%	A	AA
S008	Supplier NC - Service Unit	2.38%	A	1.79%	A	AA
A012	Lack of technical information / instructions	3.24%	A	1.57%	A	AA
P011	Package Forming Issue	1.04%	B	5.34%	A	AB
B018	FM test run for customer visit or training	1.16%	B	1.58%	A	AB
B038	Missing part due to cannibalization	1.78%	A	1.28%	B	BA
SP01	Test line conveyor stopped	2.41%	A	0.96%	B	BA
S033	Supplier NC - Assembly/Disassembly/Cleaning/Packing	2.35%	A	0.83%	B	BA
S020	Supplier NC - Filling Section	0.98%	B	1.16%	B	BB
I010	Internal NC - Supertstructure	1.10%	B	1.13%	B	BB
S030	Supplier NC- Cap Application Unit (CAU)	1.31%	B	1.08%	B	BB
S005	Supplier NC - Final folder	1.13%	B	0.97%	B	BB
SP02	Water supply problem	1.31%	B	0.88%	B	BB
S027	Supplier NC - Machine Body Lower [TR]	0.68%	B	0.86%	B	BB
I016	Internal NC - Lid Forming Unit	0.92%	B	0.78%	B	BB
B020	Package collection request	1.16%	B	0.75%	B	BB
S010	Supplier NC - Jaw system	1.04%	B	0.74%	B	BB
I003	Internal NC - Electrical Cabinet FM	1.25%	B	0.72%	B	BB
S014	Supplier NC - DIMC	0.92%	B	0.65%	B	BB
P010	Test release new SW	0.92%	B	0.63%	B	BB
I015	Internal NC - Package Section	0.77%	B	0.61%	B	BB
SP03	Electrical power supply problem	0.80%	B	0.49%	B	BB
SI001	Test not done	0.50%	B	0.43%	B	BB
B021	Missing part due to supplier	0.42%	B	0.38%	B	BB
I007	Internal NC - ASU	0.42%	B	0.34%	B	BB
I002	Internal NC - Machine Body	0.62%	B	0.32%	B	BB
B027	Waiting for B-Group	0.53%	B	0.32%	B	BB
B012	Electrical setting tools broken	0.45%	B	0.31%	B	BB
B032	Waiting support for troubleshooting	0.42%	B	0.29%	B	BB
B015	Waiting for packaging material	0.33%	C	0.54%	B	BC
I014	Internal NC - Filling Section	0.33%	C	0.53%	B	BC
I006	Internal NC - Jaw System	0.24%	C	0.53%	B	BC
S024	Supplier NC - Bottom Sealing Unit [TR]	0.18%	C	0.48%	B	BC

Loss code	Loss title	Frequency %	Freq. Class.	Duration %	Duration Class.	Combination
SI002	Test done, but issue not filtered	0.45%	B	0.26%	C	CB
I013	Internal NC - Carton Section	0.48%	B	0.26%	C	CB
I024	Internal NC - Cap Application Unit (CAU)	0.45%	B	0.23%	C	CB
SP08	Machine stopped due to a plenary meeting	0.42%	B	0.11%	C	CB
B001	Waiting Test Engineer assignment	0.65%	B	0.09%	C	CB
S023	Supplier NC - Openings and Closures	0.06%	C	0.24%	C	CC
B033	Waiting support for standard phase activity	0.30%	C	0.23%	C	CC
SP05	Air pressure supply problem	0.30%	C	0.20%	C	CC
S028	Supplier NC - Machine Body Upper [TR]	0.15%	C	0.20%	C	CC
B013	Electrical setting tools missing	0.24%	C	0.19%	C	CC
I022	Internal NC - Machine Body Upper [TR]	0.06%	C	0.17%	C	CC
B017	D&E test longer than planned	0.06%	C	0.16%	C	CC
T001	B-group damaged during transportation	0.24%	C	0.13%	C	CC
B011	Mechanical setting tools missing	0.15%	C	0.13%	C	CC
SP10	Granulate Supply Problem	0.06%	C	0.12%	C	CC
I005	Internal NC - Railing and Platform	0.18%	C	0.10%	C	CC
B034	Waiting outfeed conveyor installation	0.18%	C	0.09%	C	CC
SP07	Utility connection tools missing	0.12%	C	0.09%	C	CC
S009	Supplier NC - Railing & Platform	0.27%	C	0.07%	C	CC
S026	Supplier NC - Filling system [TR]	0.09%	C	0.07%	C	CC
I001	Internal NC - Final Folder	0.15%	C	0.06%	C	CC
I021	Internal NC - Machine Body Lower [TR]	0.12%	C	0.06%	C	CC
I020	Internal NC - Filling system	0.06%	C	0.06%	C	CC
B002	Waiting slot assignement	0.24%	C	0.05%	C	CC
SP09	Cap Supply Problem	0.06%	C	0.05%	C	CC
I025	Internal NC - Electrical Cabinet PT	0.03%	C	0.04%	C	CC
B031	Packing list error	0.12%	C	0.04%	C	CC
B014	Packaging material defective	0.09%	C	0.03%	C	CC
I004	Internal NC - Service Unit	0.09%	C	0.03%	C	CC
S029	Supplier NC - Magazine [TR]	0.09%	C	0.03%	C	CC
I009	Internal NC - DIMC	0.06%	C	0.03%	C	CC
SP06	Utility connection tools damaged	0.09%	C	0.03%	C	CC
S018	Supplier NC - kit ICU	0.09%	C	0.02%	C	CC
B037	Unpredictable/Unfortunate events (flod, earthquake ...)	0.06%	C	0.02%	C	CC
S032	Supplier NC - Electrical Cabinet DIMC	0.06%	C	0.02%	C	CC
B036	Waiting overhead crane (Organization)	0.03%	C	0.02%	C	CC
I018	Internal NC - Bottom Sealing Unit [TR]	0.03%	C	0.02%	C	CC
I012	Internal NC - kit ICU	0.06%	C	0.02%	C	CC
S025	Supplier NC - Cleaning System [TR]	0.06%	C	0.02%	C	CC
S017	Supplier NC - kit HVA	0.03%	C	0.01%	C	CC
S016	Supplier NC - Strip Applicator	0.06%	C	0.01%	C	CC
I026	Internal NC - Electrical Cabinet DIMC	0.06%	C	0.01%	C	CC
B010	Mechanical setting tools broken	0.03%	C	0.01%	C	CC
I008	Internal NC - PullTab	0.03%	C	0.01%	C	CC
I023	Internal NC - Magazine [TR]	0.03%	C	0.01%	C	CC
B035	Waiting overhead crane (Breakdown)	0.09%	C	0.00%	C	CC

Appendix E: Proposal for consolidation

(The table is in the next page)

PROPOSAL			PROCESSING		
Groups	Level 1	Level 2	Original loss code	Original loss level 2/level 1*	Remarks
QUALITY	Startup loss	Abnormal startup loss	3020	Abnormal_Startup_loss	Extra operation, dismounting during startup etc
		Material loss	3000	Material_loss	Pipe welding, Red buffing wheel cut into parts
		Program errors	3010	Programme_error	Built-in programs in the machine doesn't work properly during startup
	Production resources	Yield loss	3800, 3810, 3820, 3830, 3840, 3850	Yield loss*	Surface damage, Material loss
		Consumables	4000	Other_Consumable_loss	Financial related loss
		Necessities	4200, 4210, 4220, 2640, 2650, 2680	Energy environment loss*, Power failure, Transportation_related_failure, Utility_related_breakdown_failure	Energy supply problem & Utilities/Tools failure: Tools breakdown-forklifts, Pallet trucks; Energy: water, electricity, etc
	Engineering related Defects & reworks	Internal Design faults	700, 800, 1220, 1220	Design, Over_Engineering, Product document, Product documentation	PD: Technical product documentation error
		Change in design (due to customer's requests)	1240	Change_in_design	
		Manufacturing	500	Manufacturing	
		Welding	600	Welding	
		Assembly	100, 200, 300	Electrical_Automation, Mechanical_Assembly, Hydraulic_Pneumatic	
		Logistics	400	Logistic_Storage	
PERFORMANCE	Waiting time	Lack of information	1420, 1440, 1450, 1510, 1460, 1020, 1030	Waiting for drawing/ instruction SOP&OPL/ BOM/ plan, No workinstruction available, No or unclear despatch documentation	Drawing, Instruction, BOM
		Waiting for technical support	1500	Waiting for inspection	Troubleshooting, inspection
		Waiting for Input material	1410, 1430, 1480, 1470	Waiting for material from eariler cells/ other resources/ stock goods/ stock goods to order	Waiting for input material from eariler cells/ from storage
		Waiting to enter next step	1490	Waiting for packing nextcell	
	Speed loss & Minor stoppage	Production related losses	3600	Other speed loss	Machine operation, CIP, Water boiler, Heating of machine
		Test/Meeting longer than planned			
		Office related losses	3400, 3600, 1810	Other stoppage loss, Other speed loss, Wrong_layout	Server crash, Internet down, software issue
	Management	Meetings	1040, 1050	WCM_related_Meetings, Non_WCM_related_Meetings	WCM related or non-related meeting
		Trainings	1090	Training_time	Official training activities
		Assistance needed	1060, 1610, 1630, 1810, 1600	Searching, Less_skill, Assistance_needed, Wrong_layout, Walking_time	Searching for instructions, Helping other people, Ask for help, Spontaneous training or assistance
		Data related losses	1080, 1130, 1120	Records_data_reporting, System_malfunction_SAP, Missing	Record data, SAP malfunction, Wrong data, Mismatch between SAP and actual
		Internal works	1150	Internal_Work	Admins, Development, Utility works
		Missing materials and tools	1120	Missing	Missing material, Missing tool
		Bad planning	1000, 1010, 1140, 1110, 1120	1000_No_manpower, No_order_from_customer, Replanning_change_in_plan, Lack of space, Missing	Change in plan, No manpower, Lack of space, No order from customers, underestimated planned working hours or wrongly allocated hours

PROPOSAL			PROCESSING		
Groups	Level 1	Level 2	Original loss code	Original loss level 2/level 1*	Remarks
AVAILABILITY	Breakdown	Electrical - automation related failure	2610, 2670	Electronic_related_machine_failure, Machine broken	PCB issues, Cable failure, false alarm, etc
		Mechanical related filure	2620, 2670	Mechanical_related_machine_failure, Machine broken	U-/B- axis stopped, Slider failure, T drill machine breakdown, End mill cutter problem, Rotating shaft got cracked, etc
		Hydraulic related failure - Leakage	2600, 2660, 2670	Hydraulic_related_machine_failure, Leakage, Machine broken	Oil filter fail, hose leakage, welding leads, etc
	Changeoever	Tools replacement	3200	Tool_Replacement	Cutting wheel change, etc
		Extra operations	2820, 3220	Extra_operation, Other_changes_in_machine_or_assy	Set up after breakdown, etc
		Change in orders/ products	2800, 2810	Time_taken_on_machine_to_change_order_product, Time_taken_to_change_from_one_order_to_another	Set up
	Logistics	Wrong delivery	2030, 1120	Wrong_delivery_point, Missing	Wrong delivery point, Wrong items sent from supplier, Missing - Unplanned usage of materials
		Late delivery	1400, 1100, 1120	Waiting for material from supplier, Order_to_late_to_pick_from_stock, Missing	Delayed goods receipt, Material arrived but not in stock
		Internal material handling	2010, 2020	Material_handling_between_differnt_processes, Other_type_of_material_handling	Moving towers, Moving jobs around, Moving barrels/chambers/scissor lift, etc
		External material handling	2000, 2020	Material_handling_from_Warehouse_to_process, Other_type_of_material_handling	Collecting material from stores, Picking error, External movement
	Measurement	Quality related measurement	2230, 2200	Calibration, Measurement_time_related_to_Quality	
		Periodic measuring/monitoring activities	2240, 2220	Equipment_capability, Other_Messurement_Adjustment_loss	Measuring
	Motion loss	Collect materials and tools	1620, 2040, 3210, 1060, 1070, 1600	Collect_measuring_tools, Fetching_materials_from_other_cell, Fetching_tools, Searching, Machine_cleaning_before_shipment, Walking_time	Searching or finding tools and materials, Time to go collecting them
		Applying PPE	1650	Applying PPE	
		Processing	1640	Processing	
PLANNED DOWNTIME	Scheduled Shutdown	Machine maintenance	2410	Machine_maintenance	Daily check, Safety check (VAT spinner, VAT rotator, etc)
		APM 5S activity	2400	APM_5S_activity	Cleaning activity (plastic found in wrong places, cleaning area once tower work completed, end of day clean up, pack up, tidy up, etc); CLIT activity joint; Tag management (Filling in loss bank form)
		Building maintenance	2420	Building_Maintenance	

PROPOSAL			Packaging	
Groups	Level 1	Level 2	Loss code	Loss description
AVAILABILITY	Breakdown	Electrical - automation related failure	B012	Electrical setting tools broken
		Mechanical related filure	B010	Mechanical setting tools broken
		Hydraulic related failure - Leakage		
	Changeoever	Tools replacement		
		Extra operations		
		Change in orders/ products		
	Logistics	Wrong delivery		
		Late delivery	B021	Missing part due to supplier
		Internal material handling	B023	Waiting support for troubleshooting
		External material handling		
	Measurement	Quality related measurement		
		Periodic measuring/monitoring activities		
	Motion loss	Collect materials and tools		
		Applying PPE		
		Processing		
PLANNED DOWNTIME	Scheduled Shutdown	Machine maintenance	P006, P007	Automation mandatory kit (SW or HW) installation, Mechanical mandatory kit installation
		APM 5S activity		
		Building maintenance		

PROPOSAL			Packaging	
Groups	Level 1	Level 2	Loss code	Loss description
QUALITY	Startup loss	Abnormal startup loss		
		Material loss		
		Program errors		
	Production resources	Yield loss		
		Consumables		
		Necessities	B035, SP01, SP02, SP03, SP05, SP06	Waiting lifting unit headcrane (Breakdown), Test line conveyor stopped, Water supply problem, Electrical power supply problem, Air pressure supply problem, Utility connection tools damaged
	Engineering related Defects & reworks	Internal Design faults	P002, P003	Automation design fault, Mechanical design fault
		Change in design (due to customer's requests)	B019	Rework due to configuration changes
		Manufacturing		
		Welding		
		Assembly		
		Logistics		
PERFORMANCE	Waiting time	Lack of information	A012	Lack of technical information / instructions
		Waiting for technical support	B032, B033	Waiting support for troubleshooting, Waiting support for standard phase activity
		Waiting for Input material	B015, B027	Waiting for packaging material, Waiting for B-group
		Waiting to enter next step	B020	Package collection request
	Speed loss & Minor stoppage	Production related losses		
		Test/Meeting longer than planned	B017	R&D test longer than planned
		Office related losses	P009	Software error
	Management	Meetings	SP08	Machine stopped due to a plenary meeting
		Trainings		
		Assistance needed		
		Data related losses	B031	Packing list error
		Internal works		
		Missing materials and tools	B011, B013, SP07	Mechanical setting tools missing, Electrical setting tools missing, Utility connection tools missing
		Bad planning	B016, B001, B002	R&D test not planned, Waiting Test Engineer assignment, Waiting slot assignement