LEAN TPM APPLICATION IN MAXIMIZING PRODUCTION EFFECTIVENESS

PRAPAT SUPASIRISATTAYAKUL

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Thesis
entitled

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ABSTRACT

There have been many recent studies relevant to manufacturing practices including Total Productive Maintenance (TPM), which was the basis for establishing a leaner process. More importantly, they revealed that there were many factories which failed to use TPM implementation. As a consequence, this study proposed a framework for TPM, especially the effective lean manufacturing transformation which is referred to in this study as Lean TPM, by employing a modified Unified Theory of Acceptance and Use of Technology (UTAUT) structural model, as well as force field analysis (FFA) factors that influence Lean TPM implementation of continuous manufacturing industry with a Thai management style. For the application of UTAUT mode, after the Lean TPM training, there was an initial survey to measure the level of acceptance of Lean TPM implementation at the factory in this case study. Regarding the survey during the initial stage, it was found that based on the structural equation model, the employees' Lean TPM implementation acceptance and participation behavior was very low. The framework for developing Lean TPM implementation was applied, resulting in increased manufacturing process effectiveness, as measured by overall equipment effectiveness (OEE) and overall plant effectiveness. It also had shorter lead time in value stream and higher overall plant effectiveness.

KEY WORDS: LEAN MANUFACTURING/ TOTAL PRODUCTIVE MAINTENANCE/ UNIFIED THEORY OF ACCEPTANCE AND USE OF TECHNOLOGY/ STRUCTURAL EQUATION MODELING

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LEAN TPM APPLICATION IN MAXIMIZING PRODUCTION EFFECTIVENESS

ประภาส ศุภศิริสัตยากุล 5136483 EGIE/M

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บทคัดย่อ

ช่วงเวลาที่ผ่านมามีผลงานวิจัยหลายกรณีที่เกี่ยวข้องกับเครื่องมือปฏิบัติการผลิตรวมทั้งการบำรุงรักษาทวีผลที่ทุกคนมีส่วนร่วม (ทีพีเอ็ม) ซึ่งถือเป็นปฏิบัติการพื้นฐานสำหรับการพัฒนาไปสู่การผลิตแบบลีน งานวิจัยเหล่านั้นแสดงให้เห็นว่ามีหลายองค์กรที่พยายามทำทีพีเอ็มแต่ก็มักประสพกับความล้มเหลว งานวิจัยนี้ได้นำเสนอการประยุกต์แบบจำลองโครงสร้างตามทฤษฎีรวมพฤติกรรมการยอมรับและใช้เทคโนโลยีร่วมกับการวิเคราะห์สนามแรงเพื่ออธิบายถึงปัจจัยที่มีอิทธิพลในการกำหนดกรอบงานของการดำเนินการทีพีเอ็มขององค์กรบริหารแบบไทยที่มีกระบวนการผลิตแบบต่อเนื่องไปสู่การผลิตแบบลีนซึ่งเรียกว่า “ลีนทีพีเอ็ม” กรอบงานดังกล่าวนี้เริ่มจากการสำรวจพฤติกรรมการยอมรับและมีส่วนร่วมการพัฒนาลีนทีพีเอ็มหลังจากการอบรมระบบลีนทีพีเอ็ม ผลการสำรวจแสดงให้เห็นว่าทัศนคติและพฤติกรรมการยอมรับของพนักงานอยู่ในระดับต่ำ แบบจำลองสมการโครงสร้างที่ได้จากการประมวลผลข้อมูลที่สำรวจถูกนำมาใช้ในการกำหนดกรอบงานการพัฒนาลีนทีพีเอ็มทำให้โรงงานกรณีตัวอย่างมีประสิทธิผลของกระบวนการผลิตที่ดีขึ้นพิจารณาจากประสิทธิผลโดยรวมของเครื่องจักรและอุปกรณ์การผลิตที่ดีขึ้น รวมถึงเวลานำของกระบวนการผลิตในสายธารคุณค่าที่สั้นลงและประสิทธิผลโดยรวมของโรงงานที่ดีขึ้น

312 หน้า

CONTENTS

CONTENTS (cont.)

CONTENTS (cont.)

CONTENTS (cont.)

LIST OF TABLES

LIST OF TABLES (cont.)

LIST OF TABLES (cont.)

LIST OF TABLES (cont.)

LIST OF TABLES (cont.)

LIST OF FIGURES

LIST OF FIGURES (cont.)

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LIST OF FIGURES (cont.)

CHAPTER I
INTRODUCTION

1.1 Background

The council of the ministers agreed on the Industrial Enhancement Master plan from 2008-2012 (Office of Industrial Economics, 2007) which was planned by The Office of Industrial Economics (OIE) of the Ministry of Industry and permitted the budget of 2007 for about 1,100 million baht for the Thailand's total country economic driving plan. The status of production of Thailand and economic expansion was based on the expansion of the quantity more than on the expansion of the quality which depends on assets and labor. While the whole of the increasing of the productivity in Thailand is in the low level, it averages 6.03 percent per year. The result of labor factor is 0.6 percent, while result of other two factors such assets factor and productivity factor were 4.73 and 0.7 percent respectively. It shows that these three factors were not balance. While the asset factors of the country were limited, it depended on the assets from other countries and lacks of the suitable control. For the labor factor, it is in the state of full employment which effects the country development in the long period in the future because they used the labor strategy to fulfill their business instead of increasing productivity effective manufacturing practice and management tools.

From the table 1-1, it shows the sources of the growing of economic of Thailand. There was expansion of the industry which averaged 8.13 percent per year from 1982 to 2005 which resulted from factor 2.12 percent and factor assets 5.45 percent. While Total Factor Productivity (TFP) supported growing 0.57 percent, it is a low rate. However the expansion of industry grew just in quantity, there were weak points and lack of good management. Almost of production was increased primary value and production employment which has an advantage over about employment assets. It needs high important of material, assets and technology from other countries while laborers lack essential skills for working because production laborers are graduated as primary or lower 61.9 of percent.

Table 1-1: Sources of Economic Growth of Thailand

	2540	2541	2542	2543	2544	2545	2546	2547	2548	เฉลี่ย 2525-2548
ประเทศ										
อัตราการขยายตัว	-1.37	-10.51	4.45	4.75	2.17	5.32	7.14	6.28	4.49	6.03
แหล่งที่มาของการเจริญเติบโต										
แรงงาน	0.60	-1.56	0.82	0.54	0.89	0.93	0.83	1.01	0.44	0.60
ทุน	3.54	-0.57	1.42	1.12	0.19	1.99	1.88	1.98	2.08	4.73
ผลิตภาพการผลิตโดยรวม (TFP)	-5.51	-8.38	2.20	3.07	1.07	2.39	4.41	3.28	1.90	0.70
ภาคอุตสาหกรรม										
อัตราการขยายตัว	1.44	-10.86	11.89	6.07	1.39	7.14	10.70	8.18	5.19	8.13
แหล่งที่มาของการเจริญเติบโต										
แรงงาน	-0.41	-0.33	0.04	3.43	5.59	3.78	1.97	1.22	0.18	2.12
ทุน	0.09	-9.19	7.31	2.35	-2.83	1.23	5.70	3.99	3.06	5.45
ผลิตภาพการผลิตโดยรวม (TFP)	1.76	-1.35	4.54	0.29	-1.37	2.13	3.04	2.97	1.95	0.57

Source: Office of Industrial Economics, (2007)

The information of table 1-2 of Thailand's competitiveness ranking which was arranged by the International Institute for Management Development (IMD) shows that the ability of Thailand competitiveness decreased from other countries in Asia-Pacific. Thailand's rank moved down to 32nd from 27th in 2005 due to rising price of fuel, higher living costs and failed to improve its long-standing weak point. IMD considered from business efficiency which had productivity as index. IMD reported 2 weak points of Thailand, productivity and efficiency of the small and medium enterprises (SME) when it considered details of estimation of efficiency and productivity. When we compared ourselves with the standard, it is a dangerous signal because productivity and efficiency of management business is important for motivation productivity of our country to grow up for a long period in the future.

In addition, the last rank report in 2007, the competitive ability of Thailand has continually decreased from 29th of the rank in 2006 to 33rd of the rank in 2007. OIE concluded that important topics of development and immune for the stable industry, independent and stable expansion which depended on the limited labor and limited assets of the country. Due to intense and constantly changing competition, entrepreneurs must increase their productivity and efficiency both to survive and to contribute to expansion of the country's industrial sector. The major factors which had to develop were 3 factors including 1) Capital Investment Factor: Thailand had limited/ insufficient capital investments needed to depend on the funds from other countries and was also lack of the appropriate control. 2) Labor Factor: Thailand's labor situation was in the "Full Employment" and 3) Productivity Factor: Thailand still had low production level.

Table 1-2: Thailand's Economic Competitiveness

ประเทศ	อันดับ 2548	คะแนน 2548	อันดับ 2547	การเปลี่ยนแปลง 2547 - 2548	การเปลี่ยนแปลง 2547 - 2548
ไต้หวัน	18	72.993	11	⬇	-7
สิงคโปร์	3	90.993	3	--	0
มาเลเซีย	23	70.080	28	⬆	5
ไทย	32	62.598	27	⬇	-5
ฟิลิปปินส์	49	49.041	49	--	0
อินโดนีเซีย	60	36.051	59	⬇	-1

Source : Office of Industrial Economics (2007)

1.2 The increasing Efficiency and Productivity of Industry Strategy of Industrial Productivity Enhancement Master plan from 2008-2012.

To gain the concrete productivity development for the continuous economic growth; to have the long term profitability in the competition and the sustainable development for the country; therefore, the government prioritized the industrial productivity enhancement. The Office of Industrial Economics under the Ministry of Industry was authorized to set up "Master Plan on Enhancing Industrial

Efficiency and Productivity", a part of "Master Plan on Enhancing National Productivity" which is one of the government major policies, integrates a joint cooperation from both public and private sectors. The 3 main strategies of the master plan are as following:

1) Enhancing human skills: both the existing skills and the ones entering to the industrial sector

2) Enhancing the capability of management: both manufacturing management and machinery technology and management.

3) Improving and developing the enabling factors of productivity enhancement, namely corporation of supply chain network and logistics development.

1.3 Lean Manufacturing Strategy to Enhance Increasing Effectiveness of Manufacturing Process

The case study factory was a continuous process polyester film manufacturers. Its problems was low process effectiveness. There was process failure which wastes a lot of material and time. There were very high readymade products in the stock due to executives who had the policy to keep the product in stock or make to stock (MTS) plus some amount of stock due to management error also. They kept the products in stock when they considered the past sale amount. Executives though that they could be able to sell all of the products but they could not because of many reasons such as wrong estimation, or from the economic problem. Moreover there were several hundred tons of work in process (WIP) in various process. The causes of the problems of over production came from traditional solving the problems of the process randomness and machines reliability problem. There were a lot of wastes and losses when the researcher considered the Overall Equipment Effectiveness (OEE). The effectiveness of the main machines were in the low level, e.g. 20-60 percent. It showed that these machines had low availability (A), low performance (P), and low reliability which results from the low quality rate (Q). Considering supply chain management which has the modern viewpoint needs to realize the responsiveness to respond the increasing and various desires of customers. It shows that the enterprise should realize the combination of 2 methods, Agile Manufacturing, which is the management that focuses on the agility and quickness to respond the demand of marketing and Lean manufacturing. As mentioned lean manufacturing becomes popular and it is very well-known among the industrial organization. In the survey conducted by Industry Week (IW) and Manufacturing Performance Institute (MPI), plants closest to world-class report higher capacity utilization. The survey included 100 questions and received 967 responses from manufacturers across the USA. Table 1-3 gives the primary improvement methodology in place in IW/MPI Census plants. The most established methodologies among manufacturing plants are lean manufacturing, Total Quality Management (TQM) and a hybrid approach of Lean and Six Sigma (Taninecz, 2004b). This means that lean manufacturing is now the most suitable approach to improve the manufacturing process, so lean manufacturing concept will be candidate assigned to improve both case study factories in this research.

1.4 The Composition of the Production for the Lean Manufacturing

As mentioned, lean manufacturing was popularized. (Womack et al., 1990). It has become a standard to emulate by firms throughout the world. Although a number of principles and tools appear to be derived from TPS, cellular manufacturing and world- class manufacturing, lean manufacturing has emerged relatively recently as an approach that integrates different tools to focus on the elimination of waste and produce products**.**

The primary consideration of the TPS is to reduce costs by completely eliminating waste such as excessive production resources, overproduction, excessive inventory and unnecessary capital investment. Two key concepts to TPS are Just-In-Time (JIT) and Autonomation. These two concepts are the pillars of the TPS. Two concepts also key to the TPS includes flexible work force, which means varying the number of workers to demand changes, and creative thinking or inventive ideas (‘Soikufu’), which means capitalizing on worker suggestions. To realise these four concepts, Toyota has established ‘kanban system’ to maintain the JIT production, ‘production smoothing method’ to adapt to demand changes, ‘shortening of the set-up

Table 1-3: Primary Improvement Methodology in Place in IW/MPI Census Plants

Primary methodology	*No. of plants in use*	*Plants (%)*
Agile manufacturing	41	4.6
Lean manufacturing	316	35.7
Six Sigma	29	3.3
Lean and Six Sigma	68	7.7
Theory of constraints (TOCs)	43	4.9
TQM	125	14.1
Toyota production system (TPS)	12	1.4
No methodology	186	21
Other	64	7.2
Total	884	100

Source: Taninecz (2004b).

time' for reducing the production lead time, 'standardisation of operations' to attain line balancing, 'machine layout' and 'multifunction workers' for the flexible work force concept, 'improvement activities by small groups and suggestion system' to reduce the work force and increase worker morale 'visual control system' to achieve the Autonomation concept, 'functional management system' to promote company-wide quality control (Monden, 1993). If we proceed strictly production process following the Lean Manufacturing or Toyota's type, it can reduce the assets of production, increase the efficiency of competition and be the lead of the business in that part of industry. We can see the example from Motor Toyota Company which is now the lead of the motor-vehicles products marketing. The goal of the factory case study is to develop visually the Lean Manufacturing production process. It is flexible mass production which has 2 important methods such as limited quantity production in type of Just-In- Time (JIT) and continuous flow. The automation production or smart automation production has the high reliability of machines. The activities to promote company-wide quality control is essential (Monden, 1993).

A value stream is defined as all the value-added and non-value-added actions required to bring a specific product, service or combination of products and services, to a customer, including those in the overall supply chain as well as those in internal operations. Value Stream Mapping is an enterprise improvement technique to visualize an entire production process, representing information and material flow, to improve the production process by identifying waste and its sources (Rotheret al., 1999, Womack et al., 1998). Lean manufacturing needs the combination of many manufacturing practices which are different approach and different primary goals. It depends on the continuous process type or the discrete process type. Most four well-known lean bundles which were used to realize lean manufacturing in various manufacturing in USA including Just-In Time (JIT), Total quality management (TQM), Total productive maintenance (TPM), and Human resource management (HRM). TPM proceeding effects the effectiveness for the continuous type industry. The TPM (Ben-Daya et al., 1995) proceeding relates between repairing machines which is important for production and the quality of the products. So, the quality of repairing is important. TPM has goals to eliminate 6 main wastes and losses of the machines which relate to the direct and indirect quality and process reliability. Besides effecting the quality level, it effects cost, delivery, and flexibility of the industry. Effective TPM implementation together with other lean bundles always needs the suitable combination of methods and activities or good manufacturing practices to enhance these ultimate goals. Among all the continuous improvement methodologies surveyed, no single methodology can be crowned as the best. This research would propose TPM, world-class manufacturing concept, in combining with several lean bundles and manufacturing practices to improve overall plant effectiveness of case study SME factory. The approach would help factory professionals to systematically perform factory focusing on manufacturing system effectiveness.

1.5 Research Questions.

The lean manufacturing environment is very important to have the certain production and produce products which have the low wastes in the limited. The executives of the case study factories tried to develop the high productivity by development the production to the lean manufacturing but it could not succeed because there are lots of problems with production. This may be the similar causes mentioned in above report of OIE. This leads interesting in research to find out on how to improve the manufacturing productivity. It sounds implementing lean manufacturing is not so easy Although most industry knows lean manufacturing but very few of them successes this best practice depends on characteristics of the factory's environment which is some important part of productivity improvement enhancement. Factor's environment of this case can be divided in 3 portions such as 1) Unionization, 2) The old of the factory, and 3) The size of the factory while the other literature review identified the 4 important combined components of the Lean Manufacturing production process (Rachna et al., 2002)

In the survey conducted by Industry Week (IW) and Manufacturing Performance Institute (MPI), plants closest to world-class report higher capacity utilization. The survey included 100 questions and received 967 responses from manufacturers across the USA. More than 95% of plants closest to world-class indicated that they have an established improvement methodology in place but most of them cannot achieve significant improvement. Table 1-4 gives the summary of IW/MPI Census plants' progress towards achieving world-class manufacturing status (Taninecz, 2004a).

Table 1-4: Summary of IW/MPI Census Plants' Progress Towards Achieving World-Class Manufacturing Status

	No. of Plants	*Plants (%)*
No progress	236	25.9
Some progress	448	49.2
Significant progress	207	22.7
Fully achieved	19	2.1

Source: Taninecz (2004a)

TPM implementation is also the same case, for example implementing TPM's activities strategy by the definition of Japan Institute of Plant Maintenance (JIPM) may not be suit to apply in Western industry culture. Western implementer experienced TPM failed when there were not additional strategies. The strategies and key success factors of TPM implementation of different organization culture are not same.

It is very interesting mater problems on how ensure proceeding of TPM activities in various industrial and organization culture such as the case study factory which was old Thai culture environmental manufacturing. This led highlighting the interesting research questions such as “What kinds of lean bundles is suitable for Thai SMEs such as the company in this case study?”, “How to proceed lean bundles?” and “What are key success factors of this implementation?”

1.6 Objective

This research illustrates generalized framework considering the way to apply fundamental effective process management tool such TPM strategy of the company in this case study toward lean manufacturing firm. Since this TPM, a lean bundle, is suit for continuous process and using machines to produce product, it is very important to study factors which affect the ability of production process management, which are prepared for lean transformation.

1.7 Scope of Conducting Research

The scopes of the study were focused on finding the systematic framework for success in applying Lean TPM or TPM concept together with other lean bundles and manufacturing practices in lean transformation process through a middle size company with Thai style working culture. This company had continuous manufacturing processes.

1.8 Outline of Thesis

The research is divided into 8 chapters. Chapter 2 is about the combination of the relative history of research and details about production management, productivity development and planning the succeed in the goals enterprise’s business.

Chapter 3 explains about research methodology on how to do and find the fact and construct the way of production process management system. Chapter 4 through 7 reports the result of the proceeding process of production management which was derived from the research. Chapter 8 concludes the whole of the research.

1.9 Expected Advantages of Research

1.9.1) To provide conceptual framework of studying the manufacturing contextual factors before applying the TPM toward Lean Manufacturing transformation for the company in this case study.

1.9.2) To enhance better effectiveness of process value stream in the main production which had higher overall equipment effectiveness (OEE) and lower eight major plant losses or higher overall plant effectiveness (OPE) after applying partial TPM activity in this case study factory.

CHAPTER II
BACKGROUND OF MANUFACTURING PRACTICE AND TECHNIQUE

In this chapter, there are many value suggestions from various literature of history and particular characteristics of each manufacturing practices and essential component with focusing on the relationships among each of them to constitute high performance manufacturing firm. Almost people in manufacturing have heard of Lean Manufacturing which is one of production approach pioneered by Toyota Motor Company. Definition of lean manufacturing and its tools will be summarized.

2.1 Lean Manufacturing – Tools and Characteristics

Lean thinking for Lean Manufacturing approach is powerful antidote to muda (Womack et al., 1998). Japanese word means waste that all manufacturing people must know. It provides a way to specify value and all collection of action to create value in the best sequence. It is called "Lean" because it provides a way for action more and more in order to use resource less and less, ie. less human effort, less equipment, less time and less space while providing as closest as customer satisfy what they want. Lean thinking also provides an efficient and ease way with immediate effort to visible all 7 wastes and convert them into value. Taiichi Ohno had started work on the Toyota Production system in the 1940s, he decided new manufacturing disciplined, process-oriented system, which is known and very popular today as the "Toyota Production System" that create birth of Lean Manufacturing. Taiichi Ohno defined 7 mudas as following items.

a) overproduction ahead of demand,
b) waiting for the next processing step,
c) unnecessary transport of material,

d) overprocessing of part due to poor tool and product design ,
e) inventories more than the absolute minimum,
f) unnecessary movement by employee during the course of their work, and
g) production of defective parts

Lean thinking to focus on value which is defined by customer in term of specific product at specific price and time. Value is created by producer from the customer's standing point. So it is critical to start lean thinking by specifying value clearly. The value stream or set of most efficient action to obtain specific product through the three critical management tasks of any business including problem-solving task, information management task and physical transformation task to cover since from raw material to delivered finished product in hand of customers. Most of muda will be exposed once finishing the value stream analysis and fully mapped. Then it is time to eliminate all kinds of waste or muda. Next step is then to create continuous flow process instead of batch-and-queue mode and let customers pull value form process or enterprise. These all set of actions must be decided perfectly. In summary, Lean Thinking means the way to think about value, value stream, continuous flow, pull system and perfection of effort and system.

2.1.1 The Benefit of Being "Lean"

The benefits of implementing lean manufacturing seen within non-process industries, such as the automotive (Melton, 2005).

a) Decreased lead times for customers;
b) Reduced inventories for manufacturers;
c) Improved knowledge management;
d) More robust processes (as measured by less errors and therefore less rework).

2.1.2 Plant Characteristics and Lean Manufacturing Practices

To ensure implementing Lean transformation effectively, it was suggested considering the contextual factors and Lean bundles (Rachna et al.,2002). The study used the data from *Industry Week*'s Census of Manufacturers and reviewed entire literature that associated plant characteristic obstructs lean implementation to conclude the factors that impacts lean implementation. It was examined the effect of 3 contextual factors of firm on the lean implementation successfully, plant age, plant size and unionization The study concluded that all three factors may be effect whether firm will success implementation of high performance lean manufacturing approach. It should first observation to be considered. This following is summary of those 3 contextual factors and effect on lean implementation.

2.1.1.2 Unionized plants are less likely to implement lean manufacturing practices than nonunionized or partially unionized plants. There is some evidence that unionization is negatively associated with organizational performance.

2.1.1.3 Plant age (it is called the older plant if the age is more than 20 years) Older plants are less likely to implement lean manufacturing practices than newer plants. It is because of a younger, arguably less cynical workforce and also because of fewer physical barriers to lean practices such as set up time reduction. Once organization develop a set of work procedure over a long period with less change, this trend to inhibit lean transformation or any change to new practice. This implies that plant age has a negative impact on the likelihood of implementation of lean manufacturing practices.

2.1.1.4 Plant size with numbers of employee is more than 200 is large. The tendency, large manufacturers are more likely to implement lean practices than small manufacturers. In actually the plant size associates the availability of both capital and human resources that directly facilitate adoption lean transformation.

But for some case for change cannot be appear to be due to resistance force field (Melton, 2005). Figure 2-1 is force field analysis diagram which shows some of drivers and resistors within the manufacturing industries. It is only when the specific driving forces for an organization are greater than the opposing forces that the change will occur. The ultimate sustainability then requires additional support forces to further reduce and eliminate opposing. Furthermore to ensure enhancement lean implementation, organization has to focus on 5 key critical and necessary element to success expect situation (William, 2001). The 5 primary elements for lean manufacturing are 1) Manufacturing flow, 2) Organization, 3) Process control, 4) Metrics. And 5) Logistics

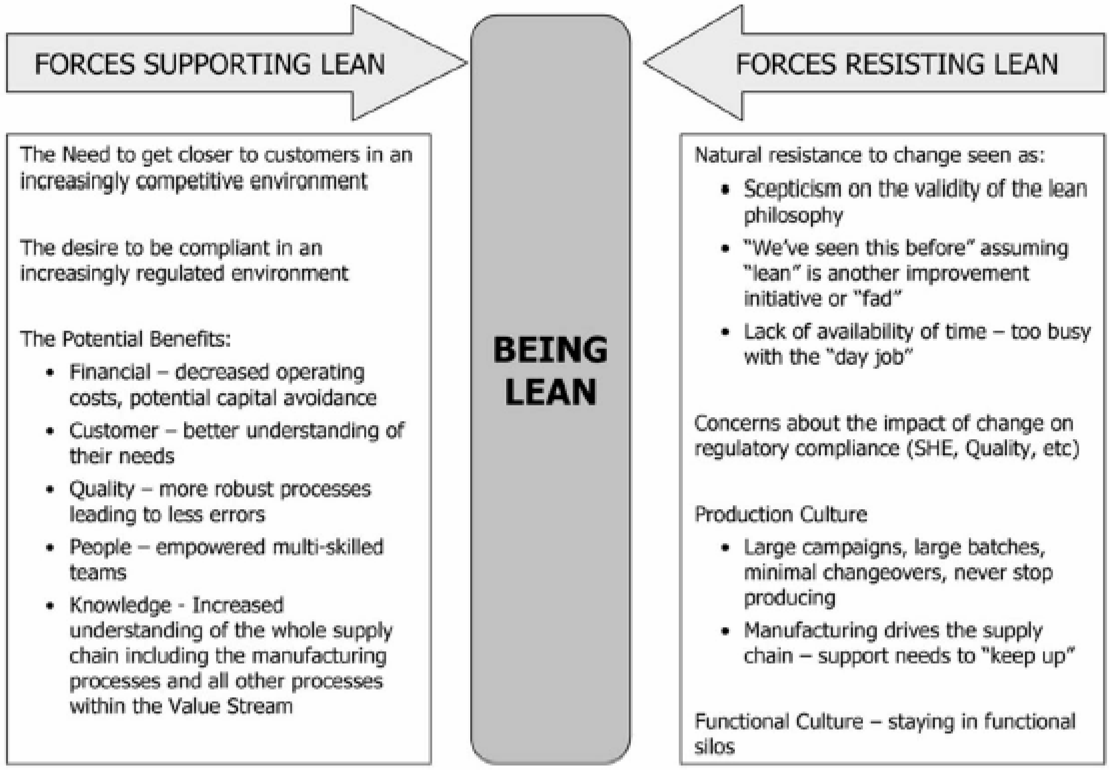


Figure 2-1: The "Force Field Analysis Diagram' Force Opposing and Driving a Change to 'Lean' (Melton , 2005).

2.1.3 Lean Tools in Lean Manufacturing

Lean manufacturing is a multi-dimension approach that integrate several manufacturing concepts and management practices toward to high performance of plant (Fawaz et al., 2006, Mahapatra et al., 2006, Dennis et al., 2005, Kristy et al., 2001). This part presents the result of several literature review and research result on what kind of content or manufacturing practice that are commonly associated with lean production system. The study proposed that each different representing group of related lean practices the implementation of 4 lean bundles (Rachna et al., 2002), just in time (JIT), total productive/preventive maintenance (TPM) and human resource management (HRM), have positive impact on operation performance. Each bundle is positive association and synergistic effects of implementing practice is higher performance level.

2.1.3.1 JIT with the primary goals to reduce or eliminate all form of wastes especially two major form such work-in-process (WIP) and inventory. It is continuous reduction of such wastes and it is more fit for discrete manufacture in comparison to process manufacture. Discrete part industries are more likely to implement JIT.

2.1.3.2 TQM is quality management program with sustainability of quality of both process and product by mean of endless improvement.

2.1.3.3 TPM goal is to maximize overall equipment effectiveness via various equipment maintenance techniques, planned predictive and preventive maintenance, and using maintenance optimization technique. Plant in process industries are more likely to implement TPM bundle.

2.1.3.4 HRM bundle practice includes job design and change, formal training programs, cross-training programs, work teams, problem solving group and employee involvement promotion. It is also included flexible, cross-functional work force, and self-directed work teams.

Among 4 bundles relates to combination of various manufacturing practices, the principle component analysis to validate lean bundles, it shows that it just only JIT that is assembled of higher load factor of those above practices than TPM bundle so it means that JIT and TPM is very important in lean manufacturing implementation. Followings are manufacturing practices referred in this study. (see Table 2-1 Parts of 4 Lean Bundles) It was explained the synergistic relationships among 10 factors constitute the operational complement to the philosophy of lean production and characterize 10 distinct dimensions of a lean system (Rachna et al., 2007). There was some published empirical evidence about the implementation lean bundle partially, for example large integrated steel mill process industry adapted TPM, Kanban and Setup reduction. The 10 distinct operation components includes supplier feedback, JIT delivery by suppliers, supplier development, customer involvement, pull, continuous flow, set up time reduction, TPM, SPC (statistical process control) including TQM, and employee involvement.

The role of each element would be defined as the following. Table 2-2 shows the 10-distinct operation components role in Lean manufacturing.

Table 2-1: Parts of 4 Lean Bundles

No.	Manufacturing Practice	No.	Manufacturing Practice
1	Bottleneck removal (production smoothing)	12	New process equipment/technologies
2	Competitive benchmarking	13	Cross-functional work force
3	Total quality management	14	Focused factory production
4	Cycle time reductions	15	Lot size reduction
5	JIT/continuous flow production	16	Maintenance optimization
6	Cellular manufacturing	17	Planning and scheduling strategies
7	Preventive maintenance	18	Process capability measurements
8	Pull system/Kanban	19	Quality management programs
9	Quick changeover techniques	20	Safety improvement programs
10	Reengineered production process	21	Continuous improvement programs
11	Agile manufacturing strategies	22	Self-directed work teams

Table 2-2: 10-Distinct Operation Component Roles in Lean Manufacturing.

Operation	**Role of each operations**
1. Supplier feedback:	provide regular feedback to suppliers about their performance
2. JIT delivery by suppliers:	ensures that suppliers deliver the right quantity at the right time in the right place.
3. Supplier development:	develop suppliers so they can be more involved in the production process of the focal firm.
4. Customer involvement:	Focus on a firm's customers and their needs.
5. Kanbans pull system:	A typical inter-process demand transferring system for implementing JIT production. This tool goal in this -

Table 2-2: 10-Distinct Operation Component Roles in Lean Manufacturing (cont.)

Operation	Role of each operations
	implementation is to reduce level of inventory in process or Work-in-process
6. Continuous flow:	establish mechanisms that enable and ease the continuous flow of products.
7. Set up time reduction:	reduce process downtime between product changeovers.
8. TPM :	addresses equipment downtime through total productive maintenance and thus achieve a high level of equipment availability. Promotion of workers involvement in carry out basic equipment maintenance to establish and maintain its peak condition. It is usually defined in terms of an increase in overall equipment effectiveness (OEE), which in turn is a function of down time and other production
9. SPC (statistical process control):	ensure each process will supply defect free units to subsequent process.

The analysis of correlation among factors result has shown that are positively and significantly correlated with each other. It revealed that TPM is the least associated with other factors. TPM, Standardization, Quality at source and Kanban are typical attribute responsible for reducing inventory considerably. Among several lean tools bundles, TPM will impact in various functional area of continuous process industry such as Maintenance, Production, Quality and Production process design. Furthermore the author needed to know the judgment of manufacturer which kinds of lean tools is most useful by asking "Which LM (Lean Manufacturing) ideas, tools and techniques have been/would be most useful to the business?" It is shown that TPM is the first rank level of applicability of lean tools for continuous manufacturing. It means that adequate maintenance activity are not practice currently or do more carefully in maintenance in lean system is needed more effort. So we can finalized speaking TPM is the essential component for lean implementation in view of process manufacturing. Very interesting strong word of suggestion that TPM must be addressed before and during a significant change initiative. The architecture was developed from and enterprise perspective, strategic issues, internal and external key stakeholder relationships before any change initiative to go for Lean to eliminate 7 mudas or enemies of business process. The authors suggested that a well-developed lean strategy will include many different lean practices. Therefore, a state of the art implementation will require firms to exert considerable effort along several dimensions simultaneously.

In conclusion if entire process industries sector exerts to transform to Lean Enterprise Architecture, it must first start implementing some part of TPM (at least 5 TPM components that will be clarified later) in parallel with some part of TQM and set-up time reduction. Key success factors of implementing TPM is very essential and to be evaluated and monitored periodically. Question why TPM is very important in Lean transformation. There is a word about "Maintenance and quality: the missing link" (Ben-Daya et al., 1995) The study proposed a broad framework for modeling the interaction among three important component of production system, maintenance, quality and production. Traditional maintenance task does not focus on adequate linkage of quality. Possible reasons include:

a) Traditionally maintenance has been regarded as a necessary evil and at best a secondary subsystem driven by production. Not until recently has its importance to profitability been recognized.

b) Maintenance as a function in an organization has complex relationships with other functions.

c) The outputs of the maintenance department are difficult to define. Hence it is much harder to develop an explicit input/output relationship. Also to measure and quantify maintenance output and its effect on quality is difficult compared with production.

Authors suggested that Maintenance that is a function in an organization that operates in parallel with production should be the secondary output of production. The demand for maintenance, which is in turn an input for the maintenance function as shown in figure.

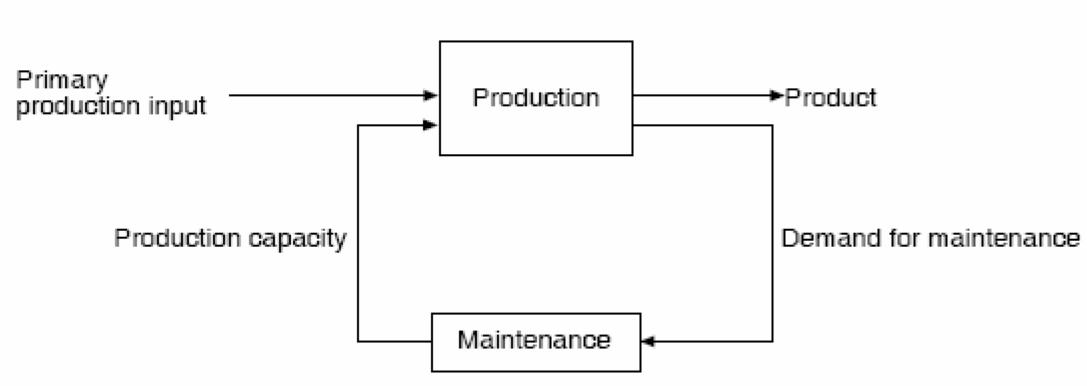


Figure 2-2: Production and Maintenance Linking (Ben-Daya et al., 1995)

The link has been identified by TPM, TPM is one most important that pay role a part of quality maintenance The focus of total productive maintenance is equipment management. As pointed out later, quality is a key factor in measuring equipment effectiveness. One of six big losses of any equipment is directly related to quality. In TPM a measure of equipment effectiveness that takes into account all the six losses has been defined. The overall equipment effectiveness (OEE) (Robert, 2001) is given as

OEE = Availability x Performance efficiency x Quality rate

Where :
Availability: A = (Loading time – Downtime)/(Loading time)
Performance efficiency: P = (Theoretical cycle time)x(Amount processed)/(Operating time)
Quality rate: Q = (Amount processed – Defective amount)/(Amount processed)

Overall equipment efficiency can be reduced to the following:

$$OEE = A \times P \times Q = \frac{\text{Theoretical cycle time} \times \text{Amount processed} \times \text{Quality rate}}{\text{Loading time}}$$

To achieve overall equipment effectiveness, TPM works towards eliminating the following major equipment losses:

1) Equipment failure;
2) Set-up and adjustment;
3) Idling and minor stoppage;
4) Reduced speed;
5) Process defects;
6) Reduced yield.

Two approaches have been proposed for linking and modeling the relationship between maintenance and quality so that they can be jointly optimized.

One approach is models using imperfect maintenance concepts based on the idea that maintenance affects the failure pattern of the equipment. The second approach is based on Taguchi's approach to quality. The basic idea is to perform PM when the amount of deviation in the product characteristic used to measure quality reaches a given threshold.

2.1.4 Value Stream Mapping (VSM)

A value stream is a collection of all actions (value added as well as non-value-added) that are required to bring a product (or a group of products that use the same resources) through the main flows, starting with raw material and ending with the customer (Fawaz et al., 2006). These actions consider the flow of both information and materials within the overall supply chain. The ultimate goal of VSM is to identify all types of waste in the value stream and to take steps to try and eliminate these. While researchers have developed a number of tools to optimize individual operations within a supply chain, most of these tools fall short in linking and visualizing the nature of the material and information flow throughout the company's entire supply chain.

Taking the value stream viewpoint means working on the big picture and not individual processes. VSM creates a common basis for the production process, thus facilitating more thoughtful decisions to improve the value stream.

VSM is a tool is created using a predefined set of standardized icons. The first step is to choose a particular product or product family as the target for improvement. The next step is to draw a current state map that is essentially a snapshot capturing how things are currently being done. This is accomplished while walking along the actual process, and provides one with a basis for analyzing the system and identifying its weaknesses. The third step in VSM is to create the future state map, which is a picture of how the system should look after the inefficiencies in it have been removed. Creating a future state map is done by answering a set of questions on issues related to efficiency, and on technical implementation related to the use of lean tools. This map then becomes the basis for making the necessary changes to the system.

2.1.4.1 VSM: Current State Map. All data for the current state map were collected. Data collection for the material flow started at the shipping department, and worked backward all the way to the blast furnace process, gathering snapshot data such as inventory levels before each process, process cycle times (CTs), number of workers, and changeover (CO) times. Fig. 2-3 shows the current state map that was constructed; the small boxes in the map represent the process and the number inside the box is the number of workers at each process. Also, each process has a data box below, which contains the process CT, machine reliability (MR), the number of shifts, and the CO time. It should be noted that this data was collected whilst walking the shop floor and talking to the foreman and operators at each workstation. The processing and set-up times are all based on the average of historical data. Note that there are two inventory triangles ahead of some processes, one for annealed products and one for all other products. This simply indicates that other products could be scheduled to use the process in addition to the annealed products considered herein, so that the total inventory is actually higher than what is shown. After collecting all the information and material flows, they are connected as indicated by arrows in the map, representing how each workstation receives its schedule from business planning.

The timeline at the bottom of the current state map in Fig. 2-3 has two components. The first component is the production waiting time (in days or any), which is obtained by summing the lead-time numbers from each inventory triangle before each process. The time for one inventory triangle is calculated by dividing the inventory quantity into the daily customer requirements. For example, the lead-time for the inventory triangle ahead of pickling is 17.65 days; this is calculated by dividing

45,000 tons (the total inventory ahead of the pickling) by 2550 (the daily average demand rate for the annealed product). The total observed value for the waiting time is calculated. The second element of the timeline is the processing (or value-added) time. This time is calculated by adding the processing time for each process in the value stream.

The CT for each process is the average CT, which was determined by using actual data from the company.

2.1.4.2 VSM: Future State Map. The process of defining and describing the future state map starts while developing the current state map, where target areas for improvement start to show up. Looking at the current state map for company several things stand out: (a) large inventories, (b) the difference between the total production lead-time and the value added time, and (c) each process producing to its own schedule. Inventory and lead time may be viewed as two related issues since the more the inventory, the longer any item must wait for its turn and thus, the longer the lead time. In creating the ideal future state map we try to identify lean manufacturing tools to drive both of these down, while looking at the schedule across the entire value stream. We follow a systematic procedure where we try to answer a series of structured questions; this allows us to come up with an ideal future state map that will help in eliminating or at least reducing different types of waste in the current manufacturing system.

2.2 Total Productive Maintenance (TPM)

TPM is productive maintenance carried out by all employees through small group activities (Seiichi, 1989)

2.2.1 Implementation of total productive maintenance

(Chan et al., 2003, Bamber et al., 1999). TPM, its aim to address equipment downtime through total productive maintenance and thus achieve a high level of equipment availability. Promotion of workers involvement in carry out basic equipment maintenance to establish and maintain its peak condition. In fact the operators are the closest to the machines so it has to be most suitable and best one to be included in maintenance activity.

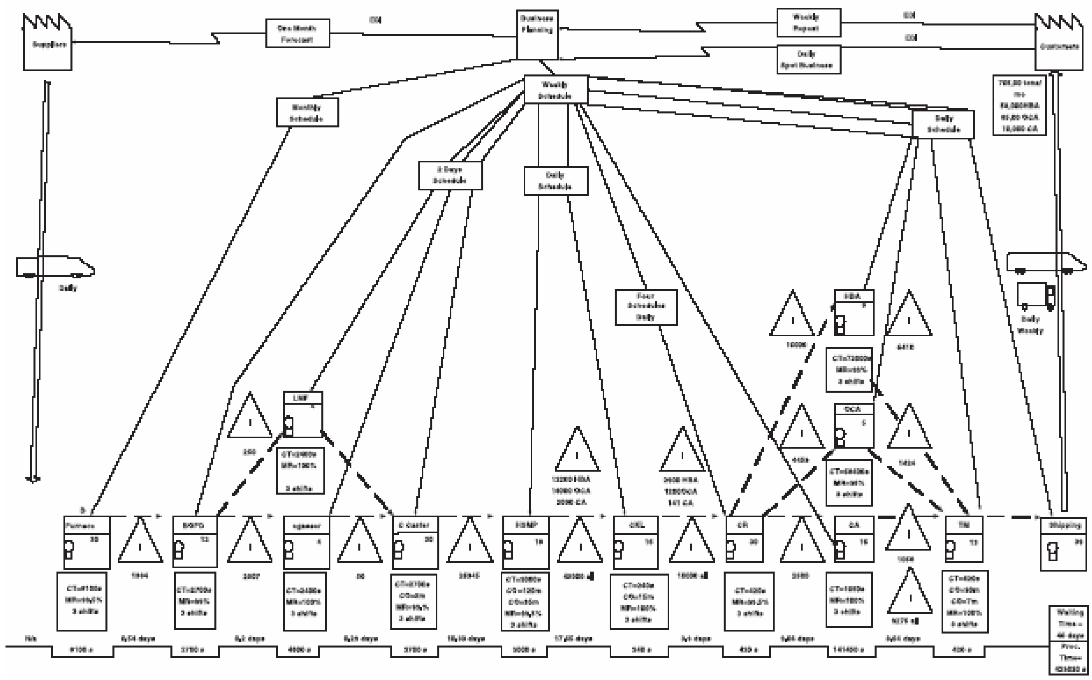


Figure 2-3: Current Value Stream Map (Fawaz et al., 2006).

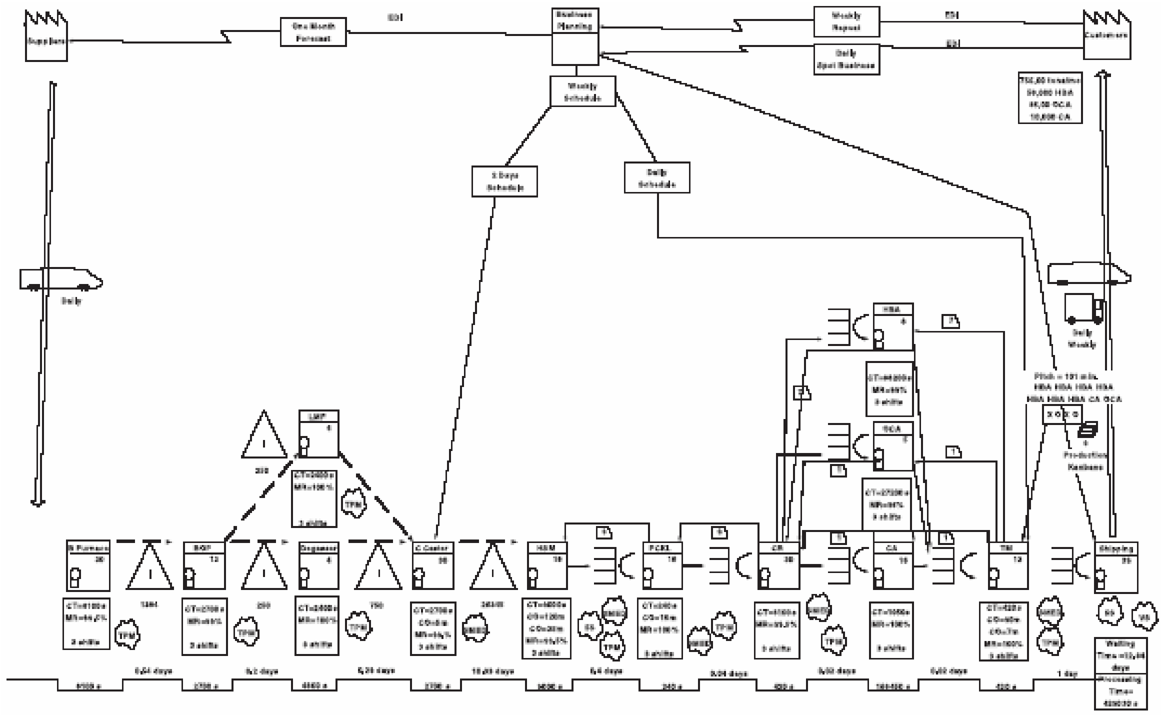


Figure 2-4: Future State Map (Fawaz et al, 2006).

In the research, the analysis of effect of TPM it shows that TPM can significantly reduce random machine breakdowns and in turn, inventory and lead-time. It is usually defined in terms of an increase in overall equipment effectiveness (OEE), which in turn is a function of down time and other production Japanese style TPM recognizes that a full definition of TPM contains the following five points:

a) It aims at getting the most efficient use of equipment (i.e. overall efficiency).

b) It establishes a total (company-wide) PM system encompassing maintenance prevention, preventive maintenance, and improvement related maintenance.

c) It requires the participation of equipment designers, equipment operators, and maintenance department workers.

d) It involves every employee from top management down.

e) It promotes and implements PM based on autonomous, small group activities.

TPM is implemented in four phases or stages with 12 steps as describe shortly in 2.2.2.

2.2.2 Twelve Steps for the TPM Implementation Program

Table 2-3: TPM Implementation Program

Phase 1 : Introduction-preparatory stage	
Step 1: Introducing TPM	The top person's declaration of the resolve to introduce TPM. The declaration is made in an internal TPM lecture meeting, and should be printed in an internal bulletin or newsletter
Step 2: Introduction education and campaign	For managerial staff: Staff of the same echelon are scheduled together for training and conducting slide-show meeting with general employees. Moreover it must understand the current situation. The steering organization should carry out a situational analysis of the current level of TPM development; this can be done through established review techniques or using audit

Table 2-3: TPM Implementation Program (cont.)

Phase 1 : Introduction-preparatory stage (cont.)	
	methodology. 9 Recommended key success factors in this step are 1) The existing organization 2) Measures of performance 3) Alignment to company mission. 4) The involvement of people. 5) An implementation plan. 6) Knowledge and beliefs. 7) Time allocation for implementation. 8) Management commitment. 9) Motivation of management and workforce.
Step 3:Formation of TPM promotion organizations and formal organizational models	To create a steering organization. A steering organization or committee, specialized subcommittees, promotion secretariat if not already in place should be created with the authority and responsibility to develop the TPM program.
Step 4: Setting of basic TPM principles and targets.	Benchmarks and targets; prediction of effects
Step 5: Preparation of a master plan for implementation of TPM	From preparation for introduction to undergoing examinations.
Phase 2 : Start of Introduction stage	
Step 6: Kickoff TPM.	To from preparation for introduction to undergoing examinations.
Phase 3 : Introduction-execution stage	
Step 7: Establishment of a system for improving.	Improvement of production efficiency through 4 main activities.
Step 7.1: Focused Improvement or Kobetsu –Kaizen	First start model machine, project-team activities and workshop small-group activities in eliminating major losses of selected model machine. Effective improvement procedure had been addressed in following portions. • Model machine selection: criteria for model machine

Table 2-3: TPM Implementation Program (cont.)

Phase 3 : Introduction-execution stage (cont.)	
	selection were developed if it is bottleneck process among the whole production line, unique machine in production with low availability. Establishing project team organization. • Major losses analysis and target setting • Initial inspection: • Mapping out of improvement (Kaizen) plan: • Evaluation of analysis and countermeasures • Implementation of improvement (Kaizen) • Effect confirmation: • Recurrence prevention measurement: • Horizontal replication:
Step 7.2 Jishu Hozen or Autonomous Maintenance (AM)	AM team implementation activities. • AM team formation: • AM preparation (training and motivation) • Initial cleaning: and Basic equipment conditions establishment • Countermeasures (for the causes of forced deterioration and improving hard to access areas)
Step 7.3 Planned maintenance	To establish maintenance system encompasses all effective naintenance technology such Corrective maintenance, eriodic maintenance, predictive maintenance
Step 7.4 Operation/ maintenance skill development.	Collective education of leaders and education concerning ransmission of education to members
Step 8 Establishment of initial phase management systems	Establishment of initial phase management systems for new products and new equipment includes development of easy-to-manufacture products and easy-to-use equipment.

Table 2-3: TPM Implementation Program (cont.)

Phase 3 : Introduction-execution stage (cont.)	
Step 9 Establishment of quality maintenance systems	Creation of conditions in which defects do not occur, and the maintenance/management of those conditions
Step 10 Creation of systems for improvement of the efficiency of administrative.	Creation of systems for improvement of the efficiency of administrative/indirect departments, production support, improvement of the efficiency of related sectors, and improvement of efficiency of equipment
Step 11 Creation of systems for the control of safety health, and the environment,	Creation of systems for the control of safety health, and the environment, creation of systems for zero accidents and zero pollution cases
Phase 4 : Establishment stage	
Step 12 Complete implementation of TPM and level improvement	To continue undergoing examinations for the receipt of TPM awards and setting sight on higher targets for higher company competitiveness.

Evaluation of TPM involves accessing whether the company had achieved the policy and goals set at the introduction of TPM and realized the intended benefit. Both the tangible as well as the intangible benefits have been assessed.

2.2.3 Suggestion on Failure and Successful Factors for TPM Implementation

TPM implementation was demonstrated through a case study in an electronics manufacturing company which is multinational company, important task is a leading company active in design and manufacturing of semiconductor devices (Chan et al., 2003, Bamber et al., 1999) advanced telecommunications and electronics equipment. The company started this TPM implementation in the first quarter of 1998 and ended in 2000. The company employs more than 2,500 people in Hong Kong. It experienced postpone the implementation of TPM in early attempt. There are many interesting reasons behind with is in below.

2.2.3.1 Causes of TPM Implementation Failure. TPM is a synergistic relationship among all organizational functions, particularly between production and maintenance. This aims for continuous improvement of product quality, as well as operational efficiency and capacity assurance. An efficient TPM depends on both production and maintenance activities. The 3 key supporting elements of TPM are 1) Productive Maintenance and Proprietary Technology to govern equipment, 2) good training worker and good workplace organization and 3) quality maintenance to enhance reliable equipment and production defect-free. That is no matter how well plants are equipped with advanced manufacturing techniques, it is always the operators, not managers or systems, who affect the plant's performance (Chan et al., 2003). In this connection, operators should participate in the maintenance function by becoming responsible for the prevention of deterioration.

In accordance with the strategic plan in TPM implementation, we have to avoid some TPM collapse causes as the following.

1) Simultaneous introduction of TPM on too many machines.

2) Lack of sufficient training. Need more effort to change mindsets from a traditional maintenance approach. good awareness, education and training strategic plan to be an essential factor in the success of implementation

3) No associates education and training on TPM know-how

4) Lack of management support and understanding

5) Lack of involvement of production associates

6) Lack of resources

7) No specific measurement method on result

8) Lack of structural format in TPM implementation

9) Lack of long-term vision—quick return expected by management

10) Lack of sustained momentum

11) No delegate person. The program does not implement change on the shop floor and is not managed

12) Programs are initiated and run exclusively by engineering and seen by production as a project that does not involve them

13) Failure to allow sufficient time for the evolution. Time requires to change from a reactive program to a proactive approach

14) The program is not serious about change

15) Inexperienced consultants/trainers are used

16) The program is too high level, run by managers for managers

17) Attempts to apply TPM in the same way it is implemented in Japan, using the standard approach found in Japanese publications but is not suitable for company culture.

18) TPM teams lack the necessary mix of skills and experience

In many companies, one notices the overload in work on the production people, preventing this way that the operator effectively participates in TPM process, limiting him, when it happens, to the putting of "TPM Cards", so that maintenance makes its intervention (Marcelo, 2006). This is a negative factor when it comes to the question of the professional development of the operator, because in the beginning of TPM process he is stimulated, encouraged and appreciated for being capable of making small maintenance and adjustments in the equipment. When this activity is diminished due to overload in production activities, he gets professionally frustrated. Another not motivating factor for the production people is when their ideas, suggestions are not "heard", discussed or they do not have feedback.

Other negative facts that occur in companies are:

a) problems of purchase of replacement material, preventing the performance of planned maintenance;

b) budget cuts without reasonable explanation for the team involved with TPM;

c) incorrect dimensioning of the maintenance team to deal with the programmed activities;

d) no follow-up of maintenance backlog;

e) impediment of liberation of machines for maintenance in planned date;

f) constant change in schedule;

g) non-systematic accomplishment of maintenance planning giving a feeling of non-credit to it;

h) the collaborators' non-commitment;

i) the return to the maintenance team of the feeling of "firemen extinguishing the fire".

2.2.3.2 Key Success Factors of TPM Implementation

1) Provide proper TPM concept training and guideline for realizing the benefits in the production and maintenance department during TPM implementation. Supervisors or management are required to convince their subordinates to buy into the concept of TPM by providing proper training.

2) Be careful on selection of team members if there are much different education level of members. Resistant of change always be there. Most effort of management and supervisor are required to educate and communicate the subordinate to be willing to accept new changes and new culture.

3) As maintenance skill is required to be transferred to production operators, a well-developed maintenance training system is one of the key factors for TPM implementation. The system needs to update frequently as technology was changing rapidly.

4) Management support and commitment for TPM implementation is very important.

5) Not simultaneous implementation of TPM that may cause insufficient resource allocation. This causes a negative psychological effect and production people lost interest in the implementation. So, model machine implementation is also one of the crucial factors for TPM

In conclusion, TPM implementation of Asian process industry, TPM must be implemented as step-by-step approach with in effective 4 phases. 5 key success factors have to be held, this includes below items.

1) TPM guideline and concept training.

2) Team members selection

3) Maintenance transferring system

4) Strong management support and commitment
5) No simultaneous implementation

Success of a TPM program is closely connected to the way of managing people (Marcelo, 2006). because the focus of the proposed work in this methodology is the human being. As it happens in all management process, it is necessary to create indicators for the evaluation of performance indicators of the program. In this context the indicators used to verify and control TPM are:

a) Productivity (P)
b) Costs (C)
c) Supply, levels and circulation (D)
d) Quality can achieve zero defects.(Q)
e) Safety, almost total eliminating of violations.(S)
f) Morale, suggestions and participation of all employees in the small group meetings (M)

2.2.4 Different TPM Approach in Different Culture

It said that there are some different in implementation (Bamber, 1999) of TPM by Western from Japanese but the common feature of either the Japanese or Western style in some area but same final outcome such as approach to TPM is to strive for the three goals of zero defects, zero accidents and zero breakdowns and similar aim of TPM activities is to improve the productivity, quality costs, cost of products, delivery and movement of products, safety of operations and morale of those involved (PQCDSM).

The difference being the focus of approach the exception of the publication from Wireman (1991), these experts consider operational elements of any TPM program should aim to provide the five pillars of TPM development as shown in the following. (see Figure 2-5: 5-TPM Pillar Western Style Proposed by Yeomans and Millington (1997))

a) Implement improvement activities designed to increase equipment efficiency. This is accomplished mainly by eliminating the six big losses

b) Establish a system of autonomous maintenance to be performed by equipment operators. This is set up after they are trained to be “equipment conscious” and “equipment skilled.”

c) Establish a planned maintenance system. This increases the efficiency of the maintenance department.

d) Establish training courses. These help equipment operators raise their skill levels.

e) Establish a system of maintenance prevention (MP) design and early equipment management. MP design generates equipment that requires less maintenance, while early equipment management gets new equipment operating normally in less time.

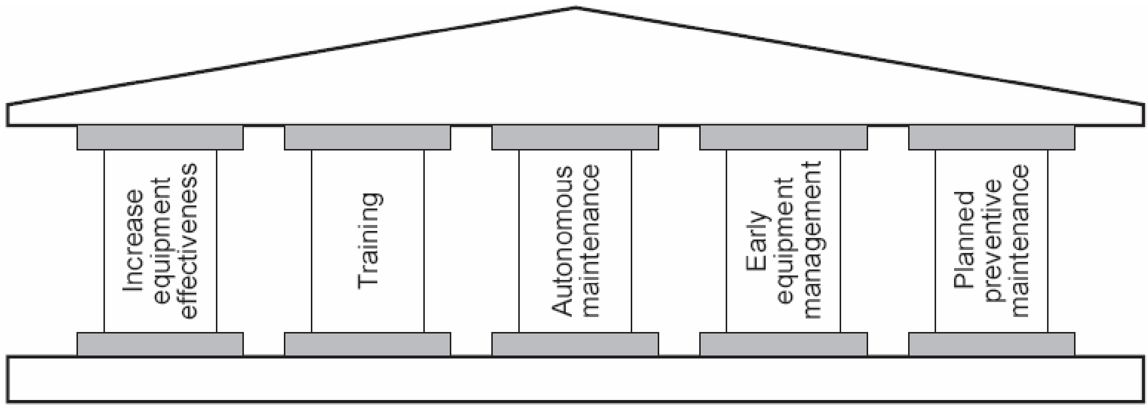


Figure 2-5: 5 TPM Pillar in Western Style **(**Yeomans et al.,1997)

2.3 TPM-Focused Improvement

Like all activities designed to revitalize organizations, TPM’s goal is to improve corporate business results and create cheerful and productive workplaces (Tokutaro, 1994). An important feature of TPM is its potential impact on the bottom line. Hearing others talk about “profiting through TPM,” however, some people conclude that it is an easy way to make money for their company. This passive attitude cannot yield significant results. Only by adopting a proactive approach and putting in the time and effort required to make a TPM program profitable can a company realize TPM's benefits such as a 1.5-fold increase in productivity or a 10-fold increase in return on investment.

Focused improvement is an improvement activity performed by cross-functional project teams composed of people such as production engineers, maintenance personnel, and operators. This activity is a priority in any TPM development program and is at the top of the list of the eight fundamentals of TPM development. It is one of the major activities in the TPM master plan, and its implementation begins simultaneously with the TPM kick-off. Focused improvement includes all activities that maximize the overall effectiveness of equipment, processes, and plants through uncompromising elimination of losses and improvement of performance. Entire process losses as per Table 2-4 is some kinds of losses should be considered in the initial TPM project.

Table 2-4: Major Losses and Associated Improvement Topics

Loss	Improvement Topic
1. Equipment failure loss	Eliminate failures by improving construction at main-shaft bearings in product separators
2. Process failure loss	Reduce manual work by preventing dogging at pH meter electrodes in decolorizes
3. Idling and minor stoppage loss	Increase production capacity by reducing malfunction of un-loaders in separators
4. Speed loss	Increase performance rate by improving attachment of stirrers in crystallizers
5- Process defect loss	Prevent contamination with foreign matter by improving lubrication of intermediate bearings in screw-type product conveyors.
6. Startup and yield loss	Reduce normal production losses by improving re-melting work during startup

Table 2-4: Major Losses and Associated Improvement Topics (cont.)

Loss	Improvement Topic
7. Energy loss	Reduce steam consumption by concentrating liquid feed to crystallization process
8. Quality defect loss	Eliminate customer complaints by preventing product adhesion resulting from moisture absorption by kraft-paper product sacks
9. Leakage and spillage loss	Increase product yield by improving lower bearing take-up in bucket elevators
10. Manual work loss	Reduce number of workers by automating acceptance of subsidiary materials

2.3.1 Step-by-Step Procedure for Focused Improvement

1) Step 0: Select improvement topic
2) Step 1: Understand situation
3) Step 2: Expose and eliminate abnormalities
4) Step 3: Analyze causes
5) Step 4: Plan improvement
6) Step 5: Implement improvement
7) Step 6: Check results
8) Step 7: Consolidate gains

2.3.2 The Philosophy of Zero Equipment Failures

TPM specifies six zero-breakdown measures in corporation with implementation of Planned Maintenance pillar via 4-phases zero breakdown, all of which must be performed to thoroughly eliminate equipment failures in general machinery, then to establish basic conditions and ensure that comply with conditions of use.

2.3.3 Clarification Improvement Type

After considered to implement TPM project, Focused Improvement team has to be set and the next step is to classify the improvement topic by type (profit-seeking or autonomous-maintenance-backup). In process industries, with large-scale contamination sources, it is extremely important to adopt the correct approach for each of these two types of improvement.

It is relatively easy to budget for a profit-seeking improvement, because the return on investment is easily calculated, it produces highly-visible results, and the capital payback period is clear. The autonomous-maintenance-backup improvement, on the other hand, addresses contamination sources and inaccessible places and is, therefore, less spectacular in effects. Its direct financial benefit is small compared with its cost and it takes longer to pay for itself, which makes it harder to justify economically.

If, however, the plant uses a smaller return as an excuse for putting off this type of improvement, the autonomous maintenance program will not get beyond the cleaning stage. This can easily kill people's enthusiasm and stop the program in its tracks. The working environment will remain dark, dirty, and smelly, and younger employees will shun it. Leaking powders and liquids are major causes of accelerated deterioration, so give high priority to the autonomous-maintenance-backup improvement.

The two types of improvement require different approaches to budgeting Table 2-3 shows an approach to devising and budgeting a focused improvement system for both types of improvement. A fixed budgeting framework makes cash available on an ad hoc basis for profit-seeking improvements. Funds for autonomous-maintenance-backup improvements are appropriated in lump sums every accounting year or half -year.

2.3.4 Assess Difficulty

After categorizing an improvement topic, the next step is to assess its difficulty against preset criteria and decide who is to implement it. Table 2-5 is an example of a ranking system, but each industry and workplace must develop criteria to suit its own characteristics.

Based on this assessment, decide who will be responsible for implementing the improvement project. Ideally, all improvements should be carried out by people in the course of their daily work or as part of autonomous maintenance activities. This avoids contention about who is responsible for what. When tackling difficult topics, however, form teams with a good cross – section of members, including people from production, maintenance, design, engineering, quality control, and so on. For certain topics, some teams will be more effective if they also include operators and equipment manufacturers' representatives.

Table 2-5: Focused Improvement System

Type of Focused Improvement	Improvement Topic	Degree of Difficulty	Responsibility
Profit-seeking, i.e., ad hoc budget appropriation	All-out elimination of losses	Rank A Rank B Rank C	Project team Maintenance department Autonomous maintenance teams
Autonomous Maintenance backup, i.e., lump-sum budget appropriation	Contamination-source Countermeasures Inaccessible-place countermeasures	Rank A Rank B Rank C	Project team Maintenance department Autonomous maintenance teams

Table 2-6: Sample Criteria for Assessing Difficulty

Rank	Assessment Criterion
A	1) Losses and problems affecting many departments 2) Major sources of spills and leaks left unchecked for many years 3) Serious urgent problems causing late deliveries, significant customer claims etc. 4) Complex problems requiring a high level of technology 5) Improvements cost is very high.
B	1) Losses and problems restricted to a single department; medium-severity contamination sources 2) Correcting equipment weaknesses such as structural strength, construction, materials etc. 3) Improvements requiring an intermediate level of engineering technology and cost is moderate
C	1) Losses that operators can eliminate with guidance and assistance 2) Improving inaccessible places hampering routine operation, inspection, and lubrication 3) Eliminating contamination sources without major equipment modifications

Above tables show the equipment maintenance department as responsible for B-ranked improvement projects, this is not and unbreakable rule. For example, the quality control or quality assurance department can take charge of improvements concerned with quality losses, while the production or engineering department can handle those dealing with adding value or simplifying processes.

2.4 TPM-Autonomous Maintenance in Seven Steps Implementing

TPM improves corporate business results and creates pleasant and productive workplaces by changing the way people think about and work with equipment throughout the company. Autonomous maintenance (Masaji et al., 1999, Okutaro, 1994), maintenance performed by the production department, is one of the most important basic building blocks in any TPM program.

2.4.1 The Goals of Autonomous Maintenance

The production department's mission is to produce good products as cheaply and quickly as possible. One of its most important roles is detecting and dealing with equipment abnormalities promptly, which is the goal of good maintenance. Autonomous maintenance includes any activity performed by the production department that has a maintenance function and is intended to keep the plant operating efficiently and stably in order to meet production plans. The goals of an autonomous maintenance program are:

a) Prevent equipment deterioration through correct operation and daily check.

b) Bring equipment to its ideal state through restoration and proper management

c) Establish the basic conditions needed to keep equipment well – maintained

Another important goal is to use the equipment as a means of teaching people new ways of thinking and working.

2.4.2 Classifying and Allocation Maintenance Tasks

Activities designed to achieve optimal equipment conditions and maximize overall equipment effectiveness either maintain or improve equipment. Maintenance activities aim to keep equipment in a desired state – by preventing and correcting failures.

Improvement activities, on the other hand, extend equipment life, shorten the time required to perform maintenance, and make maintenance unnecessary. Corrective maintenance, for example, focuses on reliability and maintainability improvement in existing equipment. Maintenance prevention activities promote the design of new equipment that is easier and less costly to operate and maintain as well as "vertical" startup after installation or "single – shot" startup after shutdown.

2.4.2.1 Activities of the Production Department. The production department must focus on preventing deterioration. It should build its autonomous maintenance around the following three kinds of activities in Table 2-7:

Table 2-7: Autonomous Maintenance to Prevent Deterioration

Preventing Deterioration:
1) Correct operation – preventing human errors 2) Correct adjustment – preventing process defects (quality defects) 3) Basic housekeeping (establishing basic equipment conditions) – cleaning, lubricating, and tightening 4) Early prediction and prompt detection of abnormalities – forestalling failures and accidents 5) Keeping maintenance record – feeding back information for recurrence prevention and maintenance prevention design
Measuring Deterioration:
1) Daily inspection – patrol check and five – senses checks during operation 2) Periodic inspection – part of overhaul inspection during plant shut down of shutdown maintenance
Restoration Deterioration:
1) Minor serving – emergency measures when abnormal conditions arise and simple parts replacement 2) Prompt, accurate reporting of failure and problems 3) Assistance with repairing unexpected failures

2.4.3 Overview of the Seven Steps of Autonomous Maintenance

Autonomous maintenance is implemented in seven steps, starting with initial cleaning and proceeding steadily toward full self-management. It promotes the establishment of optical process conditions by cycling through the continuous improvement (CAPD) management cycle.

Step 1 through 3 place priority on abolishing environments that cause accelerated deterioration, reversing deterioration, and establishing and maintaining basic equipment conditions. The goals of these steps are to get operators interested in their equipment and help them shake off their self-image as mere switch – flickers or button – pushers. In step 4 and 5, team leaders teach inspection procedures to their members, and general inspection expands from individual equipment units to the whole process. The goals of these steps are to reduce failures and develop operators who thoroughly understand their equipment and processes.

Step 6 and 7 are designed to entrench and upgrade autonomous maintenance and improvement activities by standardizing systems and methods and extending the sphere of action from equipment to other areas such as stores, distribution, and so on. The ultimate goal of these steps is a robust organization and culture in which every workplace is capable of full self – management.

Table 2-8: The Implementation Steps of Autonomous Maintenance Pillar

AM Implementation step	Activity
Step 1: Perform Initial Cleaning	The goal of step 1 of the autonomous maintenance program is to raise equipment reliability through three activities in following. **1) Eliminate Dirt, Dust and Grime**. Encourage operators to recognize the importance of cleaning, and resolve to keep their equipment spotless in the future. This, in turn, encourages

Table 2-8: The Implementation Steps of Autonomous Maintenance Pillar (cont.)

AM Implementation step	Activity
Step 1: Perform Initial Cleaning	them to think of ways of improving their equipment to make it easier to keep clean. **2) Expose All Abnormalities** It is classified abnormalities into seven types. Through the practical action of thorough cleaning that brings hidden irregularities to light, operators learn that "cleaning is inspection." To expose all these abnormalities during cleaning. **3) Correct Minor Flaws and Establish Basic Equipment Conditions** **3-2) Correct minor flaws.** To raise the reliability of equipment by establishing basic conditions. Begin by correcting minor flaws. When serious damage is discovered, ask the maintenance department to deal with it right away. **3-3) Lubricate.** Lubrication is one of the most important basic conditions for preserving equipment reliability, preventing wear or burnout, maintaining the operational precision of pneumatic devices, and reducing friction. **3.1) Tighten.** All machinery contains nuts, bolts, and screws as essential element of their construction. Equipment functions properly only if such fasteners are securely tightened.

Table 2-8: The Implementation Steps of Autonomous Maintenance Pillar (cont.)

AM Implementation step	Activity
Step 2: Eliminate Sources of Contamination and Inaccessible Places	The goal of Step 2 is to reduce the time if takes for cleaning, checking, and lubricating by introducing these two types of improvement. The goal of Step 2 is to reduce the time if takes for cleaning, checking, and lubricating by introducing these two types of improvement. 1) Type I Improvement : Countermeasure of sources of leaks and spillage, **2) Type II Improvement :** Improve Accessibility to Reduce Working Time
Step 3: Establish Cleaning and Inspection Standards	The goal of this step is to lock into place the gains made in Steps 1 and 2, that is, to ensure maintenance of basic conditions and keep equipment in peak condition. To achieve this, operator teams must standardize cleaning and inspection procedures and take responsibility for maintaining their own equipment. **1) Preparing Standards,** Provisional standards allow operators to begin performing checks easily, correctly, and without omissions. Standards, therefore, must answer the "5 Ws and 1H" (Where? What? When? Why? Who? And How?) includes inspection items, key points, method, tools, times, intervals and responsibility.**2) Introduce Extensive Visual Controls**, The key to consistent performance of cleaning, checking, and lubricating tasks to make them easy to perform correctly by anybody. An effective way of achieving this is to use visual controls (workplace

Table 2-8: The Implementation Steps of Autonomous Maintenance Pillar (cont.)

AM Implementation step	Activity
	displays). Place these directly on the equipment to be controlled and clearly indicate operating conditions by marking name and equipment number, putting match-mark on nuts, indicating acceptable operation range, indicating lubricant level, labeling the cover of devices and pipes.

2.5 TPM-Planned Maintenance

Planned maintenance (Kinjiro, 2006, Tokutaro, 1994) should establish and maintain optimal equipment and process conditions it should also be efficient and cost-effective. In a TPM devilment program, planned maintenance is the deliberate, methodical activity of building and continuously improving maintenance system.

Equipment management in a process industry is profoundly influenced by its unique types of equipment, the nature of is process and equipment failures, and the skill levels and roles of its maintenance personnel.

2.5.1 Equipment Failure and Process Problems

In addition to equipment problems, process industries are plagued by process problems such as blocks, leaks, contamination, and powder spills. Preventing sudden plant shutdown due to such problems is crucial.

Process problems are often chronic, resulting from a complex combination of causes. For example, the external shape or internal construction of a piece of equipment many create local non-uniformities in fluidity, dispersion, temperature, composition, or other properties of the substances being processed, and this in turn may produce unwanted physical of chemical changes.

Equipment failures and process problems (losses) in process industries can be classified into five broad categories.1) Equipment failures or process problems that cause shutdown 2) Quality abnormalities 3) Unit-consumption abnormalities 4) Capacity reductions and 5) Safely and environmental problems

Most of these problems result from equipment disorders of abnormalities. A plant can prevent them by bringing equipment and processes into their ideal state. A basic approach to reducing process failures is to select the most suitable system of maintenance for each functionally important component or equipment item. Use the reliability-centered maintenance (RCM) approach to determine this, based on failure records and physical principles. RCM approach will be expressed and discussed later.

2.5.2 Achieving Zero Breakdowns

Most serious accidents in production plants occur in the course of responding to problems such as equipment failures. Very few occur when processes operate normally and operators merely monitor or check their equipment. Likewise, most process defects and product defects occur when plants shutdown because they fail, are under repair, or are restarting. Defect rates are naturally very low in plants that continue to operate normally for long periods. In other words, achieving zero breakdowns is the quickest way to eliminate accidents and defects. To prevent accidents and defects, prevent the possibility of serious failures that shut down major systems or complete processes. The key is to construct a planned maintenance system that combines various specialized maintenance activities which are classified into 6 measures called Six Zero-Breakdown Measures in 4 phases that also called Four Phases to Zero Breakdown.

2.5.2.1 The Six Zero-Breakdown Measures. It can be seen many plants neglect basic equipment conditions (cleaning, lubricating, and tightening bolts) and do not comply with conditions of use. Equipment in such plants is subject to accelerated deterioration. Idling, minor stops, and minor failures are rife, and failure intervals vary widely. It is pointless to attempt to carry out periodic or predictive maintenance in such a situation. The maintenance department cannot achieve zero breakdowns through planned maintenance alone, Nor can the production department achieve it solely through autonomous maintenance. Both can achieve significant results, however, by combining planned and autonomous maintenance and painstakingly implementing the six zero-breakdown measure detailed earlier.

Table 2-9: Six Zero-Breakdown Measures of Planned Maintenance Pillar

Measurement	Activity
Measure 1- Eliminate accelerated deterioration by establishing basic equipment conditions (cleaning, lubricating, and tightening).	The most basic activity is to establish and maintain the minimum conditions required to keep equipment running – that is, to keep it clean, well-lubricated, and securely tightened. Failures are far less likely in equipment that is uncontaminated and well-oiled and has no loose parts.
Measure 2 - Eliminate accelerated deterioration by complying with conditions of use.	Equipment is designed for use under certain design conditions, and these must be adhered to. Operating them under different conditions is bound not only to cause accelerated deterioration, greatly shorten their lifetimes, and result in unexpected failures but also to produces abnormal changes in the products being treated, adversely affect the rest of the production process, and leads to process failures (blocks and so forth) and quality failures. It is particularly important in process industries to operate all machinery, static equipment, catalysts, and so on in accordance with their specifications to minimize the possibility of major accidents.
Measure 3 - Restore equipment to its optimal condition by restoring deterioration.	Equipment deterioration is of two types: 1) accelerated and 2) natural. - Accelerated deterioration is an artificial cause of failure that arises when basic equipment conditions are not maintained or when conditions of use are not heeded. It often proceeds rapidly.

Table 2-9: Six Zero-Breakdown Measures of Planned Maintenance Pillar (cont.)

Measurement	Activity
	- Natural deterioration is a gradual form of deterioration due to such factors as wear, corrosion, and changes in the properties of materials. It can result in a succession of failures, starting from the weakest part of the equipment. The quickest way to achieve zero failures is thus to examine every part of the equipment, measure its degree of deterioration accurately, detect and predict deterioration accurately through shutdown maintenance and predictive maintenance as part of a planned maintenance system.
Measure 4 - Restore processes to their optimal condition by abolishing environment that cause accelerated deterioration	Cooperate with Autonomous Maintenance activities and Focused Improvement projects to eliminate major contamination sources. It is vital to clean up and control environments that encourage accelerated deterioration.
Measure 5 - Lengthen equipment lifetimes by correcting design weaknesses.	To change or correct the material, dimensions or construction of the weak part due to poor design is the only way to achieve zero breakdowns. Insufficient strength, inadequate materials, or structural defect is to shorten the interval between periodic services, which can result in extravagant maintenance bills.
Measure 6 - Eliminate unexpected failures by improving operating and maintenance skills.	Even when equipment is extremely reliable, unexpected breakdowns may still occur as a result of operating errors and repair errors. 1) Production departments must cultivate operators' abilities to detect abnormalities at an early stage and to maintain basic conditions and inspect using their five senses. Improving their inspection and operating skills will also eliminate operating errors.

Table 2-9: Six Zero-Breakdown Measures of Planned Maintenance Pillar (cont.)

Measurement	Activity
	2) Meanwhile, maintenance departments to enable maintenance technicians to master the most advanced maintenance skills.

2.5.2.2 The Four Phases to Zero Breakdown. The six zero-breakdown measures introduced earlier involve tremendous work. Implementing all at the same time is well-nigh impossible. Even if we could put all six into effect at once, we would still waste time trying to carry out periodic maintenance on dirty, unlubricated equipment exposed to accelerate us to set ridiculously short service intervals. In either case, periodic maintenance fails. Predictive maintenance is subject to the same limits. No matter how good we diagnostic techniques, optimal service intervals cannot be predicted in an environment where failures persist as a result of loose nuts and bolts, operator errors, and so on. Many production plants have found that the most effective way of successfully implementing the six zero-breakdown measures is to distribute them among four phases and proceed through those four phases systematically.

The six zero-breakdown measures mentioned above entail a tremendous amount of work. Trying to speed up a failure reduction program by putting all six countermeasures into effect simultaneously is counterproductive. Implementing a planned maintenance system before establishing basic condition when equipment is still dirty, nuts and bolts are loose or missing, and lubrication devices are not working properly frequently leads to failures before the next major service is due. To prevent these would require making the service interval unreasonably short, and the whole point of the planned maintenance program would be lost.

Rushing into predictive maintenance is equally risky. Many companies purchase diagnostic equipment and software that monitors conditions, while neglecting basic maintenance activities. It is impossible, however, to predict optimal service intervals in an environment where accelerated deterioration and operating errors are unchecked.

The most effective way of achieving the zero-breakdown target is to implement the six measures in the following four phases.

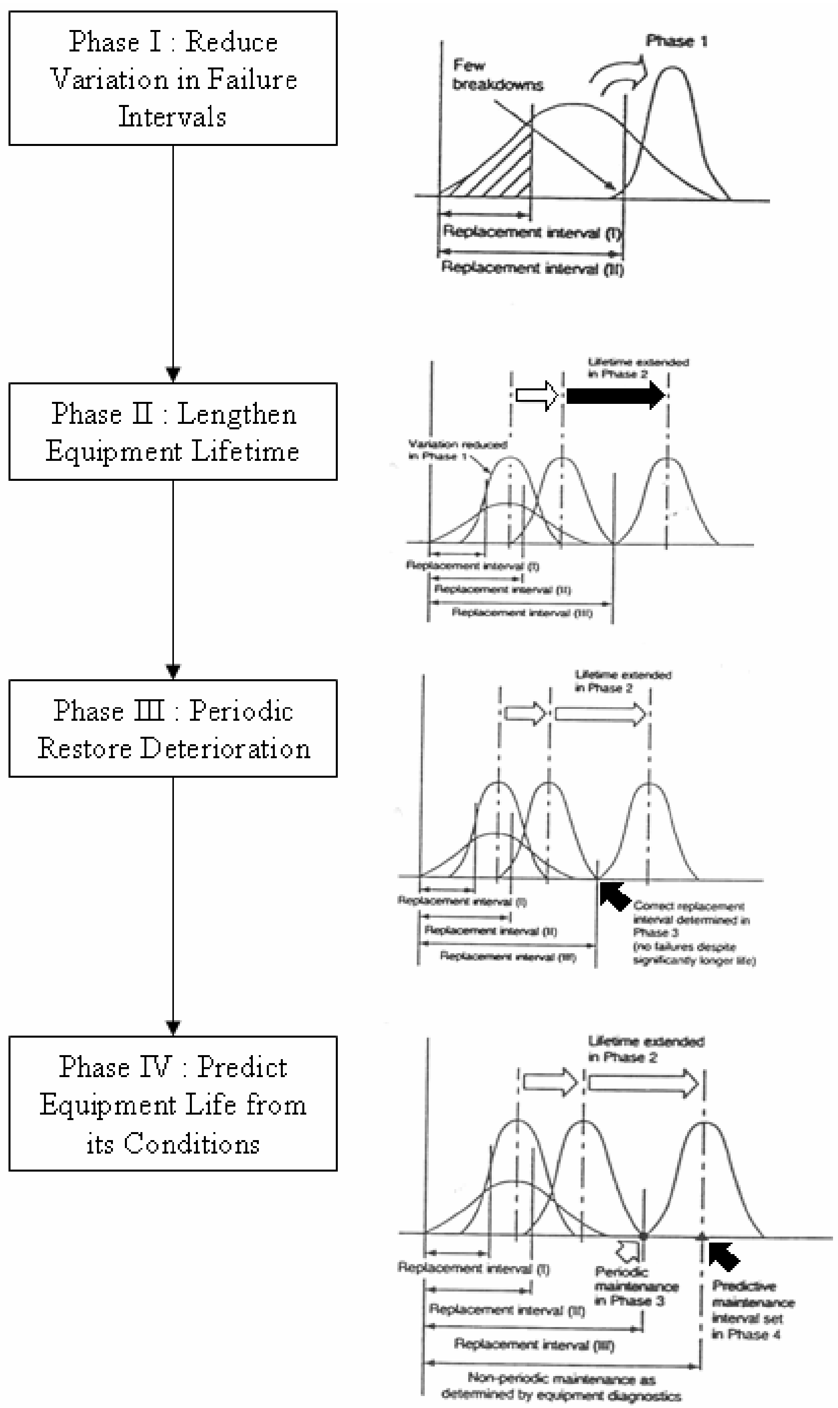


Figure 2-6: The Four Phases to Zero Breakdown (Tokutaro, 1994)

Table 2-10: Four Phases of Planned Maintenance Pillar

Phase	Activity
Phase I- Reduce Variation in Failure Intervals	In this phase, it includes 2 major maintenance activities 1) Restore deterioration and 2) Prevent accelerated deterioration. 1) Restore Deterioration*:* This activity restores equipment in a deteriorated state to its original condition, thereby reducing variation in failure intervals. It is must to reduce the dispersion to decrease the failure frequency. Deterioration is often left unchecked, even when people are aware of it and understand that it will lead to breakdowns. Phase I is designed to break out of this vicious failure cycle. 2) Prevent Accelerated Deterioration: After restore deterioration of equipments, the next task is to extend equipment life and continue to reduce the variation in failure intervals by preventing further accelerated deterioration that requires the following actions. 2.1) Establish basic conditions. 2.2) Comply with conditions of use. 2.3) Eliminate accelerated deterioration. 2.4) Prepare user-friendly daily inspection and lubrication standards.
Phase II- Lengthen Equipment Lifetime	Phase-II activities are generally lumped together under the title corrective maintenance or improvement activities or Kaizen. The Kaizen idea to prolong the equipment life should be raised as most initiative including three major activities in the following items. 1) Correct Design and Fabrication Weaknesses 2) Prevent Major Breakdowns from Recurring: The counter measures based on the results of extensive failure analysis are extremely effective in lengthening equipment life. 3) Prevent Operating and Repair Error: The fact that human error is involved makes these failures difficult to solve quickly. The only way to deal with them is through comprehensive, sustained training in operating and maintenance skills and the use of visual controls and error – proofing (poka-yoke) measures.

Table 2-10: Four Phases of Planned Maintenance Pillar (cont.)

Phase	Activity
Phase III- Periodically Restore Deterioration	To preserve and extend the lengthened equipment life achieved in Phases I and II, establish a system of planned or preventive maintenance. 1) Perform Periodic Serving and Inspection: Determining optimal servicing and inspection intervals then keeping a maintenance calendar for equipment units or components, continually re-evaluate and establish the most economical inspection and service intervals to extend a service interval. It is to perform a simple diagnostic check a few months before as scheduled service. 2) Establish Maintenance Work and Inspection Standards 3) Control Spare Parts and Maintenance Materials: To perform planned maintenance effectively with a small team of maintenance personnel, just-in-time control of spare parts and maintenance materials is essential. 4) Recognize Signs of Process Abnormality: Production and maintenance departments must work together to develop finely – tuned diagnostic skills by sharpening their sensitivity and honing their “five – senses” checking skills
Phase IV- Predict Equipment Life from its conditions	To be on the safe side, maintenance personal usually set service intervals shorter than necessary. If you try to guarantee trouble – free operation of all equipment through planned maintenance, however, you will inevitably over-maintain it, because not all equipment fails between services. On the other hand, operators’ abilities to recognize danger signals are limited. Therefore, instruments are used to assess equipment condition and accumulate data, and then to predict equipment lifetimes from trends in this data.

2.5.3 Maintenance Regimes and Maintenance Policy

There are different maintenance regimes used today. An efficient planned maintenance program combines preventive maintenance (PM) combines time based maintenance (TBM) and condition – based maintenance (CBM) to keep equipment functioning by controlling equipment components, assemblies, subassemblies, accessories, attachments, and so on. It also maintains the performance of structural materials and prevents corrosion, fatigue, and other forms of deterioration from weakening them. Breakdown maintenance (BM) as rationally as possible. Corrective maintenance (CM) improves equipment and its components so that preventive maintenance can be carried out reliably, Equipment with design weaknesses must be redesigned.

2.5.3.1 Time-Based Maintenance in Planned Maintenance

Time-based maintenance consists of periodically inspecting, servicing, and cleaning equipment and replacing parts to prevent sudden failure and process problems. It should be part of both autonomous maintenance and specialized maintenance activities.

The goals of planned maintenance are to eliminate equipment failures and process problems and minimize losses. The first step toward achieving those goals, is time – based maintenance that is performing maintenance tasks according to a fixed schedule or age-related interval, Deciding what maintenance to perform on which equipment will depend on a company's policies, long – and mid – range plants, annual plans, and so on. Many literature reveals various maintenance policies. Maintenance optimization would be very necessary to minimize losses due to maintenance tasks. Maintenance optimization will be explained later. To maintain equipment and processes in their ideal state, however, it is vital to use all available maintenance data and technology. Close cooperation between the maintenance departments and other department and other departments is, therefore, essential.

2.5.3.2 Condition-Based Maintenance in Planned Maintenance

The second principle activity of planned maintenance, condition-based maintenance. Condition-based maintenance uses equipment diagnostics to monitor and diagnose moving machinery conditions continuously or intermittently during operations and on-stream inspection (OSI) checking the condition of static equipment and monitoring sign of change by nondestructive inspection techniques.) As its name implies, condition-based maintenance is triggered by actual equipment conditions rather than the elapsing of a predetermined interval of time. It has two main thrusts:

2.5.3.3 Breakdown Maintenance in Planned Maintenance

Unlike the preceding two systems, breakdown maintenance means waiting until equipment fails to repair it. Breakdown maintenance is used when failure does not significantly affect operation or production or generated and financial losses other than repair costs. The third main activity of planned maintenance, breakdown maintenance, consists of replacing parts or performing other repairs and prevention, make it easy for operators to detect abnormalities when they perform their daily checks or routinely monitor the equipment.

2.6 Reliability-Centered Maintenance (RCM)

Since the 1930's, the evolution of maintenance can be traced through three generations (Mourbrey, 2001). RCM is rapidly becoming a cornerstone of the Third Generation which the process of change in industry has gathered even greater momentum. The changes can be classified under the headings of new expectations, new research and new techniques., but this generation can only be viewed in perspective in the light of the First which prevention of equipment failure was not a very high priority in the minds of most managers, and Second Generations which downtime issue came into sharper focus. This led to the idea that equipment failures could and should be prevented, which led in turn to the concept of preventive maintenance. Figure 2-7 shows how expectations of maintenance have evolved.

Downtime has always affected the productive capability of physical assets by reducing output, increasing operating costs and interfering with customer service. In manufacturing, the effects of downtime are being aggravated by the worldwide move towards just-in-time systems, where reduced stocks of work-in-progress mean that quite small breakdowns are now much more likely to stop a whole plant. Greater automation also means that more and more failures affect our ability to sustain satisfactory quality standards. This applies as much to standards of service as it does to

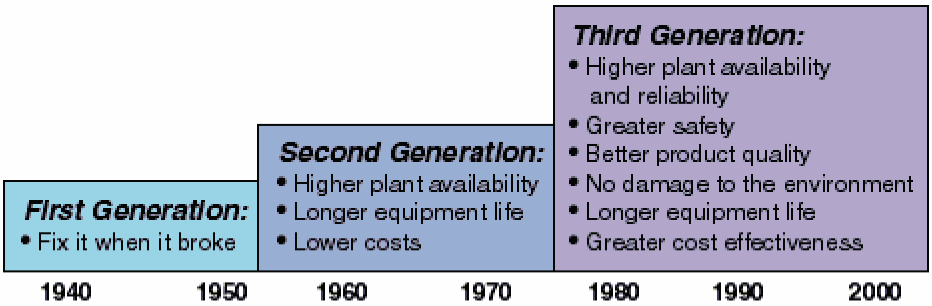


Figure 2-7: Growing Expectations of Maintenance (Mourbrey, 2001)

product quality. More and more failures have serious safety or environmental consequences, at a time when standards in these areas are rising rapidly There was new research of equipment failure patterns. Quite apart from greater expectations, new research is changing many of our most basic beliefs about age and failure. In particular, it is apparent that there is less and less connection between the operating age of most assets and how likely they are to fail. Figure 2-8 shows how the earliest view of failure was simply that as things got older, they were more likely to fail. A growing awareness of 'infant mortality' led to widespread Second Generation belief in the "bathtub" curve.

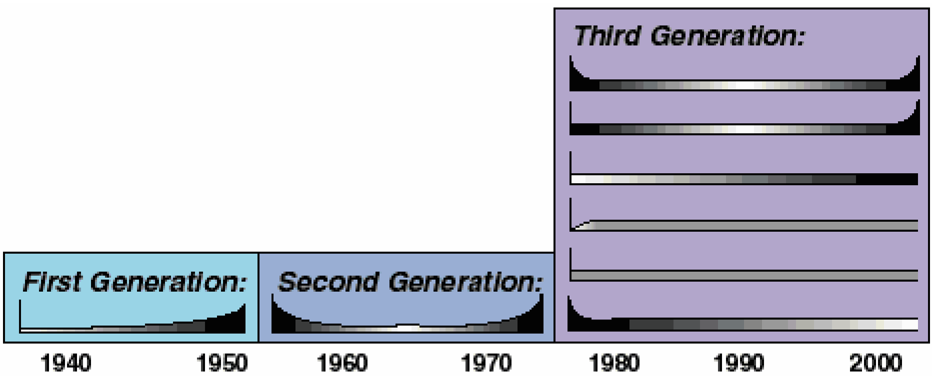


Figure 2-8: Changing Views on Equipment Failure (Mourbrey, 2001)

However, Third Generation research has revealed that not one or two but six failure patterns actually occur in practice. There has been explosive growth in new maintenance concepts and techniques. Hundreds have been developed over the past fifteen years, and more are emerging every week. Figure 2-9 shows how the classical emphasis on overhauls and administrative systems has grown to include many new developments in a number of different fields.

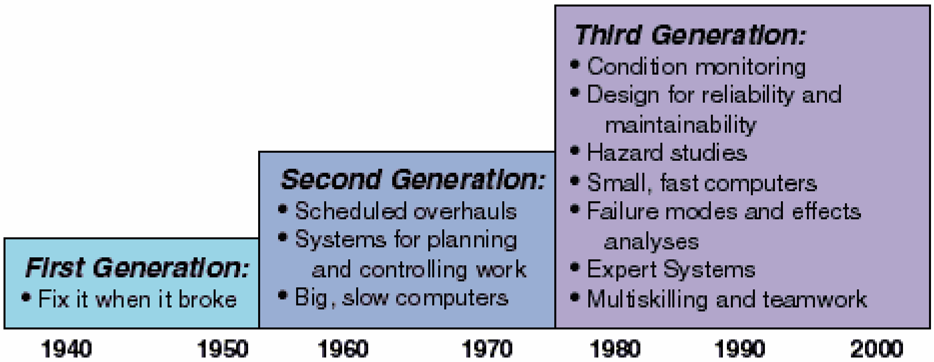


Figure 2-9: Changing maintenance Techniques (Mourbrey, 2001)

a) RCM provides a framework which enables users to respond to these challenges, quickly and simply. It does so because it never loses sight of the fact that maintenance is about physical assets. If these assets did not exist, the maintenance function itself would not exist. So RCM starts with a comprehensive, zero-based review of the maintenance requirements of each, asset in its operating context.

RCM approach to preserve physical asset function, primary and secondary function, The users of the assets are usually in the best position by far to know exactly what contribution each asset makes to the physical and financial well-being of the organization as a whole, so it is essential that they are involved in the RCM process from the outset. The objectives of maintenance are defined by the functions and associated performance expectations of the asset under consideration. But how does maintenance achieve these objectives? The only occurrence which is likely to stop any asset performing to the standard required by its users is some kind of failure. This suggests that maintenance achieves its objectives by adopting a suitable approach to the management of failure. However, before we can apply a suitable blend of failure management tools, we need to identify what failures can occur. The RCM process does this at two levels: firstly, by identifying what circumstances amount to a failed state then secondly, by asking what events can cause the asset to get into a failed state.

In the world of RCM, failed states are known as functional failures because they occur when an asset is unable to fulfill a function to a standard of performance which is acceptable to the user.

In addition to the total inability to function, this definition encompasses partial failures, where the asset still functions but at an unacceptable level of performance (including situations where the asset cannot sustain acceptable levels of quality or accuracy). Clearly these can only be identified after the functions and performance standards of the asset have been defined.

As mentioned in the previous paragraph, once each functional failure has been identified, the next step is to try to identify all the events which are reasonably likely to cause each failed state. These events are known as failure modes. "Reasonably likely" failure modes include those which have occurred on the same or similar equipment operating in the same context, failures which are currently being prevented by existing maintenance regimes, and failures which have not happened yet but which are considered to be real possibilities in the context in question. Most traditional lists of failure modes incorporate failures caused by deterioration or normal wear and tear. However, the list should include failures caused by human errors (on the part of operators and maintainers) and design flaws so that all reasonably likely causes of equipment failure can be identified and dealt with appropriately. It is also important to identify the cause of each failure in enough detail to ensure that time and effort are not wasted trying to treat symptoms instead of causes. On the other hand, it is equally important to ensure that time is not wasted on the analysis itself by going into too much detail. Next, RCM process entails listing failure effects, which describe what happens when each failure mode occurs. These descriptions should include all the information needed to support the evaluation of the consequences of the failure. The process of identifying functions functional failures failure modes and failure effects yields surprising and often very exciting opportunities for improving performance and safety, and also for eliminating waste.

A detailed analysis of an average industrial undertaking is likely to yield between three and ten thousand possible failure modes. Each of these failures affects the organization in some way, but in each case, the effects are different. They may affect operations. They may also affect product quality, customer service, safety or the environment. They will all take time and cost money to repair. It is these consequences which most strongly influence the extent to which we try to prevent each failure. In other words, if a failure has serious consequences, we are likely to go to great lengths to try to avoid it. On the other hand, if it has little or no effect, then we may decide to do no routine maintenance beyond basic cleaning and lubrication.

A great strength of RCM is that it recognizes that the consequences of failures are far more important than their technical characteristics. In fact, it recognizes that the only reason for doing any kind of proactive maintenance is not to avoid failures per se, but to avoid or at least to reduce the consequences of failure. The RCM process classifies these consequences into four groups, as

a) Hidden failure consequences: Hidden failures have no direct impact, but they expose the organization to multiple failures with serious, often catastrophic, consequences. (Most of these failures are associated with protective devices which are not fail-safe.)

b) Safety and environmental consequences: A failure has safety consequences if it could hurt or kill someone. It has environmental consequences if it could lead to a breach of any corporate, regional, national or international environmental standard.

c) Operational consequences: A failure has operational consequences if it affects production (output, product quality, customer service or operating costs in addition to the direct cost of repair)

d) Non-operational consequences: Evident failures which fall into this category affect neither safety nor production, so they involve only the direct cost of repair.

The consequence evaluation process also shifts emphasis away from the idea that all failures are bad and must be prevented. In so doing, it focuses attention on the maintenance activities which have most effect on the performance of the organization, and diverts energy away from those which have little or no effect. It also encourages us to think more broadly about different ways of managing failure, rather than to concentrate only on failure prevention. Failure management techniques are divided into two categories, 1) proactive tasks: these are tasks undertaken before a failure occurs, in order to prevent the item from getting into a failed state. They embrace what is traditionally known as 'predictive' and 'preventive' maintenance, although we will see later that RCM uses the terms scheduled restoration scheduled discard and on-condition maintenance and 2) default actions: these deal with the failed state, and are chosen when it is not possible to identify an effective proactive task. Default actions include failure-finding, redesign and run-to-failure. Figure 2-10 illustrates the fixed interval view of failure.

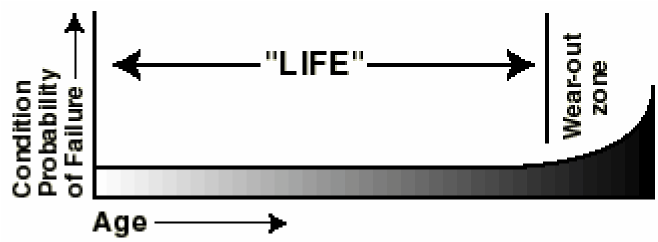


Figure 2-10: The Traditional View of Failure (Mourbrey, 2001)

Figure 2-11 is based on the assumption that most items operate reliably for a period of time, and then wear out. Classical thinking suggests that extensive records about failure will enable us to determine this life and so make plans to take preventive action shortly before the item is due to fail in future. This model is true for certain types of simple equipment, and for some complex items with dominant failure modes. In particular, wear-out characteristics are often found where equipment comes into direct contact with the product. Age-related failures are also often associated with fatigue, corrosion, abrasion and evaporation.

However, equipment in general is far more complex than it was twenty years ago. This has led to startling changes in the patterns of failure, as shown in Figure 2-11; The graphs show conditional probability of failure against operating age for a variety of electrical and mechanical items.

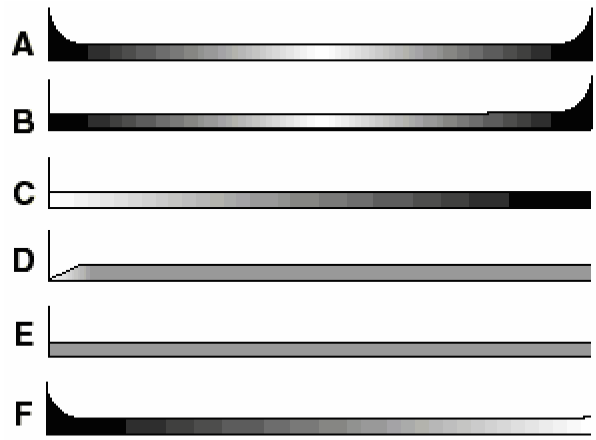


Figure 2-11: Six Patterns of Failure (Mourbrey, 2001)

Pattern A is the well-known bathtub curve. It begins with a high incidence of failure (known as infant mortality) followed by a constant or gradually increasing conditional probability of failure, then by a wear-out zone.

Pattern B shows constant or slowly increasing conditional probability of failure, ending in a wear-out zone (the same as Figure 2-11).

Pattern C shows slowly increasing conditional probability of failure, but there is no identifiable wear-out age.

Pattern D shows low conditional probability of failure when the item is new or just out of the shop, then a rapid increase to a constant level, while pattern E shows a constant conditional probability of failure at all ages (random failure).

Pattern F starts with high infant mortality, which drops eventually to a constant or very slowly increasing conditional probability of failure.

Studies done on civil aircraft showed that 4% of the items conformed to pattern A, 2% to B, 5% to C, 7% to D, 14% to E and no fewer than 68% to pattern F. (The number of times these patterns occur in aircraft is not necessarily the same as in industry. But there is no doubt that as assets become more complex, we see more and more of patterns E and F.)

These findings contradict the belief that there is always a connection between reliability and operating age. This belief led to the idea that the more often an item is overhauled, the less likely it is to fail. Nowadays, this is seldom true. Unless there is a dominant age-related failure mode, age limits do little or nothing to improve the reliability of complex items. In fact scheduled overhauls can actually increase overall failure rates by introducing infant mortality into otherwise stable systems.

An awareness of these facts has led some organizations to abandon the idea of proactive maintenance altogether. In fact, this can be the right thing to do for failures with minor consequences. But when the failure consequences are significant, something must be done to prevent or predict the failures, or at least to reduce the consequences. This brings us back to the question of proactive tasks. As mentioned earlier, RCM divides proactive tasks into three categories, as follows:

a) scheduled restoration tasks

b) scheduled discard tasks

c) scheduled on-condition tasks.

2.7 TPM Quality System: The Defect Free Process: Zero QC Method

Quality is becoming a business strategy leading to success, growth, and enhanced competitive position. Organizations with successful quality improvement programs can enjoy significant competitive advantages. With increasing automation and mechanization, production processes are shifting from workers to machines. Consequently, the role of equipment maintenance in controlling quantity, quality and costs is more evident and important than ever. To succeed in this new environment, equipment must be maintained in ideal operating conditions and must run effectively. The link between quality improvement and productivity is well established. Quality improvement means elimination of waste such as scrap and rework, which increases productivity and often leads to cost reductions (Ben-Daya et al., 1995). Under the total quality management (TQM) philosophy, quality can no longer be inspected into the product. Final control inspection is being moved to the process level through adequate process control techniques. Consequently defects and variations are eliminated at their source. In particular machine performance problems are identified early on. Equipment effectiveness is no longer restricted to availability, but involves other factors, such as quality and efficiency as well. In the past, final inspection was the principal check for quality. If it is not only effort to prevent defect from being passed on, however, problems arise. In recent years, it has become necessary to conduct inspections at each operation. Furthermore, to achieve zero defects, quality must be built into the entire process (Seiji, 1996). Basic concepts for a zero QC system (Andrew , 1990) is built on the 4 ideas 1) use source inspection, 2) always use 100 percent inspection rather than sampling inspection, 3) minimize the time it takes to carry out corrective action when abnormalities appear, and human workers are not infallible, Poka-Yoke is solution and device tom fulfill control functions. Perfect quality cannot be guaranteed unless the sources and causes of quality defect are eliminated in advance. To achieve this find those equipment parts that effect quality, label them “quality components” The foundation of this achievement are 5S activity and Autonomous inspection of quality component or Quality Maintenance Before tackling quality maintenance clarify its relationship with the seven other main TPM activities, including the early management of new products and equipment (see Figure 2-12)

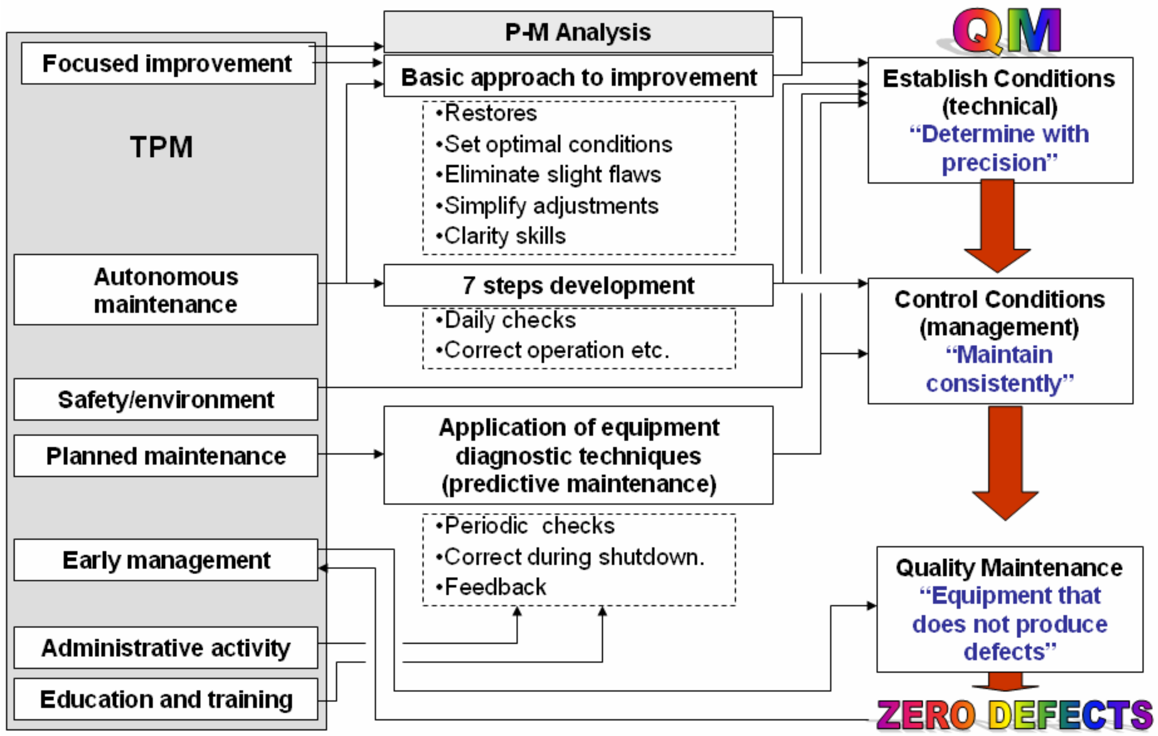


Figure 2-12: Relation of TPM Pillars Create Quality Maintenance (Tokutaro, 1994)

In process industries, product is produced by a combination of equipment units. Each unit consists of modules, which in turn are made up of components. Units, modules, and components govern different types of quality. It is essential to clarity the relationship among them. Table 2-11 in following is Quality Maintenance Step-By-Step Implementation.

Table 2-11: Step-By-Step Implementation Quality Maintenance

Quality Maintenance Step 1: Prepare a QA (Quality Assurance) Matrix	
Preparing a QA (quality assurance) matrix involved the following four sub-steps:	
1.1	Investigate the types of defect occurring in each process.
1.2	Classify the product's quality characteristics precisely and identify the all defect modes related each characteristic.
1.3	Rank the defect modes according to their seriousness and indicate which ones have caused problems in the past as frequent or occasional.

Table 2-11: Step-By-Step Implementation Quality Maintenance (cont.)

Quality Maintenance Step 1: Prepare a QA (Quality Assurance) Matrix	
1.4	Divide the process into the smallest possible units (subprocesses) and indicate the relationships between these and the defect modes
Quality Maintenance Step 2: Analyze Production-Input Conditions	
After preparing the QA matrix, analyze the production-input (4M) conditions	
2.1	Identify all the conditions for equipment, materials, people, and methods.
2.2	Determine whether standards for these quality conditions exist and whether people follow them, investigation revealed that standards were unclear, and that each operator ran the process differently.
Quality Maintenance Step 3: Prepare a Problem Chart	
Prepare problem chart by the following activities.	
3.1	Listing any irregularity uncovered in the process by problem type. Note how it is investigated and the results and use this information as a basis for proposing countermeasures.
3.2	Also consider any sub-processes which the production-input conditions analysis revealed not properly standardized.
3.3	Investigate the problems noted and propose countermeasures. As far as possible, express the results quantitatively.
Quality Maintenance Step 4: Evaluate Seriousness – Perform FMEA	
Examine the problems on the problem chart and rank them in terms of their effects on the defect modes. Then, prioritize the problems by scoring their frequency of occurrence, effect, and difficulty of detection. Determine the assessment criteria in advance. Multiply the scores for each problem together and use the results to prioritize the improvement effort.	
Quality Maintenance Step 5: Use P-M Analysis to Devise Improvement Measures	
For more challenging problems, use P-M analysis to clarify the observed phenomena and develop improvement proposals.	

Table 2-11: Step-By-Step Implementation Quality Maintenance (cont.)

Quality Maintenance Step 5: Use P-M Analysis to Devise Improvement Measures	
5.1	Begin by stratifying phenomena in terms of their type and mode of occurrence. Analyze them physically
5.2	Be sure to uncover and consider all the necessary conditions in producing a given problem. If improvement teams overlook vital conditions at this step
5.3	List all the condition that tend to produce the phenomenon
Quality Maintenance Step 6: Assess Impact of Proposed Countermeasures FMEA(2)	
Use FMEA again to assess the effects of implementing the improvement proposals based on the P-M analysis and other investigation results	
Quality Maintenance Step 7: Implement Improvements	
Second FMEA on the improvement proposals based on the P-M analysis and investigation results showed that the best plan of improvement.	
7.1	The new seal is self-flushing, so there is no need to supply during the operation.
7.2	The seal is not affected by water use in other processes.
7.3	Operators need to check water pressure only at startup and shutdown.
7.4	No foreign matter is produced.
7.5	The seal does not leak, so the surroundings stay clean.
Quality Maintenance Step 8: Review Production-Input Conditions	
Review and update the Production-Input Conditions Analysis to determine whether the production-input conditions are appropriate and correct, whether any deficiencies remain in the standards, and whether conditions are being satisfied. In this case, solving the easy problems identified on the Problem Chart and implementing the equipment improvements indicated, satisfied all the production-input conditions.	
Quality Maintenance step 9 : Consolidate and Confirm Checkpoints	
Use result of step 8 to consolidate and establish checkpoints for production-input conditions. Draw up a quality check matrix, standardize quality, and checking procedures, and ensure that standards can be followed about difficulty.	

Table 2-11: Step-By-Step Implementation Quality Maintenance (cont.)

Quality Maintenance step 10 : Prepare a Quality Component Table
To establish visual control and ensure that checks are carried out, quantify destitute characteristics using the quality check matrix, developed in Step 9 and prepare a quality component table to set practical standards

2.8 Set up Time Reduction

Setup operations have traditionally demanded a great deal of time (Shigeo, 1983), and manufacturing companies have long suffered the extreme inefficiency this causes. Setup time reduction solution was found to this problem. In traditional setup operations, internal and external setup are confused; what could be done externally is done as internal setup, and machine therefore remain idle for external periods.

2.8.1 Basic Elements of a Set-Up

A set-up can be defined as the elapsed time between the last product A leaving the machine and the first good product B coming out (Dirk et al., 2000) The 'quality' of a set-up is determined by three key elements ,technical aspects of equipment and tools, the organization of the work ('who does what when') and the method used ('how'). All three key elements have to be optimized. The final necessary condition for having a 'good quality' set-up is the motivation of the people performing the set-up. They are usually production operators or sometimes machine setters from the technical/maintenance department. This motivation is also determined by appropriate training. Even with a perfectly designed machine, made to enable fast set-ups, and the most efficient method and organization of work, described in a set-up instruction, there will be no good set-up if the people who have to perform the work do not see the importance of a short set-up or are not motivated or trained for obtaining short set-up times

The need to reduce changeover times, or set-up reduction (SUR), was first realized by Shingo'. This arose from Toyota's development of their Just-In-Time based production system. Shingo's contribution was the development of SMED

(Single Minute Exchange of Dies), which gained improvements mainly by adopting improved working methods, become increasingly focused on market and customer responsiveness. The problem has been to achieve this while at the same time reducing stocks throughout the whole process of manufacture. This has led, particularly in the automotive industry, to the adoption of a series of techniques that are collectively termed lean manufacture.

2.8.2 Set-Up Reduction Approaches

Basically, all the approaches are derived from the ‘single minute exchange of die’ method (SMED), originally developed by the Japanese Industrial Engineer Shigeo Shingo for reducing the time to exchange dies Setup or changeover itself does not add value to product; it must be viewed as waste. Since waste is something we must always strive to eliminate, we must find the ways to minimize changeover. According to the SMED method all activities related to a set-up can be divided into two categories 1) Internal or on-line activities which are performed while the machine is down and thus the production process is stopped, and 2) External or off-line activities which take place while the machine is running. These can be performed either before or after the actual downtime of the machine.

2.8.3 The Set-Up Reduction Process and Zero Changeover Step

Set-up reduction to reduce waste time during changeover the equipment to switch production process may be separated into 3 rough step as shown in Table 2-12.

Changeover cannot be eliminated completely. Zero changeover (Kenichi et al., 1994) is one kind of setup reduction approach towards to zero setup waste that the setup task can be completed within 3 minutes. The steps for achieving zero changeover without incurring substantial costs include 1) Gain a practical grasp of changeover loss time 2) A declaration of support from top management and formation of the changeover improvement team 3) Open changeover demonstrations and observation, video recording, and analysis of factory operations, 4) Applying analysis results to three types of waste , setup waste, replacement waste and adjustment waste, 5) Goal-based thinking to remove waste, 6) Red-tag strategy (creating wide-participation improvement plan, 7) Implementing improvements and 8) Evaluating results and horizontal deployment.

2.8.4 Technical Design Guidelines and Categorization of Techniques

In general, set-up reduction is considered a problem for production people. The basic philosophy for the designer should be that set-up must be as easy as possible to minimize mistakes and to make sure that no special technical skills are needed to do the set-up. The two most important technical issues that need to be considered for short set-ups deal with exchanging parts of a machine (how many parts, how is it done) and the setting/re-adjusting of parameters. These are related to steps 2 and 3 of the SMED methods Author had added some rule in former design rules by previous initiator.

Table 2-12: Set-Up Reduction Step

No	Activity
Step No.1	Separating on-line and off-line activities: In this step, all set-up activities are reviewed and one simple question is asked: ‘‘Does the machine have to be stopped for this activity, yes or no? If the answer is ‘no’, then this activity is moved off-line.
Step No.2	Transferring on-line activities to off-line: This can be done by technical modifications, e.g., instead of exchanging 10 small parts on-line, a sub-assembly containing these parts is exchanged, and the preparation and after care (the actual removing and attaching of the 10 parts on the sub-assembly) is done off-line.
Step No.3	Minimizing or streamlining on-line and off-line activities: Can the on-line and off-line activities be done in a different/smarter way, which takes less time? In this step, all the adjusting and readjusting issues are considered.

Table 2-13: General Design Rules for Less Set Up Time Equipment

Design rules	Techniques
Rule 1:Less weight	• Use lighter materials • Use less material • Reduce number of mechanisms • Eliminate the need to remove non changeover parts • Eliminate the need to remove complete assemblies • Remove complete assemblies/modules that can be prepared off-line instead of removing and mounting several smaller parts on-line • Eliminate pipe connections or use quick release couplings • Reduce the number of hand/power tools required • Reduce the total number of components in a tool • Simplify control procedures such as timing diagrams • Use short power drive connections • Use Poka Yoke systems (mistake-proof systems) • If a part that needs to be exchanged has only 2 sizes, put one fixed on the machine
Rule 2: Standardization	• Use the same size shut heights for presses • Use the same size securing bolts • Use the same type of electrical motors • Design universal machine parts that do not need to be exchanged
Rule 3: Securing	• Use the minimum number of fasteners consistent with strength • Eliminate manually operated clamps • Use manual clamps as a cheap and fast alternative for bolts and screws • Use ¼ turn devices • Use quick fixtures • Use hydraulic, pneumatic or electromagnetic fixtures

Table 2-13: General Design Rules for Less Set Up Time Equipment (cont.)

Design rules	Techniques
Rule 5: Location and adjustment	• Provide intelligent adjustment and monitoring • Eliminate the use of spacers and shims • Provide dead stop positioning • Provide positioning using centering pins holes • Use discrete positioning of parts in stead of continuous • Settings 'right from the first time'. 1) Identify all parameters that influence the process 2) Determine the correct setting values for all parameters, per type of product – these values need to be written in the set-up instruction. 3) Install means to effectively set these values • Enable off-line checking of products by improving the quality of setting activities • Provide measuring devices, preferably using digital displays Use stepping motors for accurate setting that influence the process 2) Determine the correct setting values for all parameters, per type of product – these values need to be written in the set-up instruction. 3) Install means to effectively set these values • Enable off-line checking of products by improving the quality of setting activities • Provide measuring devices, preferably using digital displays • Use stepping motors for accurate setting
Rule 4: Handling-movements	• Eliminate the need for or ensure easy cleaning/purging • Eliminate the need to handle hot items • Eliminate the need to handle awkward items • Provide power aids • Provide remote actuation • Ensure easy delivery of tools etc. to the machine

Table 2-13: General Design Rules for Less Set Up Time Equipment (cont.)

Design rules	Techniques
	• Provide good access • Appropriate placement of buttons and control panels to avoid additional/unnecessary movements
Rule 5: Off-line activities	• Enable off-line mounting/removing of aids, supports and fixtures • Enable off-line loading of numerical control data for PLC, CNC (before set-up)
Rule 6: Decouple	• Machine lines. Decouple the drive of every station to enable set-up activities on a single station while the last/first products run through the other workstations
Rule 7: Method and organization	• Separate on-line and off-line set-up activities. • Optimize the order in which the activities are performed to minimize movements and walking distance • Divide the work on the different stations between the operators so that the machine on which the most activities need to be performed is not waiting • Balance the workload between the available operators and make separate instruction sheets per person • Use the Kipling questions on every activity of the set-up for critical review (What, where, when, who, how, why) • Provide set-up sets with all necessary tools and parts, determine the exact location where the tools and parts have to be placed before the actual set-up starts • Provide set-up instruction guides

2.8.5 Categorization of Techniques

The wealth of information on set-up reduction has been categorized to enable it to be more readily usable by engineers and practitioners who are engaged in increasing the speed of changeovers (Gest et al., 1995). Twelve primary categories have been developed, supported by a number of classifications which are not detailed in this paper. The 12 general categories are listed below, and described in detail in the following sections:

Table 2-14: Categorization of Techniques for Less Set Up Time

Category	Techniques
Category 1: Elimination	Elimination of set-ups these are excess 1) capacity and 2) automation. • Excess tooling or machine capacity is used to eliminate the need for set-ups by using duplicate machines or tooling which can be simply substituted for the old product set or alternatively, to allow machines to be pre-set before the run producing the old product is halted. • Automation, tool turrets and carousels are extensively utilized on lathes and machining centers, and allow tool changes to be simply and quickly effected without intervention by operators to the production process.
Category 2: Motion systems	The gathering and delivery of tools and equipment required for a changeover have a significant effect on the overall changeover time. During a changeover moving tools to and from the machine and looking for equipment required for the change-over for easier moving the heavy tools and equipments.
Category 3: Move internal to external	Perhaps the easiest way to achieve a significant reduction in a processes set-up time is to move certain aspects of the set-up to the external stage. These will pre-set a group of tooling for a particular run. A subset of pre-setting is the rectification of any tool faults prior to changeover. Using last lift inspection, where the tooling and its performance are examined at the end of each run, the operators can ascertain what problems, if any,

Table 2-14: Categorization of Techniques for Less Set Up Time (cont.)

Category	Techniques
	have occurred with the tooling. Rectification can then be undertaken whilst the machine is still set-up and running, hence avoiding the situation where a tool is brought to the machine for a changeover and is then found to be faulty. In addition, the settings, etc. for a good part produced at the end of a run can be recorded and used so that the system can be quickly adjusted for the next run.
Category 4: Securing	This case clamping operations are a significant aspect of changeover time. This has two causes, 1) use too high a safety factor in the design of the clamping, and 2) use of screw thread devices for clamping purposes. • Using power tools to speed the removal of bolts or the bolts. • Simplification cramp removal method such as toggle clamps, hydraulic clamping, vacuum clamping, . magnetic chucks, 'T'-slots, 'Slam tools' and so on.
Category 5: Adjustment	The primary reason for this is that most machines are designed to be infinitely adjustable. • In general, this adjustment is not needed and could be easily replaced by dead stops, numbered positions, etc. • Adjustments are made by simply entering the required value into the controller. • Tools are pre-set off line to determine the offsets required. Some adaptive control aspects have been implemented, primarily in the area of tool breakage and tool wear monitoring. The automation of adjustments has been observed in a number of instances for presswork processes. • The lack of clear instructions and specifications is one

Table 2-14: Categorization of Techniques for Less Set Up Time (cont.)

Category	Techniques
	cause of time consume. As an aid to their tool master system, utilize digital read-outs, pre-recorded settings and air wrenches to speed up the adjustment process.
Category 6: Clean-out/purging	• Automatic changeover and purging may be suit utilizes two hoppers mounted on an automatic shuttle system. • Using this device to simultaneously unload the old and load the new tools changeover occurs almost instantaneously. • In the printing industry, duplicate drums are utilized to effect quick changeover by removing clean-out to the external arena.
Category 7: Access	Access is a very significant problem encountered within all types of industry. Examples have been observed where guarding was welded into place because it once rattled and fell off; the solution worked but then gave problems at every set-up which significantly increased the time required
Category 8: Machine design	Effective machine design is essential if zero set-up time is the ultimate aim. Most of the aspects detailed in the previous sections have been 'fixes' to account for the inappropriate design of current machines (access, location, adjustment, etc.) The design of the machine, its interaction with tooling and associated systems and the amount by which ergonomics are taken into account are critical aspects of the set-up problem. A primary area for the reduction of tool loading time is the way in which the tool presented to the machine. Standardization of clamping and location can greatly reduce many of the problems highlighted in the securing section.

Table 2-14: Categorization of Techniques for Less Set Up Time (cont.)

Category	Techniques
Category 9: Product design	Product parts are designed using as many common features as possible, then the set-up between runs can be significantly reduced and many of the problems experienced can be countered at the design stage.
Category 10: Tooling design	The weight of tooling has a great effect on the methods used to deliver it. This can sometimes be a problem if the transportation equipment used for this process is being utilized elsewhere. A welding jig of heavy work-piece required a hoist to be loaded into the welding machine. Delays in the delivery of the hoist then resulted in excessively long set-ups. By sectioning the jig so that only the required parts had to be changed, the load was reduced and the set-up time can be reduced.
Category 11: Housekeeping aspects and methodology	Housekeeping is essentially the organization of the workplace and changeover personnel so that tools can be quickly and easily located and efficiently changed over.
Category 12: Preparatory work for SUR	This approach begins with a basic definition of what set-up time comprises, and bases the program around the reduction of each of these elements. This process, which is implemented in a top-down manner, can be briefly outlined as: • Concentrate on one line, typically the bottleneck; Develop and implement a training program for shopfloor and support staff; Standardize set-up method once improved.

2.9 P-M Analysis

In implementing TPM P-M Analysis. (A methodology that makes zero losses a reality in your TPM program.) P-M Analysis is designed to help TPM teams analyze and eliminate chronic problems that have been neglected or unresolved in the past (Kunio et al., 1995). Chronic quality defects and other chronic losses are hard to eradicate, because they typically have multiple, interrelated causes that vary with every occurrence. Common improvement strategies, like cause-and-effect analysis, are usually ineffective in dealing with such complex problems. P-M Analysis was specially developed to overcome the weaknesses of traditional methods. It offers a rigorous 8-step method for ensuring that all possible factors are identified and investigated. Through P-M Analysis, teams really get in touch with their equipment. Its unique skill-building process improves technological know-how while delivering solutions to persistent problems. The first four steps of this rigorous 8-step program help teams isolate and understand the root causes of defects and failures within main equipment mechanisms and peripheral systems. The final four steps provide a systematic approach for effectively controlling those causes. A critical concept in P-M Analysis is physical analysis -a way of thinking about how defects and failures are generated that forces us to look at the physical principles involved and to quantify the changes in the relationship between the equipment mechanisms and product parts involved. When a proper physical analysis is carried out, teams are far less likely to overlook important factors or to waste time pursuing unrelated ones. Although not a cure-all, P-M Analysis has reduced chronic losses to zero and raised technological expertise in many manufacturing environments. P-M Analysis is examined as an approach to eliminating chronic losses. The actual steps are as follows.

a) Step 1: Clarify the Phenomenon
b) Step 2: Conduct a Physical Analysis
c) Step 3: Identify Constituent Conditions
d) Step 4: Study 4Ms for Causal Factors
e) Step 5: Plan and Conduct a Survey of Factors
f) Step 6: Identify Abnormalities to be Addressed
g) Step 7: Propose and Make Improvements

2.10 Reliability

Definition of reliability of item "The reliability of an item is the probability that it will adequately perform its specified purpose for a specified period of time under specified environmental conditions" (Lawrence, 1995, Paul, 1998)

A system is a collection of components, subsystems and/or assemblies arranged to a specific design in order to achieve desired functions with acceptable performance and reliability. The types of components, their quantities, their qualities and the manner in which they are arranged within the system have a direct effect on the system's reliability.

The definition of reliability allows for the specification of demand time to be either an instant in time or time interval. If the demand time of an item's performance is time interval or is continuous . We describe the performance as time dependent. A time dependent performance may be for specified mission or may be continuously operating. Time dependent items are expected to operate throughout their demand intervals without interruption or. In the case of continuously operating items, all the time.

2.10.1 Time-Dependent System Reliability

In the previous chapter of this on-line reference different system configuration types were examined, as well as different methods for obtaining the system's reliability function analytically. Because the reliabilities in the problems presented were treated as probabilities (*e.g.* $P(A)$, R_i), the reliability values and equations presented were referred to as static (not time-dependent). Thus, in the prior chapter, the life distributions of the components were not incorporated in the process of calculating the system reliability. In this chapter, time-dependency in the reliability function will be introduced. The researcher will develop the models necessary to observe the reliability over the life of the system, instead of at just one point in time. In addition, performance measures, such as failure rate, MTTF and warranty time, will be estimated for the entire system. When deal with $R_i(t)$ which defined as a function of time t or the reliability for the specified duration t. All examples in this chapter assume that no repairs are performed on the components.

More useful reliability parameter for continuously operating items are the mean time between failure (MTBF) and the availability, The MTBF tells us how frequently. On the average, we can expect our item to experience an outage. The availability tells us the proportion of the time that we can expect our item to be operating. Associated with these characteristics are the mean down time (MDT), the average time that it takes to return to an operating state after an outage has occurred, and the outage rate, the complement of availability, or the portion of the time that we can expect our item to be down.

Availability and outage rate are related as follows.

Availability = 1-outage rate (2.1)

A = (MTBF)/(MTBF+MDT) (2.2)

Item's outage rate (OR) = (MDT)/(MTBF+MDT) (2.3)

2.10.2 Component Configurations – Series and Parallel System

In order to construct a reliability block diagram, the reliability-wise configuration of the components must be determined. Consequently, the analysis method used for computing the reliability of a system will also depend on the reliability-wise configuration of the components/subsystems. That configuration can be as simple as units arranged in a pure series or parallel configuration. There can also be systems of combined series/parallel configurations or complex systems that cannot be decomposed into groups of series and parallel configurations. The configuration types considered in this reference includes series systems and simple parallel system.

2.10.3 Series Systems

In a series configuration, a failure of any component results in failure for the entire system. In most cases when considering complete systems at their basic subsystem level, it is found that these are arranged reliability-wise in a series configuration. These are reliability-wise in series and a failure of any of these subsystems will cause a system failure. In other words, all of the units in a series system must succeed for the system to succeed.

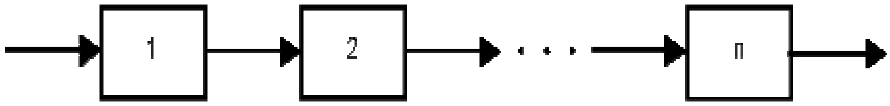


Figure 2-13: Reliability Block Diagram of Series Configuration System

The reliability of the system is the probability that unit 1 succeeds and unit 2 succeeds *and* all of the other units in the system succeed. So, all *n* units must succeed for the system to succeed. The reliability of the system is then given by:

$$\begin{aligned} R_S &= P(X_1 \cap X_2 \cap \ldots \cap X_n) \\ &= P(X_1)P(X_2 \mid X_1)P(X_3 \mid X_1X_2)\ldots P(X_n \mid X_1X_2\ldots X_{n-1}) \end{aligned} \quad (2.4)$$

where :

- R_S = reliability of the system.
- X_i = event of unit i being operational.
- $P(X_i)$ = probability that unit i is operational.

In the case where the failure of a component affects the failure rates of other components (*i.e.* the life distribution characteristics of the other components change when one fails), then the conditional probabilities in equation (2.4) must be considered.

However, in the case of independent components, equation (2.4) becomes:

$$R_s = P(X_1)P(X_2)...P(X_n)$$

or

$$R_s = \prod_{i=1}^{n} P(X_i)$$

or, in terms of individual component reliability :

$$R_s = \prod_{i=1}^{n} R_i \quad (2.5)$$

2.10.4 Simple Parallel Systems

In a simple parallel system, as shown in Figure 2-14, at least one of the units must succeed for the system to succeed. Units in parallel are also referred to as redundant units. Redundancy is a very important aspect of system design and reliability in that adding redundancy is one of several methods of improving system reliability. It is widely used in the aerospace industry and generally used in mission critical systems.

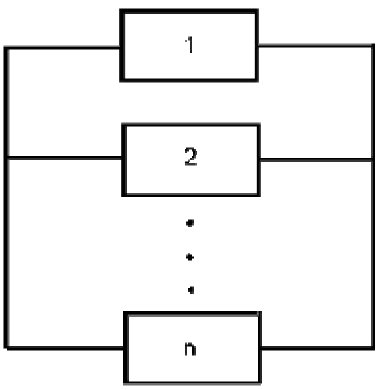


Figure 2-14: Reliability Block Diagram of Simple Parallel System

The probability of failure, or unreliability, for a system with *n* statistically independent parallel components is the probability that unit 1 fails *and* unit 2 fails *and* all of the other units in the system fail. So in a parallel system, all *n* units must fail for the system to fail. Put another way, if unit 1 succeeds or unit 2 succeeds or any of the *n* units succeeds, then the system succeeds. The unreliability of the system is then given by:

$$\begin{aligned} Q_s &= P(X_1 \cap X_2 \cap \ldots \cap X_n) \\ &= P(X_1)P(X_2 \mid X_1)P(X_3 \mid X_1X_2)\ldots P(X_n \mid X_1X_2\ldots X_{n-1}) \end{aligned} \quad (2.6)$$

Where Q_s is unreliability of the system, X_i is event of failure of unit *I* and $P(X_i)$ is probability of failure of unit *i*.

In the case where the failure of a component affects the failure rates of other components, then the conditional probabilities in equation (2.6) must be considered.

However, in the case of independent components, equation (2.6) becomes:

$$Q_s = \prod_{i=1}^{n} P(X_i)$$

or, in terms of component unreliability:

$$Q_s = \prod_{i=1}^{n} Q_i \quad (2.7)$$

Observe the contrast with the series system, in which the system reliability was the product of the component reliabilities; whereas the parallel system has the overall system unreliability as the product of the component unreliabilities. The reliability of the parallel system is then given by:

$$R_S = 1 - Q_S = 1 - (Q_1 \cdot Q_2 \cdot \ldots \cdot Q_n)$$
$$= 1 - [(1 - R_1) \cdot (1 - R_2) \cdot \ldots \cdot (1 - R_n)]$$
$$= 1 - \prod_{i=1}^{n} (1 - R_i) \qquad (2.8)$$

2.11 The Weibull Distribution

The Weibull distribution is one of the most widely used lifetime distributions in reliability engineering (Robert B.A.,2002). It is a versatile distribution that can take on the characteristics of other types of distributions, based on the value of the shape parameter, β. Dealing with Weibull distribution, there are 3 Weibull parameters as η scale parameter, β , shape parameter (or slope), and γ called location parameter. Table 2-15 shows 3 types of Weibull pdf. distribution bases on concerned parameters.

Table 2-15: Weibull pdf.

The Three-Parameter The Weibull Distribution	
$f(T) = \frac{\beta}{\eta}\left(\frac{T-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{T-\gamma}{\eta}\right)^{\beta}}$	$f(T) \geq 0, T \geq 0$ or $\gamma, \beta > 0, \eta > 0, -\infty < \gamma < \infty$
The Two-Parameter Weibull Distribution	
$f(T) = \frac{\beta}{\eta}\left(\frac{T}{\eta}\right)^{\beta-1} e^{-\left(\frac{T}{\eta}\right)^{\beta}}$	When γ= 0
The One-Parameter Weibull Distribution	
$f(T) = \frac{C}{\eta}\left(\frac{T}{\eta}\right)^{C-1} e^{-\left(\frac{T}{\eta}\right)^{C}}$	When γ= 0, and assuming β= *C* = constant

2.11.1 The Mean or MTTF

The mean, $\overline{T}$ (also called MTTF or MTBF by some authors) of the Weibull *pdf* is given by:

$$\overline{T} = \gamma + \eta \cdot \Gamma\left(\frac{1}{\beta} + 1\right) \tag{2.9}$$

where $\Gamma(\frac{1}{\beta}+1)$ is the gamma function evaluated at the value of $(\frac{1}{\beta}+1)$.

The gamma function is defined as,

$$\Gamma(n) = \int_0^{\infty} e^{-x} x^{n-1} dx \tag{2.10}$$

2.11.2 The Weibull Reliability Function

The equation for the three-parameter Weibull cumulative density function, *cdf*, is given by:

$$F(T) = 1 - e^{-\left(\frac{T-\gamma}{\eta}\right)^{\beta}} \tag{2.11}$$

Recalling that the reliability function of a distribution is simply one minus the *cdf*, the reliability function for the three-parameter Weibull distribution is given by:

$$R(T) = e^{-\left(\frac{T-\gamma}{\eta}\right)^{\beta}} \tag{2.12}$$

The Weibull failure rate function, $\lambda(T)$, is given by:

$$\lambda(T) = \frac{f(T)}{R(T)} = \frac{\beta}{\eta}\left(\frac{T-\gamma}{\eta}\right)^{\beta-1} \tag{2.13}$$

2.12 Structural Equation Modeling (SEM)

The statistical technique, Path Analysis, is employed to investigate to causal relationships between two or more variables. Based on linear equation system, it was first developed by Sewall Wright in the 1930s to be used in phylogenetic studies. Adopted by the social sciences in the 1960s, path analysis has been used with increasing frequency in the ecological literature since the 1970s. In this field, it is used primarily to gain understanding the comparative strengths of direct and indirect relationships among a set of variables. In this regard, path analysis is exclusive from other linear equation models: Mediated pathways can be examined path analysis. Hypothesis of researches can be represented by pathway in path models. It can not be tested statistically for directionality.

In terms of the parameters of a structural equation modeling (SEM), they are the variances, regression coefficients and covariances among variables. A variance is unable to be identified by a two-headed arrow, both ends of which point at the same variable, or, more simply by a number within the variable's drawn box or circle. What represented along single headed arrow are regression coefficients that show a hypothesized pathway between two variables meaning that the weights which were applied to variables in linear regression equations. With double-headed, curved arrows between two variables or error terms, covariances are associated without definite direction. The sample variances and covariances which were taken out from a population (held in **S**, the observed sample, variance and covariance matrix) are the data for SEM.

2.12.1 Structural Equation Model Construction:

To search for a model fitting the data (**S**) sufficiently enough to serve as a useful representation of real value and a parsimonious explanation of the sample data is considered to be the main objective for creating a path diagram or other structural equation model. Involved in SEM construction, there are five steps as follows:

1) Model Specification

2) Model Identification (This step under specification or estimation are sometimes included by some authors)

3) Model Estimation

4) Testing Model Fit

5) Model Manipulation

2.12.1.1 Model Specification is the exercise for stating a model officially. It is the step in which parameters are d identified to be fixed or free. *Fixed parameters* are not estimated from the data and are typically fixed at zero (showing no relationship between variables). The fixed parameters path are quantified (there are not zero path drawn in the model) in a SEM diagram. From the observed data, *Free parameters* are estimated and are believed by the investigator to be non-zero. In the SEM diagram, asterisks label the paths of free parameters. It is significant that determining which parameters are fixed and which are free in a SEM owing to the fact that it specifies which parameters will be employed in comparing the hypothesized diagram with the sample population variance and covariance matrix so as to test the fit of the model (Step 4). The researcher determines the choice whether parameters are free or fixed in a model. This choice reveals the researcher's *a priori* hypothesis about which pathways in a system are of significance in the generation of the relational structure belonging to the observed systems

2.12.1.2 Model Identification involves with the possibility for exclusive value of each and every free parameter the observed data can give. It is based on the model option and the fixed, confided and free parameters specification. When a parameter is set equal to another one, it is constrained. It is necessary for models to be overidentified so as to be estimated (Step 3 in SEM construction) and with apurpose to test hypotheses about relationships among variables (See Ullman 1996 for a more detailed explanation of the levels of model identification). A key condition for overidentification is that the data points numbers (number of variances and covariances) are fewer than that of observed variables in the model.

2.12.1.3 Estimation: During this step, there is a selection for start values of the free parameters in order to create an estimated population covariance matrix, $\Sigma(\theta)$, from the model. The researcher can select the start value from initial information with use of computer programs used building SEMs, or from multiple regression analysis (Ullman 1996 and Hoyle 1995). The purpose of estimation is to generate a $\Sigma(\theta)$ that converges upon the observed population covariance matrix, to minimize the residual matrix value (the difference between $\Sigma(\theta)$ and S. There are various methods that can be adopted to generate $\Sigma(\theta)$. Characteristics of the data which include sample size and distribution can be used to guide choice of method. Iterative are the most used processes. The general form of the minimization function is as follows:

$$Q = (s - \sigma(\theta))'W(s - \sigma(\theta))$$

where,

s = vector with the variances and covariances of the observed variables

$\sigma(\theta)$ = vector having corresponding variances and covariances as predicted by the model

W = weight matrix.

In a function above, the weight matrix, W, comply to the selected method chosen. W is selected to minimize Q, and Q(N-1) yields the fitting function, in most cases a chi-sqiare χ^2-distibuted statistic. Sample size, error distribution, factor distribution, and the assumption that factors and errors are independent impact the χ^2 performance. (Ullman 1996). Some of the estimation methods which are the most commonly used are as follows:

1) Generalized Least Squares (GLS)

$$F_{GLS} = ½ \, tr[([S - \Sigma(\theta)]W^{-1})^2]$$

where,

tr = trace operator, use the sum of elements on major matrix diagonal

W^{-1} = optimal weight matrix selected by researcher (most usual option is S^{-1})

2) Maximum Likelihood (ML)

$$F_{ML} = \log|\Sigma| - \log|S| + tr(S\Sigma^{-1}) - p$$

in this case, $W = \Sigma^{-1}$ and p = number of measured variables

3) Asymptotically Distribution Free (ADF) Estimator

$$F_{ADF} = [S - \sigma(\theta)]' W^{-1} [S - \sigma(\theta)]$$

W, there is elements including kurtosis in this function.

The advantages and constraints of the above estimators were discussed by Ullman (1996) and Hoyle (1995) and, for normally distributed data, ML and GLS are of great use when factors and errors are independent. For nonnormally distributed data, ADF is useful as well. However this is shown only to work well with sample sizes above 2,500. Ullman points out that the Scaled ML is the best estimator for nonnormally distributed data and/or dependence among factors and errors. Regardless of selected function, the satisfactory result of the estimation process is to acquire a fitting function close to 0. It is implied for a fitting function score of 0 that the estimated covariance matrix of the model and the original sample covariance matrix are equal.

2.12.1.4 Assessing Fit of the Model: As mentioned in the last section, what desired for good model fit is function value of close to 0. Nevertheless, generally speaking, the model is a good fit if the ratio between χ^2 and degrees of freedom is less than two, (Ullman 1996).

To retain confidence in the goodness of fit test, a size of the sample for 100 to 200 is recommended (Hoyle 1995). By and large, a model should have 10 to 20 times as many observations as variables (Mitchell 1993).

Ullman (1996) described a variety of non-χ^2-distributed fitting functions called "comparative fit indices." Hoyle (1995) uses the "adjunct fit indices." when referring to this. Primarily, these modes compare the fit of an independence model (a model which shows no relationships between variables) to the fit of the estimated model. The finding of this comparison appears to be a number between 0 and 1, with 0.90 or greater accepted as values that identify good fit. When setting model fitness, there is used multiple choices as suggested by Hoyle and Ullman. This research adopted the model assessment of fit by using fit indices based on the following criteria with the χ^2 value without significant at p> 0.05 as recommended by Vassilios P. A. and Prodromos D.C., (2009): χ^2/df < 3.0, GFI > 0.90 and RMR<0.05 including other fit indices such as AGFI>0.90, NFI>0.90, NNFI>0.90, CFI>0.90, RMSEA<0.06, and SRMR<0.05.

2.12.1.5 Model Modification: The hypotheses can be adjusted and the model should be retested if the covariance/variance matrix estimated by the model does not sufficiently reproduce the sample covariance/variance matrix. In order adjust a model, there should an addition of new pathways or removal original ones. In fact, there is a change of parameters from fixed to free or from free to fixed. Modeler should bear in mind that, to adjust a model after the start of the test, it can cause opportunity in making a Type I error as in other statistical procedures.

Used for the model modification, the Lagrange Multiplier Index (LM) and the Wald test are the common procedures used. The change in χ^2 value when there is an adjustment of pathways are reported in both of these test. The possibility of an increase of model fitness by addition of free parameters is commonly asked by the LM. There is used of the same logic as forward stepwise regression in this test. There is an enquiry for an increase of model fitness by the deletion of free parameters in the Wald test. In fact, the logic of backward stepwise regression is adopted in the Wald test.

Ullman (1996) suggests use of a low probability value (p<0.01) to modify for increase Type I error rates when adding or removing parameters. He also recommends cross-validation with other samples. Since the order in which parameters are freed can yield an impact on the choice of remaining parameters, there should be an application of LM before the Wald test (i.e., add all parameters before beginning to delete them) (MacCullum 1986, cited in Ullman 1996). Refer to Ullman (1996) and Hoyle (1995) for further description of these and other model modification techniques.

2.12.1.6 Final Presentation of Model: after an attainment of the model with an acceptable fit, there are assessment of individual estimates of free parameters. Using a z-distributed statistic, they are compared to a null value,. By dividing the parameter estimate by its standard error, the z statistic is obtained. They must be an excess of +/-1.96 in the ratio of this test for the relationship to be of significance. After an assessment for the individual relationships within the model, parameter estimates are then standardized for presentation of final model. When this is undergone, they can be interpreted with referring to other parameters in the model. Also, relative strength of pathways within the model can be compared.

CHAPTER III
RESEARCH METHODOLOGY

The aim of this research is to get the framework on how to apply effective Total Productive Maintenance (TPM) in order to start lean manufacturing transformation of a case study factory. The study proceeding was divided into many parts comprising 1) document research or literature review in order to investigate proper management technique guideline for improving the manufacturing process with details shown in chapter II which described TPM as basic tool in effective production management toward lean transformation manufacturing 2) Field base analysis 3) study on factors effecting TPM implementation as suggested in 1) with effectiveness. The research details were as follows:

3.1 Documentary Research

Chapter II showed four Lean bundles with TPM as one of its part. The related literatures suggested two important points which are a) the systematic determination of TPM implementation and b) important factors leading to a success in TPM implementation. The researcher applied these suggestions to this research with details as follows:

a) The research investigated four phases of TPM implementation process as follows: 1) Introduction-preparatory stage, 2) Start of introduction stage, 3) Introduction-execution stage, and 4) Establishment stage. This research included only three first phases with TPM major activities comprising focused improvement pillar, autonomous pillar, and planned maintenance pillar.

b) In TPM implementation, important factors leading a success in TPM implementation needed to realized. As a result the research was conducted to investigate characteristics of the small group members so as to achieve the machine improvement so that it would be in the expected level. These characteristics would be further discussed in the item 3.3.2.

3.2 Field Base Analysis

It was discovered that the whole production process could be divided into seven different main processes. The study on process value stream of each process was to view the chance in improving the effectiveness of the processes. This research was conducted to determine the current value stream and the overall plant effectiveness which was the whole picture of production process prior to the TPM implementation.

3.2.1 The Study on the Current VSM

All data for the current state map were collected for further analysis. It was collected whilst being at the site through conversing with the foreman and operators at each workstation. The processing and set-up times were all based on the available historical data. The following data was used to construct the process value stream mapping. The collection for the material flow started at the shipping department, and worked backward all the way to the upstream process in order to gathering snapshot data such as inventory levels before each process including the following data:

- Raw material level – the average number of the raw material held each day extracted from the daily report of raw material level stock.
- Semi-finished products or work-in-process (WIP) – the average number of the work-in-process each day extracted from the daily process report of work-in-process level at the end of date.
- Process cycle times (CTs) or one batch producing lead time (LT) (defined by the researcher) – the average amount of time in producing a mill roll of film on a monthly basis calculated from the set time monthly in order to produce it, then divided by the number mill rolls of film produced each month.
- machine up-time- the average total time the machine could produce each day
- available time –the set time for use of the machine each day

- Overall equipment effectiveness (OEE)

OEE = Availability (A) x Performance Efficiency (P) x Quality Rate (Q)

whereas; Availability (A) = (Loading Time – Down Time) / (Loading Time)

Performance efficiency (P) = (Theoretical Cycle Time)x(Amount Processed)/(Operating Time)

Quality rate (Q) = (Amount processed – Defective amount)/(Amount processed)

Overall equipment efficiency can be reduced to the following:

$$OEE = A \times P \times Q = \frac{\text{Theoretical cycle time} \times \text{Amount processed} \times \text{Quality rate}}{\text{Loading time}}$$

- The number of workers and operators - number of workers and operators who worked in each production process
- The process changeover (CO) times. – the average amount of time in setting up the machine of each production of mill roll of film on a monthly basis.

From the stream mapping diagram, the timeline at the bottom of the current state map has two components:

The first one is the production waiting time (in a unit of "day" or any), which is obtained by summing the lead-time numbers from each inventory triangle before each process. The time for one inventory triangle is calculated by dividing the inventory quantity into the desirable unit of time based on the quantity purchased by customers.

The second one of the timeline is the processing (or value-added) time. This time is calculated by adding the processing time for each process in the value stream.

3.2.2 The Study on Current Overall Plant Effectiveness

Describing overall plant effectiveness by firstly calculate eight major process losses of each equipment bases on desired production schedule at desired equipment condition and capability. Summation of this desired state is 100%

requirement. Normally the actual equipment effectiveness is not 100% so eight major process losses which are resulted from each equipment losses namely shutdown loss, Production adjustment loss, equipment failure loss, process failure losses, normal production loss, abnormal production losses, quality defect losses, and reprocessing losses Summation of each equipment results in overall eight major plant losses. Overall plant effectiveness is determined by value of 100% desired state minus overall eight major plant losses

3.3 The Research on Factors Affecting Lean TPM Implementation

Before starting Lean TPM, there must be a training on Lean TPM basic principle for all 138 employees in the Lean TPM implementation program. These people were used as population for this research. The research on acceptant behavior was divided into two parts: UTAUT and FFA with use of questionnaire as research tool. It was divided into two parts which are 1) The research on variables which had an impact on acceptance behavior according to UTAUT model and 2) the research on important characteristics of the small group activity for improving the OEE of the machines according to the following topics:

3.3.1 The Research on Variables Affecting Lean TPM Acceptance Behavior

Regarding this, the researcher set the proceeding method as follows:

3.3.1.1 The setting of population and samples: In regard to the population and samples used for the study on factors affecting acceptant behavior for TPM implementation participation of factory employees of factory in this case study, they were production line personnel Lean TPM implementation program. They were responsible for production process which used 18 major equipments. The 143 personnel were divided into 18 small groups for the improving of the machines called small group activity or SGA. A simplified formula to determine the sample size was adopted from that of Yamane (1967:886) with a 95% confidence level as assumed in following equation;

$$n = \frac{N}{1 + N(e)^2}$$

n is the sample size, whereas N is the population size, and e is the level of confidential. As a consequence, the sample size for this case must be at least 106 persons.

3.3.1.2 The development of research instrument: A questionnaire survey was specifically designed by using UTAUT module approach, as well as Likert's five rating scale questionnaire, of which the level arranging from 5 to 1 indicating the most agree, much agreeable, moderately agreeable, agreeable, less agreeable, and not agreeable.

This survey questionnaire comprises 11 parts: a series of 43 questions used to collect information on a particular component of UTAUT module that was made up of twelve structural traits as mentioned below and force field analysis in the last part of this questionnaire.

Part 1 Respondent personnel data with gender (1 item for GEN), age(1 item for AGE), education level(1 item for KN1), experience (1 item for EX1), and last two year performance appraisal level (2 items),.

Part 2 Performance expectancy comprising 6 items (PE1-PE6)

Part 3 Effort expectancy comprising 4 items (EE1-EE4)

Part 4 Social influence comprising 4 items (SI1-SI4)

Part 5 Voluntariness of use comprising 2 items (VO1-VO2)

Part 6 Behavioral intention comprising 2 items (BI1-BI2)

Part 7 Facilitating condition comprising 4 items (FC1-FC4)

Part 8 Experience including working life experience and Lean TPM experience comprising 5 items (EX1-EX5)

Part 9 Lean TPM knowledge and education level comprising 9 items (KN1-KN9)

Part 10 Trust and privacy comprising 2 items (TP1-TP2)

Part 11 Organizational culture comprising 5 items (CL1-CL5)

Part 12-1 Behavior to use comprising 1 items (BU1)

Part 12-2 Force field analysis

The validity and reliability analysis was conducted before using of the questionnaire to determine the construction validity, content validity, by the calculating the index of item-objective congruence of the questionnaire. The purpose of this test is to determine whether all important aspects of the construct are covered. Clear definitions of the construct and its components is of great use here. The test was reviewed by 3 Lean TPM experts before the modification as the actual test. Generally, each expert evaluates each question items by scoring "1", "0", and "-1" from more to less respectively in terms of its clarity and objective matching. Then IOC of each question items is calculated. A perfect rating by experts would be an average of 1.00 on the valid objective and average ratings of -1.00 on the invalid objectives. This combination would produce an index of item-objective congruence value of 1.00 for the valid objective. In case of having different experts' opinion, the accepted value of IOC much exceed 0.50.

For reliability test, Cronbach's Alpha was used as the reliability coefficient at 0.05 significant level with at least 0.70.

3.3.1.3 The Data Collection: After two trainings on Lean TPM implementation for all 143 employees in the implementation program, the researcher distributed the questionnaire which passed the reliability and validity test to the population in the research through the purposive sampling. Two weeks were allocated for responding the questionnaire without identifying the respondents' names in order to encourage the employees to answer the questionnaire. The responded questionnaires obtained were 138 copies equivalent to 96.50 %.

3.3.1.4 Data Analysis: Descriptive statistic mean and standard deviation (S) were initially used to analyze the obtained data so as to compare the factors affecting the Lean TPM implementation acceptance and participation behavior of the employees before and after the improvement of measures to promote the Lean TPM implementation.

Analysis of the acceptance and participation behavior of Lean TPM implementation with use of structural equation modeling (SEM) via confirmatory path analysis using LISREL 8.5 from the obtained data according to the UTAUT model mentioned in 3.3.1.2. In doing this, there was a validity analysis of the causal relationship model for the Lean TPM implementation acceptance and participation behavior of employees and the influence value between the variables within the model through the non-latent variable analysis for the whole picture of company in this case study. This research adopted the model assessment of fit by using fit indices according to the following criteria with the chi-square value without significant at p> 0.05 (Vassilios P. A. and Prodromos D.C.,2009): chi-square/df < 3.0, GFI > 0.90 and RMR<0.05 including other fit indices such as AGFI>0.90, NFI>0.90, NNFI>0.90, CFI>0.90, RMSEA<0.06, and SRMR<0.05. Generally, the key steps of structural equation modeling are as follows 1) Model specification, 2) Identification, 3) Estimation, 4) Testing fit, and 5) Respecification, respectively.

3.3.1.5 Interpretation: The model is then interpreted so that claims about the constructs can be made, based on the best fitting model. For the model obtained form the data after the first training, the factors influencing the acceptance and participation behavior of TPM implementation of employees were then considered in the initial phase. For the most influencing factors, they would be used to be the significant TPM activity drivers whereas for those having relatively less influence but seem promising were used for improvement of measures to promote the TPM implementation. However, for those having relatively less influence but did not seem promising were skipped.

3.3.2 The Research on Important Characteristics Affecting OEE Improving

This part consider correlation between test score for knowledge and skill of population after 2nd basic Lean TPM training and the final OEE after conducting the focused improvement for two months.

3.3.3 Force field analysis (FFA)

The force field analysis which was used to survey the force field of drivers and resistors within the manufacturing industries. These two force fields determines the level of support and restraint behavior of accepting the new coming technology of Lean TPM. K-J brainstorming method among key persons including all managers, section heads, and engineers was used to initiate FFA sheet. 1-5 ranking scale is used for ranking FFA by concern employees. Determining the Lean TPM implementation force field by comparing the summing of driving score to summing restraint score. Enhance Lean TPM implementation is only when the specific driving forces for an organization are greater than the opposing forces that the change will occur. The ultimate sustainability then requires additional support forces to further reduce and eliminate opposing. During surveying force field analysis, using this opportunity to allow all concern employees to expose their Lean TPM opinion and suggestion for improvement before implementing of Lean TPM.

3.3.4 Deployment of Key Lean TPM Implementing Program Success Factors

There were then presented for organizing the framework of Lean TPM implementation for successful lean transformation of the company in this case study. Finally, the results in terms of OEE and overall plant effectiveness of both before and after Lean TPM implementation were compared.

CHAPTER IV
PRELIMINARY INVESTIGATION AND PREPARATION

4.1 Company profile and manufacturing environment

The company has established itself as a highly qualified manufacturer and distributor of high quality Biaxially Oriented Polypropylene Films (BOPP), Biaxially Oriented Polyester Films (BOPET), Biaxially Oriented Polyamide Film (BOPA) and Metallized film. Today, the company has been supplying a wide and varied range of film products to the global packaging industries.

As a result of extensive investment, the company achieved a plant capacity of 81,000 metric tons per year, this annual plant capacity is achieved by producing 36,000 metric tons of Biaxially Oriented Polypropylene Film (BOPP), 32,000 metric tons of Biaxially Oriented Polyester Film (BOPET), 5,000 metric tons of Biaxially Oriented Polyamide Film (BOPA) and 8,000 metric tons of Metallized Film.

In fact, there were 7 main film production process lines as shown in Figure 4-1, P1 and P2 are 2 production lines used to produce BOPET while B1-B4 and N1 were used to produce BOPP and Nylon film respectively. The company used the most advanced production machinery incorporating the latest technology around the world. In all high-speed production process computer control in order to ensure the constant high quality of its manufacturing process.

Unfortunately, the company had been confronting severe economic challenges caused by a series of global economics crisis, coupled with facing other serious difficulties in business, such as sudden and frequent changes in raw material and oil prices as well as unpredictable currency exchange rates, it therefore, had been seriously searching for effective measures to survive in the marketplace. The effectiveness of a plant's production depended on the effectiveness equipment, materials, personnel, and methods which it used. Top management person, the Vice President wanted to raise production effectiveness in process industries, as the consequence, starting with the vital issues of maximizing overall plant effectiveness (equipment), raw material and fuel efficiency (materials), work efficiency (personnel), and the management efficiency (method). This was done by examining the inputs of the production process (equipment, materials, people, and methods) and identifying as well as eliminating the losses associated with each of these to maximize the outputs (productivity, quality, cost, delivery, safety and environment, and morale). It was very important to search data and fact leading the author to understand the related current situation of wastes and losses elements including long lead time process, high raw material inventory level, high finished goods inventory level, scrap and overall eight major plant loss. Hence, preliminary investigation method was initially administered to obtain all kinds of such data by going through the main process so as to interview and collect all relevant data pertaining to overall plant effectiveness as explained as follows.

The whole process for the production of the company's any plane film comprises 5 sub-processes namely Feeding Drying & Extrusion, Main Processing (MDO-TDO and Winding), Testing, Slitting and Packing. In regard to the raw material, there were 2 kinds of chips which were virgin chips ordered from the supplier and recycled chips produced in the company. Beside, there were 7 main lines in producing a wide range of products as shown in Figure 4-1.

4.2 Value stream mapping of one batch process.

Main film process composes of 2 main lines, P1 with 30 tons/day capacity and P2 with 60 tons/day capacity. The OEE for both P1 and P2 were around 45%. TPM concept incorporated with Pareto has normally been applied for solving the significant problem in order to reduce losses. But in this case since there had been a limited resources in solving the problem, management personnel had decided to start with 3 model machines including Feeding process, Recycle process and Slitting process which were a part of Film process P1 as P1 was older than P2. Figure 4-2 shows an example process chart of P1 main film production process which was used in producing polyester film approximately 30 tons a day or 1.5 tons per hour while Slitter of P1 process is 35 tons/day or 3.7 tons/hour capacity. This P1 film process was called a continuous process difficult to explain per unit lead time. In this study, the author

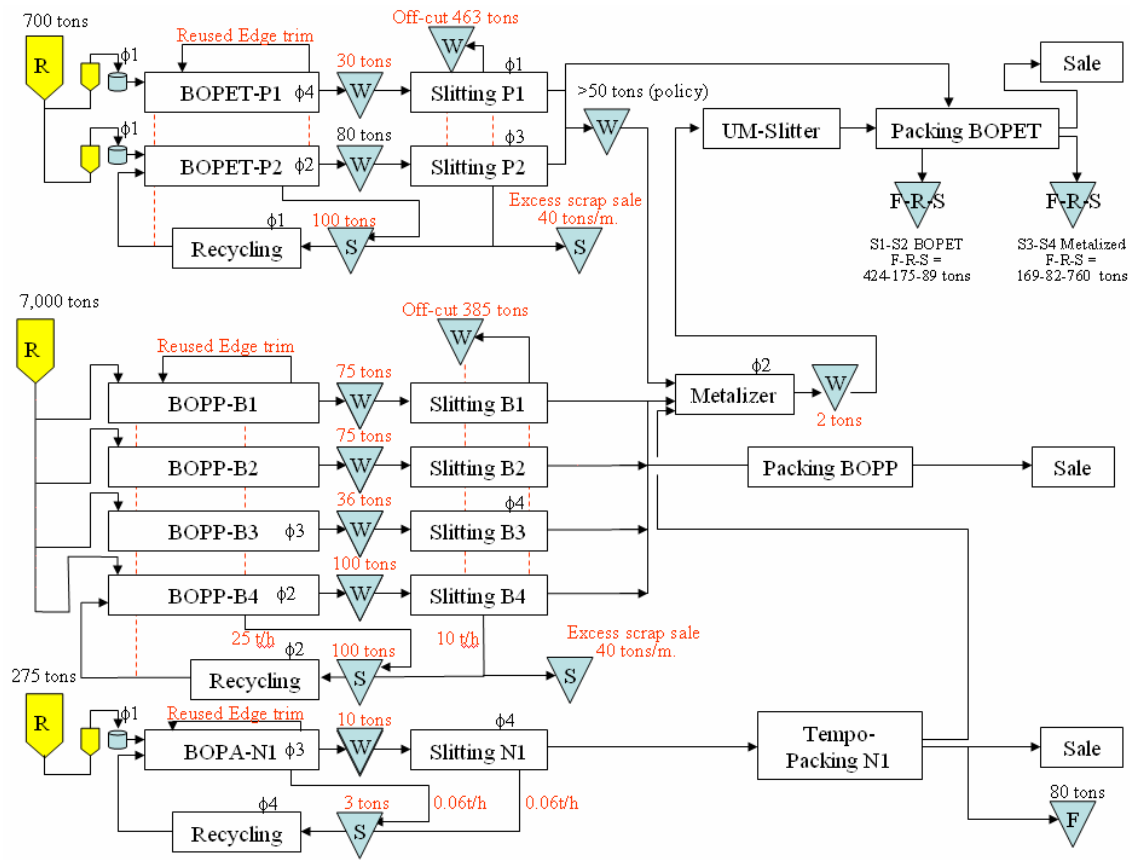


Figure 4-1: Main Production Process Lines

would assume one batch or one mill roll of film on a roll is 1 unit produced so one batch P1 main film production process lead time means total time to produce one mill role of film. Usually, the weight of film on one mill roll equals to 7 tons. This later consideration of plant effectiveness will be based on one batch process so one batch process lead time is 5.60 hours. (24 hrs.)/[(30 ton per day/7 ton per batch or mill roll)] at 100% of OEE. In fact as mentioned above, it was found that P1 process with 45.45% OEE would take longer process lead time. P1 process, comprising Feeding & Drying and Processing, lead time would be 5.60/0.4550= 12.64 hours plus changeover or setup 20 minute. So the P1 process lead time at 45.45% OEE was 12.64 hours or

0.53 day. So overall process lead time would equal to the total sub-process lead time of 48.33 days with value added time of 0.69 days.

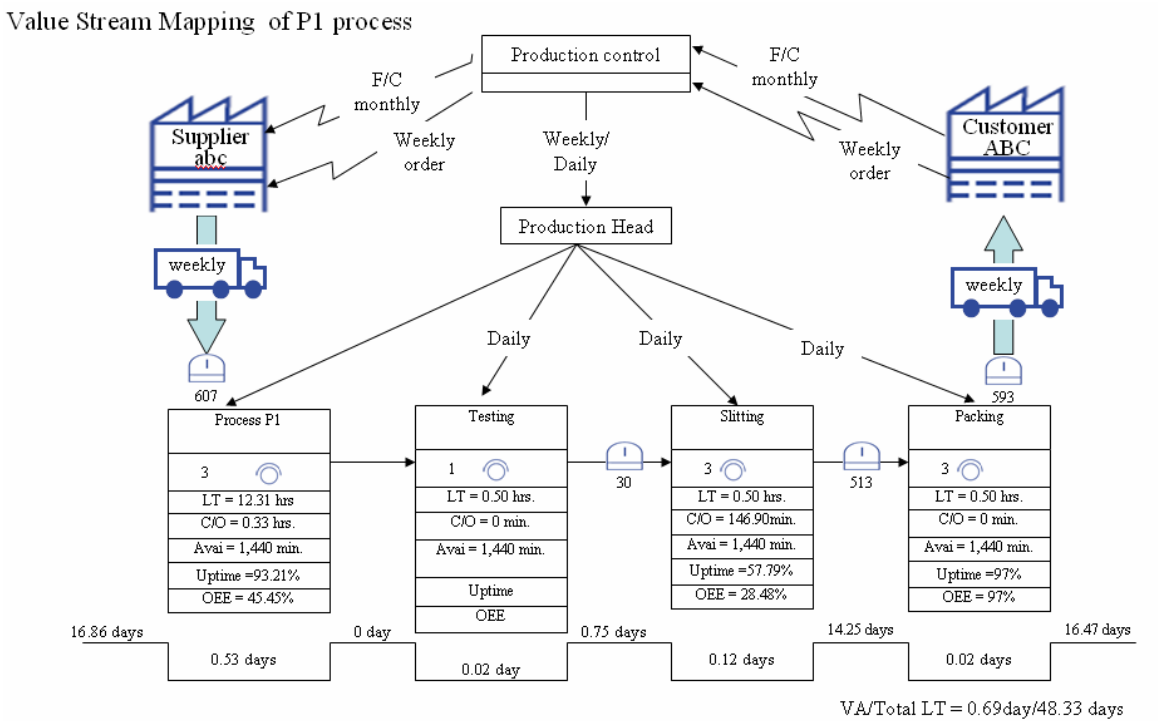


Figure 4-2: Typical Value Stream Mapping of Film Production Process P1

Losses visualization as shown in Figure 4-2 lead us to understand that the main causes of low process productivity of film process was the time waste. This diagram showed the ratio of value added time to one batch cycle time is only 1.39 days/27.14 days or just around 5.12 %. In fact there had been not only the waste of time but also the inventory loss for the amount of 607 ton chips of raw material, 593 tons of finished goods and 543 tons of work in process. The next paragraph shows overall losses of the company that was detected during first process investigation.

4.3 Overall plant losses

Overall effectiveness was raised by painstakingly eliminating everything that tended to lower it. In other word, maximizing plant effectiveness involves bringing the plant to peak operating conditions and then keeping it, there by eliminating or at least minimizing any factors such as failures, defects, or problems that might diminish its performance. This part highlights overall plant loss including inventory, WIP, eight major plant loss and scrap.

4.3.1 Inventory level

The company usually finds a huge of un-sale stock of product kept in stock in various areas of the company called S1-S4 and Nylon film stock area. This stock is approximately 1,700 tons as shown in Table 4-1.

Table 4-1: Quantity of Finish Goods, Rework and Scrap Sock Level (S1-S4 and Nylon Stock Area).

Type of product	Stock level (tons)
BOPET grade A	551
BOPET Rework	228
BOPET Scrap	115
Metalized Film grade A	219
Metalized Film Rework	107
Metalized Film Scrap	988
Nylon Grade A	104
Total	**2,312**

4.3.2 The Eight Major Plant Losses and Scrap

The following eight plant losses were the major losses that prevent plant from achieving its maximum effectiveness and also it was an obstacle in enhancing lean process environment.

The eight major plant losses data was discovered during plant investigation. Daily production records of all process are available in terms of amount of defect, process failure duration, production period and so on. The losses were then calculated pertaining to the Slitting BOPET P1 with 3.7 tons per hours. It was also found that annual production plan was changed for 50 times. This immediate change of schedule led to an urgent production shutdown so as to start the urgent orders. During this process, the production line was needed to be re-setup and changed over that consumed the total unexpected time of 79.17 hours per year. This time loss caused production loss for about 292.92 tons per year in the Slitting BOPET P1 process.

4.3.2.1 Shutdown Loss: Shutdown loss is the time loss when production stops for planned annual shutdown maintenance or periodic servicing. Production process equipment is usually operated continuously throughout the year with periodically process shutdown to perform planned shutdown maintenance around once in few months based on deteriorated characteristics of each part. Therefore shutdown losses arose as a result of periodic servicing required while the plant was operated.

4.3.2.2 Production Adjustment Loss: Production adjustment loss is a time loss occurring when changes in supply and demand require adjustment in production plans. It would never arise if all products that a plant manufactured could be sold according to the set plan. If the demand for a product falls because of the market needs change, the plant that manufactures the product may, however, have to close down temporarily. In fact, production adjustments are governed by production plans based on factors such as demand and inventory and are, to some extent, unavoidable for producers. Normally, plane films produced from main process lines are always in stock so this kind of loss will not occur in the main processing line but sometimes it will between 4-5 times in a day in the Slitting process.

4.3.2.3 Equipment Failure Loss: Equipment Failure Loss is a time loss when a plant stops because equipment suddenly loses its specified functions. Two types of equipment-related loss can be distinguished: function-failure loss and function-reduction loss. Function-failure loss is a time loss that occurs when equipment suddenly loses its specified functions and stops. Function-reduction loss, on the other hand, is a physical loss such as defects or reduced yield that occurs while a plant is operating, when various factors cause equipment to under-perform.

4.3.2.4 Process Failure Losses:Process failure loss is a time loss when a plant shuts down as a result of factors external to the equipment, such as operating errors or changes in the physical or chemical properties of the substances being processed. This problem is quite not clear. It is very difficult to find the root cause within short time. During the process shutdown, the production staff always identified the cause of the loss as equipment failure, so this kinds loss is thought be zero which it may not be.

4.3.2.5 Normal Production Loss: Normal production losses are rate losses that occur during normal production at plant startup, shutdown, and changeover. A plant's standard production rate cannot be achieved during the warm up period when the plant is started up or maintained during the cool-down period when it is shut down, or during changeover periods when production switches form one product to another. Also, drops in production that occur at these times should be treated as losses. The time which a plant takes to warm up after shutdown maintenance (from the time it first starts up until acceptable product emerges) is a lost time.

4.3.2.6 Abnormal Production Losses: Abnormal production losses are rate losses that occur during when a plant performs inadequately as a result of machine malfunctions and other abnormal conditions of the machine that interfere with the performance. The overall capacity of a plant is expressed by the standard production rate (t/h). When a plant must run at a rate lower than its standard production rate, the difference between the standard and actual production rates is the abnormal production loss.

4.3.2.7 Quality Defect Losses: Quality defect losses include the time loss in producing rejected product, physical loss in scrap, and financial loss due to product downgrading.

Quality defects can have many causes. Some may arise when production conditions are set incorrectly due to instrument malfunction or operating errors; others may appear from external factors such as failures, problems with raw materials, or contamination.

4.3.2.8 Reprocessing Losses: Reprocessing losses are recycling losses that occur when rejected material must be returned to a previous process to make it acceptable. This kind of loss is not identified due to the staff's misunderstanding in the process so it was identified as zero which it may not be. Figure 4-3 shows percentage of plant major losses of 2008 obtained form losses surveyed as shown in Table 5-2. It was found that the eight major plant losses comprising value of 1,729.34 shutdown loss, 6,369.07 production adjustment loss, 13,368.67 equipment failure loss, 106,313.03 normal production loss, 230,101.41 abnormal production loss, 109.78 reprocessing loss, and 10,168.37 defect loss of ton per year out of the maximum plant capacity value of 368,159.67 ton per year. Evidently there are two kinds of the company loss. The first one is an abnormal production loss or speed loss making the company performance drop down for about 40.95%; and, the second one is a normal production loss from normal process warm up making the company performance drop down for about 18.92%. In reducing the losses, the Lean TPM will not ignore removing even insignificant ones. Regarding the researcher's preliminary report of the losses, it includes 0.31% shutdown loss, 1.13% production adjustment or management loss 2.38% equipment loss, 1.81% defect, 0.02% reprocessing loss apart from the process failure loss, so the major structures including the eight major losses can be visualized in Figure 4-4. The overall plant effectiveness was simply calculated as only 34.48%.

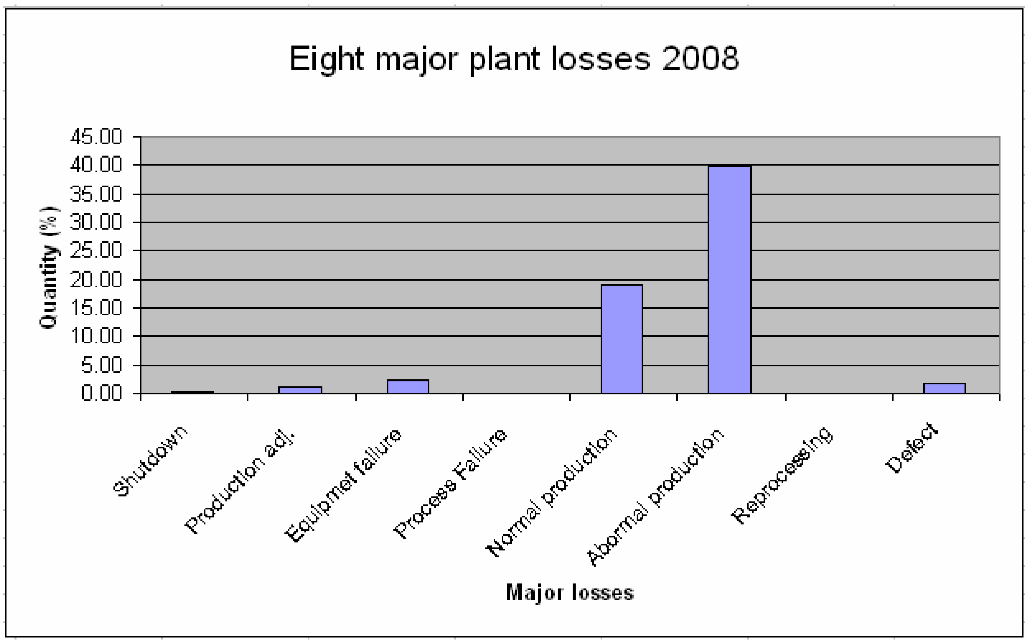


Figure 4-3: Percentage of Eight Major Plant Losses

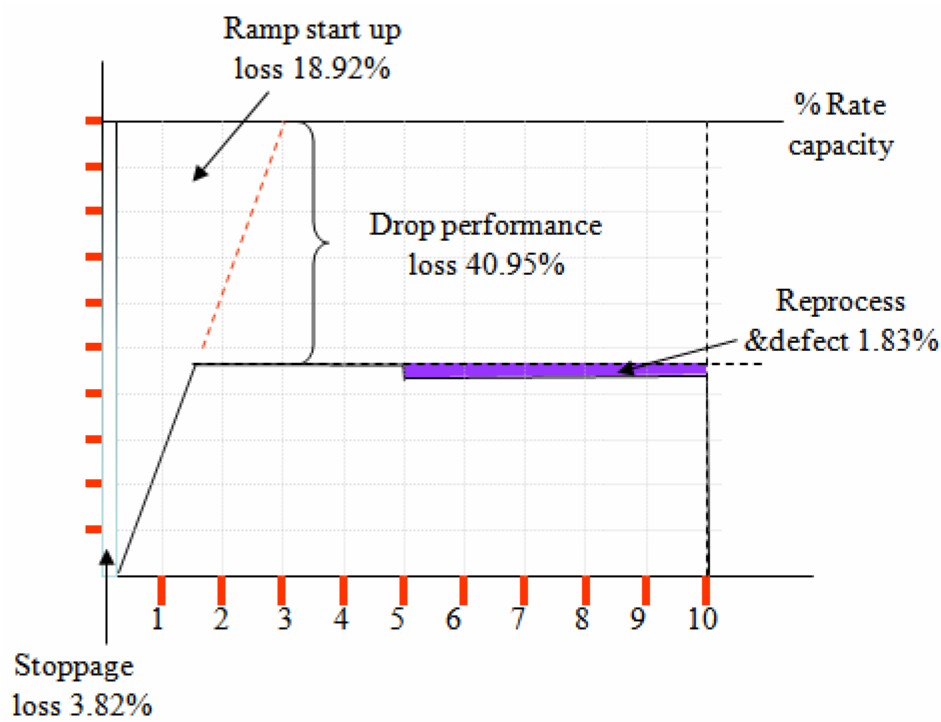


Figure 4-4: 8-Major Plant Losses Structure

4.3.3 Overall plant losses conclusion

Lean TPM goal is to eliminate all kinds of losses. It is very important issues in process industries to identify deficiencies in the process as a whole than in individual equipment items. The goal is to improve the plant's overall effectiveness. For example, to increase the production capacity of a process, investigate the entire process and clearly identify the sub-processes and equipment that create bottlenecks. The preliminary figures show the clear evidences of eight major losses of the plant. Table 4-2 in following is the conclusion of plant effectiveness in terms of inventory level, WIP, and scrap and so on.

Table 4-2: Conclusion of Plant Effectiveness

No.	Items	Unit	Quantity.
1.	Overall plant effectiveness	%	35.51
2.	Value added time to one batch cycle time ratio.	%	1.92

Table 4-2: Conclusion of Plant Effectiveness (cont.)

No.	Items	Unit	Quantity.
3.	Raw material-Virgin Chips storage	Tons.	2,283
4.	Finish goods inventory	Tons.	804
5.	Work in process	Tons.	1,280
6.	Rework product outside factory	Tons.	335
7.	Average excess side trim sale	Tons/month	104
8.	Maintenance part inventory	million Bath	97

4.4 General problems with special reference to the company and the maintenance system

4.4.1 General problem of company; The following factors caused the company's poor performance in products manufacturing.

4.4.1.1 Lack of efficient skilled human resources

4.4.1.2 Time constraint in providing professional training to company employees and lack of interest among the company administrator in sending the employees for elsewhere training and development;

4.4.1.3 Emphasis only on short-term gains and lack of long-range vision and plans;

4.4.1.4 Lack of participation from non-manufacturing units such as administration, marketing, purchasing and maintenance, i.e. looking at the system from the point of sub-optimization contrary to high performance practices;

4.4.1.5 Lack of state-of-the-art (modern) technology such as TPM, Lean, and TQM and lack of understanding about the role of technology.

4.4.2 Problems related to equipment maintenance

4.4.2.1 Low level of overall equipment effectiveness comprising: availability, performance rate, and quality rates (see Table 4-3 Overall Equipment Effectiveness of 7 Production Line Process)

4.4.2.2 Lack of understanding about capacity and capability improvement through the discovery of equipment and human related "hidden" resources;

4.4.2.3 Lack of the maintenance principles, use of breakdown signals for corrective maintenance (repairing);

4.4.2.4 Long response to work order request;

4.4.2.5 Poor skills and low level of knowledge of equipment users for maintenance work.

Table 4-3: Current Stage Overall Equipment Effectiveness of 18 Sub-processes

Process/ Equipment	Max. Capacity (tons/hr.)	Availability: A (%)	Performance: P (%)	Quality: Q (%)	OEE (%)
Main Process BOPET-P1	1.50	93.21	50.80	96.08	45.50
BOPET Slitting P1	3.70	58.64	49.74	97.62	28.48
Main Process BOPET-P2	2.50	78.49	71.98	80.55	45.50
BOPET Slitting P2	6.30	65.73	46.40	95.09	29.00
BOPET Recycle process	1.40	94.77	69.58	98.58	65.00
Main Process BOPP-B1	3.50	80.59	58.24	96.93	45.50

Table 4-3: Current Stage Overall Equipment Effectiveness of 18 Sub-processes (cont.)

Process/ Equipment	Max. Capacity (tons/hr.)	Availability: A (%)	Performance: P (%)	Quality: Q (%)	OEE (%)
BOPP Slitting B1	9.50	77.70	33.63	95.81	25.04
Main Process BOPP-B2	3.50	74.52	91.35	95.07	64.71
BOPP Slitting B2	9.50	79.34	35.53	96.12	27.09
Main Process BOPP-B3	2.00	74.54	91.35	95.06	64.73
BOPP Slitting B3	9.50	78.77	35.45	96.80	27.03
Main Process BOPP-B4	0.85	75.36	91.61	95.14	65.68
BOPP Slitting B4	9.50	82.36	37.44	98.72	30.44
BOPP Recycle process	0.92	99.43	76.05	92.52	69.96
Main Process BOPA-N1	0.90	99.27	78.82	84.48	66.02
BOPA Slitting N1	6.50	77.57	33.58	98.48	25.65
BOPA Recycle process	0.30	99.37	71.63	92.11	65.56
Metalizing process	0.50	61.19	49.63	98.71	29.97

4.5 The Research on Factors Affecting TPM Implementation

Regarding the implementing of Lean TPM or TPM for Lean transformation, ultimate goals of lean manufacturing includes : 1) a decrease of lead times for customers, 2) a reduction of inventories for manufacturers, 3) an improvement of knowledge management and 4) an increasing strength for robust processes (as measured by less errors and therefore less rework). It seems that implementing TPM toward lean manufacturing is not so easy. Although most industry knows it, very few of them have succeeded this best practice depending on characteristics of the factory's environment which is of great importance for the productivity enhancement. Environmental factors can be divided into 3 portions: 1) unionization, 2) factory age, and 3) factory size. This research has aimed to construct the framework of Lean TPM transformation whereby the following procedure would be taken into account:

1) Application of UTAUT model after the instruction of Lean TPM concept instruction in order to evaluate the organization behavioral acceptance of the concept

2) Survey on the restraining and supporting forces called force field analysis (FFA)

3) Review on the key success factors of TPM implementation to be used in constructing a measure to supplement the implementation

4) Identification of suitable manufacturing practices for individual factory's manufacturing environment

4.5.1 Factors Influencing Lean TPM Implementation Adoption in Plant

This study adopted the UTAUT model (Venkatesh et al., 2003) to determine factors that foretell the behavioral intention in using TPM principle after finishing training of TPM principle and related topics in order to transform individual sub-process into Lean Manufacturing environment. The proposed research model shows the direction of the hypothesized relationships among the proposed extension of the UTAUT. UTAUT postulates that four constructs act as determinants of behavioral intentions and usage behavior:

1) Performance expectancy: ‘‘The degree to which an individual believes that using the system will help him or her attaint gains in job performance.’’

2) Effort expectancy: ‘‘The degree of ease associated with the use of the system.’’

3) Social influence: ‘‘The degree to which an individual perceives that important others believe he or she should use the new system. Social influence is system or application-specific, whereas subjective norm relates to non-system-specific behavior.’’

4) Facilitating conditions: ‘‘The degree to which an individual believes that an organizational and technical infrastructure exists to support use of the system.’’

In addition, origin UTAUT also posits the role of four key moderator variables: gender, age, experience, and voluntariness of use. Furthermore, this study coincides with the idea emerging education and knowledge, and Thai working culture from the research relating to the Thai’s working culture (Buripakdee et al., 1986) as found from the research that, on average, Thai people mainly work for income only without considering on their satisfaction for the expression of their human capability. Besides, they do not set a clear purpose for their work and seldom appraise their work against the ultimate goals. They are not motivated to challenge using new relevant methods and approaches to enhance more productive efficiency. Still, they usually rely on conventional way of working. The team work is usually organized in a horizontal line, namely people in the team work have a similar role in their duties. However there is no hierarchical priority for the staff role like some modern companies with complex working lines. Nor is there a strong interest to develop human resources in their workplace. Finally the factory staff seems more considerate for personal relationship than long term development of people at large. At a consequence, this research includes the idea pertaining to Thai people's working culture in formulating the questionnaire.

4.5.1 Research Questions

The current research tries to answer questions relevant to the relationship among the UTAUT construct: PE, EE, SI, FC, and Behavioral Intention of Usage (BU). As describe in the conceptual framework, these constructs were the same as other ones in eight models consisting of the aggregated model. As a consequence, the nature of these relationships were addressed in the set of research question.

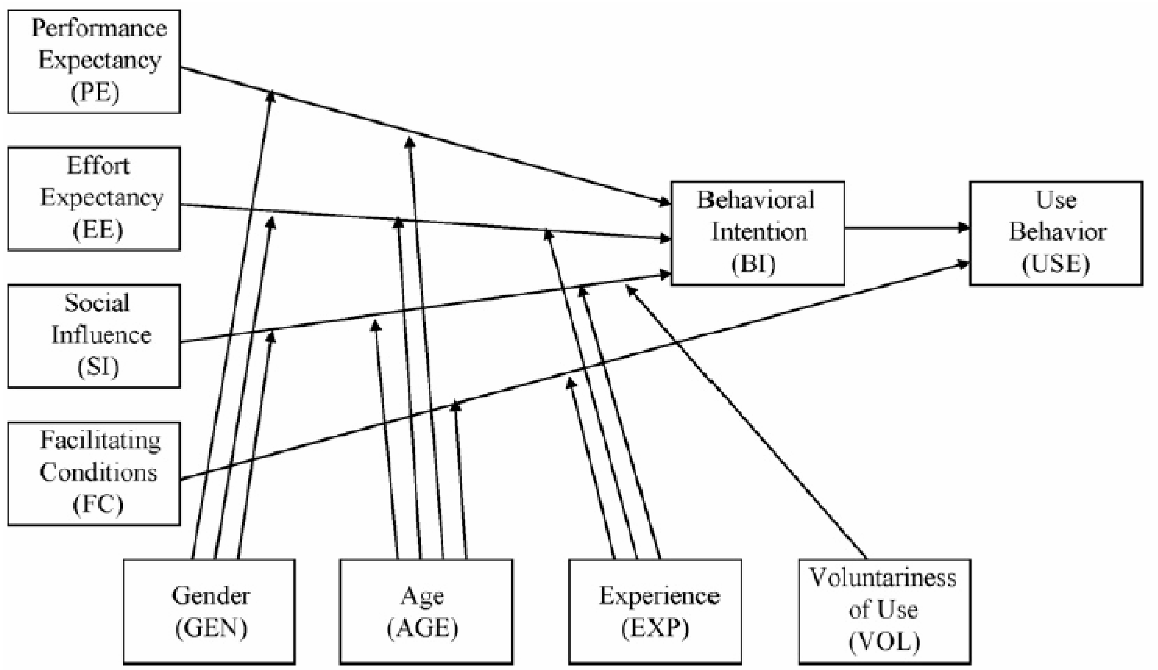


Figure 4-5: The Theoretical Framework of Unified Theory of Acceptance and Use of Technology UTAUT Model (Venkatesh et al., 2003)

4.5.2 Research Hypotheses

Regarding to the evaluation on Lean TPM implementation acceptance in the company for this case study the research hypotheses could be grouped into three items: the relations among the key constructs in the extended model; hypothesized impacts on the proposed model; and the impact of moderators.

4.5.2.1 Hypothesized Relations of the Keys Constructs: This set of hypotheses included the relations among independent variables in the proposed research model: PE, EE, SI, and FC and the dependent variable. The UTAUT model comprised four important constructs and four moderators. This study is addressing a connection between effort expectancy (EE) and performance expectancy (PE), and between social influences (SI) and performance expectancy (PE). The authors of the UTAUT gave definition for performance expectancy as the degree to which an individual believed that employing the system would assist him / her to get more job performance and acknowledged that this construct resembled other ones in the integrated models namely TAM's perceived usefulness. The effort expectancy construct in UTAUT was defined as the degree of ease related with the system use. As mentioned before, this study considered the Thai working style which did not set a clear purpose for their work and seldom appraise it against the ultimate goals. Therefore, the set of hypothesis items investigated such connection in the proposed general UTAUT research model as shown in Figure 4-5 were formed as follows:.

1) H1: Performance expectancy will have a positive influence on behavioral intentions to implement Lean TPM (PE-BI).

1.1) H1a: Male will be more moderate the influence of performance expectancy on behavioral intentions to implement Lean TPM than female.

1.2) H1b: Older employee will be more moderate the influence of performance expectancy on behavioral intentions to implement Lean TPM than the younger one.

1.3) H1e: Working with high expectation towards performance results will moderate the influence of performance expectancy on behavioral intentions to implement Lean TPM.

Again, we anticipated a positive influence of effort expectancy on behavioral intentions Lean TPM implementation. There was no reason to be in doubt that the impact of the ‘‘degree of ease related with the system use’’ should be affected by the cultural measures. In any company, increased levels of ease of Lean TPM implementation should be linked with increased behavioral intentions in implementing the Lean TPM. Also, we had considered interaction of age with this relationship. However, more experienced employees would be likely to be more influenced by the ease of implementation. Thus, the followings were hypothesized:

2) H2: Effort expectancy will have a positive influence on behavioral intentions to implement Lean TPM (EE-BI).

2.1) H2a: Male will be more moderate the influence of effort expectancy on behavioral intentions to implement Lean TPM than female.

2.2) H2b: Older employee will be more moderate the influence of effort expectancy on behavioral intentions to implement Lean TPM than the younger one.

2.3) H2c: Experience will moderate the influence of effort expectancy on behavioral intentions to implement Lean TPM.

2.4) H2d: Knowledge and education will moderate the influence of effort expectancy on behavioral intentions to implement Lean TPM.

Normally, individuals would comply to the expectations of others who were perceived as important or influential. As a consequence, in Thai working culture, employees may exhibit a stronger association between social influence variables and behavioral intention. The low score for individualism towards working culture was the feature of a culture that values collective achievements and interpersonal relationships. A group-oriented idea suggests that the opinions of others would affect an individual's behavioral intentions. As the result, the collective opinions of others would highly influence of intention of individual behavior resulting in a positive relation between subjective norm and behavioral influence.

Furthermore, young people were likely to take over subordinate roles and therefore tend to be influenced by the social influence in a culture characterized by Thai working culture style. Therefore, it was hypothesized as follows:

3) H3: Subjective norm will have a positive influence on behavioral intentions to implement Lean TPM (SI-BI).

3.1) H3a: Male will be more moderate the influence of subjective norm on behavioral intentions to implement Lean TPM than female.

3.2) H3b: Older employee will be more moderate the influence of subjective norm on behavioral intentions to implement Lean TPM than the younger one.

3.3) H3c: Experience will moderate the influence of subjective norm on behavioral intentions to implement Lean TPM.

3.4) H3d: Knowledge and education will moderate the influence of subjective norm on behavioral intentions to implement Lean TPM.

3.5) H3e: Working with high expectation towards performance results will moderate the influence of subjective norm on behavioral intentions to implement Lean TPM.

3.6) H3f: Voluntariness of use will moderate the influence of effort expectancy on behavioral intentions to implement Lean TPM.

Regarding UTAUT, it could be claimed that the relationships between facilitating conditions and use behavior would be strong for cultures that had high score on uncertainty prevention. We reasoned were always given that increasing levels of facilitating conditions should lend themselves to decrease uncomforting levels of uncertainty or ambiguity with Lean TPM implementation. Thus, we estimated that a direct relationship between facilitating conditions and use behavior would be true in any organizations. Besides, the reason was given that age and experience should positively interact with the influence of facilitating conditions on Lean TPM implementation. In particular, it was speculated that increase of age and experience would promote the dependence on Lean TPM implementation, as hypothesized below:

4) H4: Facilitating conditions will have a positive influence on Lean TPM implementing. (FC-BU).

4.1) H4b: Older employee will be more moderate the influence of facilitating conditions on behavioral intentions to implement Lean TPM than the younger one.

4.2) H4c: Experience will moderate the influence of facilitating conditions on behavioral intentions to implement Lean TPM.

4.3) H4d: Knowledge and education will moderate the influence of facilitating conditions on behavioral intentions to implement Lean TPM.

4.4) H4e: Working with high expectation towards performance results will moderate the influence of facilitating conditions on behavioral intentions to implement Lean TPM.

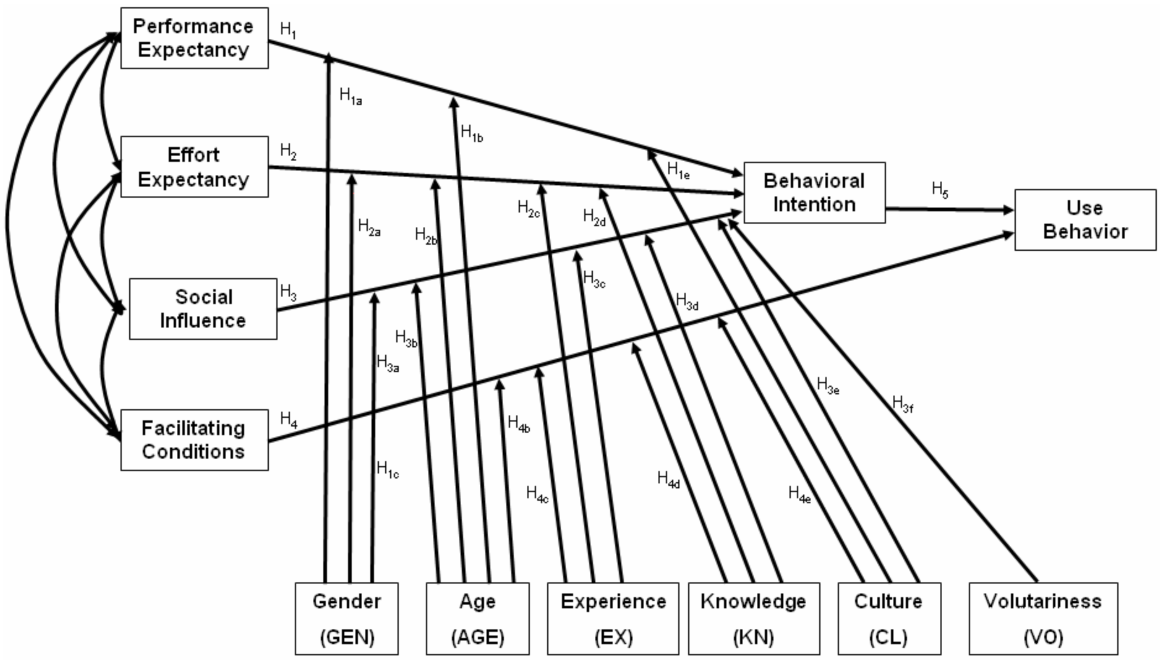


Figure 4-6: General UTAUT Research Model With Moderators

4.6 Instrument Development and Design

This section addresses the constructs' measurement for the proposed research model.

4.6.1. Constructs' Measurement

The difference between the term "construct" and the term "variable" is linked to the measurement. By giving an actual measure (e.g., score on scale), the operational definition of the construct change it into a variable (Ghauri et al., 2004). Operationalizing a concept to become measurable is undergone by focusing on behavioural dimensions or properties given the meaning in terms of the concept, which are then converted into observable and measurable elements so as to enhance a measurement index for the concept (Sekaran, 2003). Operational definitions for the important constructs in the proposed model were identified by Venkatesh et al.'s (2003) work. This study, the combination of both instruments which measured the constructs in the proposed research model. There were an adaptations of the measurement items for performance expectancy, effort expectancy, social influences and behavioural intentions from Venkatesh et al.'s (2003) study with some modification to mirror the particular target behaviour of Lean TPM implementation.

4.6.2. Instrument Development

Research instrument, a questionnaire survey was specifically designed by using UTAUT module approach, as well as Likert's five rating scale questionnaire. Of which the level arranging from 5 to 1 indicating the most agree, much agreeable, moderately agreeable, agreeable, less agreeable, and not agreeable.

This survey questionnaire comprises a series of questions used to collect information on a particular component of UTAUT module that is made up of nine structural traits such as performance expectancy (PE), effort expectancy (EE), social influence (SI), facilitating condition (FC), gender (GD), age (AG), Lean TPM knowledge and education level (KN), experience (EX) including working life experience and Lean TPM experience, voluntariness of use (VO), organizational culture (CL), and behavioral intention to use (BI).

The validity and reliability analysis was conducted before using of the questionnaire to determine the construction validity, content validity, by the calculating the index of item-objective congruence of the questionnaire. The purpose of this test is to determine whether all important aspects of the construct are covered. Clear definitions of the construct and its components is of great use here. The test was reviewed by 3 TPM experts before the modification as the actual test. Generally, each expert evaluates each question items by scoring "1", "0", and "-1" from more to less respectively in terms of its clarity and objective matching. Then IOC of each question items is calculated. A perfect rating by experts would be an average of 1.00 on the valid objective and average ratings of -1.00 on the invalid objectives. This combination would produce an index of item-objective congruence value of 1.00 for the valid objective. In case of having different experts' opinion, the accepted value of IOC much exceed 0.50 In fact, there were items in Table A-1 in the appendix**.** IOC test result of proposed questionnaire with ratings provided from three content experts. The index value of 1 for Item 1 indicates that all experts agreed that the item is clearly measured, whereas Objectives 2 through 5 are considered unclear as hypothesized by the test developer. For reliability test, Cronbach's Alpha was used as the reliability coefficient at 0.05 significant level. Pre-testing or Field-testing of questionnaire was administered to Eight senior managers and 32 production staffs of the company experiencing TPM implementation more than a year during their experience in using TPM managers' machine models. As summarized in Table 4-4, several of the scales that represent the UTAUT constructs appear to have a good degree of reliability since each computed statistic is above 0.70. Unfortunately, it appears that effort expectancy, trust and privacy, experience, and organizational culture are questionable because their respective test statistic falls well below 0.70.

Table 4-4: Reliability Analysis of Each UTAUT Construct Factors. (n=40)

UTAUT Construct	Cronbach's Alpha	Number of Items
Performance Expectancy	0.7637	6
Effort Expectancy	0.6602	4
Social influence	0.8310	4
Facilitating condition	0.8610	4
Lean TPM knowledge and education level	0.9691	9
Experience	0.5615	5
Voluntariness of use	0.9260	2
Organizational culture	0.6632	5
Behavioral intention to use	0.8900	2
Behavior of use	0.9500	1

After the questionnaire was tested for its reliability and validity and obtained the satisfactory result, then it was distributed to the respondents for the data analysis.

The questionnaire survey was conducted at a factory with contexts in manufacturing determine factors influencing the Lean TPM adoption of such enterprises. Table 4-5 provides a summary of plant characteristics.

It was found that the company size was medium. More than half of its productions were for export with modern and high technology machines used in the production process. Most of the employee were educated but the employees at the leader level had good experience but with low educational background. The company had started to hire the engineers when deciding to do Lean TPM so that they would be responsible for it in each important process units.

For the administration line, there was a clear line of command, and there are multi-discipline like the other company but without the adoption of modern production management technology. Regarding the operation, it used the experience of employee's individual leaders more than standard operation. The company's high executive level usually own the company and did not have closed relationship with the employees much.

Table 4-5: The Summary of the Sample Plant Characteristics

Size	Age	Unionization	Culture	Process
Medium	22 years	No	Modern Chinese Thai	Continuous

4.7 Data analysis

Spearman's correlation analysis as the equation (4.1) was used to test the relationships among the UTAUT constructs which was formed from data obtained from the questionnaire from the employees of company. While the UTAUT model suggests a relationship between behavioral intention and other nine UTAUT components such as performance expectancy, effort expectancy, social influence, facilitating condition, gender, age, experience, culture, and voluntariness of use.

$$Correl(X,Y) = \frac{\sum (x-\bar{x})(y-\bar{y})}{\sqrt{\sum (x-\bar{x})^2 \sum (y-\bar{y})^2}} \qquad (4.1)$$

4.8 Descriptive Analysis

After first trainings on TPM implementation for all 143 employees in the implementation program, the researcher distributed the questionnaire which passed the reliability and validity test to the population in the research through the purposive sampling. Two weeks were allocated for responding the questionnaire without identifying the respondents' names in order to encourage the employees to answer the questionnaire. The responded questionnaires obtained were 138 copies equivalent to 96.50 %.

A descriptive statistical analysis is described in this section in order to provide a richer understanding of perceptions of the employees of company in this Lean TPM implementation case study. Table A-2 summarizes the frequencies and corresponding percentages for the employees' perceptions with respect to Performance Expectancy.

Those of 138 employees who responded to the questionnaire came from different position and responsibility: Managers, Engineers, Supervisors, and operators with the age ranging between 19-39 years old, with the mean score of 25.69 years and the value of standard deviation (S.D.) was 7.6.

Table 4-6: Participant Age (n=138)

Age Group	Frequency	Percent
$\leq$ 20	23	16.67%
21-25	54	39.13%
26-30	35	25.36%
31-35	19	13.77%
> 35	7	5.07%

Table A-3 provides a descriptive analysis of the employees' perceptions regarding Effort Expectancy. It appears that the employees tended to disagree that Lean TPM is understandable, difficult to become skillful, and difficult to learn; however, they tended to be more the neutral in terms of understanding of Lean TPM and knowing their roles in Lean TPM implementation.

Table 4-7: Recorded Job Level (n=138)

Level	Frequency	Percent
Manager	10	7.25%
Engineer/Supervisor	19	13.77%
Leader	36	26.09%
Operator	63	45.65%

Table A-4 suggests that the employees may not be influenced by the others who think they should do Lean TPM activity, but they tended to agree that they were willing to implement the Lean TPM if it was the company policy which every staff must follow. Also employees tended to follow Lean TPM concept if their superior asked them.

Not only did not the social environment motivate them willing to do the Lean TPM activity, but also the employee themselves did not voluntarily did it. This could be revealed in Table A-5.

Table A-6 shows that the employees thought the company did not really support them in terms of the resources for instance there was an inadequate participation to the activity, there was a lack of helping labor, and necessary material including not providing document and text supporting the adequate knowledge and understanding of Lean TPM. It also includes the tendency for them to think that they may not get any full help or advice regarding the Lean TPM implementation.

Not surprisingly, it was found that the employees were the least interested in Lean TPM implementation and had the perception the Lean TPM was hard to understand. From Table A-7 and Table A-8, it clearly shows that the employees tended to have knowledge and experience relevant to Lean TPM and other modern creative activities such as small group activity, Kaizen, 5S, problem solving and loss reduction**.** The most surprising evidence was that employees did not know and understand about how to manage there job. The mentioned activities were considered to be basic ones very necessary for the Lean TPM implementation which, in fact needs close intention from the company executive.

What was really dangerous about the implementation of productivity improvement activities was that the employees tended to perceive that the improvement activities would make them unimportant as a resource person to solve the factory problem as that in the past. The survey result of obtained from the medium size company #3 corresponded with what mentioned before. That is, the employees thought that the Lean TPM implementation would reduce significant role in their working line and might have negative impact on their work as well.

Table A-9 shows that the company's employees tended to ignore the important of work purpose and work outcome much including their indifference to express their capability when having opportunity. This is a typical work culture of Thai people. However it could result in a severe impact on implementation process of Lean TPM activities that needs clear set of activity purposes. It was also found that employees had tendency to request the company in clearly dividing the level of responsibility in organizing small group activities comprising the head and the members of small group, which is the basic activity necessary for Lean TPM implementation activity.

Interestingly, the study also reveal that Behavioral Intention for Lean TPM implementation of employees who tended to implement the Lean TPM at the moderate level and also had tendency of not intending to do it as shown in Table A-10**.** Nevertheless the employees tended more to participate with Lean TPM activity as shown in Table A-11.

In regard to the finding obtained from company in the case study, the company executives wanted to implement the Lean TPM. It also revealed that the factors influencing the Lean TPM implementation of this company complied with what appeared in the Table A-12**:** Spearman's Correlation R (n=138) for the company in this case study**.** The table shows that all four UTAUT constructs, which acted as the determinants of TPM implementation acceptance and participation behavioral intention (BI) and usage behavior (BU), had strong correlation with the correspondent predicted latent variables which were BI and BU. The moderator variables which were voluntariness of use (VO), TPM knowledge level (KN), and working culture (CL) had positive strong correlation with behavior intention BI whereas age of employees (AGE) variable had very strong negative correlation with behavior intention and experience level of employees also had slightly negative correlation with behavior.

Following Table 4-8 showed statistical values of 6 UTAUT modules in which the data obtained from 1st questionnaire launching in the company for this case study.

Table 4-8: Statistics Values of 6 UTAUT Modules in Which the Data Obtained from 1st Questionnaire Launching (n=138)

	PE	EE	SI	FC	BI	BU
Mean	2.06	1.50	2.43	2.29	1.93	1.49
Std. Dev.	0.51	0.34	0.60	0.59	0.65	0.61

4.9 The Research Model Validity

The conceptual model created by PLS-Graph to access direct impact and Generalized Linear model, the most common method used in information systems research for moderator analysis, was adopted and used to measure the direct and interaction impact between the constructs moderated by other variables. In this study, the research model consists of twelve observed variables that can be measured directly and can be accessed through their indicators. The variables employed in this study were "Performance Expectancy, Effort Expectancy, Social Influence, Facilitating Conditions, Working Culture, Voluntariness of Use, Experience, Age, and Knowledge" determining behavioral intentions and Behavior of Use.

The test for impact of moderator variables such age, experience, voluntariness of use, culture, knowledge by using LISREL 8.80 covariance structure analysis of this study which could not consider the impact of gender on Lean TPM implementation due to the fact that most of employees in the company for the case study were male. So the effect of gender for this research would be reduced, then Figure 4-6 the research model with gender moderator would be modified into Figure 4-7 the research model as shown in the following:

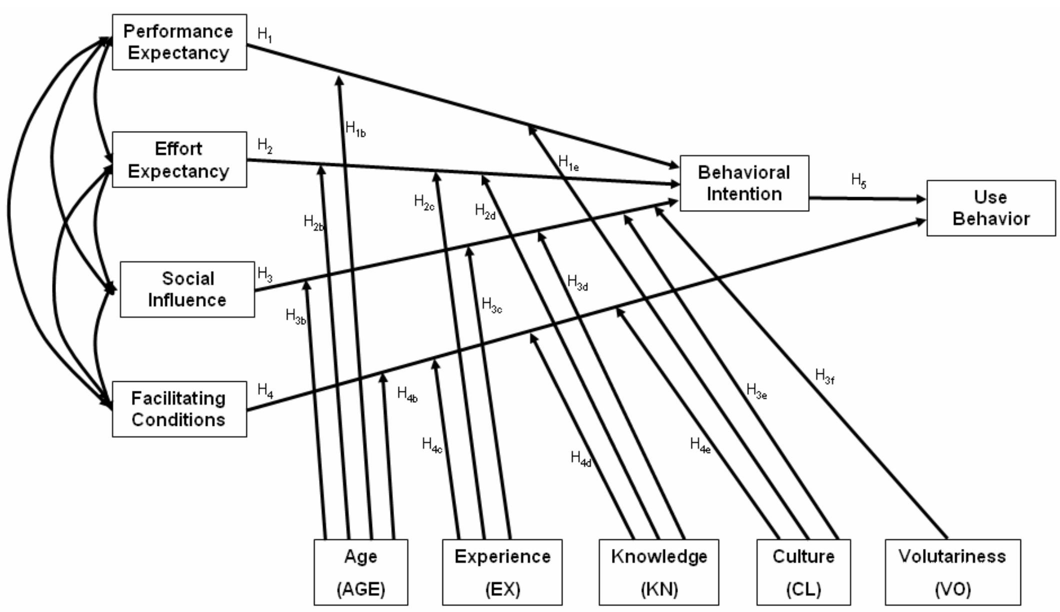


Figure 4-7: The Research Model for the Case Study

4.9.1 Measurement Structure

For the component of measurement structure, each UTAUT construct was divided for the calculation of path weight value by maximum likelihood estimation. The results are shown in Table 4-9. The data indicates that the measures are robust in terms of their good of fit indices. This research adopted the model assessment of fit by using fit indices according to the following criteria with the chi-square value without significant at $p > 0.05$ (Vassilios P. A. and Prodromos D.C., 2009): $\chi^2/df < 3.0$, GFI > 0.90 and RMR<0.05 including other fit indices such as AGFI>0.90, NFI>0.90, NNFI>0.90, CFI>0.90, RMSEA<0.06, and SRMR<0.05. In general, the key steps for structural equation modeling are as follows 1) Model specification, 2) Identification, 3) Estimation, 4) Testing fit, and 5) Re-specification, respectively.

Table 4-9: Measurement Structure Parameter Estimation Report

	Path	λ_X	λ_Y	χ^2	*d.f.*	χ^2/d.f.	p-value	RMSEA	t-test	S.E.	R^2
BI	BI1-BI	***	0.75	0.31	1	0.31	0.581	0.000	0.00	****	1.00
	BI2-BI	***	0.41						8.86	0.05	0.36
PE	PE1-PE	0.48	***	3.3	5	0.66	0.654	0.000	9.30	0.03	0.53
	PE2-PE	0.35	***						10.28	0.05	0.6
	PE3-PE	0.54	***						10.82	0.05	0.65
	PE4-PE	0.54	***						10.58	0.05	0.65
	PE5-PE	0.58	***						11.30	0.05	0.71
	PE6-PE	0.35	***						9.30	0.04	0.52
EE	EE1-EE	0.21	***	0.07	1	0.07	0.797	0.000	4.23	0.05	0.18
	EE2-EE	0.31	***						5016	0.06	0.25
	EE3-EE	0.21	***						6.63	0.03	0.51
	EE4-EE	0.25	***						6.57	0.04	0.49
SI	SI1-SI	0.44	***	0.03	1	0.03	0.853	0.000	8.86	0.05	0.49
	SI2-SI	0.61	***						13.64	0.04	0.93
	SI3-SI	0.47	***						10.18	0.05	0.60
	SI4-SI	0.65	***						9.56	0.07	0.54
FC	FC1-FC	0.69	***	0.28	2	0.14	0.868	0.000	13.57	0.05	0.91
	FC2-FC	0.36	***						7.93	0.05	0.40
	FC3-FC	0.58	***						11.21	0.05	0.69
	FC4-FC	0.21	***						5.64	0.04	0.22
EX	EX1-EX	2.43	***	0.02	1	0.02	0.897	0.000	8.85	0.04	0.46
	EX2-EX	-0.6	***						13.16	0.05	0.83
	EX3-EX	-0.37	***						6.26	0.04	0.28
	EX4-EX	-0.62	***						14.05	0.04	0.90
VO	VO1-VO	0.58	***	2.28	1	2	2.28	0.097	9.91	0.06	0.53
	VO2-VO	0.64	***						16.55	0.04	1.00
KN	KN1-KN	0.06	***	24.97	20	1.25	0.203	0.043	0.71	0.09	0.00
	KN2-KN	0.51	***						11.85	0.04	0.69
	KN3-KN	0.61	***						10.96	0.06	0.62
	KN4-KN	0.45	***						10.18	0.04	0.56
	KN5-KN	0.33	***						7.01	0.05	0.32
	KN6-KN	0.55	***						12.48	0.04	0.74
	KN7-KN	0.61	***						14.97	0.04	0.91
	KN8-KN	0.58	***						11.22	0.05	0.64
	KN9-KN	0.33	***						7.16	0.05	0.33

Table 4-9: Measurement Structure Parameter Estimation Report (cont.)

	Path	λ_X	λ_Y	χ^2	*d.f.*	χ^2/d.f.	p-value	RMSEA	t-test	S.E.	R^2
CL	CL1-CL	0.45	***	2.87	4	0.717	0.579	0.000	8.45	0.05	0.44
	CL2-CL	0.5	***						9.61	0.05	0.53
	CL3-CL	0.5	***						13.39	0.04	0.83
	CL4-CL	0.33	***						7.18	0.05	0.34
	CL5-CL	0.7	***						13.45	0.05	0.84

4.9.2 Structural Model

Based on the obtained data in responded questionnaires, by using Structural Equation Modeling (SEM) software named LISREL 8.80 to determine the structural model, Figure 4-8 shows the structural model results omitting the influence of the interacting moderator variables. The figure, all beta path coefficients are positive (i.e. in the expected direction) and statistically significant (at $p < 0.05$). Figure 4-8 revealed the result of structural model which omitted the influence of the interacting moderator variables. All beta path coefficients were positive with estimated parameters using LISREL maximum likelihood estimation with statistical significant at 0.05 level: $\chi^2 = 8.85$ $\chi^2 = 8.85$, *d.f.* = 8, χ^2/d.f. = 1.106, p-value = 0.355, RMSEA= 0.028, RMR= 0.017 and squared multiple correlations for Structural Equations (R^2) of BI and BU = 0.88 and 0.64, respectively as reported in the following table:

Table 4-10: Estimated Path Coefficients of Initial Model

Path	Path coefficient	t-test	S.E.
PE-BI	0.53	9.96	0.05
EE-BI	0.41	4.44	0.09
SI-BI	0.44	7.61	0.06
FC-BU	0.37	5.42	0.07
BI-BU	0.47	7.49	0.06

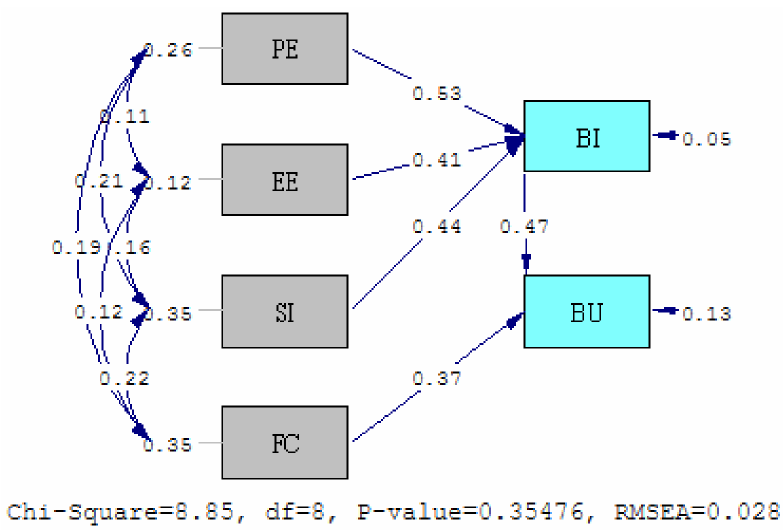


Figure 4-8: Initial Structural Model without Moderator Variables

The researcher complied his study with that of Chin et al (1996) in order to determine the interaction effect. Interaction terms were formulated by multiplying the corresponding indicators average value of the predictor and moderator constructs. Next section are the study on the influence of each construct moderator variables (AGE, EX, VO, CL, and KN) separately with related figures showing the structural models with each interaction effect. Finally, it presents the results of the structural models with all statistical significant moderator variables.

4.9.3 The Assessment of Age Influence

In determining the value of age impact on UTAUT model for TPM implementation of the employees of the company in this case study, it was based on the conceptual structure as shown Figure 4-9. There was determination for variables stemming from the interaction between different variables: AGE and PE, AGE and EE, AGE and SI, and AGE and FC respectively as shown below:

AGPE – a variable stems from the interaction between AGE and average PE which was the influence of the employees' age on path PE-BI.

AGEE- a variable stems from the interaction between AGE and average EE which was the influence of the employees' age on path EE-BI.

AGSI- a variable stems from the interaction between AGE and average SI which was the influence of the employees' age on path SI-BI.

AGFC- a variable stems from the interaction between AGE and average FC which was the influence of the employees' age on path FC-BU

The number of different variables calculated through use of LISREL 8.8 were as follow: number of input variables 12, number of Y - variables y2 and y2, number of X - variables 4, number of ETA - variables BI and BU, number of KSI - variables 4, and number of observations 138.

In regard to SEM construction in order to assess the impact of AGE on UTAUT model through use of LISREL 8.80, after obtaining the model specification, then there was the model modification until the best one was achieved through use of assessment of fit indices according to the following criteria: χ^2/df < 3.0, p-value > 0.05, RMSEA <0.06, CFI > 0.90, GFI 0.90, t-value > 1.96. For the model modification in according with Figure 4-9, there were three replications by removing each variable in each round (AGEE, AGSI, and AGFC) out of the model respectively yielding the result as shown in Table 4-11. In short, it can be said that age had an influence on path PE on UTAUT model as Figure 4-10.

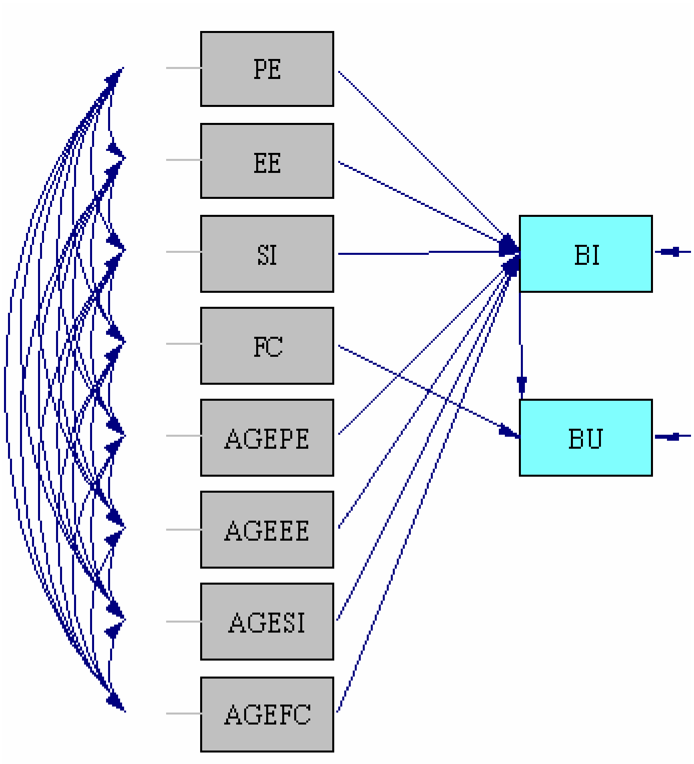


Figure 4-9: Conceptual Diagram with Age Interaction Influence

Table 4-11: The Report on the Outcome of the Best Model with Age Influence

Modification no.	modification	χ^2	χ^2/d.f.	p-value	RMSEA	CFI	GFI	t-value
0	-	14.28	0.8925	0.57786	0.000	1.00	0.98	<1.96
1	Remove AGEE	17.11	1.0065	0.4471	0.007	1.00	0.98	<1.96
2	Remove AGSI	17.65	0.9806	0.4792	0.000	1.00	0.97	<1.96
3	Remove AGFC	18.27	0.9616	0.50441	0.00	1.00	0.98	>1.96
Final	-	18.27	0.9616	0.50441	0.00	1.00	0.98	>1.96

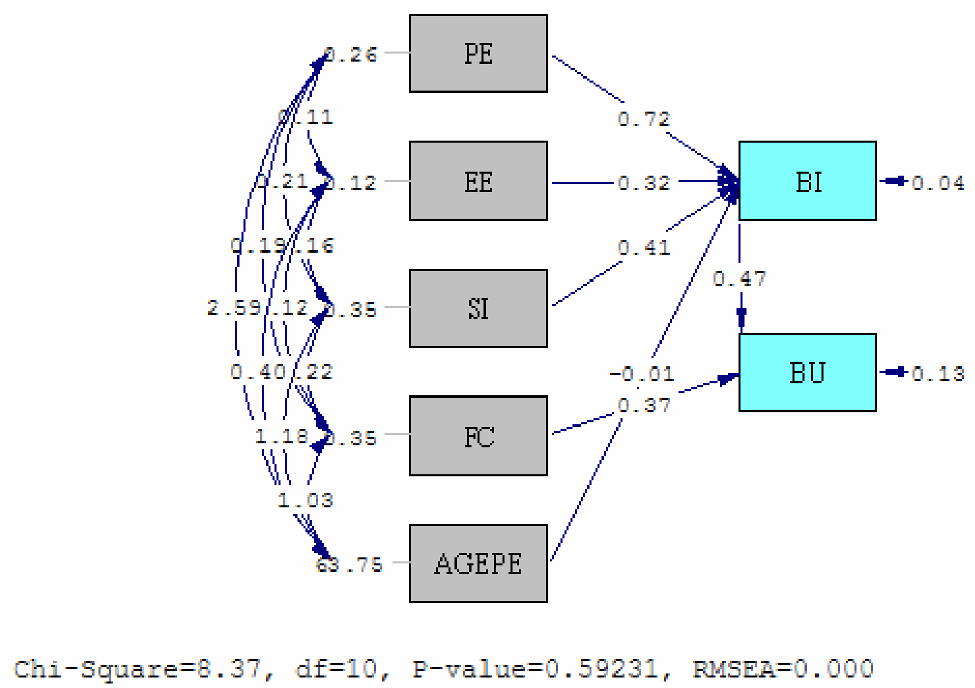


Figure 4-10: The Final Model with Age Influence

4.9.4 The Assessment of Employees' Knowledge Influence

In determining the value of employees' knowledge influence on UTAUT model for TPM implementation of the employees of the company in this case study, it was based on the conceptual structure as shown Figure 4-11. There was determination for variables stemming from the interaction between different variables: KN and EE, KN and SI, and KN and FC respectively as shown below:

KNEE – a variable stems from the interaction between KN and average EE which was the influence of the employees' knowledge on path EE-BI.

KNSI - a variable stems from the interaction between KN and average SI which was the influence of the employees' knowledge on path SI-BI.

KNFC - a variable stems from the interaction between KN and average FC which was the influence of the employees' knowledge on path FC-BU

The number of different variables calculated through use of LISREL 8.8 were as follow: number of input variables 19, number of X - Variables (KN1-KN9) 9, number of KSI - variables 1, and number of observations 138.

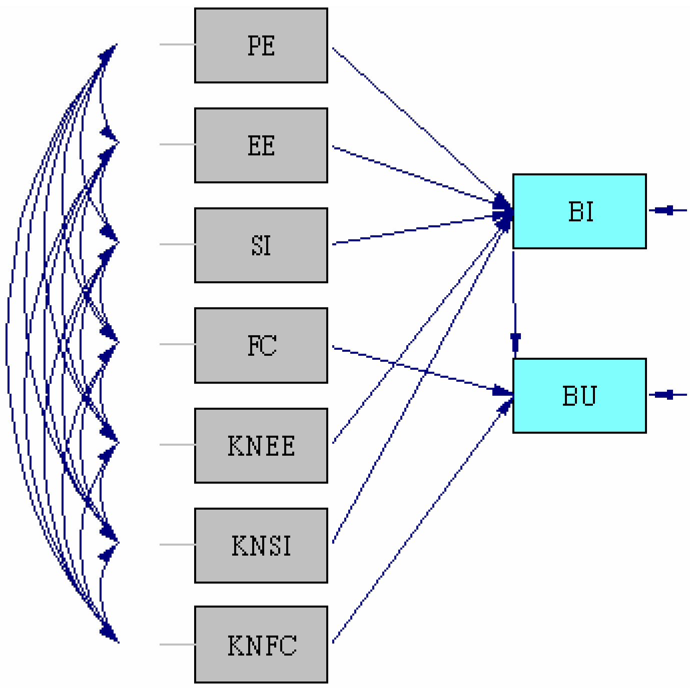


Figure 4-11: Conceptual Diagram with Knowledge Interaction Influence

In regard to SEM construction in order to assess the influence of KN on UTAUT model through use of LISREL 8.80, after the model modification in accordance with Figure 4-11, there were two replications by removing each variable in each round (KNSI and KNFC) out of the model respectively yielding the results as shown in Table 4-12. In short, it can be said that employees' knowledge had an influence on path SI-BI on UTAUT model as shown in Figure 4-12.

Table 4-12: The Report on the Outcome of the Best Model with Employees' Knowledge Influence

Modification no.	modification	χ^2	χ^2/d.f.	p-value	RMSEA	CFI	GFI	t-value
0	-	7.91	0.565	0.8942	0.00	1.00	0.99	<1.96
1	Remove KNSI	7.90	0.5267	0.9276	0.00	1.00	0.99	<1.96

Table 4-12: The Report on the Outcome of the Best Model with Employees' Knowledge Influence (cont.)

Modification no.	modification	χ^2	χ^2/d.f.	p-value	RMSEA	CFI	GFI	t-value
2	Remove KNFC	8.04	0.5025	0.9476	0.00	1.00	0.99	>1.96
Final	-	6.94	0.694	0.7313	0.00	1.00	0.99	>1.96

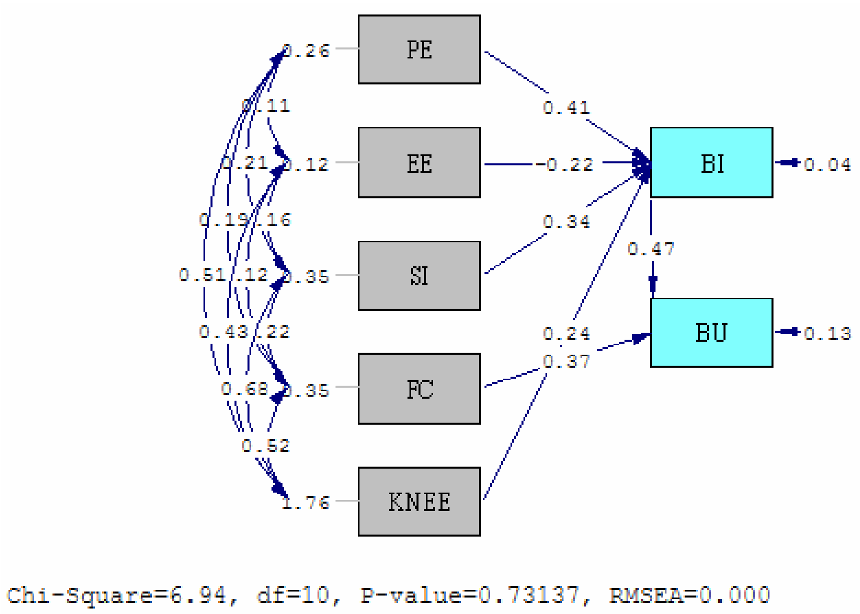


Figure 4-12: The Final Model with Employees' Knowledge Influence

4.9.5 The Assessment of Employees' Experience Influence

In determining the value of employees' experience influence on UTAUT model for TPM implementation of the employees of the company in this case study, it was based on the conceptual structure as shown in Figure 4-13. There was determination for variables stemming from the interaction between different variables: EX and EE, EX and SI, and EX and FC respectively as shown below:

EXEE – a variable stems from the interaction between EX and average EE which was the influence of the employees' experience on path EE-BI.

EXSI – a variable stems from the interaction between EX and average SI which was the influence of the employees' experience on path SI-BI.

EXFC- a variable stems from the interaction between EX and average FC which was the influence of the employees' experience on path FC-BU.

The numbers of different variables calculated through use of LISREL 8.8 were as follows: numbers of input variables 4, numbers of X - Variables 4, numbers of KSI - variables 1, numbers of observations 138

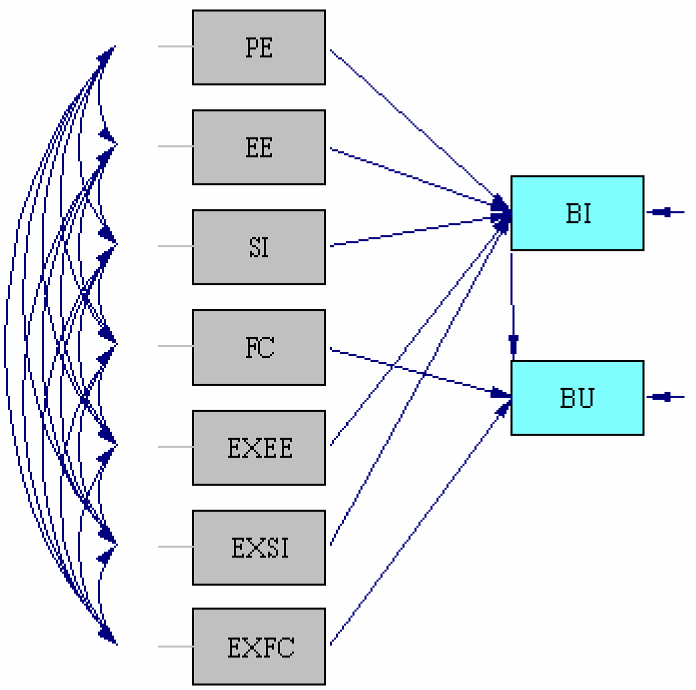


Figure 4-13: Conceptual Diagram with Experience Interaction Influence

In regard to SEM construction in order to assess the influence of EX on UTAUT model through use of LISREL 8.80, after the model modification in accordance with Figure 4-13, EXFC was removed out of the model yielding the result as shown in Table 4-13 which can be seen that the original model with EXFC was better than removing EXFC. In short, it can be said that employees' experience had an influence on path EE-BI, SI-BI and FC-BU on UTAUT model as Figure 4-14.

Table 4-13: The Report on the Outcome of the Best Model with Employees' Experience Influence

Modification no.	modification	χ^2	χ^2/d.f.	p-value	RMSEA	CFI	GFI	t-value
0	-	13.81	1.973	0.0547	0.086	1.00	0.98	<1.96
1	TD(4,4)	13.81	0.986	0.4643	0.000	1.00	0.98	<1.96
2	Remove EXFC	14.21	1.184	0.287	0.038	1.00	0.97	<1.96
Final	Recover EXFC	13.81	0.986	0.4643	0.000	1.00	0.98	<1.96

4.9.6 The Assessment of Voluntariness of use Influence

In determining the value of influence for voluntariness of use on UTAUT model for TPM implementation of the employees of the company in this case study, it was based on the conceptual structure as shown in Figure 4-15. There was determination for variables VOSI stemming from the interaction between VO and SI with the influence on path SI-BI on UTAUT model as shown below. The numbers of different variables calculated through use of LISREL 8.80 were as follows:

1) The Number of Input Variables = 2,
2) The Number of X - Variables = 2,
3) The numbers of KSI - Variables = 1,
4) The Numbers of Observations = 138

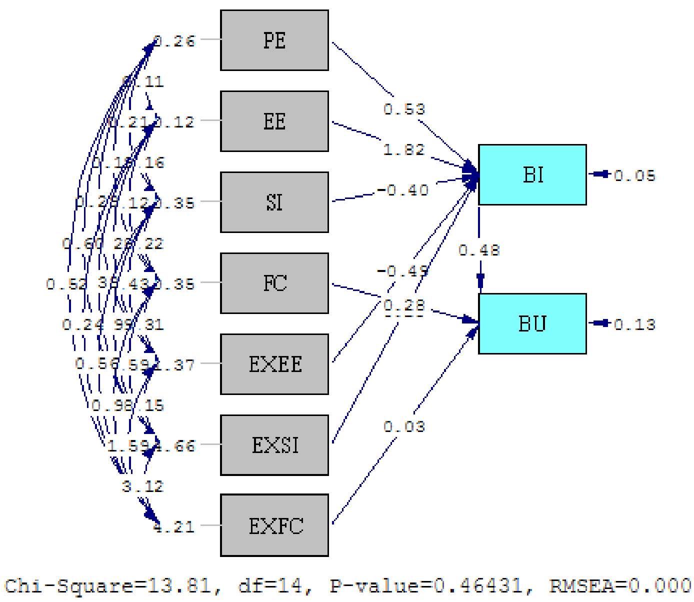


Figure 4-14: The Best Model with Experience Interaction Influence

In regard to SEM construction in order to assess the influence of EX on UTAUT model through use of LISREL 8.80, based on Figure 4-15, there was not any model modification yielding the results as shown in Table 4-14. In short, it can be said that employees' voluntariness of use had an influence on path EE-BI and SI-BI on UTAUT model as shown Figure 4-16.

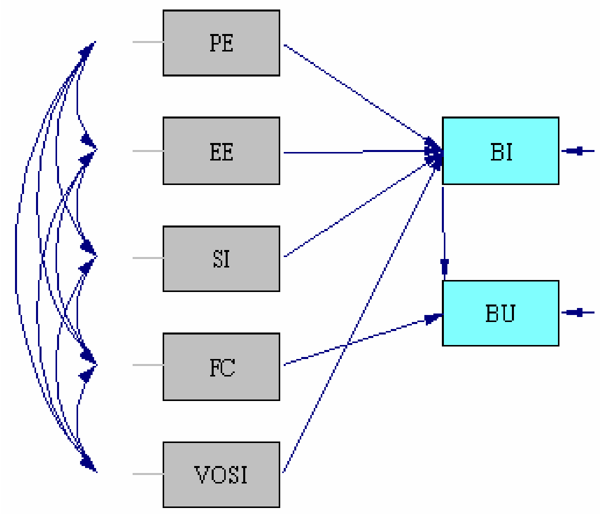


Figure 4-15: Conceptual Diagram with Employees' Voluntariness of Use Interaction Influence

Table 4-14: The Report on the Outcome of the Best Model with the Influence of Employees' Voluntariness of Use

Modification no.	modification	χ^2	χ^2/d.f.	p-value	RMSEA	CFI	GFI	t-value
Final	-	13.78	1.376	0.1840	0.053	1.00	0.97	>1.96

4.9.7 The Assessment of Working Culture Influence

In determining the value of working culture influence on UTAUT model for TPM implementation of the employees of the company in this case study, it was based on the conceptual structure as shown in Figure 4-17. There was determination for variables stemming from the interaction between different variables: CL and PE, CL and EE, CL and SI, and CL and FC respectively as shown below:

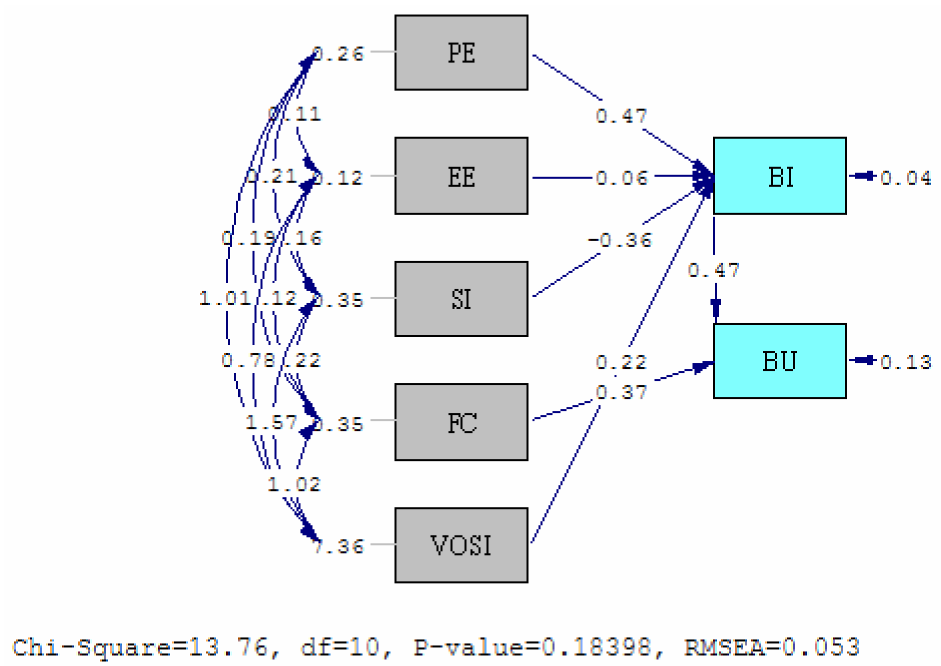


Figure 4-16: The Best Model with Voluntariness of Use Interaction Influence

CLPE – a variable stems from the interaction between CL and average PE which was the influence of the employees' working culture on path PE-BI.

CLEE- a variable stems from the interaction between CL and average EE which was the influence of the employees' working culture on path EE-BI.

CLSI- a variable stems from the interaction between CL and average SI which was the influence of the employees' working culture on path SI-BI.

CLFC- a variable stems from the interaction between CL and average FC which was the influence of the employees' working culture on path FC-BU

In regard to SEM construction in order to assess the impact of CL on UTAUT model through use of LISREL 8.80, after obtaining the model specification. For the model modification in according with Figure 4-17, there were three replications by removing each variable in each round (CLPE, CLSI, and CLFC) out of the model respectively yielding the result as shown in Table 4-15 meaning that working culture variable CL did not influence any path in research model.

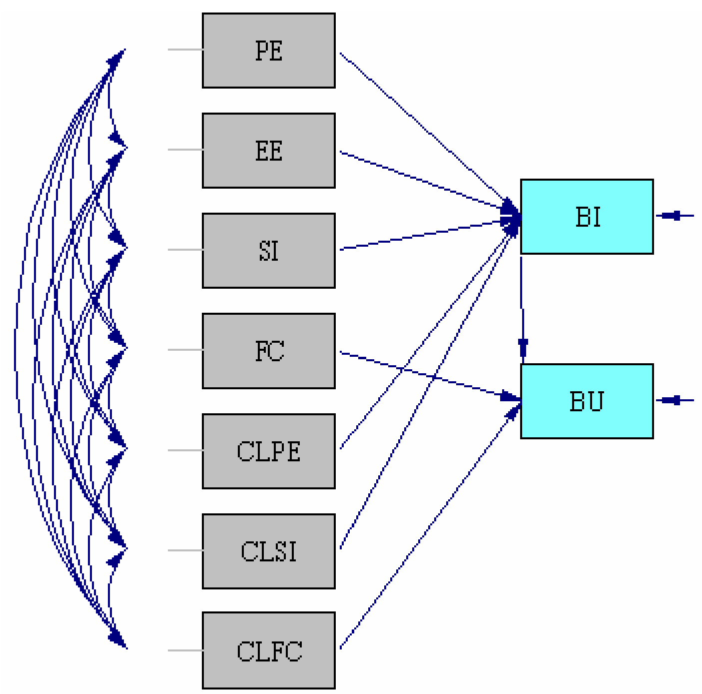


Figure 4-17: Conceptual Diagram with Working Culture Interaction Influence

Table 4-15: The Report on the Outcome of the Best Model with Working Culture Influence

Modification no.	modification	χ^2	χ^2/d.f.	p-value	RMSEA	CFI	GFI	t-value
0	-	16.88	1.055	0.393	0.021	1.00	0.97	<1.96
1	Remove CLPE	17.23	1.15	0.429	0.010	1.00	0.98	<1.96
2	Remove CLSI	11.27	0.939	0.058	0.000	1.00	0.98	<1.96
3	Remove CLFC	12.68	0.975	0.473	0.000	1.00	0.98	>1.96

The assessment on the influence of moderator variables -- AGE, EX, VO, CL and KN -- on path PE-BI, EE-BI, SI-BI, and FC-BU revealed the results as concluded in Table 4-16 and shown in Figure 4-18.

Table 4-16: Pairs of UTAUT Construct with Moderator Variables (*** with interaction effect)

	AGE	EX	VO	CL	KN
PE-BI	***	-	-	-	-
EE-BI	-	***	-	-	***
SI-BI	-	***	***	-	-
FC-BU	-	***	-	-	-

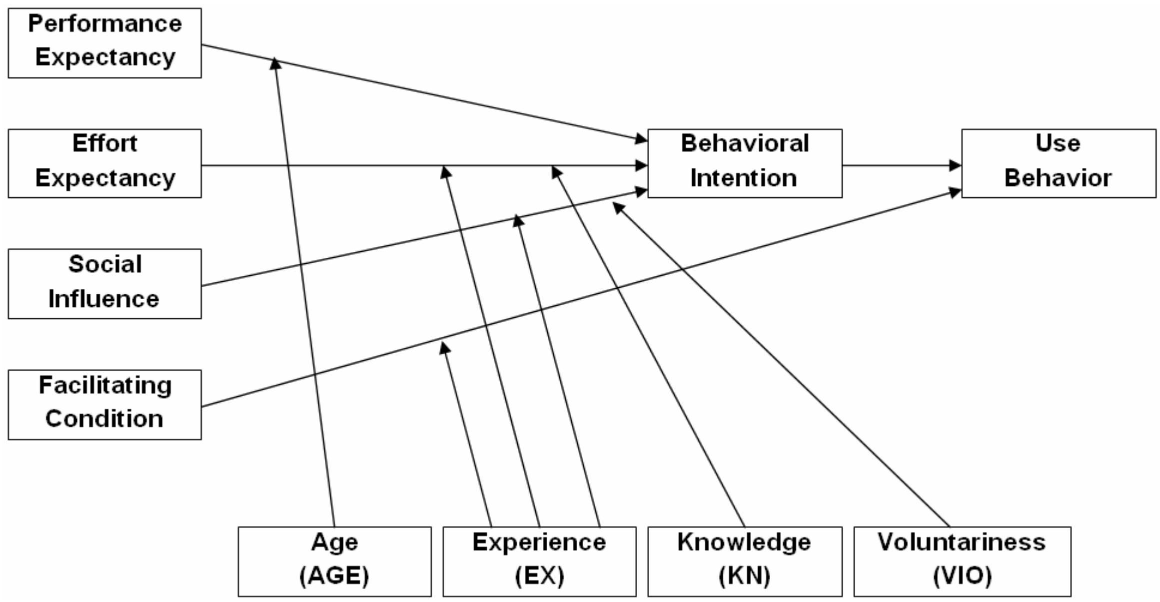


Figure 4-18: Research Conceptual Model of UTAUT during the Stage of the First TPM Training

With regard to the use of software LISREL 8.8 to determine the structural equation model of TPM implementation acceptance and participation behavior of the company employees after the first TPM training, it revealed as shown in Figure 4-19: UTAUT model during the stage of the first TPM training with the value of the model fit in terms of χ^2 = 15.38, d.f. = 20, χ^2/d.f. = 0.769, p-value=0.7544, RMSEA = 0.00, CFI = 1.00, and GFI = 0.98. Its structural equation model is shown below:

$$BI = 0.60(PE) + 0.82(EE) - 0.89(SI) - 0.01(AGEPE) - 0.33(EXEE) + 0.23(EXSI) + 0.16(VOSI) + 0.1(KNEE)$$

$$BU = 0.48(BI) + 0.28(FC) + 0.03(EXFC)$$

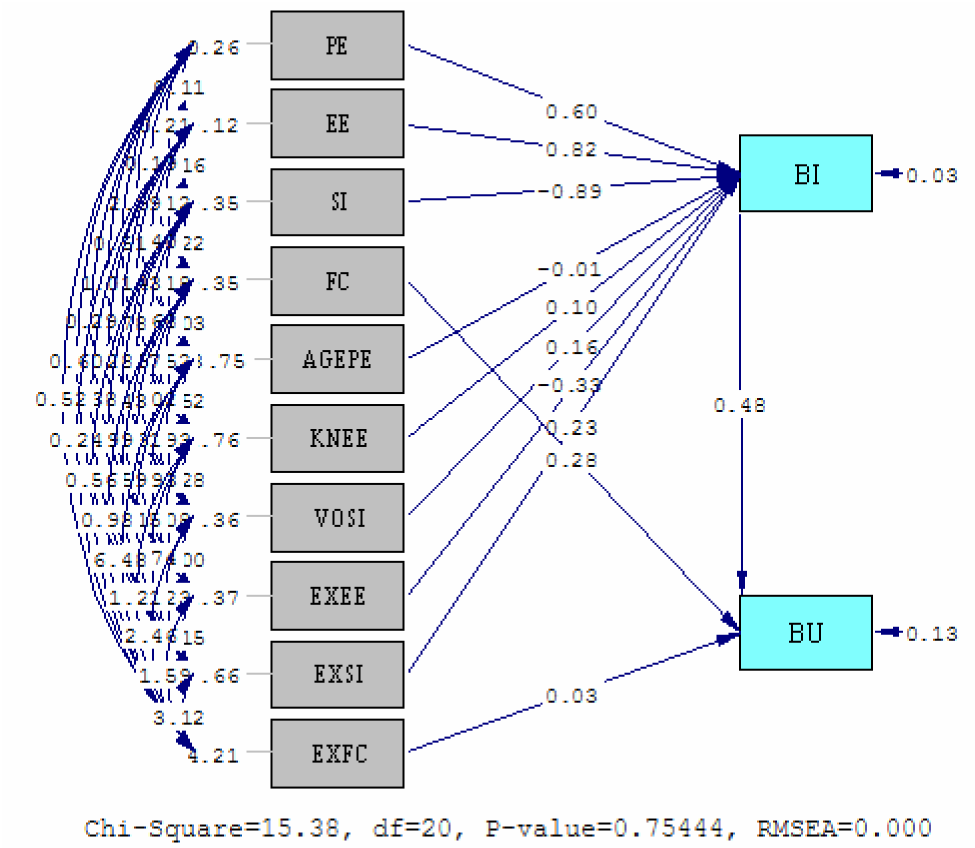


Figure 4-19: The Modified UTAUT Model during the Stage of the First TPM Training of Company in the Case Study

From Figure 4-19 shows the result of the model which highlights the factor influencing the acceptance to participate in Lean TPM activity of the company for the case study by applying UTAUT. Regarding this, it was found that there was the influence of 4 predictors comprising performance expectancy (PE), effort expectancy (EE), social influence or subjective norm (SI), and facilitating condition (FC) on behavior intention (BI) and behavior of use of technology (BU). The path beta coefficients show the level of influence for the first three predictors: PE, EE, and SI on BI with the values of beta b11 the effect of PE on BI (0.0.6), beta b12 the effect of EE on BI (0.82), and beta b13 the negative effect of SI on BI (-0.89), respectively, while the path beta coefficient from BI to BU was beta b21 (0.47). For the interaction effect of moderator variables in the final structural model with the values of beta b15 the slightly negative interaction effect of AGE and PE on BI (-0.01), beta b16 the interaction effect of KN and EE on BI (0.1), beta b17 the negative interaction effect of EX and EE on BI (-0.33), beta b18 the interaction effect of EX and SI on BI (0.18), and beta b19 the interaction effect of VO and SI on BI (0.16), In addition, the value of beta b24 (0.37) was for path beta coefficient from FC to BU.

It is evident from the study that there were some interesting points worth mentioning here. In fact, Table 4-8 shows statistics values of 6 UTAUT modules which are very low. This means that the significant TPM implementation driver factors were ignored by the employees and related work units, as a consequence, the behavioral intention and use of TPM was also low. Regarding the correlation among the variables in UTAUT shown in Table A-12 (Spearman's correlation R (n=138) for the company in this case study**,** it was found that the level of correlation value could be categorized into 4 groups which were the group of variables with strong correlation ($0.8 \leq | r | \leq 1.0$, Devoure J.L. (2008)) with BI and BU (PE, EE, SI, KN, VO, and CL); the one with moderate correlation with BI and BU (FC); the group of variables with moderate negative correlation with BI and BU and having only EX variable; and the AGE variable having strong negative correlation with BI and BU.

Regarding the Figure 4-19 UTAUT model during the stage of the first TPM training, it revealed that the employees' acceptance and participation behavior for TPM implementation depended on their perceptions and feeling towards TPM activities. In other words, if it yielded positive outcome towards their work performance, they would be willing to do it and they should be understandable and easy to perform for them. In addition they need help and support from the company which should set the strategies to promote management system to convince them that TPM activity would help them to achieve their work performance without any difficulties. The company's executives and involved work units should also provide facilities for the TPM implementation activity. In the mean time, there were the findings showing that knowledge (KN), voluntariness of use (VO), and working culture (CL) were the moderator variables having the interaction with PE, EE, and SI resulting in positive effect on the relation with BI. This means that for the employees with TPM knowledge and understanding till being able to perform the activities would have positive interaction with EE resulting in their willingness to participate more since they feel that the activities are easy to perform. Furthermore, the company must improve the company's working culture to correspond with Thai working style that still conform with TPM implementation. With this regard, the employees would be encouraged to understand that good performance needs good objectives, a search for effective performance styles and the new working unit organization focusing on the employees' clear role and duties which includes a good job evaluation system, for the company, that reflects their real performance.

From the investigation of final structural equation model of the company in this case study, it was found that, resistance force for TPM implementation participation came from social environment and organization relationships that did not seem to encourage them to accept and need to participate much in the TPM activity. Also, those with older age were likely to participate less than the younger ones. From what mentioned above, it was compared to UTAUT model of Venkatesh et al., (2003) suggesting that moderation variables namely experience, knowledge, and voluntariness of use were the moderators for moderated corresponding path as found to be at low level in this research. As a consequence, it should be enhanced as it would lead to more acceptance for the whole implementation. The next important step was to further study in order to answer the following questions.

1) How could we improve believe of employees that Lean TPM could help them enhance their work desired performance?

2) How could we improve the techniques that could help eases Lean TPM implementation?

3) How could we improve the effect of social influence on behavioral intention for better Lean TPM implementation?

4) How could we improve the effect of facilitating condition on use behavior or better Lean TPM implementation?

4.10 Force Field Analysis

Force Field Analysis is a useful technique for looking at all the forces for and against a decision. In effect, it is a specialized method of weighing pros and cons.

By carrying out the analysis decision makers can plan to strengthen the forces supporting a decision, and reduce the impact of opposition to it. To carry out a force field analysis in this study, follow these steps: first, list all forces for change in one column, and all forces against change in another column. Second, assign a score to each force, from 1 (weak) to 5 (strong). Then, draw a diagram showing the forces for and against change. Show the size of each force as a number next to it.

Force Field Analysis sheet was provided through the brainstorming among the managers and Lean TPM Pillar leader of which the whole components complied with UTAUT module that could affect employees. This is in line with Force Field Analysis sheet shown in Table A-13 with the questionnaire for the data survey on resistance and supporting forces for Lean TPM activity implementation of the organization as a whole. Figure 4-20 shows both force fields toward Lean TPM with employees' comments shown in Table A-14. Those comments were partial useful for latter drafting the company's policies and measures for creating better cooperative atmosphere among the employees. It was found that the encouragement force field to implement Lean TPM activity had 1,497 which were higher than the resistance force to implement the Lean TPM activity which had only 173.

Regarding to the frequency of each FFA 2 item number as shown in the following table, it revealed that FFA 2 item number 11 which had the highest frequency (17) and the resistance force score of 25 with the statement of "You do not know what usefulness it would make to the company." In the section that allowed the respondents express their opinion, meaning that they did not accept the participation. Likewise, FFA 2 number 12 which made the maximum resistance force field had 38 score while having the frequency of only 13, with the statement "You are afraid that you will be punished if you make something wrong.", whereas, FFA 2 number 15 had resistance force field score of 25 equal to FFA 2 item number 11. However, it was found that for every FFA 2 item except the item number 13, they had the highest rank of 5 indicating the severity of refusal to Lean TPM activity. The company executives should, therefore, consider reducing the resistance force to the least despite the high encouragement force field. In this case, it is necessary to correct FFA 2 item number 12, 11, and 15 through any relevant activity in order to create more understanding for

Lean TPM activity by emphasizing on the usefulness of Lean TPM, creation of confidence in conducting Lean TPM activity without causing them miserable in their duty performance.

Table 4-17: Frequency of Each FFA 2 Item Number

	Frequency of each FFA 2 item number							
Score	11	12	13	14	15	16	17	18
1	15	5	9	11	10	10	11	11
2	0	1	0	0	0	0	0	0
3	0	1	2	0	0	0	1	0
4	0	2	0	1	0	0	0	0
5	2	4	0	1	3	1	1	1
Total	25	38	15	20	25	15	19	16

The conclusion on the basic study of the problem and context of Lean TPM implementation

This chapter consisted of 3 parts which were general condition and problem of the production of company for this case study, the study on the acceptance of Lean TPM implementation among the employees according to UTAUT model, and force field analysis which are as follows:

1) Before the implementation of Lean TPM activity, it was found that the company did not have good and effective manufacturing practice. It had low value of overall equipment effectiveness resulting in a high overall plant loss and a high inventory.

2) Regarding the study on the acceptance of Lean TPM implementation of employees according to UTAUT model after finishing of Lean TPM introductory training across the plant, it revealed that the employees did not know what was the useful of Lean TPM implementation (low PE score) and they still thought the implementation Lean TPM was still complicated leading to difficulties to understand (low EE score). They also felt that the executives did not support the resource and gave enough suggestions (low FC score). The social relation whit in the group and the

executive was not good enough (low SI score) to motivate them to do the Lean TPM. The employees with higher experience in Lean TPM thought that the Lean TPM would reduce their performance. They worked in accordance with conventional Thai working culture style without knowing the real purpose of the work. This would oppose the effective Lean TPM implementation.

Forces FOR change	Score
No.1	137
No.2	160
No.3	182
No.4	124
No.5	184
No.6	117
No.7	150
No.8	139
No.9	146
No.10	158
TOTAL	1,497

Change proposal

TPM IMPLEMENTATION

Forces AGAINST change	Score
No.11	25
No.12	38
No.13	15
No.14	20
No.15	25
No.16	15
No.17	19
No.18	16
No.19	0
TOTAL	173

Figure 4-20: Force Field Analysis on Lean TPM Implementation

3) In the study on force field analysis, it revealed that there should be reduction of the resistance force to the least through any relevant activity in order to create more understanding for Lean TPM activity by emphasizing on the usefulness of Lean TPM, creation of confidence in conducting Lean TPM activity without causing them miserable in their duty performance.

4.11 Key Lean TPM Implement Success Factors

When considering the UTAUT model of Venkatesh et al., (2003), it would be appropriate for the company for this case study to consider the improvement of employees' performance expectancy, effort expectancy, social influence, and facility condition by directly improving them with use of any proper activities or through indirect way by improving the employees' TPM implementation knowledge and skills, small group activity experience, work units and organize working culture, and voluntariness of Lean TPM implementation.

As a consequence, the company executives considered the finding of this study to make the implementation procedure easier and create good relation with those doing Lean TPM promotion activity. This made the employees feel that whenever they confronted with any obstacles regarding the Lean TPM implementation, they should have advisers and facilitators to give adequate support in terms of resources and guidelines, for the activity implementation including the creation of good relationship and work atmosphere among the personnel and the group comprising employees at the same level of work line, the superiors and the subordinates, and the executives and every employees, which can result in the more acceptance among every personnel.

For the force field survey, the employees had comments in the attached part. The obtained comments were diversified as shown in the Table A-14. This part was partially useful for drafting the company's policies and measures for creating better cooperative atmosphere among the employees.

With regard to the study on relationships among the TPM, TOM, and TPM by Cau et al. (2001), was claimed that TQM and TPM were the two pillars with support the JIT production system of which 5 common practices used in linking special basic techniques of each programs were employed to enhance manufacturing performances. However, Lean TPM implementation at the beginning state, this study would take the following components in order to construct the framework for Lean TPM implementation

1) Common Practices which consists of follows:
   1.1) Committed Leadership
   1.2) Strategic Planning

1.3) Cross-Functional Training

1.4) Employee Involvement

1.5) Information and Feedback

2) TPM Basic Techniques

2.1) Autonomous and Planned Maintenance

2.2) Technology Emphasis

2.3) Proprietary Equipment Development

Also, there were nine categories whose parts overlap the above two components towards successful TPM implementation (Bamber and Hides, 1999). The six out of nine items which were not in overlap part were 1) the existing organization, 2) measures of performance, alignment to company missions, 3) an implementation plan, 4) knowledge and benefits, 5) time allocation for implementation, and 6) motivation of management and workforce.

For improving the key Lean TPM implement success factors, this part was performed through the allocation of three month Lean TPM implementation after trainings of mentioned TPM basic knowledge were done. On the commencement date of Lean TPM implementation (TPM kick-off), the company's executives showed his enthusiasm to participate in Lean TPM activity. More importantly, they supported the ideas and the needs useful in the long run and correspond to the Lean TPM implementation. As the result there was an announcement of the policy together with setting the activities which motivate the employees to be more willing to participate in it. In fact, the information used for organizing the activity emerged from the employees' brainstorming (K-J method) at the levels of managers, engineers, supervisors, and small group leaders. Based on the structural equation modeling information together with force field analysis data, the several TPM promotion policies and the measures obtained from the brainstorming were relevant to the creation of motivations among the employees towards Lean TPM implementation. These could be concluded as 1) Personnel Development System, 2) Creation of Motivation, and 3) Employees Performance Appraisal System.

The following study shows how to explore Personnel Development in relevant to the small group activity implementation comprising two parts: the study on the

Characteristics of SGA Members Effecting OEE Improvement and the study on the influence of the Characteristics of Managers and supervisor impacting SGA success in con junction with the SGA capacity.

4.11.1 Considerations on Characteristic of SGA Members Effecting OEE Improvement

According to the survey on research dealing with structural equation modeling which showed moderating factors influencing TPM implementation acceptance and participation behavior comprising age, experience, voluntariness of use, knowledge and working culture of the company in this case study, which, for this research, were used to moderate four UTAUT construct variables (PE, EE, SI, and FC), it was found that there were the only first four factors possessing special characteristics for each SGA member. In fact, only the knowledge can be enhanced during the preparation stage for TPM implementation. From the obtained questionnaires (138 out of 143) SGA members who worked in 18 sub-processes, of which each had SGA members SGA members attending the TPM development program. The keys to success in SGA comprise motivation, ability, and opportunity (Fujikoshi, 1990, Nakajima, 1988) as defined for the knowledge and skill level with employee's education level adopted for this research such as 1)Education level, 2) Basic mechanical/electrical techniques, 3) Mechanical part abnormality, 4) Machine losses and autonomous maintenance principle, 5) TPM introduction and group function and role, 6) Pillar implementation, 7) Human growth need relate basic TPM, 8) Basic tool of SGA and information feed back, and 9) Basic SGA management techniques and SGA activity.

Those significant Lean TPM implementation success factors could be enhanced with use of trainings so that their extent of knowledge and skills could be identified in the research. This research, therefore, adopted the below topics to be used as a set of variables to present the regression equation for describing the relation between set of related TPM basic knowledge and skill and OEE improvement outcome:

KN1= Education Level

KN2= Basic Mechanical/Electrical Techniques Knowledge and Skills Level

KN3= Mechanical Part Abnormality Knowledge and Skills Level

KN4= Machine Losses and Autonomous Maintenance Principle

KN5= TPM Introduction and Group Function and Role Knowledge and Skills Level

KN6= Pillar implementation Knowledge and Skills Level

KN7= Human Growth Need Relate Basic TPM Knowledge and Skills Level

KN8= Basic Tool of SGA and Information Feed Back Knowledge and Skills Level

KN9= Basic SGA Management Techniques and SGA Activity Knowledge and Skills Level

KN = Group mean value of all 9 knowledge and skills items

Due to the fact that TPM implementation activities were characterized as the ones needing integrated skills, knowledge and cooperation from the members within SGA group, and with the main goals in improving OEE while reducing the wastes in the production processes leading to the direct improvement of process value stream and final modification of overall plant effectiveness. OEE improvement was performed via Focused Improvement activity with cooperation with other 2 main TPM pillar such as Autonomous Maintenance and Planned Maintenance. Some example improvement cases were present in later chapter.

During the commencement of the Lean TPM activity, the company provided the training on basic TPM related knowledge and skills (K2-K9) for the employees with the primary aim to develop every employees to enhance these knowledge and skills to maintain at level four out of five. In the training, it was found that some employees could not attend every topics or understand TPM completely. Table 4-18 shows the average scores of knowledge and skills (KN1-KN9) of the groups. Two months after the company announcement for the activity implementations of 18 production groups, the value of OEE for each machine changed in a better direction as shown in Table 4-18: SGA which display SGA group's knowledge and skills value and its OEE value level. It also appears that their was a correlation between the SGA group's knowledge and skills and OEE value as shown in Table 4-19. It was interesting to find that most of the knowledge except their educational background level (KN1) had a very strong correlation with OEE level.

This could be concluded that SGA with the high level of knowledge and skills on KN2-KN9 could be more able to improve OEE of the machines than that of the lower ones, whereas the group of the employees who had lower educational level would be more able to cooperate for the OEE improvement than that of the higher one.

It also appears that their was very strong correlation between the SGA group's mean knowledge and skills (KN) and OEE value as shown in Table 4-20. From the equation showing the relation obtained structural model, it revealed that the knowledge and skill of small group was the moderator factor having interaction with effort expectancy appearing in UTAUT model.

Table 4-18: SGA Group Knowledge and Skills Value - OEE Value (n=18 groups)

Group	KN1	KN2	KN3	KN4	KN5	KN6	KN7	KN8	KN9	KN	OEE
SGA1	2.43	3.64	3.21	4.00	3.86	4.14	4.00	3.64	4.43	3.71	0.83
SGA2	1.80	1.80	2.80	3.00	2.33	3.20	3.40	2.10	2.50	2.55	0.40
SGA3	2.25	3.00	3.08	3.92	4.17	4.17	4.00	4.00	4.25	3.65	0.80
SGA4	2.09	2.91	2.82	3.73	3.45	3.55	4.09	3.45	2.91	3.22	0.56
SGA5	2.00	3.50	3.50	5.00	4.50	5.00	5.00	5.00	4.50	4.22	0.85
SGA6	1.86	3.29	2.71	4.14	4.29	4.29	4.43	3.57	2.86	3.49	0.74
SGA7	2.00	3.13	3.00	3.00	3.13	3.00	3.25	3.13	3.00	1.96	0.52
SGA8	2.00	3.25	3.25	4.13	3.88	4.00	3.88	3.13	3.25	3.42	0.78
SGA9	2.00	2.86	2.71	3.14	3.71	4.00	3.86	3.71	2.71	3.19	0.57
SGA10	2.14	4.29	3.71	4.29	4.00	4.29	4.29	3.86	3.71	3.84	0.84
SGA11	2.00	1.67	2.33	2.50	2.50	2.33	3.33	2.50	2.50	2.41	0.30
SGA12	2.40	2.80	3.20	4.00	3.80	4.00	3.80	3.40	3.20	3.40	0.76
SGA13	2.10	3.40	3.50	4.00	3.70	3.70	4.20	4.00	3.90	3.61	0.85
SGA14	2.00	4.50	3.50	5.00	4.50	5.00	4.50	5.00	5.00	4.33	0.86
SGA15	2.89	2.11	2.67	3.67	4.00	3.89	3.56	4.22	4.11	3.46	0.71
SGA16	2.25	3.00	3.25	3.50	4.50	4.25	4.50	3.75	3.25	3.58	0.70

Table 4-18: SGA Group Knowledge and Skills Value - OEE Value (n=18 groups) (cont.)

Group	KN1	KN2	KN3	KN4	KN5	KN6	KN7	KN8	KN9	KN	OEE
SGA17	2.00	4.00	3.00	4.00	4.00	4.50	3.50	4.00	4.50	3.72	0.91
SGA18	2.10	1.70	2.20	2.00	2.40	2.80	2.50	1.90	1.70	2.14	0.26
min	1.80	1.67	2.20	2.00	2.33	2.33	2.50	1.90	1.70	1.70	
max	2.89	4.50	3.71	5.00	4.50	5.00	5.00	5.00	5.00	4.33	
SD	0.25	0.83	0.41	0.77	0.69	0.71	0.58	0.83	0.89	0.58	

Table 4-19: Correlation Between SGA Group's Knowledge and Skills Value and OEE Value

	KN1	KN2	KN3	KN4	KN5	KN6	KN7	KN8	KN9	OEE
KN1	1									
KN2	-0.12	1								
KN3	0.02	0.81	1							
KN4	0.06	0.81	0.81	1						
KN5	0.26	0.74	0.66	0.84	1					
KN6	0.09	0.78	0.70	0.90	0.91	1				
KN7	-0.05	0.65	0.73	0.84	0.81	0.78	1			
KN8	0.25	0.73	0.67	0.86	0.88	0.85	0.78	1		
KN9	0.31	0.73	0.70	0.82	0.74	0.77	0.59	0.87	1	
OEE	0.23	0.84	0.81	0.90	0.88	0.87	0.71	0.83	0.86	1

Table 4-20: Correlation Between SGA Group's Mean or Average Skill and OEE Value

	OEE	*Group mean KN*
OEE	1.000	
Group mean KN	0.93716	1.000

The finding in this part could be strongly used to describe the acceptance of participation in TPM implementation of the population (employees). The relation between SGA group's average basic knowledge and skills and the OEE level could be obtained from the regression equation obtained of which regression came from the data shown below:

$$OEE = a(\text{Group mean KN}) + b \tag{4.2}$$

or SGA group's average basic knowledge level = [(OEE - b)]/a

where KN is group's mean or average value of KN1-KN9 of each SGA group, *a* is regression coefficient with the value of 0.323 in this case, and *b* is the intersection with the value of -0.412 at 95% confident interval.

As a result, in case of improving the OEE of the machines in order to maintain at least 85% based on the above regression equation (4.2), the employees needed to maintain the groups' mean (average) KN at 95% confidence interval at least between the ranging from 3.87 to 4.03.

4.11.2 Characteristic of Managers and Supervisor Effecting SGA Success

Active joining of mangers, the SGA characteristics are essential for a success of AM (Fujikoshi, 1990, Nakajima, 1988). The requirement of both managers' and supervisors' leaderships' characteristic in successful SGA was elaborated as follows, together with the AM characteristics for small group as suggested by both of these authors.

1) The requirement for the leadership of effective Lean TPM conducted by managers and supervisors were 1) consciously assuming leadership, 2) showing worry and assuming responsibility for SGA. 3) leadership for practice session, 4) energetically observing and supporting small group activity, and 5) reinforcing members of the small group to retain their group with freshness and vigor. The five

characteristics for the leaderships would be measured through the result of the activities practices in terms of the 4 managerial skill score comprising 1) evaluation result from motivation skills of SGA members' understanding and acceptance of important of the activities, 2) understanding of AM inspection and evaluation, 3) OJT providing skill, 4) P-M analysis skill, and 5) breakdown analysis skill

2) The keys to success in SGA, in fact, there are three key factors: motivation, ability, and opportunity. Theses three factors may be enhanced with used of four types of trainings: 1) human growth needs, 2) group function, 3) basic management techniques, and 4) basic mechanical/electrical techniques.

The researcher would propose the additional AM workload as the one factors influencing Lean TPM successful within a particular schedule. It was hoped that all of the key factors to success for Lean TPM implementation as mentioned above were unfortunately difficult to perfect in a practical way.

In regard to the survey of relevant studies for constructing the framework for AM activity implementation, the researcher studied the factors impacting the activities as classified into three parts: 1) managers' and supervisors' characteristics, 2) SGA's capability as compare to the AM workload with the equipment quantity at the level of OEE and time frame.

Furthermore, for the study at this level, the variables were divided as follows:

1) Managers' and supervisors' characteristics
   - Average score of departmental member's understanding and acceptance of the importance of the activities
   - AM inspection and evaluation score
   - Score for P-M analysis skill
   - Score for breakdown analysis skill

2) SGA members' capability relevant a workload ratio: The workload consists of the correction of the existing equipment abnormality, equipment conditions as described by OEE and particular set plan time for Lean TPM implementation.

The consideration in regarding these 4 AM technical and management skill could be elaborated as follows with variables represent recorded score of each SGA team as shown in Table 4-21.

MVMGR - The average ability score of department's manager who encouraged the employees to understand and accept the Lean TPM implementation.

INMGR - The ability score of department's manager who was able to inspect the AM activity.

APMGR - The ability score of department's manager who was able to used analysis skill for P-M analysis method.

ABMGR - The ability score of department's manager who was able to used analysis skill for breakdown analysis.

TGMGR - The ability score of department's manager who was able to provide the OJT to his/her subordinates.

MVSUP - The average ability score of department's supervisor who encouraged the employees to understand and accept the Lean TPM implementation.

INSUP - The ability score of department's supervisor who was able to inspect the AM activity

APSUP - The ability score of department's supervisor who was able to used analysis skill for P-M analysis method.

ABSUP - The ability score of department's supervisor who was able to used analysis skill for breakdown analysis.

TGSUP - The ability score of department's supervisor who was able to provide the OJT to his/her subordinates.

WLMEM - The score for AM average workload per time unit of the SGA members equal to;

(Total workload of all SGA members x R_{OEE}) / time frame

FQMEM - Frequency of AM activity

EDMEM - Education background

KSMEM - The score for each employee's Lean TPM implementation understanding level

KMMEM - The score for each employee's basic management skill level

KHMEM - The score for each employee's basic mechanical understanding level

KEMEM - The score for each employee's basic electrical understanding level

SPMEM - The score for each employee's problem solving level

PFMEM - An average job performance for the past two years annually evaluated by the superior in consideration for increasing salary and promoting job title,

Table 4-22 shows approximated value of workload of each important part obtained after the initial cleaning, correcting worn out or defected part, determining tentative maintenance plan obtained from data collection through observation and empirical study which were presented by the maintenance department form the factory in the case study.

Table 4-23 showed AM activity workload of each AM small group obtained from the numbers of equipment parts and components data recorded during the proceed the activity while the data for evaluating the managers' and supervisors' ability to manage AM activity promotion and the data for knowledge and skill used to implement AM activity of small group members. The data were collected from training record and the score obtained from the evaluation on activities attainment as concluded in Table SEMSGA. These data were applied for constructing the structural equation model in accordance with the research model as shown in Figure 4-21 below to determine the relationship among predictors such as MGRIMPACT, SUPIMPACT, and SGAEFFTV which were used to predict the achievement for Lean TPM represented by the SGASUCCS at small group level yielding and impact on Lean TPM implementation, as a whole.

Table 4-21: 4-AM Technical and Management Skills Involving SGA Succeed Score

	MV MGR	IN MGR	AP MGR	AB MGR	TG MGR	MV SUP	IN SUP	AP SUP	AB SUP	TG SUP	WL MEM	FQ MEM	ED MEM	KS MEM	KM MEM	KH MEM	KE MEM	SP MEM	PF MEM	SGASU CCSS
P2	4	5	3	4	4	5	4	4	4	5	0.08	5	2.6	2.89	3.12	3.45	3.56	2.92	2.11	205.5
M2	1	0	0	2	2	1	1	1	4	1	0.02	1	1.7	1.36	1.27	1.18	1.36	0.7	2.31	40.5
S9	5	3	2	3	3	5	4	3	3	3	0.03	5	2.3	2.96	3.75	3.93	3.63	2.56	3.12	251
EREMA 2	5	3	2	3	3	5	4	3	3	3	0.01	5	1.72	3.92	3.19	3.28	3.51	2.38	4.26	250
B4	4	5	3	4	4	1	2	2	2	2	0.15	3	2.52	1.32	2.7	2.7	2.81	1.55	3.81	122
EREMA 1	4	5	3	4	4	5	4	4	4	4	0.09	3	2.73	2.87	2.97	2.95	2.99	2.69	3.27	255
S5	5	3	2	3	3	5	4	3	3	3	0.03	3	2.21	2.95	3.31	3.27	3.45	2.31	3.24	121.5
B3	3	0	0	3	2	1	2	2	2	2	0.13	3	2.74	2.75	2.86	2.59	2.73	1.96	2.31	122
N1	5	3	2	4	2	3	2	3	3	3	0.11	3	2.68	2.6	3.18	3.42	3.82	2.49	329	252
S7	5	3	2	3	3	5	4	3	3	3	0.03	1	2.23	1.52	1.53	1.79	1.31	1.1	3.12	80.5
P1	4	5	3	4	4	5	4	4	4	5	0.08	5	2.71	3.17	3.17	2.97	2.92	2.69	3.33	255
B2	3	0	0	3	2	1	2	2	2	2	0.25	3	2.06	2.58	2.79	2.87	2.79	1.64	2.34	120.5
S6	5	3	2	3	3	5	4	3	3	3	0.02	5	1.97	2.51	2.83	2.69	2.71	1.83	3.47	126.5
S8	5	3	2	3	3	5	4	3	3	3	0.03	4	1.83	2.96	2.96	3.28	3.58	2.49	2.91	162
EREM N1	5	3	2	3	3	5	4	3	4	3	0.11	3	2.26	2.72	3.05	3.41	3.81	2.19	3.16	164.5

Table 4-22: Estimated Value of Workload in Dealing with Each Machine Component

Item	Initial cleaning (mh)	Correction (mh)	Tentative AM plan (mh)
Motor	0.50	1.00	0.10
Pump	0.50	2.00	0.10
Pneumatic	1.50	2.00	0.10
Gear	1.00	3.00	0.10
Hydraulic	2.00	2.00	0.15
Coupling	0.20	2.00	0.10
Large roller chain per meter	1.00	0.50	0.05
Small roller chain	1.00	0.50	0.05
Fan	1.50	2.00	0.30
Big roller	2.00	2.00	0.10
Die	2.00	2.00	0.20
Oil pipe per meter	0.50	1.00	-
Water pipe	0.30	1.00	-
Air duct per square meter	0.50	3.00	-
Heat tunnel per square meter	0.10	0.10	-
Extruder unit	2.00	5	0.2
V-belt	0.20	0.50	0.10

In implementation of AM activity in conjunction with SGA focused improvement through Focused Improvement Pillar and Planned Maintenance Pillar of the company for this case study of which case study are shown in Chapter 5-7, many strategies in according the structural equation modeling and the comments of employees in force field analysis were made. The company's executives announced the additional policy as well as many countermeasures to support Lean TPM activity. A lot of AM small group training topics such as human growth needs, AM small group function, basic management techniques comprising departmental goals and tasks follow-up , and basic mechanical/electrical techniques. After training the instructors gave the homework to all small group members to practice in order to experience the activity. All managers were also trained. Training topics with practicing on Lean TPM for managers and supervisors level comprising Lean TPM introductory, AM stepwise evaluation, P-M analysis, and equipment breakdown analysis. However, it was found that the 2 out of 3 foreigners, European and Asian, did not showed any Lean TPM participation.

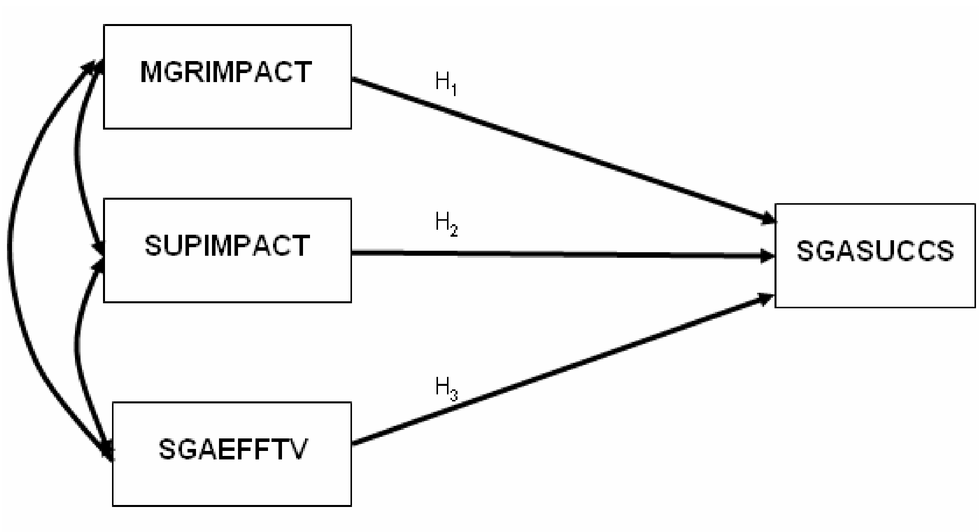


Figure 4-21: SGA Research Model without Manifest Variables

Asking participation, this case the company executives asked Lean TPM consultant for help to correct this problem by closely providing support the members. Small group members under these two foreigner managers felt they had low support of their managers, consequence 2 small groups failed the AM step 1-3. There were 8 AM groups that enhanced the satisfied AM activity while 5 AM group finished AM activity beyond company AM master plan modeling for this study so that determine the 3 factors influencing the successful of AM activity implementation consists managerial impact by line managers, managerial impact by group supervisors, and effective AM groups that represented by variables called MGRIMPACT, SUPIMPACT, and SGAEFFTV respectively. From Table 4-24 and Figure 4-22, it was found that variables such as TGMGR, MVSUP, INSUP, ABSUP, WLMEM, EDMEM, and PFMEM had very weak correlation with SGASUCCS (less than 0.50) that did not conform the study of Fujikoshi, (1990), and Nakajima, (1988). This was very clear result and understandable. The effect of 2 foreigner managers on Lean TPM.

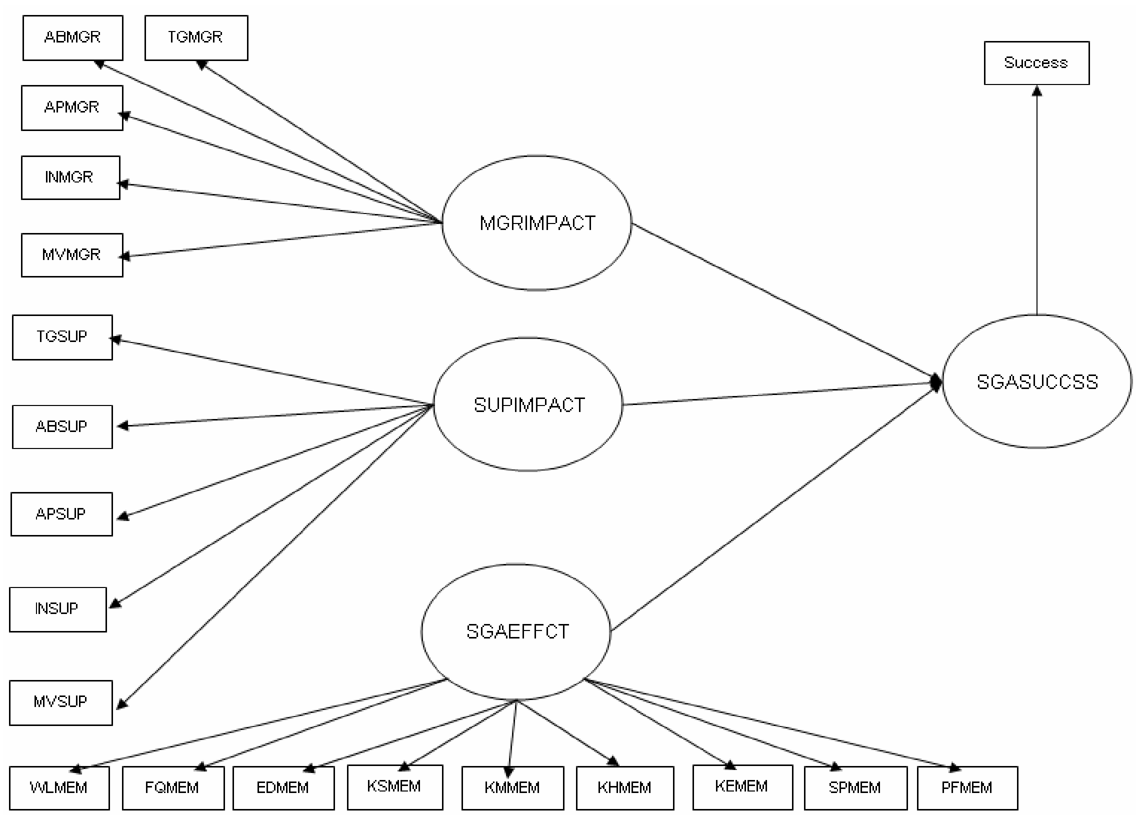


Figure 4-22: SGA Research Model with Manifest Variables

XLSTAT was software employed in constructing the structural equation were very low, so it did not surprise on report of correlation. Surprisingly, it was very interesting to see that AM workload had very low correlation with the successful of AM activity. All manifest variables with low correlation with the successful of AM activity would be removed from the construct with the remained manifest variables such as INMGR, APMGR, ABMGR, APSUP, TGSUP, FQMEM, EDMEM, KSMEM, KMMEM, KHMEM, KEMEM, SPMEM, and PFMEM as in Figure 4-23.

Table 4-23: Each AM Activity Workload

Group/ Workload	Motor	Pump	Pneumatic	Gear	Hydraulic	Coupling	Large roller chain per meter	Small roller chain	Fan	Big roller	Die
P2-PH2	160.00	130.00	72.00	328.00	41.50	276.00	310.00	31.00	190.00	164.00	4.20
M2-PH2	57.60	23.40	3.60	16.40	4.15	18.40	0.00	0.00	22.80	8.20	0.00
S9-PH2	64.00	2.60	187.20	164.00	4.15	9.20	0.00	15.50	0.00	139.40	0.00
EM-PH2	22.40	10.40	0.00	4.10	4.15	2.30	0.00	0.00	0.00	0.00	4.20
B4-PH2	240.00	182.00	360.00	123.00	12.45	46.00	387.50	46.50	228.00	287.00	4.20
EM-PH1	12.80	780.00	14.40	8.20	16.60	0.00	0.00	0.00	15.20	0.00	4.20
S5-PH1	56.00	2.60	187.20	114.80	4.15	9.20	0.00	15.50	0.00	69.70	0.00
B3-PH3	240.00	182.00	360.00	123.00	12.45	46.00	387.50	46.50	228.00	287.00	4.20
N1-P3	208.00	208.00	360.00	41.00	62.25	27.60	372.00	7.75	456.00	123.00	4.20
S7- PH3	44.80	2.60	187.20	114.80	4.15	9.20	0.00	15.50	0.00	69.70	0.00
B1-PH4	64.00	2.60	187.20	164.00	4.15	9.20	0.00	15.50	0.00	139.4.0	0.00
S1-PH4	64.00	2.60	187.20	164.00	4.15	9.20	0.00	15.50	0.00	139.40	0.00
EM-PGH	22.40	10.40	0.00	4.10	4.15	2.30	0.00	0.00	0.00	0.00	4.20
P1-PH4	128.00	104.00	57.60	262.40	33.20	220.80	248.00	24.80	152.00	131.20	3.36
B2-PH4	240.00	182.00	360.00	123.00	12.45	46.00	387.50	46.50	228.00	287.00	4.20
S6-PH4	44.80	2.60	187.20	164.00	4.15	9.20	0.00	15.50	0.00	69.70	0.00
S8-PH4	22.40	2.60	122.40	57.40	4.15	9.20	0.00	15.50	0.00	123.00	0.00
EN-PH4	25. 60	7.80	14.40	20.50	16.60	20.70	0.00	0.00	7.60	0.00	4.20

Table 4-23: Each AM Activity Workload (cont.)

Group/ Workload	Oil pipe per meter	Water pipe	Air duct per square meter	Heat tunnel per square meter	Extruder unit	V-belt	Other	Total workload (mh)	number of member (person)	Time (hour) in 9 month	OEE	1-OEE	Workload density
P2-PH2	0.00	0.00	700.00	1.00	28.80	32.00	10.00	2,478.50	17	3,240.00	45.50	0.55	0.08
M2-PH2	0.00	130.00	0.00	0.00	0.00	8.00	60.00	352.55	7	3,240.00	29.97	0.70	0.02
S9-PH2	0.00	0.00	0.00	0.00	0.00	25.60	0.00	611.65	9	3,240.00	30.44	0.69	0.03
EM-PH2	15.00	26.00	0.00	0.00	7.20	10.40	2.00	108.15	8	3,240.00	69.96	0.30	0.01
B4-PH2	75.00	195.00	105.00	180.00	36.00	16.00	0.00	2,523.65	15	3,240.00	63.60	0.34	0.15
EM-PH1	150.00	130.00	35.00	0.00	7.20	3.20	0.60	405.20	4	3,240.00	65.00	0.35	0.09
S5-PH1	0.00	0.00	0.00	0.00	0.00	19.20	0.00	478.35	6	3,240.00	25.04	0.75	0.03
B3-PH3	75.00	195.00	105.00	180.00	36.00	16.00	0.00	2,523.65	17	3,240.00	64.71	0. 35	0.13
N1-P3	180.00	130.00	35.00	84.00	21.60	8.00	6.00	2334.4	19	3,240.00	66.00	0.34	0.11
S7- PH3	0.00	0.00	0.00	0.00	0.00	19.20	0.00	467.15	8	3,240.00	27.03	0.73	0.03
B1-PH4	0.00	0.00	0.00	0.00	0.00	25.60	0.00	611.65	9	3,240.00	32.44	0.67	0.04
S1-PH4	0.00	0.00	0.00	0.00	0.00	25.60	0.00	611.65	9	3,240.00	30.44	0.69	0.03
EM-PGH	15.00	26.00	0.00	0.00	7.20	10.40	2.00	108.15	8	3,240.00	69.96	0.30	0.01
P1-PH4	0.00	0.00	560.00	0.80	23.04	25.60	8.00	1,982.80	14	3,240.00	45.50	0.55	0.08
B2-PH4	75.00	195.00	105.00	180.0	36.00	16.00	0.00	2,523.65	9	3,240.00	64.71	0.35	0.25
S6-PH4	0.00	0.00	0.00	0. 00	0.00	19.20	0.00	516.35	11	3,240.00	28.48	0.72	0.02
S8-PH4	0.00	0.00	0.00	0.00	0.00	8.80	0.00	365.45	5	3,240.00	29.00	0.71	0.03
EN-PH4	4.50	19.50	0.00	0.00	7.20	4.80	0.00	153.40	2	3,240.00	65.56	0.34	0.07

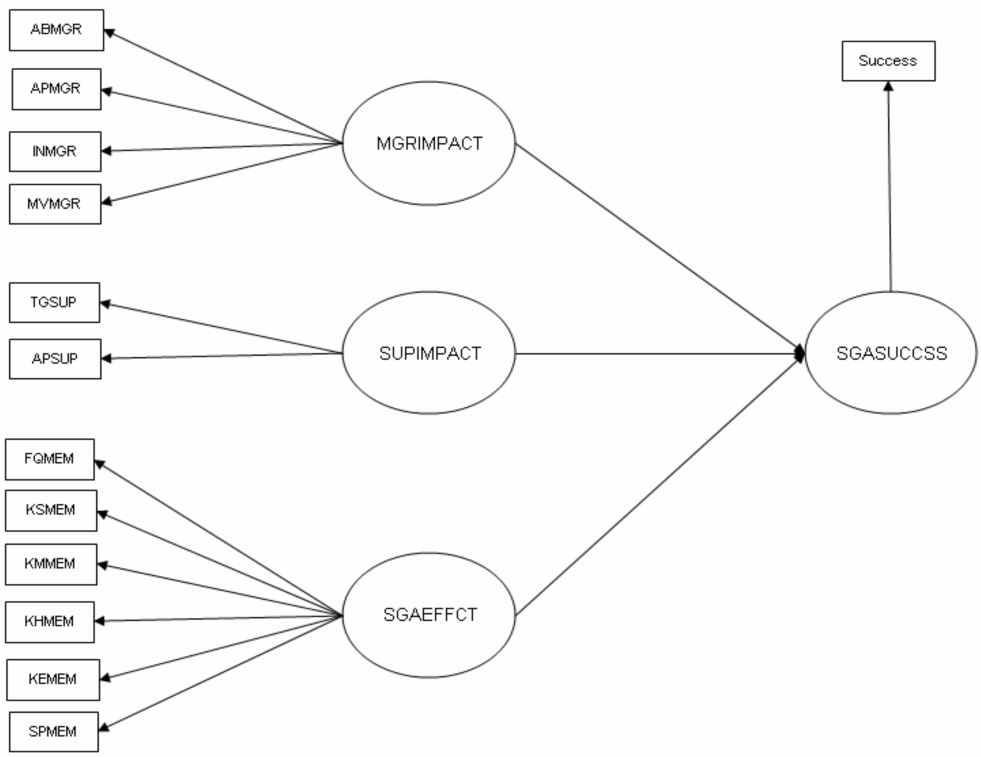


Figure 4-23: SGA Research Model

Table 4-25 showed composite reliability of latent variables. It revealed that reliability of MGRIMPACT latent variable was a bit lower than 0.90, consequently, to improve the composite reliability of this latent variable we considered to remove MVMGR and ABMGR with low cross-loadings (less than 0.90) contributing to MGRIMPACT latent variable as shown in Table 4-26**.** It was found that MVMGR and ABMGR had low loading factor (less than 0.7) with critical ratio (CR) or z-score were les than 2.0 with 0.05 significant level. Summary, to improve model fit we considered to remove manifest variables such as MVMGR, ABMGR, and SPMEM from the research model as shown in Figure 4-24**:** SGA Research Model.

Table 4-24: Correlation among SGA Characteristics and SGA Succeed

	IN MGR	*AP MGR*	*AB MGR*	*TG MGR*	*MV SUP*	*IN SUP*	*AP SUP*	*AB SUP*	*TG SUP*	*WL MEM*	*FQ MEM*	*ED MEM*	*KS MEM*	*KM MEM*	*KH MEM*	*KE MEM*	*SP MEM*	*PF MEM*	*SGA SUCCSS*
INMGR	1																		
APMGR	0.9	1																	
ABMGR	0.8	0.7	1																
TGMGR	0.9	0.9	0.6	1															
MVSUP	0.6	0.7	0.2	0.5	1														
INSUP	0.6	0.7	0.2	0.6	1	1													
APSUP	0.8	0.8	0.7	0.7	0.8	0.8	1												
ABSUP	0.4	0.4	0.1	0.4	0.6	0.4	0.5	1											
TGSUP	0.8	0.8	0.7	0.7	0.7	0.7	1	0.5	1										
WLMEM	-0.2	-0.3	0.3	-0.2	-0.6	-0.5	-0.2	-0.5	-0.2	1									
FQMEM	0.4	0.4	0.4	0.4	0.5	0.5	0.6	0.1	0.6	-0.2	1								
EDMEM	0.4	0.4	0.8	0.4	-0	0.02	0.4	0	0.5	0.4	0.1	1							
KSMEM	0.2	0.2	0.2	0.1	0.5	0.6	0.6	0.2	0.5	-0.1	0.7	0	1						
KMMEM	0.4	0.4	0.5	0.3	0.4	0.5	0.5	-0.1	0.5	0.1	0.8	0.3	0.8	1					
KHMEM	0.4	0.5	0.5	0.3	0.5	0.5	0.6	-0	0.5	0.1	0.7	0.3	0.7	1	1				
KEMEM	0.4	0.4	0.4	0.2	0.4	0.4	0.5	0	0.4	0.10	0.7	0.2	0.7	0.9	1	1			
SPMEM	0.6	0.6	0.6	0.5	0.6	0.6	0.8	0.3	0.8	-0	0.8	0.4	0.8	0.9	0.9	0.8	1		
PFMEM	0	0	0.3	-0.4	-0.1	-0.3	0.1	-0.1	0	0.1	-0.1	0.3	0	0.2	0.2	0.3	0.2	1	
SGASUCCSS	0.6	0.6	0.6	0.4	0.5	0.5	0.7	0.3	0.7	-0.1	0.7	0.4	0.7	0.8	0.8	0.7	0.9	0.3	1

Table 4-25: Composite Reliability

Latent variable	Dimensions	Cronbach's alpha	D.G. rho (PCA)	Condition number	Critical value	Eigenvalues
MGR IMPACT	4	0.852	0.943	82.345	1.464	4.892
						0.832
						0.132
						0.001
SUPIMPACT	2	0.965	0.991	7.377	0.919	1.805
						0.033
SGAEFFCT	6	0.933	0.962	16.230	0.707	3.502
						0.464
						0.167
						0.060
						0.034
						0.013
SGASUCCSS	1					

Table 4-26: Cross-Loadings with all Variables Effects

	MGRIMPACT	SUPIMPACT	SGAEFFCT	SGASUCCSS
MVMGR	**0.689**	0.535	0.558	0.469
INMGR	**0.981**	0.775	0.443	0.567
APMGR	**0.992**	0.775	0.461	0.574
ABMGR	**0.766**	0.673	0.443	0.631
APSUP	0.812	**0.986**	0.641	0.728
TGSUP	0.766	0.994	0.617	0.683
FQMEM	0.475	0.586	0.924	0.675
KSMEM	0.252	0.555	0.853	0.724
KMMEM	0.467	0.513	0.940	0.753
KHMEM	0.521	0.542	0.916	0.751
KEMEM	0.450	0.447	0.879	0.699
SPMEM	0.625	0.797	0.906	0.864
Success	0.607	0.707	0.796	1.000

Table 4-27: Weights in Outer Model

Latent variable	Manifest variables	Outer weight	Outer weight (normalized)	Outer weight (Bootstrap)	Standard error	Critical ratio (CR)	Lower bound (95%)	Upper bound (95%)
MGR IMPACT	MVMGR	0.183	0.214	0.149	0.126	1.456	-0.270	0.373
	INMGR	0.338	0.395	0.347	0.088	3.843	0.235	0.562
	APMGR	0.207	0.242	0.209	0.043	4.851	0.150	0.337
	ABMGR	0.127	0.149	0.140	0.067	1.888	0.061	0.340
SUP IMPACT	APSUP	0.476	0.454	0.489	0.112	4.247	0.320	0.767
	TGSUP	0.573	0.546	0.591	0.113	5.082	0.398	0.923
SGA EFFCT	FQMEM	0.331	0.260	0.334	0.092	3.578	0.209	0.685
	KSMEM	0.185	0.145	0.194	0.074	2.503	0.114	0.515
	KMMEM	0.175	0.137	0.176	0.038	4.612	0.125	0.279
	KHMEM	0.188	0.147	0.197	0.062	3.026	0.119	0.335
	KEMEM	0.198	0.156	0.205	0.073	2.729	0.101	0.420
	SPMEM	0.197	0.155	0.221	0.106	1.857	0.122	0.686
SGA SUCCSS	Success	0.014	1.000	0.014	0.002	8.348	0.011	0.018

Table 4-28 showed all principle components with cross-loading factor were more than 0.90 meaning that the construct model had satisfied composite reliability level. It also said that all latent variables related manifest variables at 0.05 significant level due to CR were more than 2.0 as shown in Table 4-29: Outer model, Correlation shown in Table 4-30, and Inner model R^2 of SGASUCCSS shown in Table 4-31**.** Path coefficient as shown in Table 4-32 were used to determine contribution of each variables on successful of the AM small group implementation.

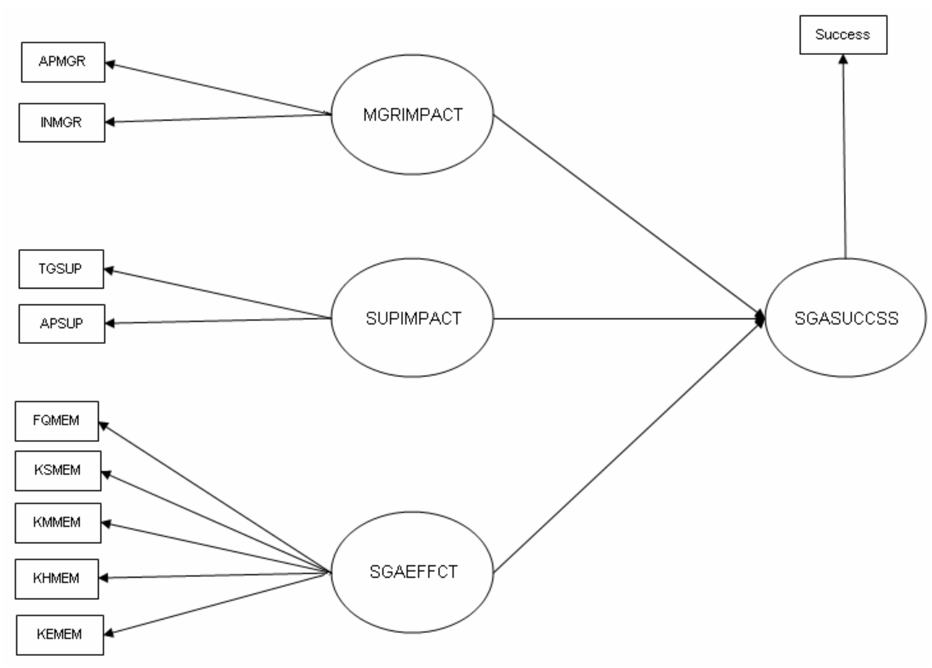


Figure 4-24: SGA Research Model without Low Factor Loading Manifest Variables

Table 4-28: Cross-Loadings without MVMGR and APMGR Effects

	MGRIMPACT	SUPIMPACT	SGAEFFCT	SGASUCCSS
INMGR	**1.000**	0.775	0.418	0.567
APMGR	**0.997**	0.775	0.438	0.574
APSUP	0.780	**0.986**	0.608	0.728
TGSUP	0.762	**0.994**	0.585	0.683
FQMEM	0.438	0.586	**0.935**	0.675
KSMEM	0.182	0.555	**0.847**	0.724
KMMEM	0.387	0.513	**0.936**	0.753
KHMEM	0.430	0.542	0.908	0.751
KEMEM	0.367	0.447	0.871	0.699
SGASUCCSS	0.570	0.707	0.775	1.000

Table 4-29: Weights of Final Outer Model

Latent variable	Manifest variables	Outer weight	Outer weight (normalized)	Outer weight (Bootstrap)	Standard error	Critical ratio (CR)	Lower bound (95%)	Upper bound (95%)
MGRIMPACT	INMGR	0.417	0.620	0.457	0.089	4.701	0.346	0.750
	APMGR	0.255	0.380	0.276	0.048	5.304	0.214	0.385
SUPIMPACT	APSUP	0.476	0.454	0.518	0.133	3.568	0.352	0.951
	TGSUP	0.573	0.546	0.631	0.130	4.399	0.420	1.022
SGAEFFCT	FQMEM	0.372	0.307	0.410	0.140	2.661	0.196	0.913
	KSMEM	0.208	0.172	0.228	0.101	2.053	0.130	0.597
	KMMEM	0.196	0.162	0.194	0.043	4.592	0.108	0.322
	KHMEM	0.211	0.174	0.213	0.068	3.118	0.113	0.393
	KEMEM	0.223	0.184	0.223	0.071	3.158	0.121	0.464
SGASUCCSS	Success	0.014	1.000	0.015	0.002	7.062	0.011	0.020

Table 4-30: Correlations among Factors in Final Model

Latent variable	Manifest variables	Standardized loadings	Loadings	Location	Communalities	Standardized loadings (Bootstrap)	Standard error	Critical ratio (CR)	Lower bound (95%)	Upper bound (95%)
MGR IMPACT	INMGR	1.000	1.691	0.059	0.999	1.000	0.000	9155.938	0.999	1.000
	APMGR	0.997	1.022	0.130	0.995	0.997	0.001	1046.880	0.996	1.000
SUP IMPACT	APSUP	0.986	0.794	0.418	0.972	0.986	0.006	158.712	0.971	1.000
	TGSUP	0.994	1.027	-0.165	0.988	0.995	0.002	449.007	0.992	1.000
SGA EFFCT	FQMEM	0.935	1.225	-1.039	0.874	0.934	0.054	17.376	0.757	0.983
	KSMEM	0.847	0.578	0.478	0.717	0.852	0.089	9.494	0.476	0.957
	KMMEM	0.936	0.579	0.714	0.875	0.903	0.106	8.855	0.465	0.982
	KHMEM	0.908	0.607	0.686	0.825	0.880	0.107	8.500	0.460	0.979
	KEMEM	0.871	0.661	0.568	0.759	0.837	0.150	5.804	0.255	0.966
SGA SUCCSS	Success	1.000	69.061	5.716		1.000	0.000		1.000	1.000

Table 4-31: Inner Model R^2 of SGASUCCSS

R^2	F	Pr > F	R^2 (Bootstrap)	Standard error	Critical ratio (CR)	Lower bound (95%)	Upper bound (95%)
0.697	8.420	0.003	0.724	0.118	5.880	0.473	0.930

Table 4-32: Path Coefficients in Constructed Model Influencing SGASUCCSS

Latent variable	Value	Standard error	t	Pr > |t|	f^2
MGRIMPACT	0.111	0.264	0.420	0.682	0.016
SUPIMPACT	0.288	0.299	0.962	0.357	0.084
SGAEFFCT	0.555	0.208	2.664	0.022	0.645

From Table 4-32 the coefficient values were used to construct the structural equation modeling as shown below.

SGASUCCSS = 0.111x(MGRIMPACT) + 0.288x(SUPIMPACT) +
0.555x(SGAEFFCT)

From the relationships of factors influencing the successful of AM activity implementation as shown in above equation, it revealed that particular key success factors for the company for this case study were FQMEM, KSMEM, KMMEM, KHMEM, and KEMEM. It means that the executive would motivate the employees to proceed the activity very often, build the understanding of Lean TPM implementation, ensure that the employees understand the self management within their work unit relate to the group performances, ensure that the employees master on technical relate to their equipments. Moreover, the company can not ignore the responsibility of line managers and supervisors on Lean TPM implementation otherwise this activity would be collapse in long term. From the study in this section it can be concluded that before starting the AM activity implementation, in framework, the company would improve 3 key AM success factors by training and practicing.

Table GFI showed the very good goodness of fit index of the research model result due to all GFI value were not less than 0.90 with CR were more than 2.0 at 0.05 significant level. R^2 was more than 0.6 with Mean Communalities (AVE) was higher than all individual latent variable squared correlations.

Table 4-33: GFI Goodness of Fit Index

	GFI	GoFI (Bootstrap)	Standard error	Critical ratio (CR)	Lower bound (95%)	Upper bound (95%)	Minimum	Maximum
Relative	0.945	0.854	0.098	9.642	0.567	0.961	0.300	1.001
Outer model	0.994	0.970	0.016	61.779	0.920	0.988	0.890	0.992
Inner model	0.950	0.880	0.097	9.825	0.601	0.982	0.309	1.030

Table 4-34: Impact and Contribution of the Variables to SGASUCCSS

	SGAEFFCT	SUPIMPACT	MGRIMPACT
Correlation	0.775	0.707	0.570
Path coefficient	0.555	0.288	0.111
Correlation * path coefficient	0.430	0.203	0.063
Contribution to R^2 (%)	61.704	29.212	9.085
Cumulative %	61.704	90.915	100.000

Table 4-35: Model Assessment (Dimension 1):

Latent variable	Type	Mean (Manifest variables)	R^2	Adjusted R^2	Mean Communalities (AVE)	D.G. rho
MGR IMPACT	Exogenous	0.000			0.997	0.999
SUP IMPACT	Exogenous	0.000			0.980	0.990
SGA EFFCT	Exogenous	0.000			0.810	0.955
SGA SUCCSS	Endogenous	0.000	0.697	0.646	1.000	1.000
Mean			0.697		0.889	

Table 4-36: Discriminant Validity (Squared Correlations < AVE)

	MGRIMPACT	SUPIMPACT	SGAEFFCT	SGASUCCSS	Mean Communalities (AVE)
MGRIMPACT	**1**	0.602	0.180	0.325	0.997
SUPIMPACT	0.602	**1**	0.360	0.500	0.980
SGAEFFCT	0.180	0.360	**1**	0.600	0.810
SGASUCCSS	0.325	0.500	0.600	**1**	
Mean Communalities (AVE)	0.997	0.980	0.810		**0**

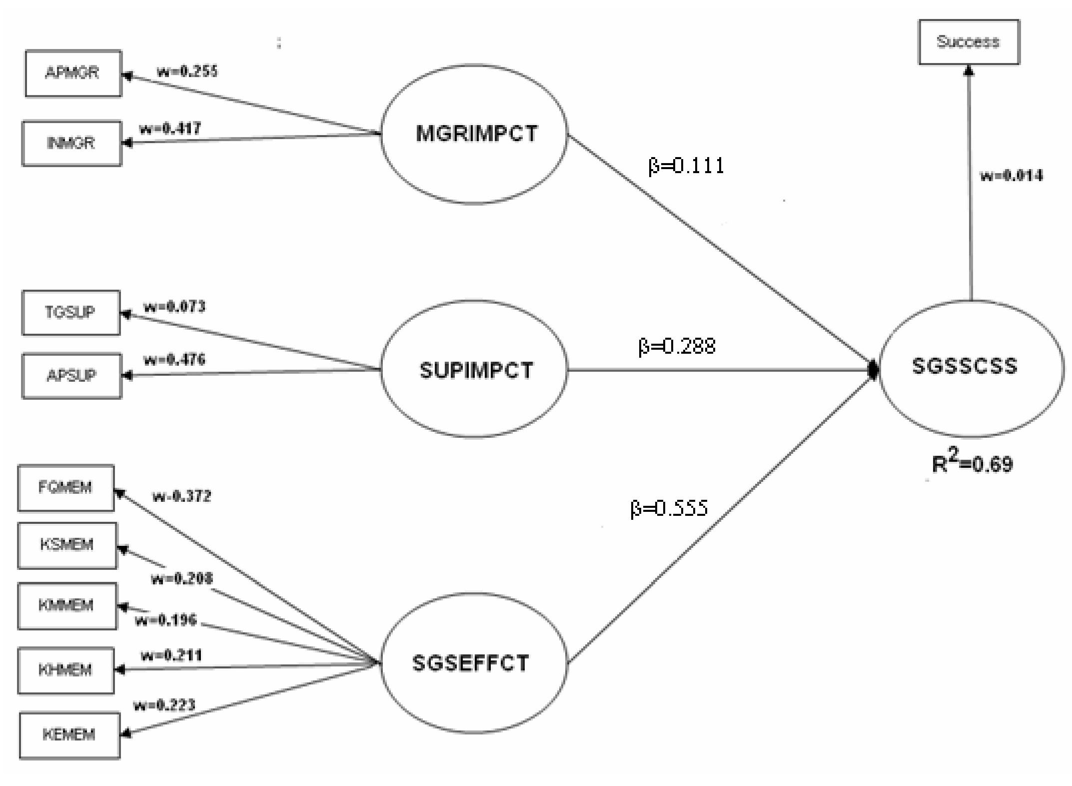


Figure 4-25: Structural Modeling of the Influencing of 3 Key AM Success Factors of the Company for this Case Study

As per the study on 12-steps TPM implementation of Zusuki , (1994) and Bamber, and Hides, (1999) in conjunction with modification found by this study, at the preparation stage, any continuous manufacturing process company should do some activity with in framework for Lean TPM implementation as the following;

a. Select not too much numbers of model machines for training and experience the managers and supervisors.

b. Improve the line managers and supervisors skills related leaderships, a autonomous maintenance inspection skill, autonomous OJT training skill, motivation skill, P-M analysis skill, and failure analysis skill through the crucial AM practicing on model machines.

c. Encourage the employees to handle their work unit performance through self-management.

This study had applied the above strategies in adopting Lean TPM implementation the company in this case study with a lot of improvement. Observation, it was found that when doing the TPM for Lean transformation, the four TPM pillars were organized in effective rhythm which you can see the dramatically outcome in latter chapters.

CHAPTER V
IMPROVEMENT CASES STUDIES

Like some activities conducted to rejuvenate organizations, the objective of TPM's is to enhance corporate business outcomes and created desirable productive workplaces with cheerful atmosphere (Tokutaro S., 1994). A significant characteristic of TPM is its potentiality effect on the bottom line. This study classified the equipment losses into 7 types, namely process or machine failure loss, set-up loss, speed loss, minor stop loss, startup loss and, quality defect loss. In fact, the focused improvement was an activity emphasizing on reduction or eliminating all sorts of these losses. Normally the focused improvement activity was set to be simultaneously implemented with the other two activities such as planned maintenance, and autonomous maintenance. The Focused Improvement has philosophy behind improving the production effectiveness as it was philosophy of continuous improvement, focused the sub-process that caused the bottleneck, focused the production effectiveness, zero quality defect approach, zero failure and zero accident goals by using effort of cross functional discipline with basic analytical techniques such as P-M analysis, Why-Why analysis, Fault tree analysis, FMEA, JIT and 7 QC tools in conjunction with TQM (Suzuki, 1994). Then the default common practice in TQM/JIT and TPM would be listed in the following Table 5-1:

Table 5-1: Manufacturing Practice and Tools Relate to TPM Implementation

No.	Practice and Tools	Relation to 6 TPM Major Results					
		P	Q	C	D	S	M
1	Bottleneck removal (production smoothing)	√					
2	Continuous improvement programs	√	√	√	√	√	√
3	Cross-functional work force	√	√	√	√	√	√
4	Process lead time reductions				√		

Table 5-1: Manufacturing Practice and Tools Relate to TPM Implementation (cont.)

No.	Practice and Tools	Relation to 6 TPM Major Results					
		P	Q	C	D	S	M
5	Focused factory production	√	√	√	√	√	√
6	JIT/continuous flow production			√			
7	Maintenance optimization	√		√			
8	New process equipment/technologies	√	√	√	√	√	√
9	Planning and scheduling strategies	√			√		
10	Preventive maintenance	√	√	√			
11	Process capability measurements		√				
12	Quality management programs		√				
13	Quick changeover techniques	√			√		
14	Safety improvement programs					√	
15	Total quality management		√				

In case that there was much the equipment failure resulting in low OEE, the maintenance department would be in charge of the failure. The executives of the company for the case study realize the significant of focused improvement activity. They therefore announce the company policy to encourage all managers to cooperate so that the chronic problem could be tackled. They are also requested to help enhance the machine so that they would have OEE at least 85% or suitable for the business requirement. Consequently, the implementation procedure of the focused improvement was listed as follows.

1-Survey the losses caused by every important equipment.

2- Prioritize the improvement for the losses

3- Assess the difficulty for the improvement of the job

4- Select the improvement topic

5- Remove the minor flaw and plan for the improvement

6-Implement the planned improvement

7-Use of horizontal deployment

5.1 Survey the Losses Caused by Important Equipments

The training for all employees in production line was held so that they would understand OEE and the six losses which affected OEE. This would enable the employees to check the data pertaining to the losses occurring in the production. They were requested to conclude the losses tracing back for one year. With this regard, it was found that the existing data of losses was incomplete. For instance, for some machines, their tracing back data could be obtained from those happened only three months ago. Thus, the calculation for average losses per month was further used to determine the loss value per year. Table 5-2 involving with 8 major plant losses and, it revealed that each machine with OEE less than 100% as shown in Table 5-3 means that there would be 8 major plant losses for each machine in different level. The combination of these losses could cause the overall major plant losses. For instance, for all machines which possessed the highest performance loss, it was found, in the Table 5-2, that the abnormal production loss having total losses value of 230,101.41 tons per year out of the maximum plant capacity of 561,883 tons per year could be used for the calculation of the percentage of overall plant performance loss percentage by dividing the value of abnormal production loss of 230,101.41 tons year with the value of the maximum plant capacity value. The percentage outcome of the calculation (40.95%) is also shown in lower part of Table 5-2. Likewise, for other type of major plant losses, the same method of calculation was applied. The total value of overall plant losses, therefore, were the summation in tons per year unit of 1,729.34 shutdown loss (0.31%), 6,369.07 production adjustment loss (1.13%), 13,368.67 equipment failure loss (2.38%), 106,313.03 normal production loss (18.92), 230,101.41 abnormal production loss (40.95), 109.78 reprocessing loss (0.02), and 10,168.37 defect (1.81%) equal to 126,941.45 tons per year. When this overall value was subtracted from 100%, the value of overall plant effectiveness was 34.48% (100%-65.52%) as shown in Figure 4-4 in Chapter IV.

Table 5-2: Equipment Losses Before Improving

Process	Shutdown loss (tons)	Production adjustment loss (tons)	Equipment failure loss (tons)	Normal production loss (tons)	Abnormal production loss (tons)	Repro-cessing Losses (tons)	Defect	Total (tons)
Main Process BOPET-P1	49.00	292.92	145.61	368.00	5,778.00	-	233.88	6,867.41
BOPET Slitting P1 (J05)	31.00	543.00	959.18	11,321.00	9,159.94	-	215.45	22,229.57
Main Process BOPET-P2	68.19	245.38	2,749.75	1,454.67	4,618.67	-	2,307.96	11,444.62
BOPET Slitting P2 (J08)	79.54	657.91	597.04	16,800.49	18,645.16	-	792.46	37,572.60
BOPET Recycle process P1	493.33	-	103.57	18.59	3,390.24	109.78	-	4,1015.51
Main Process BOPP-B1	497.34	376.04	3,746.17	1,087.27	9,893.47	-	423.86	16,024.15
BOPP Slitting B1	79.54	657.91	894.26	16,159.97	41,152.43	-	873.49	59,817.60
Main Process BOPP-B2	79.60	752.08	531.47	6,129.17	1,894.46	-	987.57	10,374.35
BOPP Slitting B2	82.31	597.19	934.01	14,872.94	40,819.47	-	873.49	58,179.41
Main Process BOPP-B3	44.59	428.00	305.54	3,499.94	1,082.67	-	564.81	5,925.55
BOPP Slitting B3	68.95	605.78	894.79	15,372.49	40,575.34	-	712.39	58,229.74
Main Process BOPP-B4	19.33	182.69	129.43	1,428.10	451.48	-	239.74	2,450.77
BOPP Slitting B4 (J09)	59.21	492.04	634.72	12,893.00	41,112.87	-	315.98	55,507.82
Main process BOPA N1	35.00	-	-	20.16	1,589.88	-	923.64	2,568.68
BOPA Slitting N1	6.23	52.97	67.82	1,757.46	4,327.41	-	33.26	6,245.15
BOPA Recycle process	-	-	9.52	6.38	710.45	-	141.46	867.81
Metalizer process	36.18	485.16	319.47	789.24	1,294.57	-	16.49	2,941.11
UM Slitter process	-	-	321.00	2,315.49	1,764.46	-	75.14	4,476.09
Total (tons)	1,729.34	6,369.07	13,368.67	106,313.03	230,101.41	109.78	10,168.37	368,159.67
% loss	0.31	1.13	2.38	18.92	40.95	0.02	1.81	65.52

Table 5-3: Overall Equipment Effectiveness of 7 Production Line Processes

Process/Equipment	Max. Capacity (tons/hr.)	A	P	Q	OEE
Main Process BOPET-P1	1.50	93.21%	50.79%	96.08%	45.50%
BOPET Slitting P1	3.70	58.64%	49.74%	97.63%	28.48%
Main Process BOPET-P2	2.50	78.49%	71.98%	80.55%	45.50%
BOPET Slitting P2	6.30	65.73%	46.40%	95.09%	29.00%
BOPET Recycle Process	1.40	94.77%	69.58%	98.58%	65.00%
Main Process BOPP-B1	3.50	80.59%	58.24%	96.93%	45.50%
BOPP Slitting B1	9.50	77.70%	33.63%	95.81%	25.04%
Main Process BOPP-B2	3.50	74.52%	91.35%	95.07%	64.71%
BOPP Slitting B2	9.50	79.34%	35.53%	96.12%	27.09%
Main Process BOPP-B3	2.00	74.54%	91.35%	95.06%	64.73%
BOPP Slitting B3	9.50	78.77%	35.45%	96.80%	27.03%
Main Process BOPP-B4	0.85	75.36%	91.61%	95.14%	65.68%
BOPP Slitting B4	9.50	82.36%	37.44%	98.72%	30.44%
BOPP Recycle process	0.30	99.43%	76.05%	92.52%	69.96%
Main process BOPA N1	0.50	99.27%	78.82%	84.39%	66.02%
BOPP Slitting N1	1.00	77.57%	33.58%	98.48%	25.65%
BOPA Recycle Process	0.30	99.37%	71.63%	92.11%	65.56%
Metalizing Process M2	0.50	61.19%	49.63%	98.71%	29.97%

5.2 Focused Improvement

5.2.1 Overall Equipment Effectiveness Improvement

Equipment losses and overall effectiveness value as shown in Table 5-3, it revealed that the value of OEE was much lower than 85%. In fact, most of the machine had a very low performance rate Performance rate which was the product of both operating speed rate and the net operating rate. The operating speed rate of equipment is the different between the ideal speed and the actual operating speed. It should be noticed that in case of requiring the value of OEE to be higher or equal to

85%, A, P, and Q should be more than 95%. If it was not so, a correction of performance rate as shown in Table 5-4 should be corrected; however, there were probably some machines needing to have its availability value corrected.

Table 5-4: The Selected OEE Improvement Topics

Process/Equipment	**A**	**P**	**Q**
Main Process BOPET-P1	Δ	O	N/A
BOPET Slitting P1	N/A	O	N/A
Main Process BOPET-P2	Δ	O	N/A
BOPET Slitting P2	Δ	O	N/A
BOPET Recycle Process P1	Δ	O	N/A
Main Process BOPP-B1	Δ	O	N/A
BOPP Slitting B1	Δ	O	N/A
Main Process BOPP-B2	O	Δ	N/A
BOPP Slitting B2	Δ	O	N/A
Main Process BOPP-B3	O	Δ	N/A
BOPP Slitting B3	Δ	O	N/A
Main Process BOPP-B4	O	Δ	N/A
BOPP Slitting B4	Δ	O	N/A
BOPP Recycle Process	N/A	O	Δ
Main process BOPA N1	N/A	O	Δ
BOPP Slitting N1	Δ	O	N/A
BOPA Recycle Process	N/A	O	Δ
Metalizing Process M2	Δ	O	N/A

O – First priority Δ – Second priority N/A – N o Action Required

According to the company executives, it stated that Lean TPM members should devoted themselves to the focused improvement in order to improve OEE value to obtain more than 85% for the important machines Therefore, it necessary to conduct

27 focused improvement tasks with proper methods and techniques for the machine based on proper measures (Tokutaro, 1992) as shown in Table 5-5.

Table 5-5: Focused Improvement Methods and Practices

Process/Equipment	Improvement	Techniques/Practices
Main Process BOPET-P1	1-Reducing electrical motor failure [illegible]Reduction of pinning sparking that cause the speed loss	1- FMEA-FTA 2- P-M Analysis-Artificial neural network
BOPET Slitting P1	[illegible]Reduction of pinning sparking that cause the speed loss	3- P-M Analysis-Artificial neural network
Main Process BOPET-P2	4- Reducing electrical motor failure [illegible]Reduction of pinning sparking that cause the speed loss	4- FMEA-FTA 5- P-M Analysis-Artificial neural network
BOPET Slitting P2	[illegible]Setup time reduction 7- Speed loss reduction	6- SMED- Quick changeover techniques 7-FMEA-FTA
BOPET Recycle process	8-Filter change improvement 9-Increasing recycle process capacity	[illegible]Why-Why analysis [illegible]Why-Why analysis
Main Process BOPP-B1	10- Reducing electrical motor failure [illegible]Reduction of pinning sparking that cause the speed loss	10-FMEA-FTA 11- P-M Analysis-Artificial neural network
BOPP Slitting B1	1[illegible]Setup time reduction 13-Speed loss reduction	12-SMED- Quick changeover techniques 13-FMEA-FTA
Main Process BOPP-B2	14-Reducing electrical motor failure 1[illegible]Reduction of pinning sparking that cause the speed loss	14-FMEA-FTA 15-P-M Analysis-Artificial neural network
BOPP Slitting B2	1[illegible]Setup time reduction 17-Speed loss reduction	16-SMED- Quick changeover techniques 17-FMEA-FTA

Table 5-5: Focused Improvement Methods and Practices (cont.)

Process/Equipment	Improvement	Techniques/Practices
Main Process BOPP-B3	18-Reducing electrical motor failure 1□̃Reduction of pinning sparking that cause the speed loss	18-FMEA-FTA 19- P-M Analysis-Artificial neural network
BOPP Slitting B3	□̃Setup time reduction 21-Speed loss reduction	20-SMED- Quick changeover techniques 21-FMEA-FTA
Main Process BOPP-B4	22-Reducing electrical motor failure □□̃Reduction of pinning sparking that cause the speed loss	22-FMEA-FTA 23- P-M Analysis-Artificial neural network
BOPP Slitting B4	□□̃Setup time reduction 25-Speed loss reduction	24-SMED- Quick changeover techniques 25-FMEA-FTA
BOPP Recycle process	26-Improve chips quality in EREMA	26-Quality maintenance-ZQC
Main process BOPA N1	□□̃Reduction of pinning sparking that cause the speed loss	27- P-M Analysis-Artificial neural network

The company executive asked the CFT for help to increase the process effectiveness. Much effort from multi-discipline taskforce was assembled. The example of focused improvement cases would be seen in section 5.4 “Improvement Cases Study”. The entire improvement activities of Lean TPM members showed their genuine devotion and dedication of both time and energy resulting in reducing equipment losses or increasing values of OEEs as shown in Table 5-6 with comparison of OEE value at the initial stage and after improvement stage as shown in Table 5-7. However, there were some machines of which the values were less than 85% due to the company business reasons and employees’ effort level in improving activities.

Table 5-6: Improvement Results of OEE of Main Equipments

Process/Equipment	Max. Capacity (tons/hr.)	A	P	Q	OEE
Main Process BOPET-P1	1.50	93.35%	88.97%	98.24%	83.24%
BOPET Slitting P1	3.70	67.86%	60.20%	97.17%	39.69%
Main Process BOPET-P2	2.50	86.92%	93.74%	98.31%	80.10%
BOPET Slitting P2	6.30	82.86%	69.04%	98.39%	56.28%
BOPET Recycle Process	1.40	95.76%	89.38%	98.78%	84.54%
Main Process BOPP-B1	3.50	94.97%	78.60%	98.86%	73.80%
BOPP Slitting B1	9.50	88.56%	59.47%	98.37%	51.81%
Main Process BOPP-B2	3.50	86.46%	92.55%	97.72%	78.36%
BOPP Slitting B2	9.50	88.95%	64.96%	98.92%	57.16%
Main Process BOPP-B3	2.00	93.29%	93.95%	95.95%	84.10%
BOPP Slitting B3	9.50	81.38%	38.60%	96.97%	30.46%
Main Process BOPP-B4	0.85	82.73%	94.65%	96.50%	75.57%
BOPP Slitting B4	9.50	94.52%	89.86%	99.53%	84.54%
BOPP Recycle process	0.30	99.83%	91.15%	94.29%	85.80%
Main process BOPA N1	0.50	99.14%	82.69%	86.06%	70.54%
BOPP Slitting N1	1.00	93.40%	75.11%	99.57%	69.86%
BOPA Recycle Process	0.30	99.75%	94.06%	96.84%	90.87%
Metalizing Process M2	0.50	62.18%	43.09%	98.72%	26.45%

Table 5-7: Comparison of OEE Value

Process/Equipment	Max. Capacity (t/hr.)	OEE improvement		
		Before improving (%)	After improving (%)	% Improving
Main Process BOPET-P1	1.50	45.50%	83.34%	37.85%
BOPET Slitting P1	3.70	28.48%	39.69%	11.21%
Main Process BOPET-P2	2.50	45.50%	80.10%	34.60%
BOPET Slitting P2	6.30	29.00%	56.28%	19.42%
BOPET Recycle process	1.40	83.12%	84.54%	1.42%
Main Process BOPP-B1	3.50	45.50%	73.80%	28.18%
BOPP Slitting B1	9.50	25.04%	51.81%	26.77%
Main Process BOPP-B2	3.50	64.71%	78.36%	13.65%

Table 5-7: Comparison of OEE value (cont.)

Process/Equipment	Max. Capacity (t/hr.)	OEE improvement		
		Before improving (%)	After improving (%)	% Improving
BOPP Slitting B2	9.50	27.09%	57.16%	30.07%
Main Process BOPP-B3	2.00	64.73%	84.10%	19.39%
BOPP Slitting B3	9.50	27.03%	30.46%	3.43%
Main Process BOPP-B4	0.85	65.68%	75.57%	9.89%
BOPP Slitting B4	9.50	30.44%	84.54%	54.10%
BOPP Recycle process	0.92	69.96%	85.80%	15.84%
BOPA Slitting N1		25.65%	69.86%	44.21%
BOPA Recycle process	0.30	65.56%	90.87%	25.31%
Metalizing process	0.50	29.97%	26.45%	-3.52%

5.2.2 Overall Plant Effectiveness Improvement

The eight major plant losses data was discovered and was calculated in the same way since preliminary investigation. We used total 1 year the maximum capacity of each equipment for 100% capacity. From Table 5-8: involving with eight major plant losses after improvement of OEE of the machines, it revealed that each machine with OEE less than 100% means that there would be eight major plant losses for each machine in different level. The combination of these losses could cause the overall major plant losses. For instance, for all machines which possessed the highest performance loss, it was found that the abnormal production loss having total losses value of 143,139.65 tons per year out of the maximum plant capacity of 561,883 tons per year could be used for the calculation of the percentage of overall plant performance loss percentage by dividing the value of abnormal production loss with the value of the maximum plant capacity. The percentage outcome of the calculation (25.47%) is also shown in Table 5-8. Likewise, for other type of major plant losses, the same method of calculation was applied. The total value of overall plant losses, therefore, were the summation in tons per year unit of 659.21 shutdown loss (0.12%), 6,193.13 production adjustment loss (1.10%), 6,530.10 equipment failure loss (1.16%), 49.368.83 normal production loss (10.57%), 143,139.65 abnormal production loss (25.47%), 123.18 reprocessing loss (0.02%), and 6,567.36 defect (1.17%) equal to 222.581.46 tons per year as the eight major plant losses summary with the losses comparison shown in Table 6-8 When this overall value was subtracted from 100%, the value of overall plant effectiveness was 60.39% (100%-39.61%) as shown in Figure 5-1.

We conclude that the Lean TPM implementation as per the mentioned framework could improve the overall plant effectiveness from 34.48% to 60.39%. It was almost twice figure as shown the major losses comparison in Figure 5-2.

5.3 Improved Process Value Stream after Focused Improvement

Since P1 was an important main process of the company, so the company executive asked the CFT for help to increase the process effectiveness. Much effort from multi-discipline taskforce was assembled. It was found that the speed loss of the equipment was very high. Team members found that when the process was operated at higher speed, it would cause the pinning spark problem. In reducing the pinning sparking, the process engineer employed the statistical method and artificial network to predict and control the process parameter causing the pinning spark problem was eliminated then the process could be operated at desired speed level. This focused improvement case would be seen in latter CASE II: Improving the pining spark problem of main film production process P1. By effort, the OEE of process P1 was improved from 45.50% to 83.34%. In fact as mentioned in Chapter IV, 83.34% OEE would take longer process lead time. P1 process at 100% OEE. Processing, lead time would be 5.60/0.8334 = 6.72 hours plus changeover or setup 20 minute. So the P1 process lead time at 83.34% OEE was 6.73 hours or 0.28 day.

BOPET Slitting P1 which was one sub-process in P1 process value stream. It was excellent reduced the setup time into half an hour with a bit higher OEE of 39.69%

Table 5-8: Equipment Losses After Improving

Process	Shutdown loss (tons)	Production adjustment loss (tons)	Equipment failure loss (tons)	Process Failure Losses (tons)	Normal production loss (tons)	Abnormal production loss (tons)	Repro-cessing Losses (tons)	Defect	Total (tons)
Main Process BOPET-P1	21.48	312.39	3.95	0.00	248.00	1,325.68	0.00	187.94	2,099.44
BOPET Slitting P1 (J05)	19.31	472.64	769.18	0.00	8,729.04	8,394.25	0.00	359.74	18,744.16
Main Process BOPET-P2	35.00	298.34	1,249.32	0.00	1 ,164.38	1,143.04	0.00	289.35	4,179.43
BOPET Slitting P2 (J08)	62.37	429.47	219.34	0.00	8,357.84	13,578.14	0.00	487.14	23,134.30
BOPET Recycle process P1	72.25	396.21	21.96	0.00	7.96	1,196.32	123.18	0.00	1,817.88
Main Process BOPP-B1	82.59	219.46	389.74	0.00	785.94	5,975.13	0.00	249.37	7,702.23
BOPP Slitting B1	52.19	541.84	691.27	0.00	7,842.18	28,641.17	0.00	684.27	38,452.92
Main Process BOPP-B2	19.48	658.21	175.94	0.00	3,125.98	1,894.46	0.00	489.37	6,363.44
BOPP Slitting B2	38.14	418.27	547.39	0.00	7,814.59	24,871.29	0.00	498.25	34,187.93
Main Process BOPP-B3	25.93	450.95	238.19	0.00	413.00	947.39	0.00	595.25	2,671.30
BOPP Slitting B3	71.28	681.29	817.21	0.00	1,328.59	39,875.28	0.00	759.47	55,492.12
Main Process BOPP-B4	15.54	235.39	87.54	0.00	894.25	315.85	0.00	195.47	1,744.31
BOPP Slitting B4 (J09)	72.48	539.15	639.12	0.00	3,129.25	7,649.00	0.00	315.98	12,340.58
BOPP Recycle process	0.00	0.00	11.10	0.00	2.05	682.55	0.00	401.50	1,097.20
Main process BOPA N1	39.65	0.00	13.94	0.00	11.46	1,297.64	0.00	864.18	2,226.87
BOPA Slitting N1	3.18	48.17	17.16	0.00	485.97	1,952.47	0.00	25.14	2,532.09
Metalizer process	36.18	491.35	306.53	0.00	749.35	1,486.21	0.00	14.39	3,089.01
UM Slitter process	0.00	0.00	334.00	0.00	2,315.49	1,746.46	0.00	75.14	4,476.09
Total (tons)	659.21	6,193.13	6,530.10	0.00	59,368.83	143,139.65	123.18	6,567.36	222,581.46
% loss	0.12	1.10	1.16	0.00	10.57	25.47	0.02	1.17	39.61

Table 5-9: Summary and Comparison of Eight Major Plant Losses

1 year Maximum capacity 561,883.00 tons per year				
Losses	Before improvement		After improvement	
	Quantity (tons)	%	Quantity (tons)	%
1) Shutdown Loss /Periodic Servicing (tons)	1,730.24	0.31	659.21	0.12
2) Production Adjustment Loss (tons)	6,370.91	1.13	6,193.13	1.10
3) Equipment Failure Loss (tons)	13,366.42	2.38	6,530.10	1.16
4) Process Failure Loss (tons)	0.00	0.00	0.00	0.00
6) Normal Production Loss (tons)	106,316.03	18.92	59,368.83	10.57
6) Abnormal Production Loss (tons)	230,101.41	40.95	143,139.65	25.47
7) Defect Loss (tons)	109.78	0.02	123.18	0.02
8) Defect and Rework (tons)	10,278.15	1.81	6,567.36	1.17
Total Eight Major Plant Losses (tons)	368,159.67	65.52	222,581.46	39.61

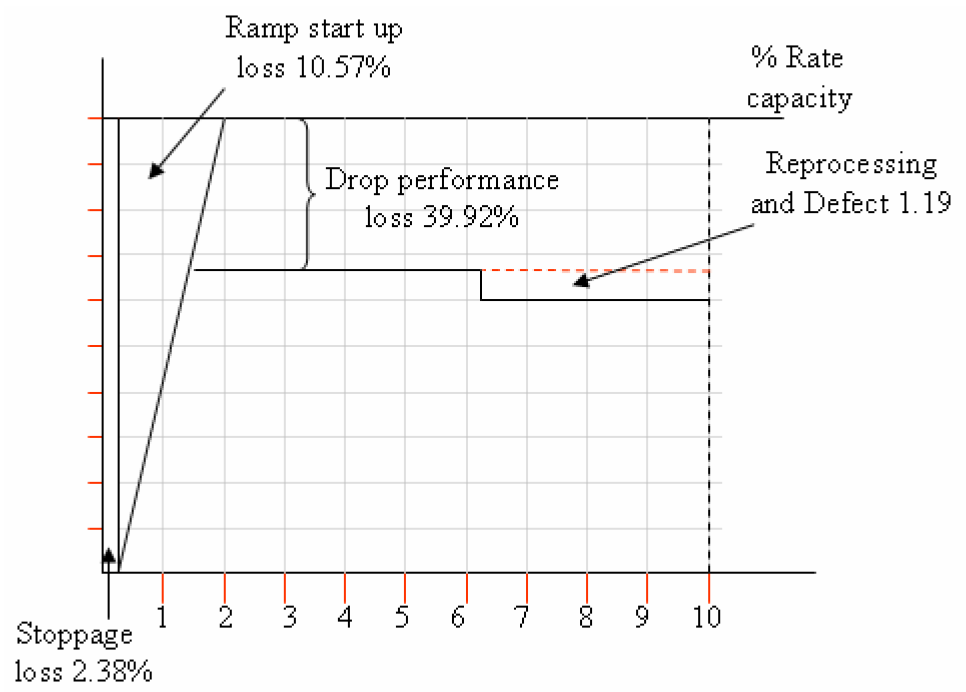


Figure 5-1: 8-Major Plant Losses Structure After Focused Improvement

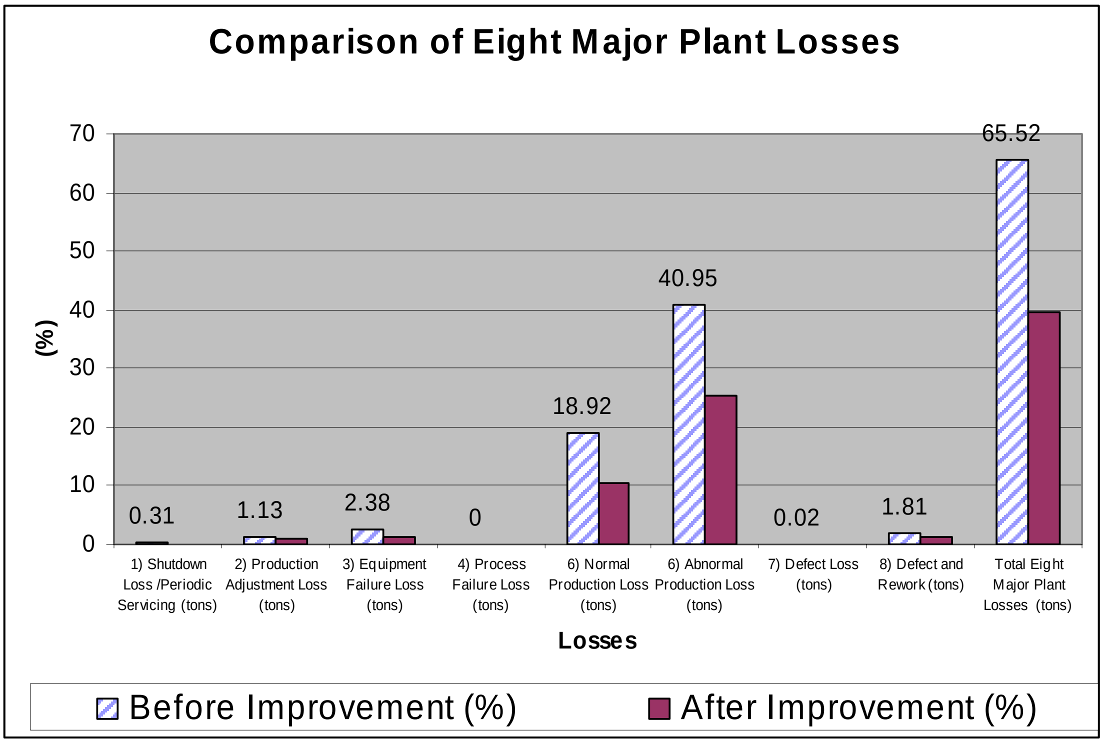


Figure 5-2: Comparison of Eight Major Plant Losses

Raw material in terms of chips inventory level was increase due to the business strategy, so the lead time of this section was also increased to 16.86 days

Work in process which was stocked on rack was total 55 tons or equal to 1.84 days and the finished goods was not much reduced. The finished goods was remained 512 tons or equivalent 17.07 days.

It was found that the overall process lead time would equal to the total sub-process lead time was reduced since from 52.32 days into 42.24 days with the shorter manufacturing value added time of 0.28 days. The value stream of process P1 would then improved as shown in Figure 5-3 the value stream of P1 after totally focused improvement activities. Process lead time in value stream was reduced around 20% and inventory was reduced around 10%.

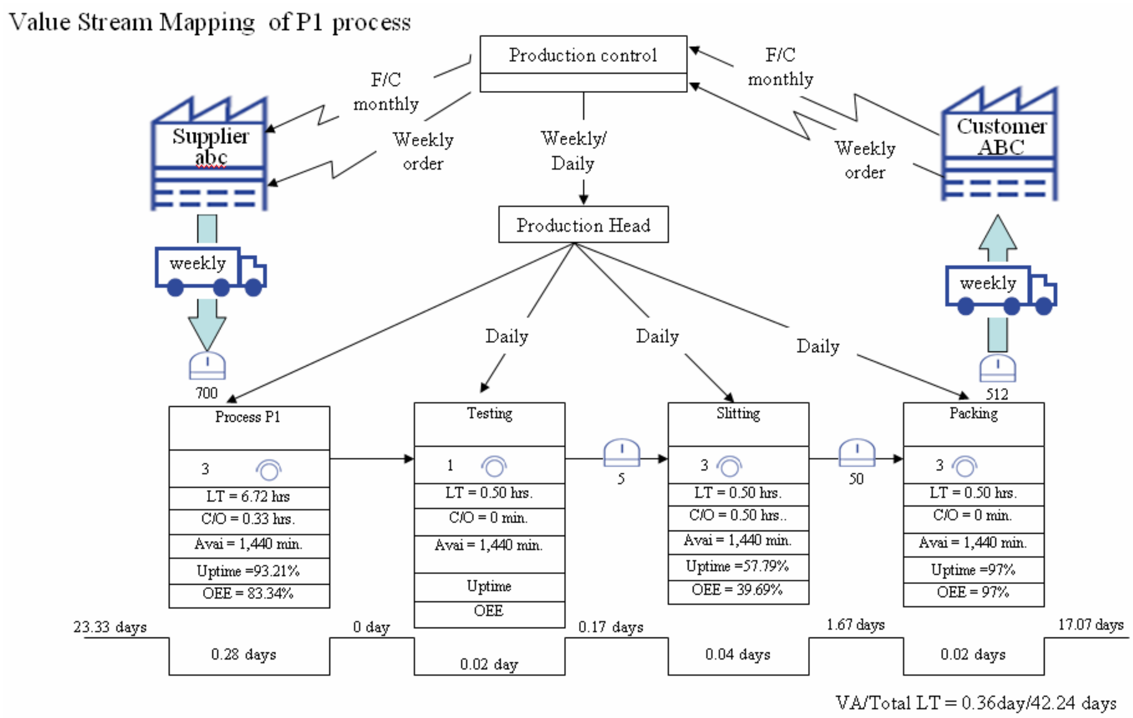


Figure 5-3: The Value Stream of P1 After Totally Focused Improvement Activities.

Table 5-10 shows the inventory level of the company after focused improvement. After improvement, the company still be found a huge stock included finished goods, rework and scrap approximately 90% (as shown in Table 5-11) compare to before Lean TPM implementation. Metalized Film Scrap was the highest level due to the company executive would keep this amount until the sale scrap price satisfied so it seem remained high. BOPET scrap was the outstanding outcome. It was zero due to the recycle process was improved and work well at higher performance, so BOPET Scrap would be no longer making loss.

Table 5-10: Quantity of Finish goods, Rework and Scrap Stock Level after Focused Improvement

Type of product	Stock level (tons)
BOPET Grade A	512
BOPET Rework	47
BOPET Scrap	0
Metalized Film grade A	197
Metalized Film Rework	107
Metalized Film Scrap	1,028
Nylon Grade A	200
Total	**2,091**

Table 5-11: Comparison of Overall Plant Effectiveness after Focused Improvement vs. the Initial Stage of Plant's Figure

No.	**Items**	**Unit**	**Overall feature**	
			Before improvement	**After improvement**
1.	Overall plant effectiveness	%	35.51	60.30
2.	Process lead time	days	52.32	42.24
3.	Raw material-Virgin Chips storage	Tons.	2,283	1,970
4.	Finish goods inventory	Tons.	804	909
5.	Work in process	Tons.	1,280	293

Table 5-11: Comparison of Overall Plant Effectiveness after Focused Improvement vs. the Initial Stage of Plant's Figure (cont.)

No.	Items	Unit	Overall feature	
			Before improvement	After improvement
6.	Rework product outside factory	Tons.	335	154
7.	Average excess side trim sale	Tons/month	104	0
8.	Maintenance part inventory	million Bath	97	95.7

5.4 Improvement Cases Study

5.4.1 CASE I: Applying the artificial neural network to predict the scratch and wrinkle defect of the ready made product instead of sampling visual inspection

It is evident that artificial neural networks (ANN) is a valuable and strong too used in creating the knowledge from database which was highly mentioned and widely applied to various aspect of industry This study presents the development of an artificial neural network model that can be applied to construct the predicting model. For the prediction of production quality, back propagation network (BPN) was chosen to develop the model. The supervised-learning process through of the process parameter data of the production process which was independent variable was employed in BPN in the online real-time mode in order to predict whether the product which was manufactured under the parametric condition of the production process at that time would yield good product or not. This would be shown through the output of BPN into 2 categories: "OK", "NO" respectively. This BPN model was used to substitute satisfactorily the quality inspection of "end product". Since it did not create the waste from the production, it helped reduce time waste in inspection, and process failure loss as well.

In Biaxial Oriented Polyester Films manufacturing process of the company in this case study, it revealed that there were some steps for stretching the film to reduce the film thickness so that it would be thinner as require by the customers. The film stretching to reduce its thickness was divided into two steps, film stretching through machine direction orientation and transverse direction orientation. The first step of stretching was done by the stretching force of the roller rotating with different speed, then the film was stretch in the second step by giving heat and transverse stretching of the film. After that the stretched film would be wound on mill roll. The quality inspector would inspect the quality of every roll of film through cutting the outer part of the film weighing 18 Kg. Out of the 18 Kg., 15 Kg of its outer part would be cut off. This would leave scratch or wrinkle on the film due to the exposure to the bother material during its transportation and handling. Next, the rest 2-3 Kg. out of the 18 Kg. would be inspected for its quality comprising scratch, wrinkle on the film through visual inspection method and other mechanical inspection of the film. Under the total quality management (TQM) philosophy, the quality does not mean the end product inspection. Instead of final product inspection, the inspection position was shifted to the monitoring the whole process and control the quality at process level through the readiness and suitability of the tool, method, and technique for individual process, individual machine and individual mechanic component of the machine used in the process. With regard to particular machine performance problem involving with quality factor was identified earlier, then the correction of several variation could be done before the defective products occur. All these were the concept in eliminating problem with the source protection. To achieve the production process with zero defects, quality must be built all through the entire production process. (Seiji T., 1996). Basic concepts for a zero QC system was built on the 4 ideas (Andrew P.D.,1990) 1) with the inspection method at the source 2) the quality inspection was done for every product instead of sampling inspection, 3) the prompt response to correct any defect, and 4) the impossibility to completely guarantee the elimination of any problem if the source or the cause of the problem and the defect could not be removed.

Data-mining algorithms is the idea of finding knowledge whose pattern comes from database which was called knowledge database discovery. This was really successful in widely applying to aspects of engineering ranging from designing, production, production control including production quality management, medical, and business applications (Da Cunha, Agard, & Kusiak, 2006; Harding, Shahbaz, Srinivas, & Kusiak, 2006; Kusiak, 2006). Some of the most widely used data-mining algorithms are (Witten & Frank, 2005):

1) Decision-tree algorithms.
2) Decision-rule algorithms.
3) Bayesian algorithms.
4) Neural networks.
5) Clustering.
6) Regression.

In order to discover knowledge or determine information pattern from database effectively according to data mining algorithm, there are process of knowledge discovering ranging from the data obtaining, accurate pattern formation based on the obtained data as follows:

The description and summary of the data. Describing typical data characteristics in both elementary and aggregated forms.

1) Segmental, division, separating the data into two subgroups: interesting and meaningful ones.

2) The description of concept or classes are described in a comprehensible form.

3) Analysis of dependency. A model describing important dependencies between objects or events is discovered.

4) Classification model assigning a correct class to the objects which are unseen and unlabeled previously.

5.4.1.1 Data Collection: In the process of data collection pertaining to the problem on scratch and wrinkle of the products for the study aim at collecting the actual problem data with its correctness in itself. As a consequence, to collect the data, there were a careful procedure starting from gathering and recording of quality inspector's results. It was found that there were 42 records out of 123 having the problems on scratch and wrinkle as shown in Table B-1.

High rank executive determined to set the cross functional team comprising engineer, process supervisor, maintenance engineer, operator, TPM consultant and the expert of machine maker company in brainstorming and discussing to search for the causing factors and the parameters of production process relevant to the scratch an wrinkle appearing on the film. After the brainstorm and discussion, the unanimous outcome showed there are at least 6 variables with significant statistical support that caused the scratch and the wrinkle in the film production, which were the thick level of the film set according to the customers' need considering to be variable number one (X1) and the some parameters of the set process considering to be variables number 2-6 comprising process speed (X2), nip roll pressure (X3), nip roll hardness (X4), film tension (X5), and pH or chemical used in process (X6). All of the obtained data were normalized and converted into category variables of which the value ranging between 1-5 accept X1 of which the values were 1 and 2 and the Output showing the outcome "OK" and "NO" as shown in Figure 5-4.

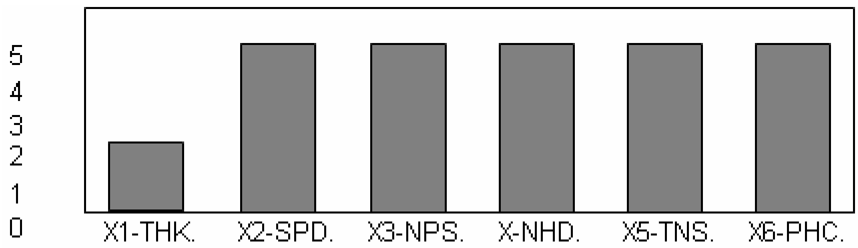


Figure 5-4: Normalization Data

5.4.1.2 The Neural Network Model for Pattern Recognition: Back propagation network (BPN) was chosen to develop the artificial neural network (ANN) model. BPN is a supervised-learning network used to explain ANN model for predicting final product from the parameter data of the process from X1-X6

1) Network Configuration: Now a day, established theoretical method to identify the optimal configuration and parameters of an ANN for pattern of quality prediction or the model of source inspection is impossible to obtain. The

design parameters are mostly application-dependent and can be found through empirical study. This ANN model comprises one 6-input layers consisting of film thickness (X1), production speed (X2), nipping pressure (X3), nipping roll hardness (X4), film tension (X5), and pH of chemical used in the process (X6). Table B-2 showed the report of test for removing the parameter that did not relate to the output.

2) The Construction Procedure for Artificial Neural Network: The 123 datasets were divided into training and test set. In this case 12-fold cross validation technique was adopted with used of supervised training algorithm. The characteristic of ANN, and the numbers optimal hidden were determined. It was found that the root mean square error with 24 optimal hidden layers were considered at the lowest level (0.249) as shown in Figure 5-5 which was plot from the data set as shown in Table B-3.

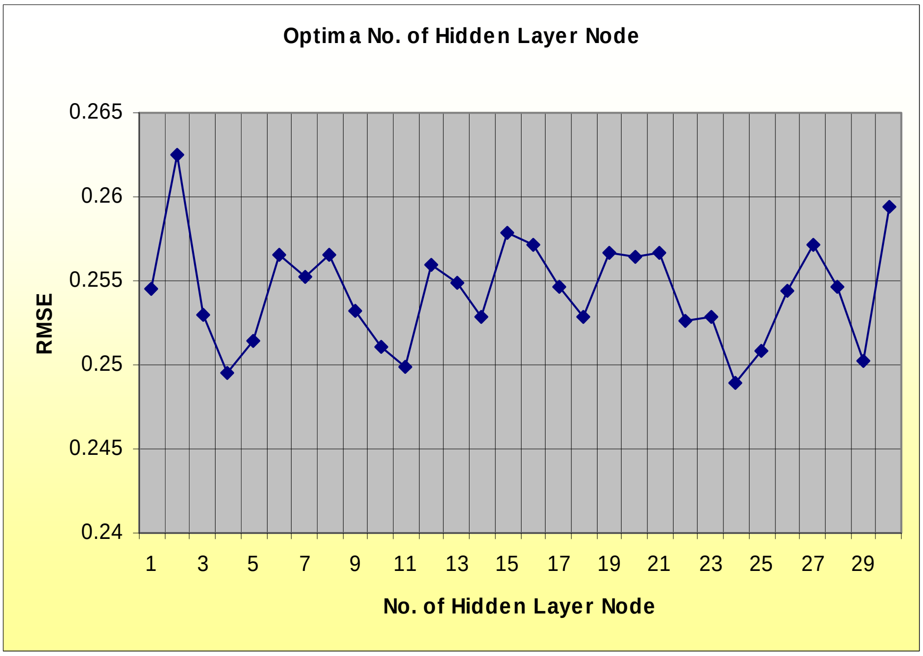


Figure 5-5: The Determination of Optimal Hidden Layer

The 24 hidden layers of network learning process and the 12-folds cross validation were used to determine the optimal learning epoch it was found that 800 epoch gave the minimum value of root mean square error RMSE at 0.249 as shown in

Figure 5-6 with obtained data as shown in Table B-4**.**

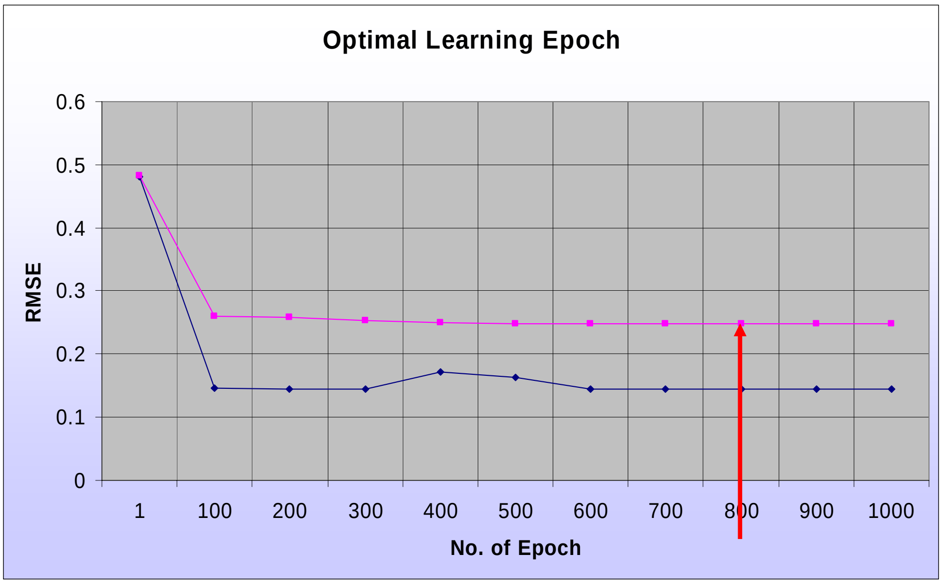


Figure 5-6: The Determination of Optimal Learning Epoch

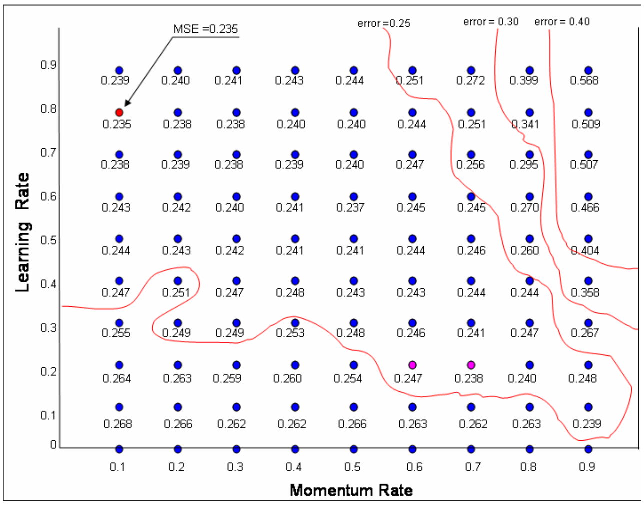


Figure 5-7: Optimal Momentum and Learning Rate

Regarding the optimal learning and momentum rate determination and the test for root mean square error RMSE, it was found that at learning rate 0.8 และ and momentum rate 0.1, it yielded the minimum value of root mean square error at 0.235 of which the contour is shown in the Figure 5-7 regarding the data shown in Table B-5 and obtain the confusion matrix from which was the outcome of 12 folds cross validation supervised learning as shown in the Table 5-12.

Table 5-12: Confusion Matrix of Scratch Mark Problems

= = = Confusion Matrix = = =		
Classified as →	**a**	**b**
a = OK	**78**	**3**
b = NO	**4**	**38**

5.4.1.2 Implementation: In the proposed method, the neural network output was the status of predicted final product quality pertaining to scratch and wrinkle on the film. Since the company in this case study required an alteration of quality inspection process obtaining into the inspection and the control of process parameter pertaining to scratch and wrinkle on film. Therefore the neural network got from this study was employed to be applied for real-time on-line mode so that the set point value of process parameters can be compared to the existing value. In case that both values tended to be different in each parameter, the process operator inthe production line must correct it immediately by choosing to use the measures ranging from the easiest one to the most difficult. The film production speed adjustment should be considered at first since it was the easiest measure to do and it might be necessary to choose the next measure which was the adjustment of the film tension, chemical change, adjustment of nipping pressure respectively. If the adjustments of the four parameters were found not be able to not to value of predicted final product quality to be better, there would be determination to change a new nipping roll considered to be the most difficult because we need to shortly stop the production process which is what we try to avoid happening. In replacing the nipping roll, planned optimal replacement interval obtained from the study of average useful life or the mean time to failure (MTTF) of nipping roll in planned maintenance activity.

Since it was found that the prediction of the neural network still has some error even 5.69 % in case of the wrong prediction when actual final product quality has 4 defects out of 123 times. This error was not expect to occur so the company required the personnel to correct the process parameters in case of finding dataset (X_1,X_2,X_3,X_4,X_5,X_6,O/P) of process parameter was (2,4,4,3,3,3,“OK”) or (2,1,4,3,3,3,“OK”) or (2,5,4,3,3,3, “OK”) or (2,1,3,3,3,3,“OK”). If this happens, there must be an adjustment for X_2 or X_5 or X_6 or X_3 respectively to become other value so as to make O/P would have the value in “OK”. The X_1 is film thickness which can not be adjusted due to customer requirement.

At this point, the application of the idea on predict scratch and wrinkle on the film got cooperation from the employees both production and quality inspection units. This could reduce some work step which was considered non value added activity resulting in becoming an easy and convenient task for the employees. However, in the initial period of applying this idea, the conventional quality inspection was still in used in order to ensure that the prediction of the neural network was still accurate without any problem on scratch and wrinkle at all.

5.4.1.3 Conclusions: This model of BPN was employed to supplement effectively the quality investigation of “end product”. The case study company could achieve the philosophy of management of the total quality management (TQM) completely. Besides the inspection method was altered to the monitoring process. The employee could appraise the production quality before the actual production. This comes from the output of the neural network. Because it did not generate the production waste, it helped decrease the waste of time for inspection, as well as the process failure loss. Due to the fact that the case study company had 7 main production lines and after it achieved in applying the idea to inspect the process parameter and predict final product quality, the company extended at the idea to the quality system in other production lines.

Figure 5-8: Interface and Control Board for Process Parameters

5.4.2 CASE II: Improving the Pining Spark Problem of Main film Production Process P1

5.4.2.1 Studying the Problem: Process of producing thermoplastic polymer, melted thermoplastic is extruded onto a cooling surface body. The method includes the steps of extrusion casting a sheet of molten polymer from a die, directing the cast sheet onto a moving, chilled and electrically grounded casting surface to solidify the polymer and extending a conductive wire transverse to a longitudinal axis of the sheet with the sheet between the wire and the chilled surface before the sheet contacts the chilled surface. An elongated conductive un-insulated shield parallel to the wire with the wire between the shield and the sheet is provided and a bias voltage is applied to the wire and the shield. Wire electrode dispose the electrostatic charge on the surface of the film in melted state by using the rotary cooling body as the counter electrode. Static electricity is impressed on the rotary cooling body through the electrode to allow the film adhere uniformly on the surface of the rotary cooling body to thereby cool the film rapidly. The bias voltage of the wire is in the range of 6 to 15 kV, and the bias voltage of the shield is adjusted to be at least 5 kV lower than the voltage of the wire to maintain a desired current flowing from the wire and the shield to the sheet as seen in Figure 5-9 Pinning sparking is known as film forming process problem due to generation of spark discharge between the wire and the rotary cooling body to generate pin hole on film which is main consequence of film breaking problem. Table 5-13 is summary of historic record of film breaking problem and process failure due to pinning spark problems.

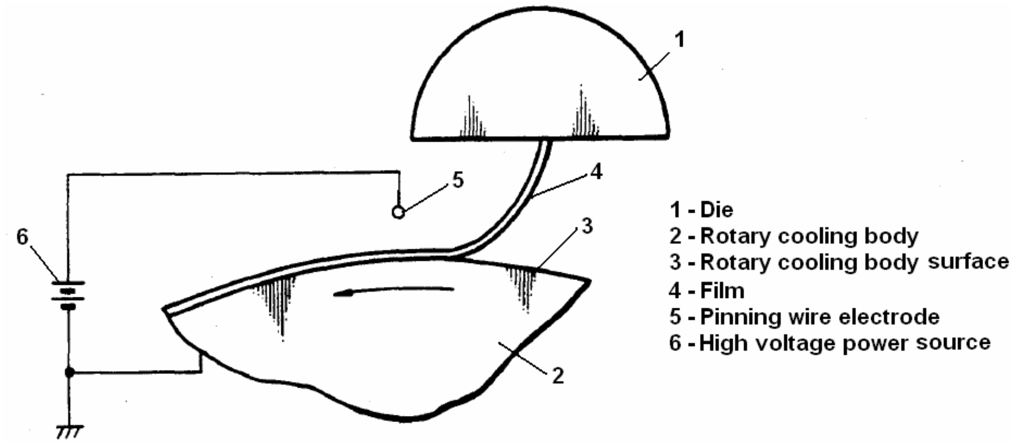


Figure 5-9: Illustration of Electrostatic Polymer Film Forming Method

Table 5-13: Historical Record of Process Failure due to Film Breaking Problem and Pinning Spark Problems

Problem	M1 (times)	M2 (times)	M3 (times)
Numbers of film breaking at TDO problem	29	14	21
Numbers of pinning spark problem	8	5	7

5.4.2.2 Analyze causes of problem: Brainstorming among P2 staffs consists of process manager, process engineer and senior supervisor was proceeded to find out problem root causes. The potential causes were raised. There were gel or air bubble in film problem, metal contamination, moisture contamination, black particle or burn film contamination, and too high disposition of the electrostatic charge on the surface of the film in melted state that may cause sparking or film breaking problems. Each potential causes was proved by setting trial and experimental methods which are shown in the following.

1) Gel or Air Bubble in Film Problem
2) Metal Contamination
3) Moisture Contamination
4) Black Particle or Burn Film Contamination

5) Too High Disposition of the Electrostatic Charge on the Surface of the Film in Melted State.

The brainstorming among the CFT and P1 staff, it was concluded that there were 20 parameters that affected pining spark problem and film broken at TDO problem

DL1-density of large size defect per length within zone 1

DL2-density of large size defect per length within zone 2

DL3-density of large size defect per length within zone 3

DM1-density of medium size defect per length within zone 1

DM2-density of medium size defect per length within zone 2

BM1-density of black spot on film surface per length within zone 1

BM2-density of black spot on film surface per length within zone 1

BM3-density of black spot on film surface per length within zone 1

T-Chilled roll ambient temperature

H-%Humidity of chilled roll ambient

SL- Line operation speed

SC-Chilled roll rotating speed

HV-High voltage supplied to pinning blade

HC-High voltage current flow through pinning blade

SW-Pinning blade feeding speed

BT-Pinning blade tension

HOS-Horizontal position of blade holder at OS side

VOS- Vertical position of blade holder at OS side

HDS- Horizontal position of blade holder at DS side

VDS- Vertical position of blade holder at DS side

Hereunder Table B-6 showed 20 datasets of pinning spark problem correspond parameters. All parameters' value was preprocessed into 1-10 scale as company's confidential aspect in this study report. The column "S" was predicted product quality status with classified into 3 categories, namely 1) "OK" means predicted quality was good, 2) "FB" means predicted quality would be film break problem, and 3) "PS" means pinning spark problem may be occur if the process was operated at this conditions.

Similar to the previous CASE I, applying the artificial neural network to predict the scratch and wrinkle defect of the ready made product instead of sampling visual inspection, the procedure to construct the multilayer-perceptron was used. The optimal configuration of neural network was revealed. It was found that the learning rate = 0.4, momentum rate=0.1, learn time = 500 epoch, and hidden layer = 550 layers was the best solution for this 20 datasets to be used. The Table 5-14 showed 100% correctly classified instant with 0.0121 root mean square error (RMSE).

Table 5-14: Confusion Matrix of Film Break Problems

a	b	c	< ----------- - Classified as
14	0	0	a= "OK"
0	3	0	b="FB"
0	0	5	c="PS"

5.4.3 CASE III: Quality maintenance of Recycle Process

It is a method for creating quality for production process and how to protect the quality problems which may be caused by the production process and the machines. This method would control the quality characteristics and other different factors leeading to the cause of quality problems which often comes from 4 production inputs which are machines, materials, operators' performance, and methods. TPM encourage the cooperation among the pillar in improving the equipment. During the autonomous maintenance discovered the equipment abnormalities and corrected them then CFT focused improvement members start to analyze the root causes of chronic problem such as quality defect and speed loss by using P-M analysis.

5.4.3.1 P.M. Analysis: It is the technique for amalyzing the real cause of the problem which was always a chronic problem by trying to understand the mechanism of the phenomena which was systematically complicate. Its steps were as follows (Shirose et al., (1995)):

1) Step 1: Clarify the phenomenon
2) Step 2: Conduct a physical analysis
3) Step 3: Define the phenomenon's constituent conditions
4) Step 4: Study production input correlation (4Ms)
5) Step 5: Set optimal conditions (standard values)
6) Step 6: Survey causal factors for abnormalities
7) Step 7: Determine abnormalities to be addressed
8) Step 8: Propose and make improvements

5.4.3.2 Study and Data Analysis: The factory for the research was the one producing polyester film sheets of which the production line was divided into 8 lines. The factory's administrative system was under the development operation based on the Total Productive Maintenance (TPM). It was determined by the factory's executives group to have a survey for more than 26 items of the main losses as defined by TPM Japanese Institute of Plant Maintenance (JIPM) of Japan in the year 1970s . it was found that there ,Regarding thiswere thevery high financial losses asper year. In fact, the cause of the losses came from the quality inconsistency of the raw materials or the recycled chips fed into the film sheets production process where the recycling process or Erema was applied. In this regard, the quality characteristics could be evaluated such as Intrinsic Viscosity: (IV), Chemical Configuration of the Plastic Chips or the Component Group of COOH of Polemer Molecules, and Chip Size.

After crucial brainstorming among the key person of the process, it was found that the potential causes of the problem was the staining caused by impured materials on the film sheets coming from recycled production were as follows:

1.1) staining from production process of film sheet such as papers, sticker tape, dust, erosion of color, lubricating oil, film sheet cutter blades, and pieces of logs

Table 5-15: Process Quality Parameter Records

Quality items	Target	Condition before improving
Productivity (Kg/hr)	≥ 915	638.28
Parameter	C_{PK}>1.30	C_{PK}= 0.7-0.9
IV	> 0.98	< 0.91
Chips/gm	0.90± 5%	0.45-0.75
Carboxylic Groups (COOH)	1.80	1.36

1.2) staining from packing the film sheets during the production process such as dust, pieces of logs, oil, lubricating materials

1.3) staining from transporting the film during the production process such as dust, pieces of logs, oil, lubricating materials –staining from the feeding of raw materials or broken film sheet occuring durring the production process of the chips such as dust, pieces of logs, oil, lubricating materials - staining from staining from insects creeping into the production process.

1.4) staining from broken machines in the production process such as oil, lubrication

The abnormality found during the production process could occur on the parts of equipment such as, Bucket for keeping bits of film, Compactor, Extruder, and Chips Cutter

5.4.3.3 Corrections and Improvement: In fact, most losses originate either in deterioration or pm failure to establish and maintain the basic conditions that assure proper functioning of equipment. In this step there was a combination of two measures to reduce this loss comprising elimination of minor flaw, and applying P-M Analysis.

1) Eliminate Minor Flaw: By doing this, employees seek all equipment abnormalities. They se plan to remove the abnormalities together small improvement as follows:

1.1) Improvement for reducing the staining caused from keeping the film rolls and renovating the workplaces

1.2) Improvement of the place to keep the film rolls waiting for the chip production by cleaning of the keeping areas and determining the standard for keeping by usually placing on the pullet

1.3) Improvement of automatic closing doors to protect insecdts from the production line

1.4) Improvement of the floor for the production line by paving the factory floor with efoxy by cleaning of the floors, the walls and the ceilings, surveys for machines defects and abnormalities, and their basic corrections as shown in Table 5-16.

Table 5-16: Seven Items of Machine Abnormal Conditions and Their Corrections

Equipment abnormality	Countermeasures	Prevention recurrence
1. Malfunction of fluff silo with causes in the followings; 1.1 Agitator screw lock 1.2 Agitator screw broken	 1.1 Repair Gear Box 1.2 Repair as found	 1.1 Set lubricating plan for bearings 1.2 Using level sensor to control film fluff in the silo
2. Compactor malfunction due to film cutter blades broken	2.1 Removing the bolts and replaced all cutter blades	2.1.1 Provided procedure for replace cutter blade and training
3. Malfunction of Extruder due to the following causes 3.1 Too low oil lubricant due to leakage of the inner oil seal	 3.1 Replaced oil seal 3.2 Cleaning	 3.1 Set cleaning schedule and install temperature measurement at the point

Table 5-16: Seven Items of Machine Abnormal Conditions and Their Corrections (cont.)

Equipment abnormality	Countermeasures	Prevention recurrence
3.2 Extruder was dirty 3.3 Filter pieces obstructed in barrel 3.4 Die lip blockage	3.3 Stopped machine and totally cleaned Extruder 3.4 Dismounted Die and removed the blockage substance such as small pieces of steel inside the die	3.2 Set cleaning schedule and install temperature measurement at the point 3.2 Set cleaning schedule 3.3 Provided manual for replace filter and training 3.4 Modified the die lip by adding more die slits
3.5 Screw was dirty 3.6 Vacuum was clogged 3.7 Vacuum enclosure was leaked 3.8 Vacuum oil level gage was blurred 3.9 Vacuum rubber hose was leaked 3.10 Oil leak and drop into the fluff silo of Extruder	3.5 Cleaning 3.6 Cleaning 3.7 Repair vacuum enclosure 3.8 Replaced Vacuum Gage 3.9 Replaced Vacuum rubber hose 3.10 Repair the leak hole on silo	3.5 Set cleaning schedule 3.6 Set cleaning schedule for Vacuum 3.7 Modified opening handle of vacuum chamber 3.8 Consider the new Vacuum Gage with resist the heat 3.9 Set inspection schedule for Vacuum hose 3.10 opened fluff silo for venting moisture and water drainage plug

2) Performed P-M Analysis: Determined the relation of all defects mode and process and sub-process using the QA matrix as shown in Figure 5-10. It was found that most of defect mode in this process were too big size of chips, twin chips, too long chips, inconsistent of carboxylic group, too low intrinsic viscosity, abnormal brown color chips, tailed chips, semi-cutting, and too high ash percentage.

Filling — Serious : ● General : ▲ Past occurence Frequent : ★ Occasion : ☆

Quality characteristic	Intermediate process			1	2	3	4	5	6	7	8	9	10							
	Defect modes	Seriousness	Past Occurrence	ตัดแผ่นฟิล์ม	เก็บแผ่นฟิล์มในไซโล	ป้อนฟิล์มเข้าเครื่อง compactor	บดอัดแผ่นฟิล์ม	หลอมแผ่นฟิล์ม	อัดพลาสติกเหลวผ่าน Die	แลกเปลี่ยนอุณหภูมิ	ตัดเส้นพลาสติก	คัดขนาด	การตรวจสอบคุณภาพ							
I.V.	Low I.V.	●		○	○			○					◇							
ASH%	Hight ASH%	●	☆	○	○								◇							
COOH	Hight COOH	●	☆					○					◇							
Chip size	Big size	●	★								○	○	◇							
	Twin size	●	★						○	○										
	long size	●	☆								○	◇								
	Small size	●	★			○		○					◇							
Colour	brown	●	☆					○		○			◇							
Appearance	ตัดแล้วมีหาง	●	☆								○	◇								
	ตัดไม่ขาด	●	★								○	◇								

Correlation Analysis

กระบวนการที่ทำให้เกิดปัญหา : ○

กระบวนการที่คาดว่าจะทำให้เกิดปัญหา : ◎

กระบวนการที่มีความสัมพันธ์กับปัญหาโดยตรง : △

ตรวจสอบกระบวนการ : ◇

ตรวจสอบผลิตภัณฑ์ : ◆

Figure 5-10: QA Matrix the Relation between Chips Defect Modes and Process

Table 5-17: The Results of Product Quality Parameters after the Improvement

Quality items	Target	Condition after improving
Productivity (Kg/hr)	$\geq$915	900-950
Parameter	C_{PK}>1.30	C_{PK}= 1.33 consist
IV	> 0.98	0.94-0.96
Chips/gm	0.90$\pm$ 5%	0.88 $\pm$ 7%
Carboxylic Groups (COOH)	1.80	1.72

Table 5-17 showed the better results after improvement. Recycle process could produce the recycle chips at higher productivity level, better process capability Cpk, range of intrinsic viscosity was very close to the target as well as chips size and the carboxylic group structure were better. CFT had provided the maintenance standards as shown in Table 5-17.

5.4.4 CASE IV: Setup Time Reduction in Slitter JAKAMP 09

As known in earlier, setup time reduction is one of the most employed and most valuable Lean practice. Shorter setup times allow the production process to achieve greater flexibility, maximize machine capacity with little or no additional cost, and shrink lead times. In this study the framework of Lean TPM implementation, setup time reduction concept was crucial studied.

In the Slitting process, it was found that there were two major losses such as speed loss and setup loss as shown in the Figure 5-11. For speed loss, the major cause was due to the loosen wrapped on mill roll of which the responsibility of main process to solve the problem. So in this case, speed loss was not considered to be corrected by Slitting work unit. The finally, the problem of loosen wrapped film on mill roll was corrected by main film process B4. Consequently, by automatically, speed loss of Slitting process was reduced to be 7,649 ton per year.

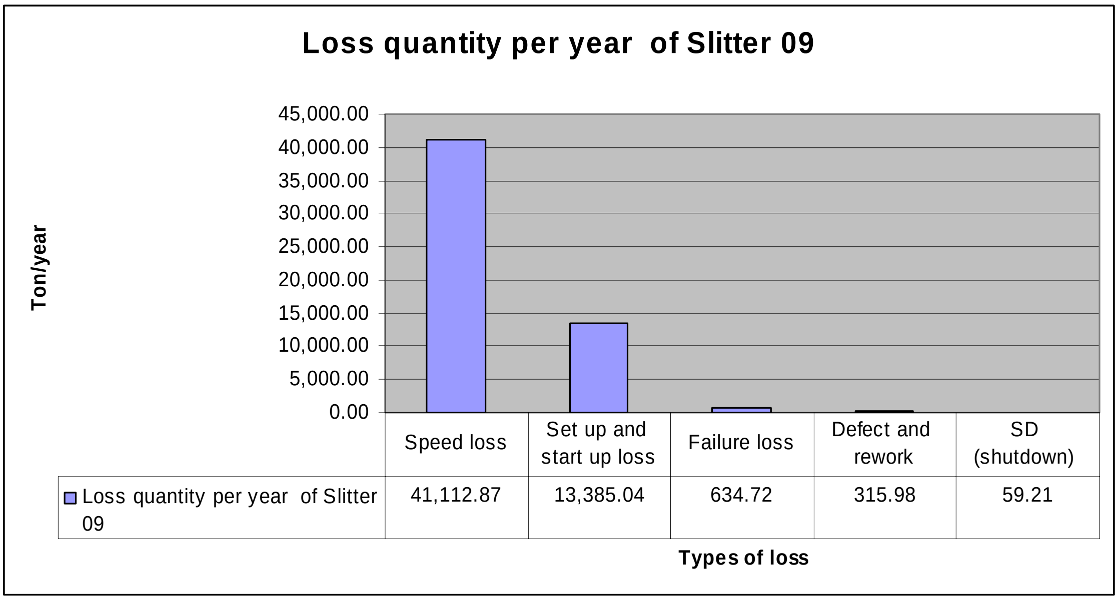


Figure 5-11: Overall Losses of Slitter JKAMP09 before Lean TPM Implementation

The setup time was very high in second order resulting in company's more overall process losses. As the consequence, it was necessary for the employees to urgently reduce this kind of loss. This began with establishment of the CFT with a line manager acting as a small group leader, And, most of the members were the machine operators including those coming from important department such as maintenance staff. TPM consultant suggested Quick changeover techniques as the technical tool for setup time reduction through the training so that the employees knew the guideline of how to reduce setup time of Slitter model JKAMP 09. Moreover, in order to set-up time reduction, the following steps needed to be followed as shown in Table 5-18**.**

Table 5-18: Set-Up Reduction Steps

No	Activity
Step No.1	Separating internal and external preparation activities: In this step, all set-up activities are reviewed and one simple question is asked: ''Does the machine need to be stop during the activity? If the answer is 'no', then this activity could be shifted to the external preparation type.

Table 5-18: Set-Up Reduction Steps (cont.)

No	Activity
Step No.2	Transferring internal activities to external preparation ones: This can be conducted by technical modifications, e.g., instead of exchanging many small parts on-line, a sub-module having these parts is shifted, and the preparation as well the post maintenance was done off-line.
Step No.3	Minimizing or streamlining internal and external activities preparation: For the rest of both internal and external preparation activities, the reduce the set up time should be reduced by modifying other innovative ideas before applying them to this task.

CFT used some suggestion of rule 9 in which is a part in general design rules for reducing set up time of equipment mentioned by (Ges et al.,1995) who talked about technique in reducing the time in terms of method and organization such as separate internal and external set-up activities, reorder the performance of the activities to decrease movements and walking distance, separate the job done on different location between the operators in order that the needing machine for the performance of the most activities were not to wait. There should also be a balance of workload between the on duty operators and separate instruction sheet for each one, as well as provide set-up instruction guides. As a result, CFT started to divide the tiniest equipment setup steps into 28 sub-steps, together with recording the existing steps of setup procedure for 31 times. Resulting in the knowing each of the actual setup time, which were 103.71, 95.54, 117.37, 100.28, 100.38, 100.53, 108.03, 112.42, 111.83, 98.57, 96.93, 98.39, 106.17, 107.70, 95.85, 108.42, 99.79, 102.82, 91.25, 92.32, 111.57,91.54, 98.11, 108.28, 101.44, 101.72, 99.75, 105.84, 92.83, 100.32, 88.63 minutes. This set of the setup time had sample mean = 101.37minutes, standard deviation = 6.8820, and sample variance = 47.3617. Table 5-19 showed average time and statistics value of each sub-steps during the data collection for the mentioned setup time. Regarding this, it was found that 3 operators, A, B, and C did the setup job in series configuration. If any sub-step was not proceeded. The rest of the operators did nothing but to wait thought there were some other works could be done simultaneously.

Table 5-19: Descriptive Statistics of Setup Time of Slitter JKAMF 09 (n=31)

No.	Sub-steps of setup	Mean	Standard Deviation	Sample Variance
1.	Feed the data into the computer	2.25	0.36	0.13
2.	Wait for the machine set the film width until they were finished	2.95	0.43	0.19
3.	Measure the width of the film as set	2.11	0.4778	0.23
4.	Cut film	3.00	0.4865	0.24
5.	Find a mill roll	2.21	0.3436	0.12
6.	Move a mill roll	3.00	0.45	0.20
7.	Flip the film	2.10	0.50	0.25
8.	Remove the mill roll out of the machine	3.05	0.50	0.25
9.	Place the mill roll into the machine	4.09	0.77	0.60
10.	Remove empty the core from the machine	3.04	0.45	0.20
11.	Connect the film	2.09	0.48	0.23
12.	Remove the nipping roll out of the machine	2.16	0.51	0.26
13.	Place the nipping roll into the machine	2.11	0.37	0.14
14.	Disconnect the air tube out	2.09	0.44	0.20
15.	Relocate the chuck from the machine	2.94	0.63	0.40
16.	Slide the new chuck into the machine	3.01	0.60	0.36
17.	Set two pairs paper core holder arm	2.07	0.47	0.22
18.	Remove the old cutting blade	2.14	0.41	0.17
19.	Replace the new set of cutting blade into the machine	3.07	0.61	0.37
20.	Release the chuck out of the machine and take the scrap roll out of the machine	3.01	0.88	0.77
.21	Put the empty scrap roll into the machine	2.10	0.47	0.22
.22	Walk to the paper core cutting machine	3.03	0.67	0.45
.23	Find proper size of the paper core	3.06	0.63	0.40
.24	Cut the paper core	30.39	4.95	24.48

Table 5-19: Descriptive Statistics of Setup Time of Slitter JKAMF 09 (n=31)(cont.)

No.	Sub-steps of setup	Mean	Standard Deviation	Sample Variance
.25	Bring the cut paper core to the Slitting area	4.03	0.82	0.67
.26	Place the core in order on the floor	2.10	0.41	0.17
.27	Hammer the paper core	2.09	0.44	0.19
.28	Put the paper core into the machine	2.08	0.46	0.22

CFT employed the separating internal and external preparation activities for the new setup : In this step, all set-up activities were reviewed using one simple question: ‘‘Does the Slitter have to be stopped during this activity.? If the answer was ‘no’, then this activity was shifted to external preparation activity. The result of separating activities are shown in Table 5-20. In case of putting aside the external preparation activities and still working with the conventional style of series configuration, it would reduce the time from 101.37minutes to 45.53minutes.

Table 5-20: Activity Separation

No.	Sub-steps of setup	Mean time of activity (min.)	Time of Internal activity (min)	Precedence work	Time of External preparation activity (min)	PIC
1.	Feed the data into the computer	2.25	-	none	2.25	C
2.	Wait for the machine set the film width until they were finished	2.95	2.95	1	-	C
3.	Measure the width of the film as set	2.11	2.11	2	-	B
4.	Cut film	3.00	3.00	2	-	A B
5.	Find a mill roll	2.21	-	N/A	2.21	C
6.	Move a mill roll	3.00	-	N/A	3.00	C

Table 5-20: Activity Separation (cont.)

No.	Sub-steps of setup	Mean time of activity (min.)	Time of Internal activity (min)	Precedence work	Time of External preparation activity (min)	PIC
7.	Flip the film	2.10	-	N/A	2.10	C
8.	Remove the mill roll out of the machine	3.05	3.05	4	-	A B
9.	Place the mill roll into the machine	4.09	4.09	8	-	A B
10.	Remove empty the core from the machine	3.04	3.04	9	-	A B
11.	Connect the film	2.09	2.09	10	-	A B
12.	Remove the nipping roll out of the machine	2.16	2.16	2	-	C
13.	Place the nipping roll into the machine	2.11	2.11	11,12	-	C
14.	Disconnect the air tube out	2.09	2.09	13	-	C
15.	Relocate the chuck from the machine	2.94	2.94	14	-	C
16.	Slide the new chuck into the machine	3.01	3.01	15	-	C
17.	Set two pairs paper core holder arm	2.07	2.07	16	-	C
18.	Remove the old cutting blade	2.14	2.14	11	-	A B
19.	Replace the new set of cutting blade into the machine	3.07	3.07	17,18	-	A B
20.	Release the chuck out of the machine and take the scrap roll out of the machine	3.01	3.01	17	-	C

Table 5-20: Activity Separation (cont.)

No.	Sub-steps of setup	Mean time of activity (min.)	Time of Internal activity (min)	Precedence work	Time of External preparation activity (min)	PIC
.21	Put the empty scrap roll into the machine	2.10	2.10	20	-	C
.22	Walk to the paper core cutting machine	3.03	-		3.03	A B
.23	Find proper size of the paper core	3.06	-		3.06	A B
.24	Cut the paper core	30.39	-		30.39	A B
.25	Bring the cut paper core to the Slitting area	4.03	-		4.03	A B
.26	Place the core in order on the floor	2.10	-		2.10	A B
.27	Hammer the paper core	2.09	-		2.09	A B
.28	Put the paper core into the machine	2.08	-		2.08	A B

This example shows the improvement stemming from just only to separate the step of setup. In fact there were possibility in organizing parallel work that could reduce the setup time to only 37.66 minutes as shown in Figure 5-12**.** The line manager encouraged the machine operators to help plot graph that showed the setup time for every machine setup leading to the operators having more desire to participate in the activity, and it made interested in the activity since they could the clear goal in reducing the setup time to not more than 37.66 minutes. Practically, it was found that all employees were the CFT members who really used the new setup procedure, and they could do it better than what were set in the ultimate goal as shown in Figure 5-13. However, if there was any employee who has to be absent from work during the week, the value of setup time would highly increase. Thus, for the improvement, there was a determination for the packing employees to attend the setup training so that they would be the standby persons when someone were absent during the week day. This would result in the successful governing of the setup time as shown in Table 5-21 that the mean time to setup was equal to 29.35 minutes resulting in the setup loss was reduced. It was found that the setup loss of this process was only 3,129.25 ton per year.

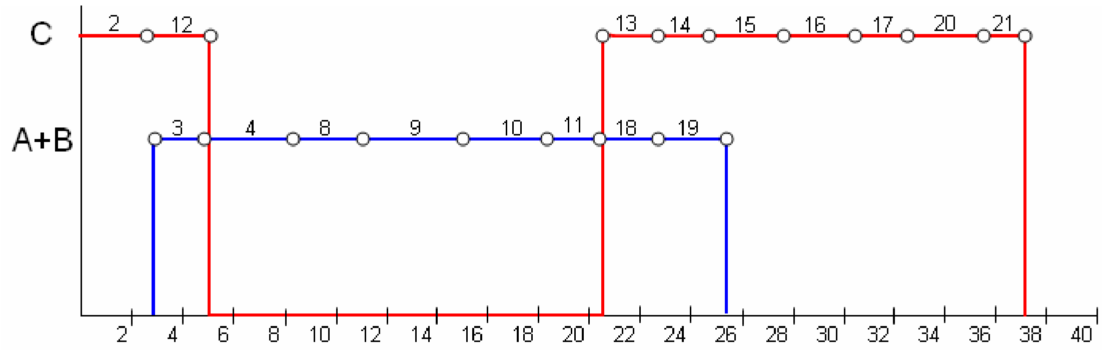


Figure 5-12: Set Up Time Reduction Task in Parallel

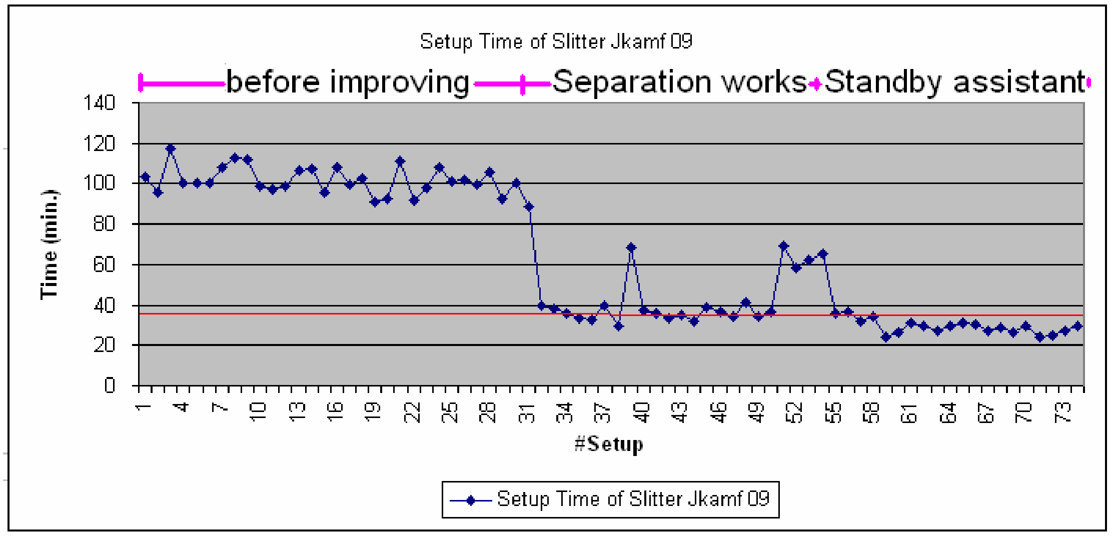


Figure 5-13: Setup Time Plot

By the good cooperation with main film process B4 that the CFT was able to solve the problem of loosen wrapped film on mill roll. As the consequence, speed loss of Slitting machine model JKAMP09 was reduced. It remained only 7,649.02 ton per year. Table 5-22 showed the losses and OEE of Slitter JKAMP09 after improvement in comparison to before the improving period. This setup time reduction concept was horizontal deployed into another 8 Slitting machines including the model machine such as Slitter ATLAS05 resulting in huge setup losses were reduced. The OEE value was dramatically increased.

Table 5-21: Descriptive Statistics of Setup Time after Improvement in Assistance of Packing Staff

	Mean (min.)	S.D. (min.)	Max. (min.)	Min. (min.)
Before	101.56	6.9758	117.37	91.25
After#1	42.06	15.5925	69.24	29.86
Packing to assist	29.35	3.5046	36.74	24.38

Table 5-22: Loss Comparison after Improving Slitting Machines

Losses	Before improving	After improving
Speed loss (ton/year)	41,112.87	7,649.02
Setup and startup loss	13,368.04	3,129.25
Machine failure loss	634.72	527.00
Defect and rework loss	315.98	479.68
Shutdown loss (ton/year)	59.21	72.17
Availability : A (%)	82.36	94.52
Performance rate: P (%)	37.44	89.86
Quality rate: Q (%)	98.72	99.53
Overall equipment effectiveness: OEE (%)	30.44	84.54

Table 5-23: Comparison of Before and After Improving OEE of all Slitting Machines

Process	Before improving	After improving
BOPET Slitting P1 (J06)	28.48%	39.69%
BOPET Slitting P2 (J08)	36.86%	56.28%
BOPP Slitting B1	25.04%	51.81%
BOPP Slitting B2	27.09%	57.16%
BOPP Slitting B3	27.03%	30.46%
BOPP Slitting B4 (J09)	30.44%	84.56%
BOPA Slitting N1	25.65%	69.81%

5.4.5 CASE V: Reducing Speed Loss of Slitter of B3

Speed loss is what the equipment is operated at lower its maximum designed speed or it is the loss caused by the difference between the desirable speed of a machine and its actual operation speed. Speed losses consists of two main types of loss: idling and minor stoppages, and reduced speed operation. . It was found that operators and engineers of this production unit preferred to operate the machine at lower speed because scratch on film produced would be occur if the operation speed was high. At the initial Lean TPM implementation of this work unit this such problem was neglected and no any effort was made to pursue and to correct their causes. An inadequate investigation of the speed loss problem happen when speed was increased. Once the loss investigation of B3 production process was finished, it was found that setup loss was the highest one with the OEE value was 64.71%. As TPM goals, in order to achieve 85% of OEE both speed loss and setup loss would be considered to reduce. Firstly, it was revealed that setup loss was created due to frequent stoppage of machine in order to clean the die lip. There were two main ideas of this loss reduction. The first, SMED or setup time reduction method introduced by Shigio Shingo would be used for this purpose but it was quite very difficult including the production manager did not need to take much risk on modification the machine. So this idea was not agreed. Improving the recycle chips quality so as to reduce die lip cleaning frequency was the second choice. So the company executive assigned the CFT to improve the quality of recycle chips which was the responsible of recycle work unit taskforce. The entire recycle chips quality improvement was illustrated in case III Quality maintenance of Recycle process using P-M analysis method. The recycle chips quality improvement task can help main film production process B3 reduced the cleaning frequency from 3 times in a day to be one time of cleaning in 3 days. Consequently, Setup loss of process B3 was reached the level not more than 413 ton per year.

Back to the speed loss issue in B3, CFT set the targets of line speed in corresponding with type of film produced. The speed of machine at low performance was only 250 m./min. The target line speed line for producing PSL202 and P202 were at least 280 m/min. and the other plane film with the thickness of 20 micron was operated at line speed at least 300 m./min.

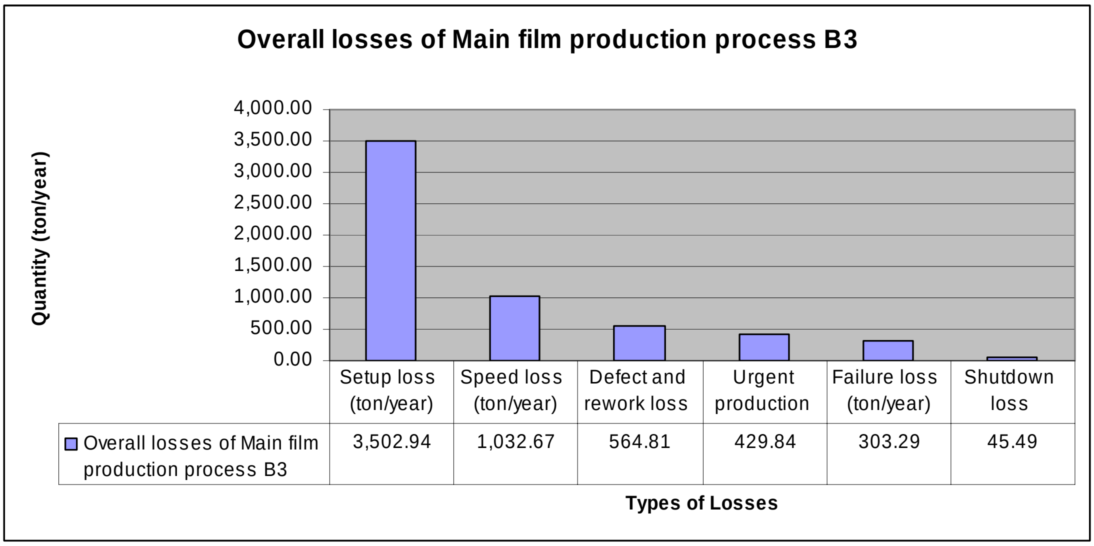


Figure 5-14: The Overall Loss of Main Film Production Process B3

Main reason of speed loss in B3 was what B3 machines cannot be operated to the specified speed because the strain marks would be happen. The mechanic problems was never resolved. Fishbone diagram was used to analyze for potential root causes of strain mark on film which was the defect that occur at higher speed operation. The speed loss reduction framework as shown in Table 5-24. It showed the adapted version of the actions framework which are ensuring in series but some would occur in parallel with one another in practice (Eti, et al.,2004).

Table 5-24: Speed Loss Reduction Strategy and Framework

Action	Related parameters and considerations
Identified the speed loss level and their outcomes on the consider activity.	Machine speed, bottleneck processes, machine down-time, minor stoppages,
Compare the speed design via the actual one.	The design of the specifications, the gap between designed speed and existing speed. Speed gaps of different products
Tracing back to identify the previous conditions of the problem	The previous maximum speed ever been greater, the problem used to occur and
Identify the relevant theories and principles	The condition and the processing of the machine which did not fulfill the theoretical
Collecting the information relating to the desirable state of mechanisms	Rated output, load ratio, tension and stress, spare parts, and specification of each part
Listing the problems	Indication of desirable conditions; Compared with existing conditions; List of Problems
Correcting all abnormal or defective parts as listed above	Actions without side effects
Confirming the results	
Perform test-runs	

This above Table showed the adapted version of the actions framework which are ensuring in series but some would occur in parallel with one another in practice (Eti, et al.,2004).

These above actions to improve the OEE of process line B3 were very simple. It did not need any complicate analysis, just only crucial observation the machine abnormalities. This effort of CFT in conjunction with other main pillar activities such as Autonomous Maintenance (AM, Planned Maintenance (PM, and Education and Training pillar (Ed&T) resulting in increasing speed of main film production process to between 309-324 m./min.

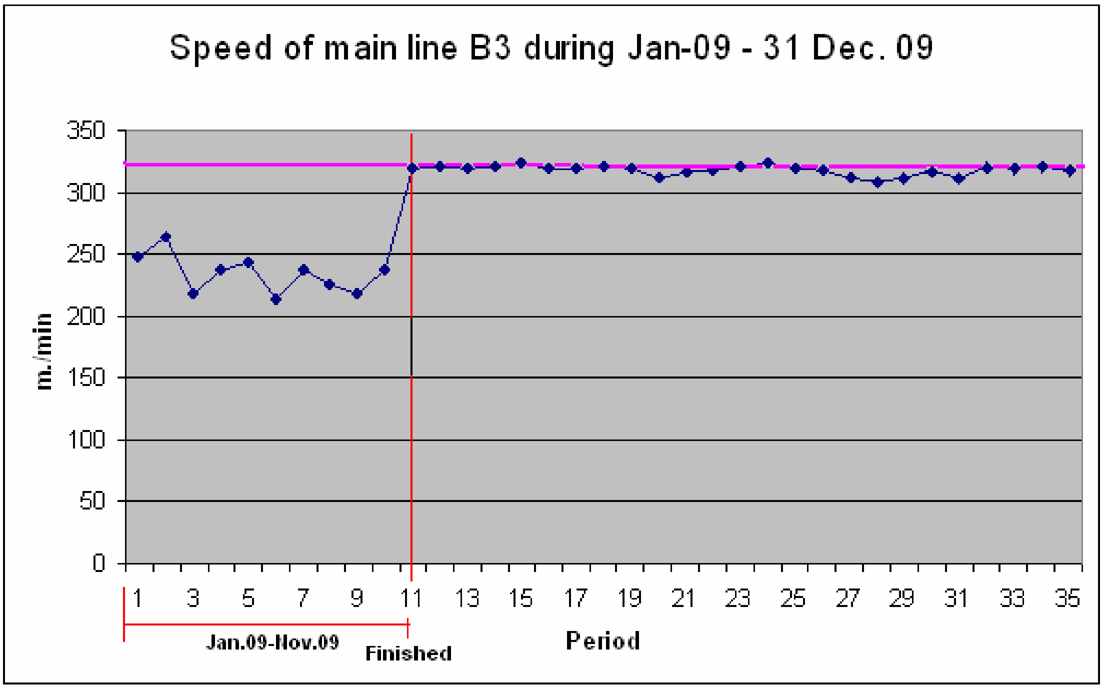


Figure 5-15: Tendency of Speed of Process B3

Table 5-25: Comparison of Loss of B3 After Improvement

Losses	Before improving	After improving
Setup loss (ton/year)	3,502.94	413.00
Defect and rework loss (ton/year)	564.81	595.84
Urgent production change loss (ton/year)	429.84	450.95
Failure loss (ton/year)	303.29	238.19
Shutdown loss (ton/year)	45.49	25.93
Availability: A (%)	74.52	93.29
Performance rate: P (%)	91.35	93.96
Quality rate: Q (%)	95.08	95.95

5.4.6 CASE VI: Mis-operation of Recycle Process P1

The company for this case study had a process for the production of a recycled plastic product from scrap plastic film of the main production process and Slitting process. Plane film or film strip were grinded and melt in recycle process before forming the plastic chips as the certain size. Melt filters were used in compounding to remove foreign particles of contamination or burnt polymer or additives & fillers/reinforcements. Piston type screen changers are the most accepted and widely used, as well as the company for this case study, continuous systems. During normal production, all screens are in operation and only during screen changer are one or more screens removed from the melt flow, which is diverted through the remaining screens. As the shear increases, the melt viscosity decreases, minimizing the pressure increase across the screen changer. Pressure variations at screen change can be minimized by changing screens early, before they are totally clogged and differential pressures have reached a high level. Most efficient and highly profitable production lines will require continuous, uninterrupted filtration, with a minimum of pressure variation at change over. De-aeration must be precise, complete and automated to insure on specification production. Automatic backflush of the filtration media for highest automation and reuse of filtration media, especially for high contamination levels as found in recycling. Screen changers should be reliable and leak free, with virtually no need for maintenance, other than routine cleaning. Operators did not really know above technical requirement. Filter was changed in case of the high pressure across the screen changer with stopping the machine. As the consequence, for each filter change which needing the machine stop, it took about 30 to 50 minutes which could be the waste for producing the recycle chips at least six hours a month or equal to 7.5 tons per month. After every filter change and starting running the machine again, there would be lots of waste lump and semi-ready chips for each time resulting in 80-250 kg. of wastes produced during each filter change. These wastes, weighting about 2.46 tons per month, could not be recycled again. From Figure 5-16, it was found that speed loss was the highest one but this loss could not be reduced due to there was not plastic scrap available enough to produce, so shutdown loss comprising filter change and planned maintenance time loss was considered to improve. The study had found the procedure to prolong the filter useful life by mean of stepwise setting set point of pressure across the changer screen together with the excellent technique in changing the filter without stopping the chips recycle machine.

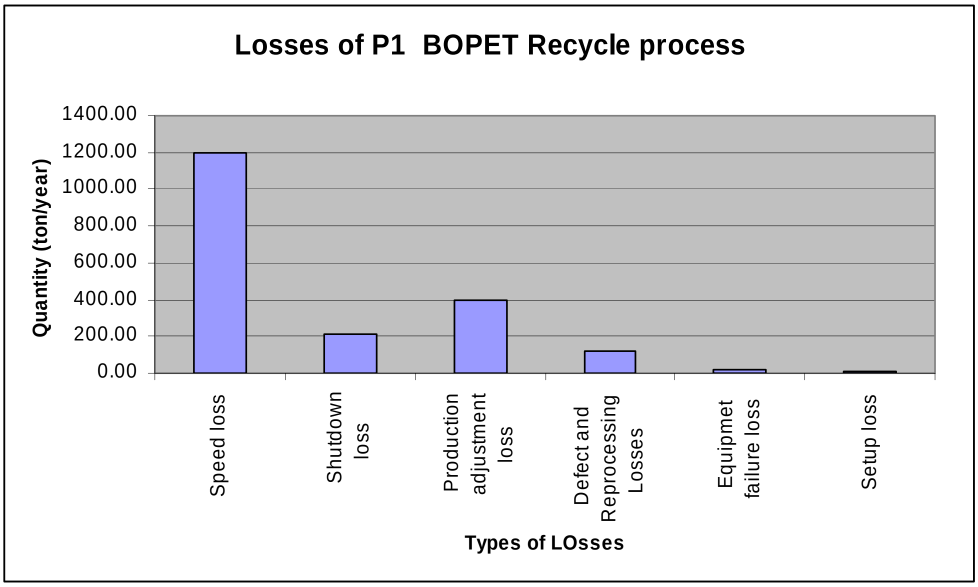


Figure 5-16: Losses of Recycle Process P1

Figure 5-16 shows various corresponding losses in the entire recycle process. Causes of these kinds of losses were originated by poor process management such as poor human resource development system and poor maintenance activity resulting in poor condition of machine and low process performance. This study with cooperation with Autonomous Maintenance and Planned Maintenance with Education Training pillar to reduce these losses. The framework of this development comprising 1) Entire process inspection for machine abnormalities through Autonomous Maintenance activity, 2) Set planned preventive maintenance for the machine as a whole, and 3) Studied the basic operation of machine and the filtration function and set the procedure for operation the filter elements. The activities in these three main activities would be seen in below.

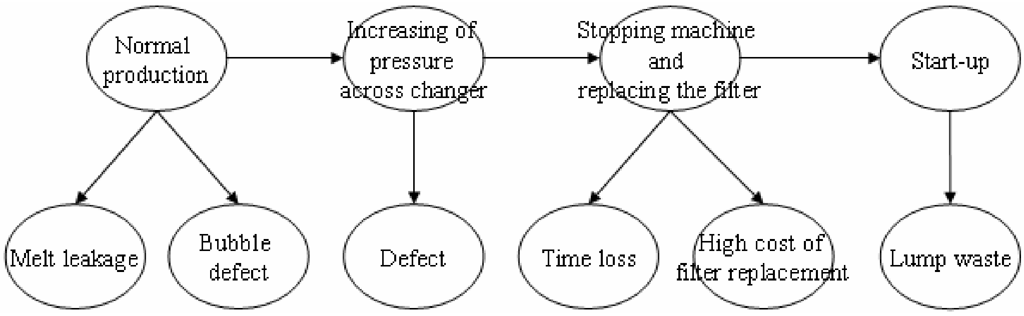


Figure 5-17: Original Filter Change and Operating Procedure

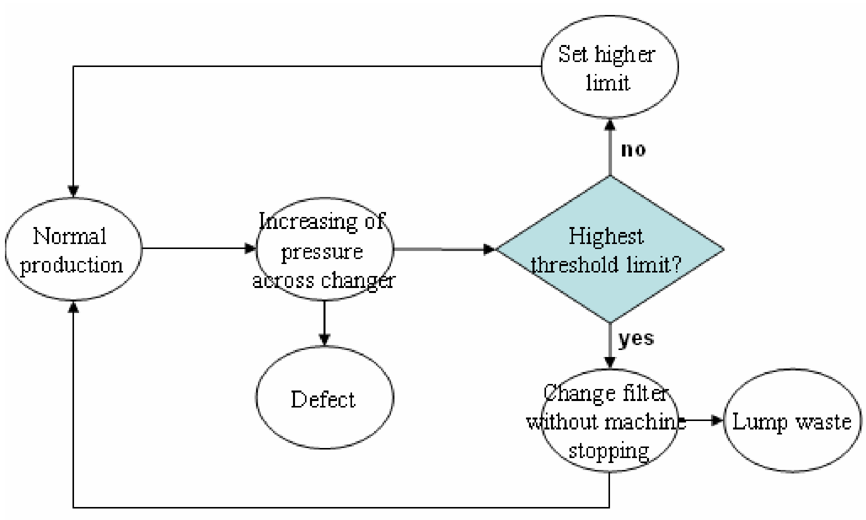


Figure 5-18: New Operation Procedure after Improvement

1) Development of Autonomous Maintenance activity step 1, initial cleaning refer to the efforts to remove completely at the commencement of autonomous maintenance activities any foreign substance such as dirt, dust chips, sludge, and scraps that adhere to the extruder and other recycle machines' parts such as die, an so on. It was found that the condition of the machine was very poor. Several machines' abnormalities as well as the Teflon ring gasket of piston breakage were found. The aim of autonomous maintenance was to establish the machine basic condition by removing all kinds of abnormalities. As a consequence, air leakage at the broken Teflon ring was corrected result in elimination of bubble chips defect problem.

2) Set planned preventive maintenance for the machine as a whole. There were two machines maintenance plan such as condition-based maintenance to replace the filter and Teflon ring gasket and the tentative cleaning standard and inspection obtained from the autonomous maintenance activity.

3) Development of new filter operation procedure; Recently study and various articles in many we-site indicated that automatic backflush of the filtration media would be most efficient temporary reducing the pressure P across the screen changer. We need to know which pressure A1 value , time duration needed to drain melt, and the order of screen pack to be flush that would be suitable for backflush pressure. These condition would not create the air bubble defect in chips and extruded forming polymer would not break and cut. Several trials and experiments were held. The experiment was designed by varying the set point of pressure A1 ranging 20 to 70 bar such as 20, 35, 55, and 70 bars, control the speed of granulator at 70 rpm., and treat backflush at difference order of filter piston. It was found that the best solution for backflush and renew the filter without stopping machine would be A1=1.25A0 with 0.25 time of A1 step increasing till it reach 70 bar at maximum desired pressure, draining time duration = 5 minutes, and filter renewal order would be 4-3-2-1 order. This set bachflush and filter change condition can help reduce waste such as melt leakage, bubble defect, time loss, prolong useful life of filter, and reduce lump and defect during stopping machine for replacing the filter. Figure 5-19 showed the new procedure for backflush and replacement of filter

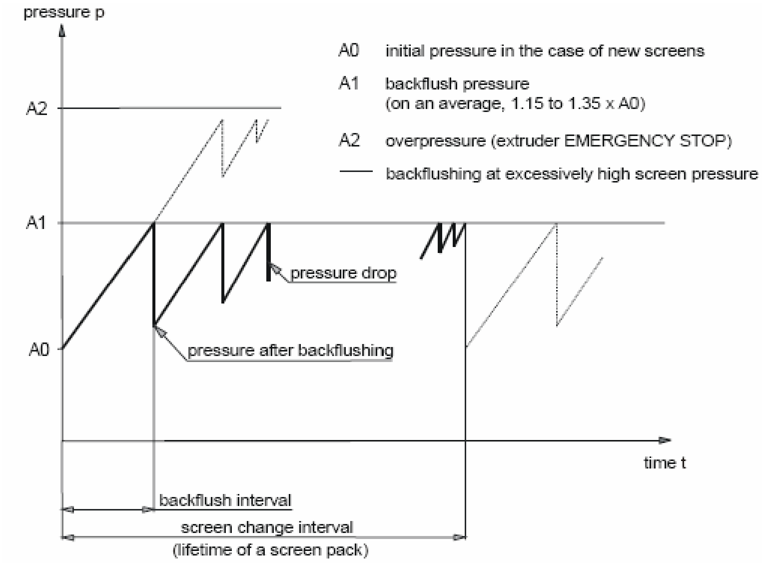


Figure 5-19: Backflush Pressure and Filter Change Interval

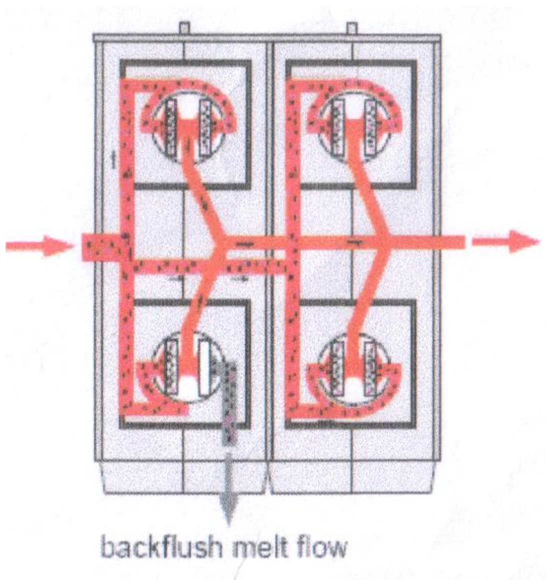


Figure 5-20: Filter Assembly and Melt Passage and Backflush

Table 5-26: Comparison all Losses of P1 BOPET Recycle Process

Items	**Before improving (tons/year)**	**After improving (tons/year)**
Speed loss	1196.32	1196.32
Shutdown loss	215.38	72.25
Production adjustment loss	396.21	396.21
Defect and Reprocessing Losses	123.18	0
Equipment failure loss	21.96	21.96
Setup loss	7.96	7.96
Availability: A (%)	94.77	95.76
Performance rate: P (%)	88.69	89.38
Quality rate: Q (%)	98.89	98.78
Overall equipment effectiveness: OEE (%)	83.12	84.54

CHAPTER VI
IMPLEMENTATION OF AUTONOMOUS MAINTENANCE

Regarding, TPM improves corporate business results and creates pleasant and productive workplaces by changing the way people think about and work with equipment throughout the company. Autonomous maintenance, maintenance performed by the production department, is one of the most important basic building blocks in any TPM program

6.1 The Goals of Autonomous Maintenance

The production department's mission is to produce good products as cheaply and quickly as possible. One of its most important roles is detecting and dealing with equipment abnormalities promptly, which is the goal of good maintenance. Autonomous maintenance includes any activity performed by the production department that has a maintenance function and is intended to keep the plant operating efficiently and stably in order to meet production plans. The goals of an autonomous maintenance program are:

d) Prevent equipment deterioration through correct operation and daily check.

e) Bring equipment to its ideal state through restoration and proper management

f) Establish the basic conditions needed to keep equipment well maintained

Another important goal is to use the equipment as a means of teaching people new ways of thinking and working. This study organized an autonomous maintenance activity as another important activity for Lean TPM implementation for the case study company by providing activity group for individual important on individual machine. In doing this the significant component which help make AM implementation effective were as follow: 1) Effective Line manager, 2) Effective supervisor, 3) Effective SGA member. These components were mentioned in Chapter IV and then particular modified based on the measures for creating understanding and good attitudes of the employees towards the activities and the company such as the activity bulletin board contest, the contest on suggestion and idea through formal presentation among the company's executives, formal weekly visit to production line by a group of the executive, and so on. After that there was a distribution of questionnaire to evaluate the acceptance of Lean TPM activity by using the same questionnaire. It was found that the value of the acceptance increased when compared with the initial response.

6.2 Setting small group activities for important machine

An important characteristic of Lean TPM is its enhancement through participation in company for small group activities. Small group activity in Lean TPM as shortly called SGA is the activity stemming from the gathering of employee to do group activities. Small groups in TPM are part of the existing organization. Members conduct their activities to achieve company's goal by tackling the problems of the organization as a whole which include initiate autonomous maintenance tasks. To promote and support these objectives, Lean TPM small groups which were under the permanent organization develop equipment-care activities systematically such as cleaning, checking, and lubrication. The achievement of small group activities relies on predetermined important factors as the study results.

6.3 Determination of an area for autonomous maintenance activity implementation

In determining an area for autonomous maintenance activity implementation, we avoided a negative psychological effect. We planned Lean TPM implementation that should not be implemented simultaneously by separation the overall Lean TPM implementation into four phases as shown in Table 6-1**.** During the implementation, it was found that there were different in terms of deterioration of each important part of the machine including the maintenance area. As a consequence, the time for each group to implement the activity based on the model set obtained from common agreement with all members in this regards.

Table 6-1: Four-Phase Initial Lean TPM Implementation

Period Area	**Nov.-08-Feb.09**	**Mar.09-Jun.09**	**Jul.09-Aug.09**	**Nov.09-Feb.10**
Phase 1	• BOPET-P1 • Slitting P1 (S05) • BOPET Recycle process			
Phase 2		• BOPET-P2 • BOPP-B4 • Slitting B4 (S09) • BOPP Recycle process • Metalizer process		
Phase 3			• Slitting P2 (S07) • BOPP-B3 • BOPA N1	

Table 6-1: Four-Phase Initial Lean TPM Implementation (cont.)

Period **Area**	**Nov.-08-Feb.09**	**Mar.09-Jun.09**	**Jul.09-Aug.09**	**Nov.09-Feb.10**
Phase 4				• BOPP-B2 • Slitting B3 (S06) • Slitting N1 (S08) • BOPA Recycle process

6.4 Maintenance job classification and allocation

Activities was created to fulfill the best condition of the machine and to uplift the overall equipment effectiveness (OEE) through the process of either maintenance or improvement. Regarding the maintenance, its objective was to keep equipment in a satisfactory state – by avoiding and correcting error or failure.

On the contrary, improvement activities help lengthen equipment life and saving the time needed for the maintenance leading to unnecessary task of maintenance. Corrective maintenance, for instance, emphasizes on reliability and maintainability improvement in available equipment. Maintenance prevention activities encourage the new equipment design that is not difficult and less costly to operate. Also it would make “vertical” startup after installation or after shutdown. The deterioration prevention must be monitored by the production department. The following three kinds of activities should be established to create autonomous maintenance as shown in Table 6-2.

Table 6-2: Autonomous Maintenance for Deterioration Prevention

How to prevent deterioration:
1) Proper operation – avoiding errors causing by humans 2) Proper adjustment – avoiding quality defects (in the process) 3) Basic equipment maintenance by cleaning, lubricating, and tightening 4) Quick inspection and forecast for machine abnormalities. Anticipation for failures and accidents 5) Recording maintenance document – reflecting information for avoiding recurrence and supplementing the design for maintenance prevention Recording maintenance document – reflecting information for avoiding recurrence and supplementing the design for maintenance prevention
How to measure deterioration:
1) Daily inspection – Intentional check and unintentional five – senses checks during operation 2) Periodic inspection – inspecting during overhaul inspection while shutting down the plant for maintenance
How to preventing deterioration:
1) Minor servicing – for abnormal condition needing to replace the simple part for the machine 2) Prompt informing of failure and problem 3) Helping by fixing any unforeseen failures

6.5 AM Implementation

Seven steps are used for the implementation of Autonomous maintenance. They start with cleaning and continue constantly toward by their own self. The optical process conditions establishment is encouraged by working through the continuous improvement (CAPD) management cycle. The priority on abolishing environment causing speedy deterioration, reversing deterioration, and establishing and maintaining basic equipment conditions is placed at AM step 1 through 3. The objectives of these procedures are to encourage operators interested in their equipment and assist them remove their self-image as irresponsible employees. This study focused on only step 1 to 3 of AM of which is step comprises sub-steps. The study on framework of AM activity implementation focusing on the important component effecting the achievement of each sub-step having different AM activity implementation, and different objective. As a consequence, the study specified the measurement method on result. The detail of these are as follows:

1) Step 1: Perform Initial Cleaning
2) Step 2: Eliminate Sources of Contamination and Inaccessible Places
3) Step 3: Establish Cleaning and Inspection Standards

In implementing of each step, the objectives differed; therefore the activities were also different. This study divided the success evaluation of each activity within each step so as to stratify the influence of success of Lean TPM implementation from the characteristic and the AM implementation of each employee. The success of each activity would reflect from its objectives in each step. The success evaluation was therefore conducted according to the success of each sub-activity which correspond with the set plan and purpose of each step.

6.5.1 Step 1: Conduct Initial Cleaning

The first goal of AM program is to increase reliability of equipment via three activities, removing dirt, dust and grime, showing all what are abnormal and correcting any small defect, as well as establishing basic condition for equipments.

6.5.1.1 Remove Dirt, Dust, and Grime: Cleaning thoroughly compel s operator to expose every part of equipment. Initial cleaning means making the equipment become spotless. Persuade operators to realize the important of cleaning, and help keep their equipment become spotless. Likewise, it helps them to think of how to improve their equipment so that it would be easily to clean.

6.5.1.2 Search for all Abnormalities. An abnormality means short of efficiency, deviation, a bit inconsistency, error, malfunction, or flaw – any factors leading to other problems. There are seven types of abnormalities together with their example. By detecting for any abnormalities through entire cleaning, operator understand that "cleaning is inspection". To seek for these defects during cleaning.

6.5.1.3 Correct Minor Flaws and Promptly Set Basic Equipment Conditions:

1) Correct minor flaws: To increase the reliability of equipment by setting the equipment basic conditions. This can begin correcting minor flaws. When severe damage is found, request the maintenance department to solve the problem immediately

2) Lubricate: Lubrication is one of the most necessary conditions for preserving equipment reliability, avoiding wear or burn out, keeping the operational exactness of device and reducing friction.

3) Tighten: Essential elements of their construction like nut, bolt and screw are contained in all machinery if such fasteners are securely tighten, equipment will suitably function.

In the step 1 of effective AM implementation of small group members, it needed to search and correct the equipment abnormalities as much as possible resulting in more reliability of the equipment. Line managers and supervisor would devote themselves to motivate all operators to search the equipment abnormalities both on-line and off-line operation because some abnormal may occur only the operation period. The most abnormalities were detected, the less risk of equipment failure and quality defect happen. Figure 6-1 showed the tendency of recovered abnormality and corrected abnormality emerging form the mentioned actions. In this step, the operators set AM activity time for cleaning the equipment and inspect the equipment condition so as to maintain the basic condition of the equipment. They had set the autonomous maintenance standards comprising the cleaning standards, lubricating standards, inspection standards, and tightening standards. These autonomous standards were used to maintain equipment health as per the determined schedule but it found that the standards would be impossible to follow because the time used for these maintenance activities were very high. When equipment got dirty again very soon or the level of cleanliness attained through initial cleaning cannot be maintained, operators typical feel compelled to do some improvement. As the consequence, operators pinpointed the causes of dirt and try to eliminate at the source or improve the inaccessible maintenance place. The operators would identify the all equipment abnormalities which were the causes of equipment deterioration and failures. After that, the abnormalities were removed. After the small group members did the activities, they jointly did AM self-evaluation until obtaining at least 85%; then they further requested to Lean TPM committee for final audit. The AM step 1 would be considered finished if the final evaluation score must not be less than 80% after that they would further to AM step 2.

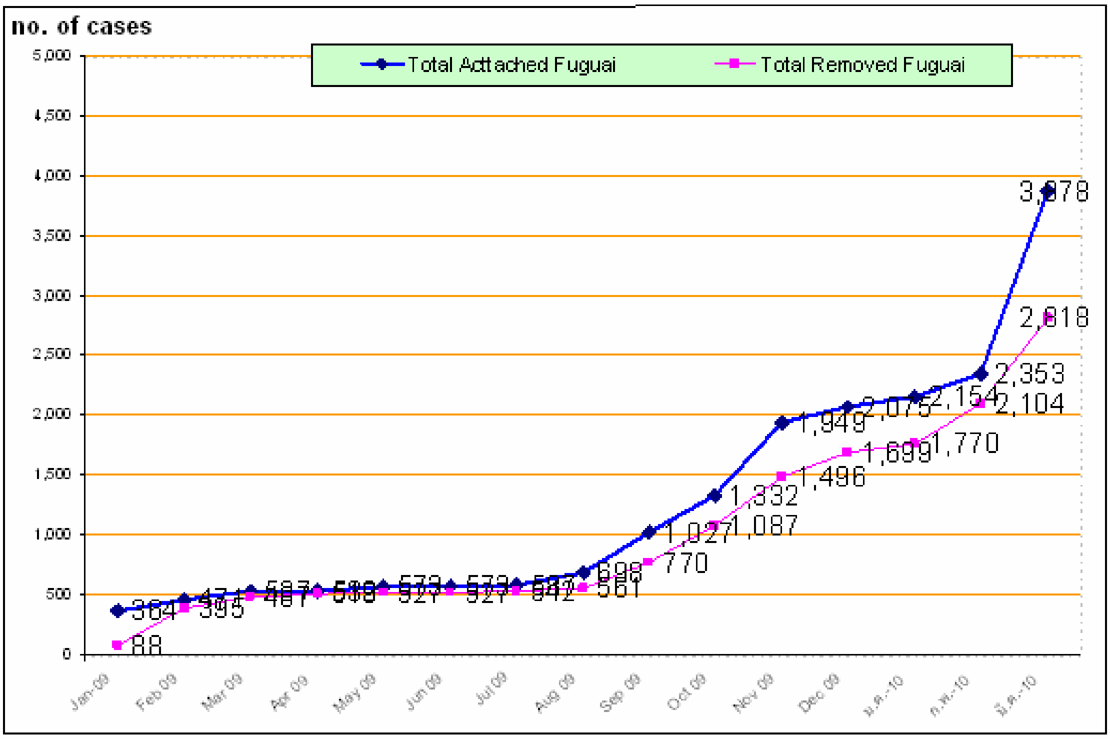


Figure 6-1: Tendency of Equipment Abnormality Found in AM Step 1

6.5.2 Step 2: Eliminate Sources of Contamination and Inaccessible Places

Objectives of step 2 is to decrease the time taking for cleaning, check, and lubricating with an introduction of this two types of improvement

1) The first type of improvement is the elimination of sources of leak and spillage.

2) The first type of improvement is the improvement of accessibility for working time reduction.

In implementing an effective AM step 2 of the small group members in improving the equipment and autonomous maintenance, tentative AM standards comprising cleaning standards, lubricating standard, inspection standard, and tightening standard were set. It was found in this regard that time used for autonomous maintenance of each group were taken 80% for cleaning the machine. The objective in doing this step was to reduce the time autonomous maintenance. As the consequence, Kaizen suggestion activity was adopted with the correction at the source of dirt and the source of spillage, an improvement of the machine of which locations were difficult to access, and improvement of the methods for AM The outcome of the AM step 2 implementation regarding the sources could reduce the time used in maintaining the machine to less than 20%. It also revealed that some groups could reduce to less than 5% but still keep the machines in good condition with good reliability. After the small group members did the activities, they jointly did AM self-evaluation until obtaining at least 85%; then they further requested to Lean TPM committee for final audit. The AM step 2 would be considered finished if the final evaluation score must not be less than 80% after that they would further to AM step 3.

6.5.3 Step 3: Establish Cleaning and Inspection Standards

The objectives of this step is to maintain the equipment condition after finishing step 1 and 2 in order to ensure basic condition maintenance and keep equipment in optimal condition. To succeed the objective, the team of operators must provide tentative equipment cleaning procedure to meet the satisfactory standards, as well as be responsible for maintaining the equipment of their own.

6.5.3.1) Preparing Standards, Determining standards, tentative standards encourage operators to begin inspecting easily, correctly and without skipping. Thus, standards must be answer for Ws and 1H" (Where? What? When? Why? Who? And How?) including checking items, important point, method, tools, times, period and responsibility. In this opportunity, line managers would promote the one point lesson (OPL) writing that was the effective strategy to increase the satisfactory attitude of operators. Figure 6-4 showed the example OPL written by the operator.

Table 6-3: Comparison of Tentative Autonomous Maintenance Standard Time

AM group	Tentative autonomous maintenance standard time		%AM standard time remaining
	Before improving (min./month)	After improving (min./month)	
BOPET-P1	3,475	495	14.25%
Slitting P1 (J06)	2,450	765	31.23%
BOPET-P2	4,526	573	12.66%
Slitting P2 (J08)	1,287	748	58.12%
Recycle process P1	731	154	21.08%
BOPP-B2	3,518	1,845	52.45%
Slitting B2 (S07)	1,485	312	21.01%
BOPP-B3	3,842	1,151	29.96%
Slitting B3 (S06)	849	146	17.1967
BOPP-B4	3,845	1,354	35.22%
Slitting B4 (J09)	847	129	15.23%
Recycle process B4	695	185	26.62%
BOPA N1	1,745	234	13.41%
Slitting N1	542	132	24.35%
BOPA Recycle process	148	74	50.00%
Metalize process	1,945	792	40.72%

6.5.3.2) Introducing control for extensive visual: The important technique for regular performance of cleaning, checking, and lubricating jobs to make them convenient to do by any one. To achieve this effectively, visual control must be used. These should be placed directly on the equipment to be inspected and clearly identified for operating conditions by giving name and number to the equipment, putting match-mark on nut identifying acceptable operating range, as well as lubricant level, including labeling the cover of device and pipe.

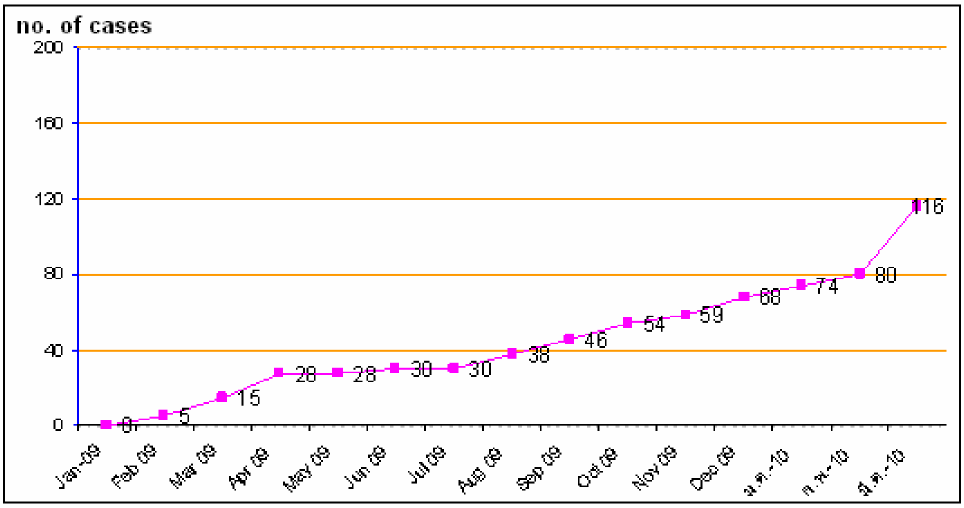


Figure 6-2: Tendency of Employees' Kaizen Suggestion Cases

The main objective in implementing effective AM step 3 of the small group members was to improve the machine inspection to be more effective with easier mode but gaining better outcome by using visual control which help reduce the inspection time. After the small group members did the activities, they jointly did AM self-evaluation until obtaining at least 85%; then they further requested to Lean TPM committee for final audit. The AM step 3 would be considered finished if the final evaluation score must not be less than 80% after that they would further to AM step 4 which were not in the scope of this study.

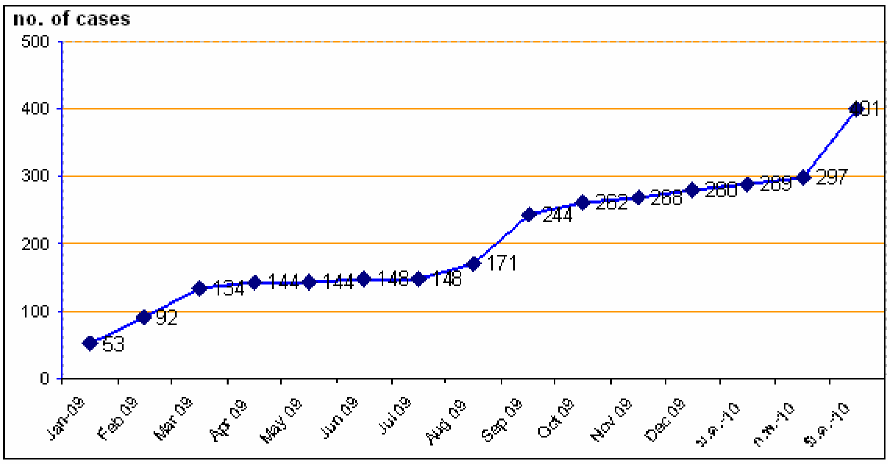
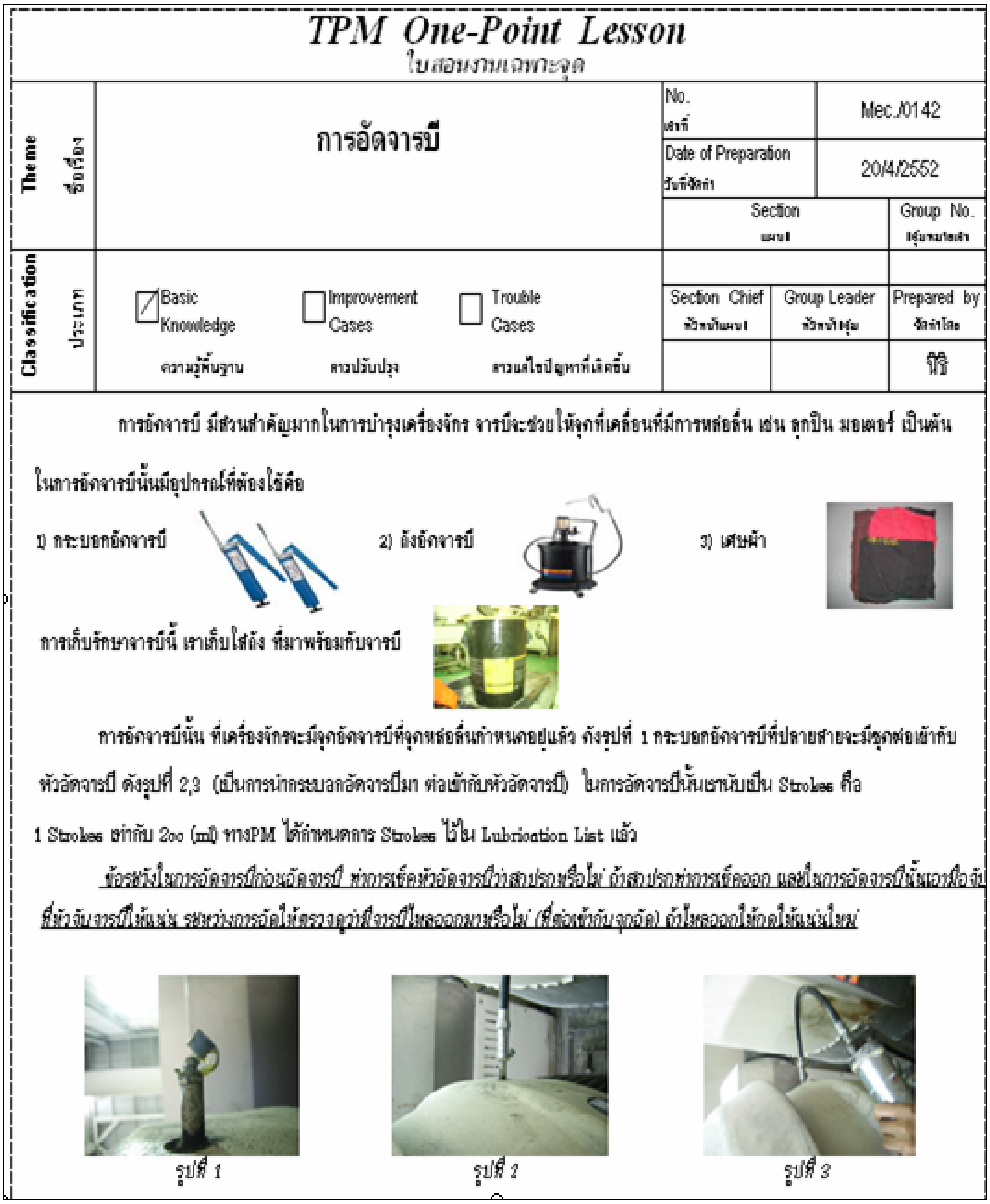


Figure 6-3: Tendency of OPL Written by Employees during AM Step 1-3 Implementation



TPM One-Point Lesson

ใบสอนงานเฉพาะจุด

Theme หัวเรื่อง	การอัดจารบี	No. เลขที่: Mec./0142
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Classification ประเภท	☑ Basic Knowledge ความรู้พื้นฐาน ☐ Improvement Cases การปรับปรุง ☐ Trouble Cases การแก้ไขปัญหาที่เกิดขึ้น	Section Chief หัวหน้าแผนก / Group Leader หัวหน้ากลุ่ม / Prepared by จัดทำโดย: ปรีชา

การอัดจารบี มีส่วนสำคัญมากในการบำรุงเครื่องจักร จารบีจะช่วยให้จุดที่เคลื่อนที่มีการหล่อลื่น เช่น ลูกปืน มอเตอร์ เป็นต้น

ในการอัดจารบีนั้นมีอุปกรณ์ที่ต้องใช้คือ

1) กระบอกอัดจารบี 2) ถังอัดจารบี 3) เศษผ้า

การเก็บรักษาจารบีนี้ เราเก็บใส่ถัง ที่มาพร้อมกับจารบี

การอัดจารบีนั้น ที่เครื่องจักรจะมีจุดอัดจารบีที่จุดหล่อลื่นกำหนดอยู่แล้ว ดังรูปที่ 1 กระบอกอัดจารบีที่ปลายสายจะมีจุดต่อเข้ากับหัวอัดจารบี ดังรูปที่ 2,3 (เป็นการนำกระบอกอัดจารบีมา ต่อเข้ากับหัวอัดจารบี) ในการอัดจารบีนั้นเรานับเป็น Strokes คือ 1 Strokes เท่ากับ 200 (ml) ทางPM ได้กำหนดการ Strokes ไว้ใน Lubrication List แล้ว

ข้อระวังในการอัดจารบีก่อนอัดจารบี ทำการเช็คหัวอัดจารบีว่าสกปรกหรือไม่ ถ้าสกปรกทำการเช็คออก และในการอัดจารบีนั้นเอามือจับที่หัวจับจารบีให้แน่น ระหว่างการอัดให้ตรวจดูว่ามีจารบีไหลออกมาหรือไม่ (ที่ต่อเข้ากับจุดอัด) ถ้าไหลออกให้กดให้แน่นใหม่

รูปที่ 1 รูปที่ 2 รูปที่ 3

Figure 6-4: One Point Lesson Sheet Involve Basic Lubrication Technique

CHAPTER VII
IMPLEMENTATION OF THE PLANNED MAINTENANCE PILLAR ACTIVITY

7.1 Planned Maintenance System

For the production process in the company for this case study, there were a lot of main machines for the production lines with inconsistent efficiency due to the deterioration causing by the unsystematic maintenance causing the production to have more quality defect and process failures. In this case study, the guideline of planned maintenance system development was employed through and adoption of those appearing in various valuable literature used for the construction of the framework of the development for planned maintenance activity. In the related literature, it indicated that it is useless to try to perform periodic or predictive maintenance in the conditions where the machines' accelerated deterioration were found, causing idling, minor stops, and minor failures, and wide variety of failure intervals. To establish effective preventive maintenance system, there should have a combination of planned and autonomous maintenance and painstaking implementation according to the six zero-breakdown measures. To implement all these at the same time is impossible. Therefore, the most effective way in achieving the zero-breakdown target is to implement the six measures in the following four phases.

1) Phase I- Reduce Variation in Failure Intervals
2) Phase II- Lengthen equipment lifetime
3) Phase III- Periodically restore deterioration
4) Phase IV- Predict equipment life from its conditions

7.2 Study the Status Quo

From the basic study on the maintenance system of the company in this case study, it was found that there were some faults for the system which could be concluded as follows:

1) There was an organization of a machine list of which details pertaining to machine names, machine codes at only in the equipment level without the list at the component level. This would make the analyses on the causes of the problem inefficient.

2) There was loosing machine grading telling only the existence of two group of machines classified as a main machine and a support machine without using PQCDSM as a criteria for prioritizing them.

3) The maintenance were not classified into PM, BM or CM except only the breakdown maintenance type.

4) There was not any record on maintenance materials and parts used for each maintenance job.

5) There was only record on time maintenance in only some maintenance jobs.

6) There was no conduct of the failure rank.

7) There was no determination for the mean time between failures (MTBF), mean time to repair (MTTR) which were indicators for maintenance work administration, except only machine down time.

8) There was no maintenance standard operating procedure pertaining to the failure recurrence prevention.

9) There was no good administrative system for the spare parts. It was found that spare part inventory costed 97 million-bath which was considered to be very high.

10) There was no clear PM standard for important maintenance tasks.

11) There was no maintenance standard operating procedure pertaining to periodic maintenance for important machines.

12) There was no maintenance standard operating procedure pertaining to condition-based maintenance for important machines.

The above the faults of the mentioned maintenance administration system would be improved during each phase as follows. For a great strength of RCM, it has been known failures consequences are far more significant than their technical characteristics. As a matter of fact, it is recognized that the only reason for implementing any types of proactive maintenance is not only to prevent occurring failures, but also to prevent or at least to decrease the consequences of the failure. This study would combine the strength of RCM in phases III and IV of planned maintenance activity.

7.3 Establishing of Equipment Planned Maintenance

7.3.1 Equipment Prioritization

For implementing the company's planned maintenance activity, it started form reviewing and completing machine list and evaluating each of equipment pieces regarding to impact its effect on safety, quality, operability, maintainability, and so on. Then prioritize the equipment (as ranks A, B, and C) and conduct planned maintenance on all of the ranked units as A or B, and those whose zero failure is a lawful requirement. The ranking criteria was set by considering from the attributes associated with safety, product quality, operation effect, and maintenance time and cost with cooperation from concerned department such as the maintenance, production, production engineering, quality assurance ,and safety departments in scoring each attribute as shown in Table 7-1. Then the criteria was employed to rank equipment. The ranking procedure complied to the process in evaluating each piece of equipment as shown in Figure 7-1**.**

The outcome of evaluating the equipment made the company know which rank of each machine should be. There were 792 machines ranked in A and B together with 71 supporting equipment or grade C machines. This means the company had 92% of machines would be considered for proper maintenance tasks, therefore, these machines' would be performed the failure mode and effect analysis and PM task selection.

Table 7-1: Criteria for Evaluating Equipment Characteristics

Attribute	Evaluation criterion	Score
Safety: Effect of failure on people and environment	Equipment failure poses explosion risk or other hazards; equipment failure causes serious pollution	5
	Equipment failure might adversely affect the environment	3
	Other equipment	0
Quality: Effect of failure on product quality	Equipment failure has a major effect on quality (could lead to product contamination or abnormal reactions and produce out-of spec product)	5
	Equipment failure produces quality variations that can be put right by the operator comparatively quickly	3
	Other equipment	0
Operation: Effect of failure on production	Equipment with major effect on the production, without standby provision, whose failure cause previous and subsequent process to shut down completely	5
	Equipment failure causes only partial shutdown	3
	Equipment failure has little or no effect on production	0
Maintenance: Time and cost of repair	Equipment take 4+hours or costs 50,000+ to repair, or fails three or more times per month	5
	Equipment can be repaired in under 4 hours at a cost of between 5,000-50,000 or fails less than three times per month.	3
	Equipment costs less than 5,000 to repair or can be left unrepaired until a convenient opportunity arises	0

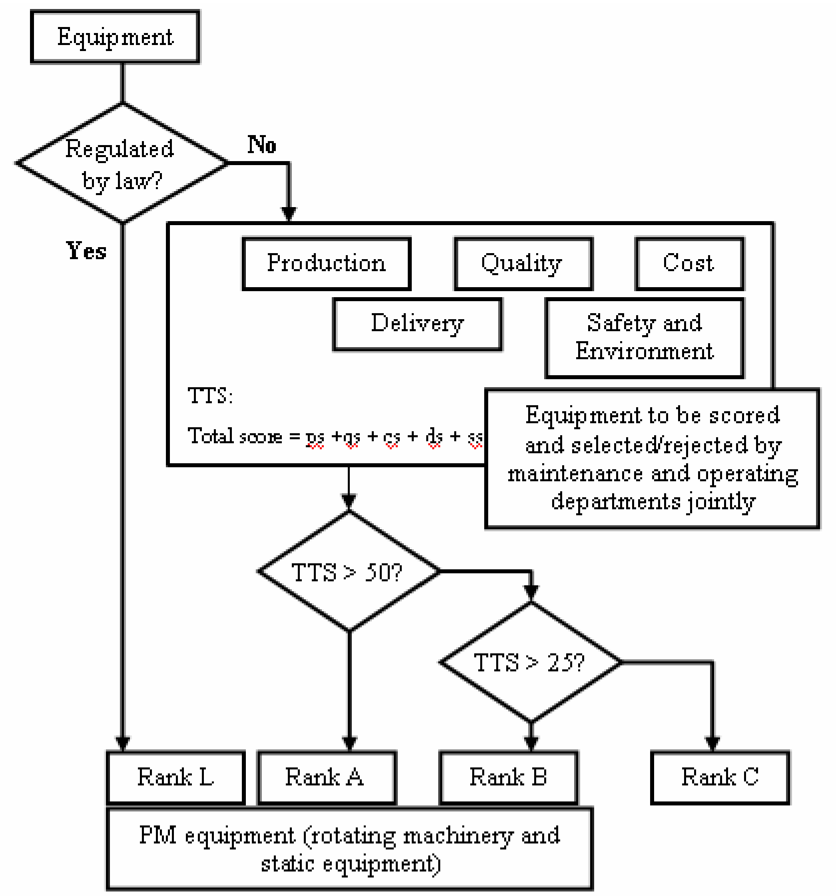

Figure 7-1: Flow Diagram for Ranking and Selecting PM Equipment

(Suzuki., (1997))

7.3.2 Logic (Decision) Tree Analysis (LTA)

All Equipment except rank C machines would be evaluated at the level of part and component failure modes. The failure mode that survive the initial screening test in the effects analysis will now be further classified in qualitative process known as *logic tree* or *decision tree analysis* (LTA). The purpose of this step is to further prioritize the emphasis and resources that should be devoted to each failure mode, recognizing as we have earlier that function, functional failures and, hence, failure modes are not created equal.

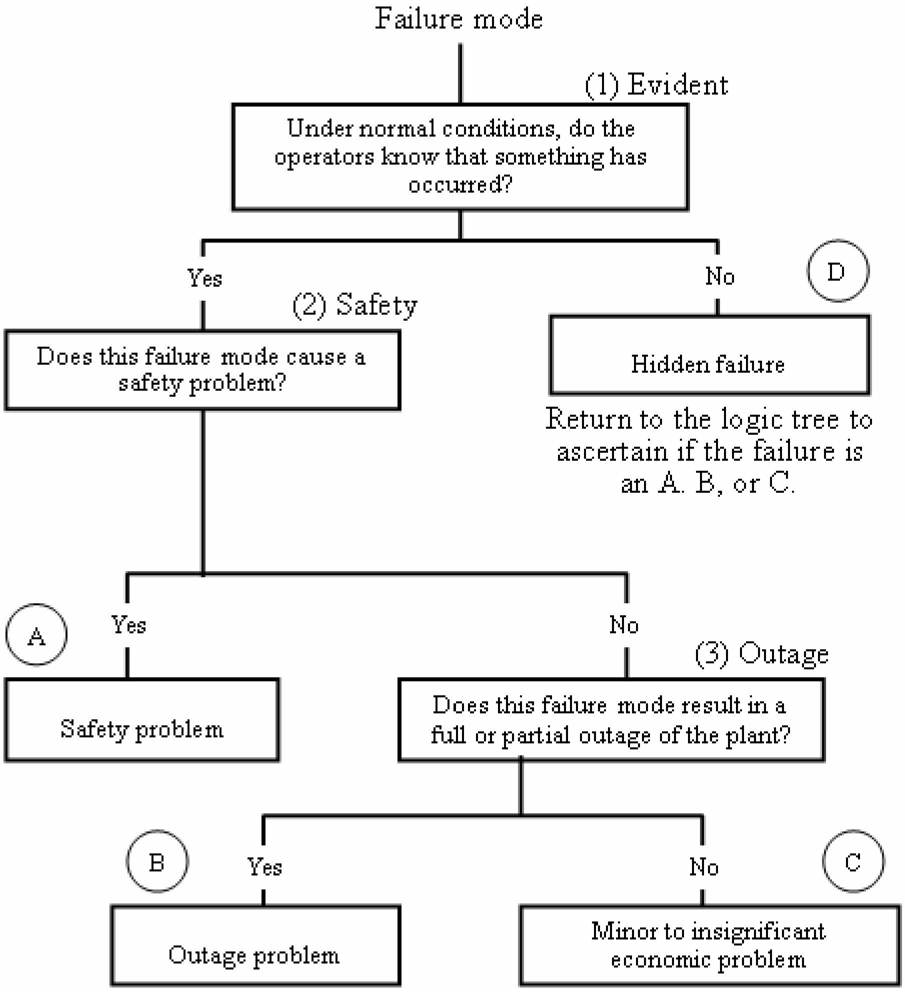

Figure 7-2: Logic (Decision) Tree Analysis Structure (Smith, 1993).

Block A involved the safety issue.

Block B involved the outage, loss of productivity or other cost, loss of output which is more or equal to 5%

Block C involved low economic loss issue.

Block D involved hidden failure, safety, outage, economic-related issue.

Table 7-2: Example Logic (Decision) Tree Analysis Sheet

FF no.	Component / failure mode	Failure mode	Critically Analysis				Candidate tasks
1.1.1	Main pump		Evident?	Safety?	Outage?	Category	
	.01-Failed bearing	.01.01-Age / Wear-out	Y	N	Y	B	Must be corrected within 4 days or serious oil deterioration occurs
	.02-Motor short/ground	.02.01-Insulation aging	Y	N	Y	B	Same as above
	.03-Leak	.03-.01-Broken gasket	Y	N	Y	B	Same as above and can cause serious motor/pump damage if not shut off within 4 hours.

Table 7-3: Criticality Analysis and Category Matrix

Evident?	Safety?	Outage?	Category
Y	Y	n/a	A
Y	N	Y	B
Y	N	N	C
N	Y	n/a	D/A
N	N	Y	D/B
N	N	N	D/C

Note : Category A and B would have priority over category C.

7.3.3 PM Task Selection Process

The effort to analysis the systems, to this point, have been focus to delineating those failure modes where a task on PM will gain the company the biggest yield for the investment to be made. Therefore, for each of these modes of failure, our job now is to determine the applicable candidate task list, and then to choose the most effective task from among the competing candidate tasks. The selection of the PM task in the RCM process needs each task meet the *applicable and effective* test defined as follows:

1) Applicable. The task will avoid or mitigate failure, detect onset of failure, or disclose a hidden failure.

2) Effective. The task is the most cost-effective alternative among the competing candidate tasks.

If there is no applicable task, the only alternative is RTF. Similarly, if there is more excess cost of an applicable PM task than the cumulative ones associated with that failure, then the effective task alternative will also be RTF. Where a design modification may be mandatory, block A, or safety-related, failure mode would be the exception to this rule.

The procedure shown in Figure 7-3 below describes how to provide task selection sheet. Particularly, the procedure is of great use in assisting the analyst to develop logically the candidate PM tasks for each failure mode.

The "Task selection Sheet" form was used to record all decisions made during the task selection process, with include the final selection recorded in "Sel. dec." column. The last column, "Est. freq.," is where we recorded the frequency suggested or interval assigned to the task. The sample of task selection sheet was shown in the Table 7-4 as follow.

Table 7-4: Task Selection Sheet

FF no.	Component / failure mode	Failure mode	Selection guide								Candidate tasks	Sel. dec.	Est. freq
1.1.1	Main pump		1	2	3	4	5	6	7	8			
	.01-Failed bearing	.01.01-Age /Wear-out	N	N	Y	N	-	N	N	N	.01-Vibration monitoring .02-RTF	RTF	-
	.02-Motor short/ground	.02.01-Insulation aging	N	N	N	N		-	N	N	.01-RTF	RTF	-
	.03-Leak	.03-.01-Broken gasket	N	N	Y	N	-	Y	-	-	.01-Inspect for signs of oil seepage at the gasket area(CD) .02RTF	.01 CD	6m.

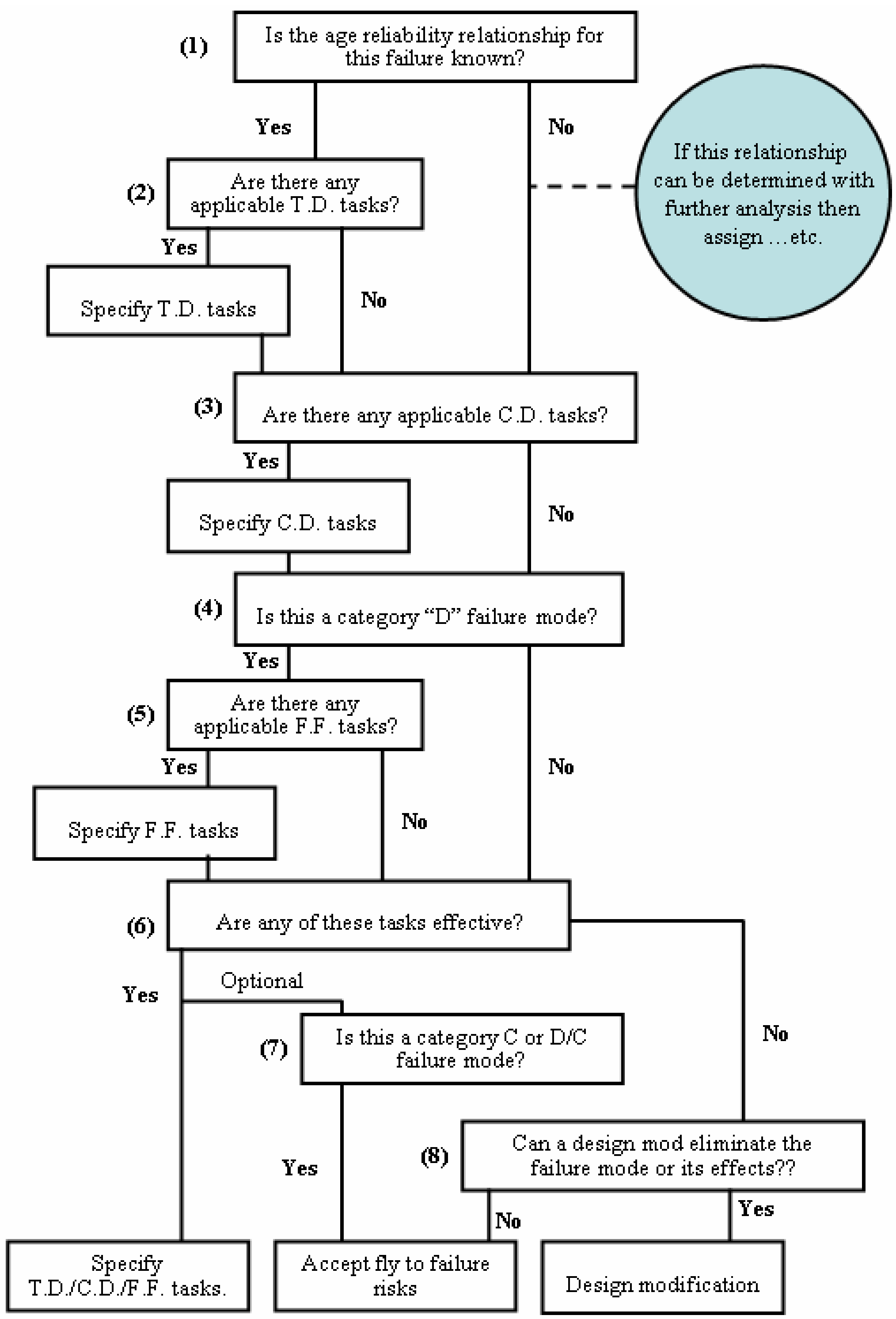

Figure 7-3: Selection Road Map (Smith, 1993).

After the ranking of the equipment and determining the maintenance task for every equipments, planned maintenance phase I-phase IV would be started.

7.4 Implementation of Four-Phases Planned Maintenance

7.4.1 Phase I- Reduce Variation in Failure Intervals

This phase including 2 major maintenance activities, which were 1) Restore deterioration and 2) Prevent accelerated deterioration.

7.4.1.1 Restore deterioration: This activity deals with the restoration of the deteriorated equipments to have its original condition which can then reduce variation in failure intervals. The dispersion must be reduced to decrease the failure frequency. Often, the deterioration is left without inspection, even when people know that it would contribute to the breakdown. Phase I is designed to get rid of the vicious failure cycle. In this phase there was restoration of the equipments by cooperation among the maintenance staff and the operators in the production department in conducting the autonomous maintenance in order to entirely detect machine abnormalities and correct any defects found. This would be elaborated in detail in the chapter relevant to implementation of the autonomous maintenance pillar activity.

7.4.1.2 Prevent accelerated deterioration: After restoration of equipments deterioration, the next job is to prolong equipment life and continue to reducing the failure interval variation by avoiding the further accelerated deterioration requiring the following procedures.

1) Establish basic conditions. In implementing the autonomous maintenance activity, the machine operator would be responsible for tentative maintenance standards comprising cleaning, lubricating, inspection, and tightening under the supervision and assistance of the maintenance staff.

2) Subject to conditions of use.

3) Remove accelerated deterioration.

4) Prepare user-friendly daily inspection and lubrication standards.

7.4.2 Phase II- Lengthen Equipment Lifetime

Phase-II activities are generally lumped together under the title corrective maintenance or improvement activities or Kaizen. The Kaizen idea to prolong the equipment life should be raised as most initiative including three major activities were 1) Correct design and fabrication weaknesses, and 2) Prevent major breakdowns from recurring.

The counter measures based on the results of extensive failure analysis are Phase-II activities are generally lumped together under the title corrective maintenance or improvement activities or Kaizen. The Kaizen idea to prolong the equipment life should be raised as most initiative including three major activities in the following items.

7.4.3 Phase III- Periodically Restore Deterioration

To preserve and extend the lengthened equipment life achieved in Phases I and II, establish a system of planned or preventive maintenance. There were 4 major maintenance task in phase III which included 1) Perform periodic serving and inspection, 2) Establish maintenance work and inspection standards, 3) Control spare parts and maintenance materials, and 4) Recognize signs of process abnormality

7.4.3.1 Perform Periodic Serving and Inspection: Determining optimal servicing and inspection intervals then keeping a maintenance calendar for equipment units or components, continually re-evaluate and establish the most economical inspection and service intervals to extend a service interval. It was to perform a simple diagnostic check a few months before as scheduled service.

In this phase equipments of which PM task were selected as shown in task selection sheet were considered for theirs maintenance aspect in terms of time direction or time-based maintenance. The case study on the preventive maintenance with use of time-based maintenance in a Planned Maintenance activity. This study highlighted the example of the maintenance design for the bearing having more than 10,000 items in the production lines with the objective for designing machine maintenance plan at component level so that it would optimize the maintenance expenditure by keeping higher reliability level or equal to the conventional ones.

Reliability is an important indicator for evaluating the system or industry process's performance. The value of reliability level for the system was based on the system structure comprising components which included potential level of availability and reliability level of various mechanics and components in those systems. The value of potential level for the availability and the reliability level would decrease when there is higher deteriorations of the use. In order to describe the reliability, the mean time to failure (MTTF) is applied. In fact, the MTTF can be formulated with use of the following equation (A):

$$MTTF = \gamma + \eta\Gamma(1 + \frac{1}{\beta}) \tag{7.1}$$

γ, η and β are the Weibull distribution parameters of which the availability can be calculated through the following equation (B):

$$Availability A = \frac{MTTF}{MTTF + MDT} \tag{7.2}$$

When MDT is mean down time having relationship with mean waiting time (MWT) and mean time to repair (MTTR) as shown in the following equation (7.3):

$$MDT = MWT + MTTR \tag{7.3}$$

In regard to exemplification of bearing maintenance design in this company for the case study, it selected only the bearing for important gear motor driving with adequate record of 36 data. It was found that 36 items of bearing had some failure during their use. And, only 32 items revealed its interval of use before the failure. And another 4 items used to out of order but without the record of the used duration. What we knew was when they were last changed for the new ones and how long they were used. From the information regarding the use duration before the failure of 36 items, it revealed that the shortest time of the failure was 6,593 hours of the use, and the period of the longest use was 25,413 hours. For 20 items of the bearing, the time to considered too short for the normal use were fewer than 20,000 hours. In this Lean TPM implementation, it was necessary to reduce a waste stemming from the bearing early failure by adjusting the environment and development of the employees' maintenance skills so that they could use the machine and technique to replace the bearing properly in the first place, including the development of Autonomous Maintenance (AM) activity for the employees who use the machines so that they could entirely participate in machine maintenance activities.

The mentioned activities must be implemented under the zero failure in four phases of maintenance system. The phase of reducing deviation of failure interval of the machine and improvement for lengthening the use of the machine was regarded as the most important one among the mentioned four phases. The two phases needing to be absolutely completed before starting the time-based maintenance. The following were the example of the design for the machine condition recovering as schedule in the third phases of process.

With regard to the data pertaining to the failure of 36 items of the bearing, it showed that the value of MTTR was 4.01 hours per reparation, MDT was 0.30 hours per reparation resulting in the value of MDT equal to 4.31 hours per reparation. As a result, the total of down time causing by the failure of the bearing was 137.95 hours with expenditure and the waste from 36 times of the failure calculated averagely equal to 13,628 bath per reparation or the total of existing failure cost equal to 490,000 bath within 3 years.

Table 7-5 was time to failure (TTF) of bearing 32 items, down time (DT), production opportunity loss (C_{f1}), repairing cost (C_{f2}) compare with preventive maintenance cost (PM cost ; C_p)

Table 7-5: Bearing Failure Data

Order	Censored	TTF	Down Time (hrs.)	Production Loss (MT)	Opportunity loss Cfp (THB.)	Repairing cost Cf (THB.)	PM cost Cp (THB.)
1	F	6,593	7.50	21.70	433,960	3,500	1,250
2	F	7,896	3.90	11.28	225,660	7,215	1,250
3	F	7,981	4.50	13.02	260,380	12,590	1,250
4	F	9,635	7.60	21.99	439,740	14,530	1,250
5	F	9,832	9.20	26.62	532,320	25,690	1,250
6	F	12,112	4.60	13.31	266,160	14,851	1,250
7	F	12,500	5.90	17.07	341,380	15,324	1,250
8	F	12,684	5.40	15.62	312,440	7,521	1,250
9	F	13,254	8.20	23.72	474,460	4,528	1,250
10	F	13,654	4.90	14.18	283,520	15,960	1,250
11	F	14,023	7.50	21.70	433,960	16,324	1,250
12	F	14,521	6.30	18.23	364,520	12,964	1,250
13	F	14,853	4.20	12.15	243,020	29,634	1,250
14	F	14,962	8.40	24.30	486,020	15,963	1,250
15	F	15,932	7.60	21.99	439,740	7,952	1,250
16	F	16,932	9.20	26.62	532,320	14,527	1,250
17	F	17,423	5.90	17.07	341,380	16,329	1,250
18	F	17,563	8.60	24.88	497,600	5,931	1,250
19	F	17,895	6.50	18.81	376,100	7,543	1,250
20	F	17,895	3.90	11.28	225,660	12,119	1,250
21	F	18,325	8.40	24.30	486,020	11,597	1,250
22	F	18,523	5.90	17.07	341,380	25,101	1,250
23	F	18,632	6.10	17.65	352,940	9,648	1,250
24	F	19,521	8.50	24.59	491,820	13,652	1,250
25	F	19,521	7.60	21.99	439,740	9,643	1,250
26	F	19,523	7.80	22.57	451,300	9,780	1,250
27	F	19,852	5.90	17.07	341,380	12,546	1,250
28	F	21,045	6.40	18.52	370,300	14,963	1,250
29	F	21,325	8.50	24.59	491,820	21,365	1,250
30	F	21,365	7.60	21.99	439,740	19,542	1,250
31	F	21,564	8.50	24.59	491,820	21,301	1,250
32	F	25,413	7.30	21.12	422,380	5,964	1,250

Median rank regression and correlation method is the standard method and the best practice for Weibull analysis (Abernethy., (2000)). Regressing X on Y was normally used to estimate the Weibull parameter beta β and eta η. The best-fit line is found by the method of least squares. First, the failure times (TTF) and median ranks are transformed as follows:

Benard's median rank = (i-0.3)/(N+0.4) (8.4)

Y_i = ln(failure time TTF)

X_i = ln(ln(1/1-Median rank of Y_i)

Here, "*i*" is the adjusted rank and "N" is the sum of the failures and the suspensions.

Least squares is then used to estimate *a* and *b* in the equation Y = *a* + *b*X. These following estimates are referred to as a and b, respectively.

Approximated Beta hat = 1/b hat

Approximated Eta hat $= e^{\text{Approximate A hat}}$

Table 7-6: Regression of Failure Data

Order	Censored	TTF	Order	Median Ranks (F(t))	1/(1-Median Rank)	X_i=ln(ln(1/(1-Median Rank)))	Y_i=ln(TTF)	X_iY_i	X^2
1	F	6,593	1	0.0216	1.0221	-3.824	8.7938	-33.6268	14.622
2	F	7,896	2	0.0525	1.0554	-2.921	8.9741	-26.2107	8.531
3	F	7,981	3	0.0833	1.0909	-2.442	8.9848	-21.9384	5.962
4	F	9,635	4	0.1142	1.1289	-2.110	9.1732	-19.3536	4.451
5	F	9,832	5	0.1451	1.1697	-1.853	9.1934	-17.0377	3.435
6	F	12,112	6	0.1759	1.2135	-1.643	9.4020	-15.4427	2.698
7	F	12,500	7	0.2068	1.2607	-1.463	9.4335	-13.7960	2.139
8	F	12,684	8	0.2377	1.3117	-1.304	9.4481	-12.3234	1.701
9	F	13,254	9	0.2685	1.3671	-1.1626	9.4921	-11.0351	1.352
10	F	13,654	10	0.2994	1.4273	-1.033	9.5218	-9.8399	1.068
11	F	14,023	11	0.3302	1.4931	-0.914	9.5485	-8.7290	0.836
12	F	14,521	12	0.3611	1.5652	-0.803	9.5834	-7.6945	0.645
13	F	14,853	13	0.3920	1.6447	-0.698	9.6060	-6.7057	0.487

Table 7-6: Regression of Failure Data (cont.)

Order	Censored	TTF	Order	Median Ranks (F(t))	1/(1-Median Rank)	X_i=ln(ln(1/(1-Median Rank)))	Y_i=ln(TTF)	X_iY_i	X^2
14	F	14,962	14	0.4228	1.7326	-0.5989	9.6133	-5.7536	0.358
15	F	15,932	15	0.4537	1.8305	-0.503	9.6761	-4.8690	0.253
16	F	16,932	16	0.4846	1.9401	-0.411	9.7370	-4.0054	0.169
17	F	17,423	17	0.5154	2.0637	-0.322	9.7655	-3.1472	0.104
18	F	17,563	18	0.5463	2.2041	-0.235	9.7735	-2.3000	0.055
19	F	17,895	19	0.5772	2.3650	-0.150	9.7923	-1.4682	0.022
20	F	17,895	20	0.6080	2.5512	-0.066	9.7923	-0.6418	0.004
21	F	18,325	21	0.6389	2.7692	0.018	9.8160	0.1806	0.000
22	F	18,523	22	0.6698	3.0280	0.103	9.8268	1.0070	0.011
23	F	18,632	23	0.7006	3.3402	0.187	9.8326	1.8420	0.035
24	F	19,521	24	0.7315	3.7241	0.274	9.8792	2.7041	0.075
25	F	19,521	25	0.7623	4.2078	0.363	9.8792	3.5814	0.131
26	F	19,523	26	0.7932	4.8358	0.455	9.8793	4.4943	0.207
27	F	19,852	27	0.8241	5.6842	0.553	9.8961	5.4681	0.305
28	F	21,045	28	0.8549	6.8936	0.658	9.9544	6.5483	0.433
29	F	21,325	29	0.8858	8.7568	0.775	9.9676	7.7214	0.600
30	F	21,365	30	0.9167	12.0000	0.910	9.9695	9.0746	0.829
31	F	21,564	31	0.9475	19.0588	1.081	9.9788	10.7867	1.168
32	F	25,413	32	0.9784	46.2857	1.344	10.1430	13.6335	1.807
					SUM	-17.736	308.327	-158.877	54.494

$$\hat{b} = \frac{\sum_{i=1}^{N} x_i y_i - \frac{\sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i}{N}}{\sum_{i=1}^{N} x_i^2 - \frac{\left(\sum_{i=1}^{N} x_i\right)^2}{N}} \qquad \hat{a} = \frac{\sum_{i=1}^{N} y_i}{N} - \hat{b}\frac{\sum_{i=1}^{N} x_i}{N} = \bar{y} - \hat{b}\bar{x}$$

The value of R Square is almost equal to Adjusted R Square convincing that there are adequate data for estimating the shape parameter β with 95% confidence interval for alpha ranging between 3.39 - 3.86 or the average value of 3.6258, while Eta η = 17,949.25 hours and the coefficient of determination equal to R^2 equal to 0.972 which is very high showing the good experimental model and Standard Error equal to 0.1837 and p-value of 4.82E-24 whose score is very low, convincing that the value of shape parameter had relation with Weibull distribution with statistical significance as shown in Table 7-7.

It could be concluded from the table 1 that Weibull distribution model for bearing time to failure was adequately appropriate to be use as a good reliability function model. Figure 3 showed that the estimated value was properly fit when compare to the samples used for creating the model of which the data had high stability around zero with 95% confidence interval with the residual score ranging between $\pm$ 0.50 as shown in Figure 7-5 leading to the ability to construct the reliability function model R(t) of this bearing group as shown in the following equation (7.5):

Table 7-7: ANOVA Analysis for Weibull Distribution

Regression Statistics	
Multiple R	0.9858
R^2	0.9719
Adjusted R^2	0.9709
Standard Error	0.1837
Observations	31

$$R(t) = e^{-(t/17{,}949.25)^{3.6258}} \tag{7.5}$$

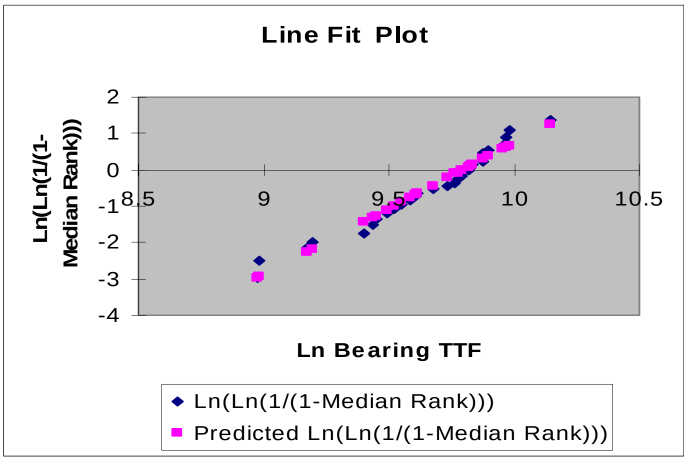

Figure 7-4: Fit Curve

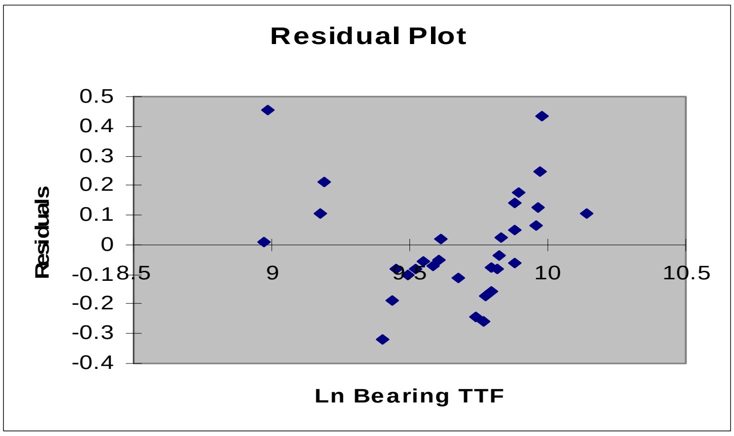

Figure 7-5: Residual: Stability Around the Zero

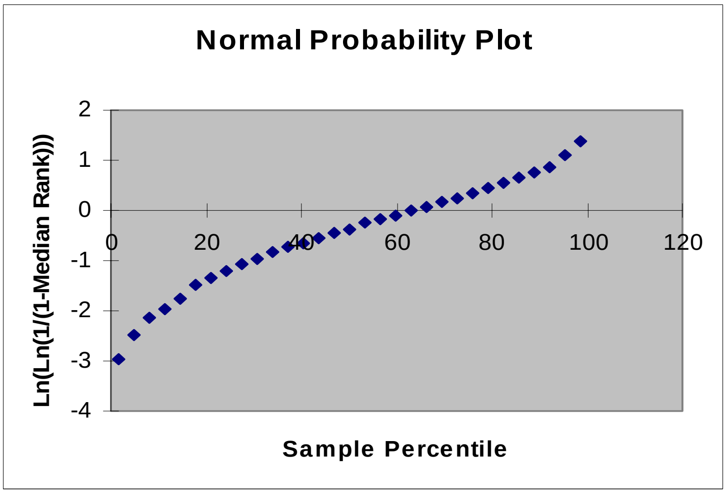

Figure 7-6: Normal Probability Plot

Considering the optimal maintenance interval, equipment was subject to sudden failure, and when failure occurred the equipment would be replaced. Since failure was unexpected, it was not unreasonable to assume that a failure replacement was more costly than a preventive replacement. To reduce the number of failures, preventive replacement can be scheduled to occur at specified intervals. However, a balance was required between the amount spent on the preventive replacements and their resulting benefit, namely, reduced failure replacements. This case company needed consider to develop a model for one operation cycle of equipment between it fail. The replacement policy called for preventive replacements to occur at fixed intervals of the time and failure replacements to occur when necessary, and we wanted to determine the optimal interval between the preventive replacement to minimize the total expected cost of replacing the equipment per unit time. This case study had desired the fixed interval replacement policy for the small bearings used in the company because it had reasons conformed the 2 important conditions as follows; (Campbell., (2001))

1) Total downtime cost was most important to consider, the total bearing failure replacement and process downtime cost was greater than preventive replacement

2) The risk of bearing failure increased as it age, as we know from the Weibull analysis shape parameter associated with the bearing failure time was 3.158 that greater than 1.0.

The fixed interval replacement policy was illustrated in Figure 7-7. C_p was the total cost of preventive replacement, C_f was the total cost of failure replacements.

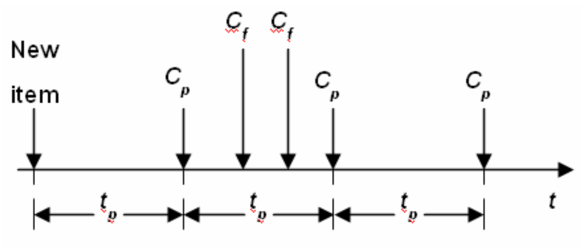

Figure 7-7: Fixed Interval Preventive Replacement Policy

$$C(t_p) = \frac{Total\_expected\_cost\_in\_interval(0,t_p)}{Length\_of\_interval}$$

or

$$C(t_p) = \frac{C_p + C_f(1 - R(t_p))}{t_p} \qquad (7.6)$$

From the Figure 7-8 it is plot C_p v.s. t_p pertaining from equation (7.6) showed the maintenance interval or the appropriate component replacement interval equal to t_p which was equal to approximately 7,200 hours. This would make the total expenditure in maintenance per time unit have the least value of about 0.2413 baht per hour. 127 times of bearing change was done during the 3 years period meaning that there was the total expenditure stemming from the maintenance according this policy for the total of 159,000 baht. Besides, this design of the maintenance bearing result in the improvement of reliability level from $R(MTTF_u = 16{,}164) = 0.5046$ to $R(t_p{=}7{,}200) = 0.9642$. This is the risk value occurring before the reduction of maintenance from 38 times to not more than 5 times which was more than 86% improvement. With the predetermining plan of maintenance and bearing replacement as per its estimated useful life. Maintenance was very easily to schedule for replace the bearing in the available time that the production had not plan to use the equipment. There were 12 items of the motor-gear that did not use in the night time. The effective pre-preparation before the stop of the machine, this would save the production waiting time because this maintenance manner would not obstruct the production schedule. Therefore, when modifying the bearing replacement plan to reduce its replacement interval, it would affect the bearing which is a component of the system and in this case it would also increase the system reliability. It was found that this affective time-based maintenance plan resulting in reducing the machine $MDT_u = 4.31$ hours per reparation into $MDT_p = 0.84$ hours per reparation.

The company had applied this policy on the parts and components which conformed the above 2 most important conditions. Consequently, maintenance schedule can be performed very easily with effective cost.

7.4.3.2 Establish maintenance work and inspection standards.

7.4.3.3 Control spare parts and maintenance materials. To perform planned maintenance effectively with a small team of maintenance personnel, just-in-time control of spare parts and maintenance materials is essential.

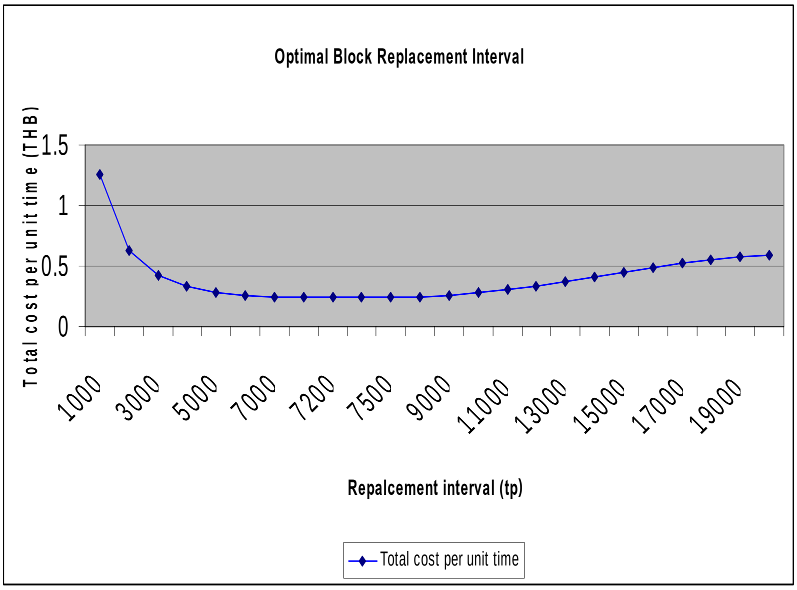

Figure 7-8: Plot Total Expected Cost Per Unit Time Versus Fixed Replacement Interval

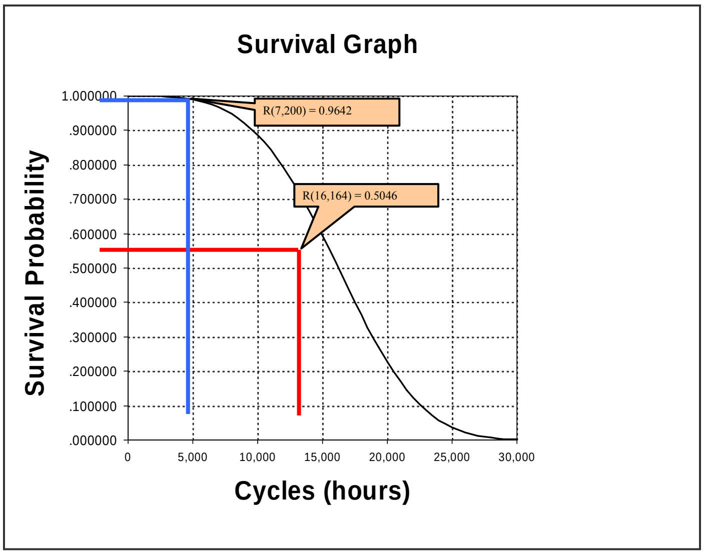

Figure 7-9: Plot the Equipment Survival Probability Versus Fixed Replacement Interval

1) Building System for Controlling Spare Parts and Materials: To analyze why stock were held long – term and to reduce on the labor required for

calculating usage and keeping track of issues and receipts, both long term list and comparison table of receipts were very carefully formulated during this study. Long – term stocks list comprising equipment and component models, specifications, order numbers, order months, expected month of use, month elapsed, quantities, and reasons for stocking. Comparison tables of receipts/issue was used to reveal the status of spare parts and materials receipts and issues.

2) Building a System for Controlling Technical Information and Drawings: In this study, there was a construction on all information that relating to maintenance, comprising design standards, technical reports, important literature , checking standards, mechanical design calculation programs, equipment diagnosis criteria, and structural analysis data by a technology management system.

7.4.3.4 Recognize Signs of Process Abnormality: Production and maintenance departments must work together to develop finely – tuned diagnostic skills by sharpening their sensitivity and honing their "five – senses" checking skills

7.4.4 Phase IV- Predict Equipment Life:

The best time for preventive repairs or machinery and component replacements is just before a failure occurs. The condition-based maintenance was considered as the second principle activity of planned maintenance. It is an effective approach to help maintenance department extend the usefulness of equipment, and overcome the challenge of predicting when it will fail. It uses equipment diagnostics to monitor and diagnose condition of continuous and intermittent machinery movement during operations and on-stream inspection (OSI) detecting the static equipment condition and monitoring the changing signal by particular nondestructive inspection techniques. The condition-based maintenance was introduced by actual conditions of equipment rather than the predicted interval of time to failure. The company had adopted various monitoring methods that produce a signal when a failure was about to occur.

7.4.4.1 Predictive Maintenance Procedure: Predictive maintenance is associated with the equipment diagnostics use. It is decided to start with vibration diagnostics because the company uses many rotating machine needed to diagnose their vibration and it was the popular basic technique in the realm of any industries. Initially, we established the following system of diagnostics for rotating machinery.

1) Step 1: Established an equipment diagnostic team by training maintenance staff to become good vibration diagnosticians.

2) Step 2: Regarding PM task selection sheet, certain items of equipment were designed as models for practicing vibration diagnostic. There was a practice of the skill on the equipment by the equipment diagnostic team members together with the external expert. The knowledge gained was imparted to others.

3) Step 3: Within the workplace, special items of equipment were designed within as models for implementing vibration diagnostics. In this process important gear-motor and nipping roll bearing were selected.

4) Step 4: Set tentative periods and criteria for inspecting the model equipment vibration. To set the vibration inspection frequency or inspection period, "Start with a short interval and gradually extend it" (Moubray, 1997). So we set the time of one month for periodic machine vibration inspection at the beginning period after replacement and then the in section frequency was adjusted by using the data recorded to determine. Regression method was employed to predict the future vibration level effectively. In case that the measured vibration level was far under the set threshold level, there must be an adjustment of periodic machine vibration inspection interval to make it longer, whereas if measured vibration level reaches potential failure as set at threshold level, the periodic machine vibration inspection interval must be reduced but not more than P-F interval (Moubray, 1997).

5) Step 5: Monitor the model equipment crucially for the set period. In this study it was agreed that whenever large degree of dispersion occurs in the measurements, there should be re-inspection to ensure that the previous inspection was right. Then if it was so, check whether the machine's load has changed, the rate of the machine's has varied, or the machine fails. Then the same measurements would be repeated again.

6) Step 6: There should a core team meeting to discuss the diagnostic techniques and their results.

7.4.5. Implementation of Predictive Maintenance:

After the training of diagnosticians towards this track, there was a construction of a comprehensive diagnostic system, performance on the diagnostic measurements, analyze and collection of the results, and dissemination of the technique throughout the company for the case study. 33 important bearings of rank A machines across the plant were assigned to do condition-based maintenance. The inspection frequency of these 33 bearing were set as the following procedure.

7.4.5.1 Set inspection schedule of bearing that just be replaced once in a month.

7.4.5.2 Keep monthly inspection till 6^{th} inspection was held.

7.4.5.3 Determine the inspection regression equation using the 6 data recorded.

7.4.5.4 Set the vibration threshold level as per ISO 2372 standard for acceptable vibration level for particular machine classes as shown in Figure 7-10.

7.4.5.5 Set next inspection would be not more than half time between the present time and predicted date of failure occurrence. This estimated inspection period should not more than P-F interval of bearing. Normally, the P-F interval would be several week to month depend on application. This study set the bearing P-F interval equal to 6 months.

All 33 bearing which assign to do CBM were used in medium machine class II with threshold level of vibration was 7.0 mm./sec. Table 7-8 showed recorded vibration data of a bearing.

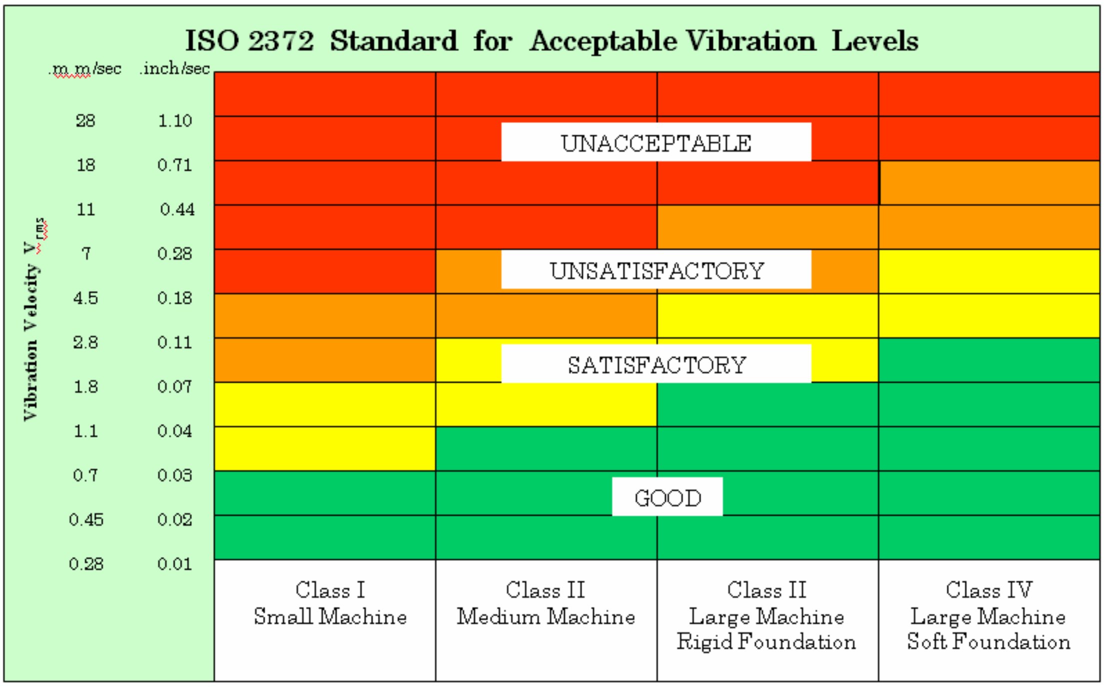

Figure 7-10: ISO 2372 Standard for Acceptable Vibration Levels

Table 7-8: Bearing B1 Vibration Records

Bearing#	Working Age (hrs)	V	H	A	Event
B1	0	1	1	1	B
B1	250	1.1	1.2	1.2	O
B1	500	1.1	1.3	1.3	O
B1	750	1.3	1.5	1.5	O
B1	1000	1.5	1.9	1.5	O
B1	1,750	1.8	2.1	1.6	O
B1	2000	2.3	2.7	1.9	O
B1	2,500	2.7	2.9	2.2	O
B1	3000	3.5	3.2	2.4	O
B1	3,250	3.8	3.7	2.6	O
B1	4000	4.5	4.9	2.9	O
B1	4,750	4.7	5	3	O

Table 7-8: Bearing B1 Vibration Records (cont.)

Bearing#	Working Age (hrs)	V	H	A	Event
B1	5000	5.1	5.2	3.1	O
B1	5,500	5.5	5.3	3.2	O
B1	6000	5.8	5.2	3.2	O
B1	6,250	6.2	5.8	4.6	O
B1	6953	7.3	7.3	7.3	EF

Table 7-9: Regression of Vertical V-Vibration

Regression Statistics	
Multiple R	0.993809
R Square	0.987656
Adjusted R Square	0.986833
Standard Error	0.236008
Observations	17

Table 7-10: ANOVA (Vertical V-vibration)

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	#	66.84921	1200.174	9.88E-16
Residual	15	1	0.0557		
Total	16	#			

Table 7-11: Regression Summary (Vertical V-Vibration)

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.675644	0	6.8111	5.88E-06	0.4642	0.8871
Working Age (hrs)	0.000893	0	34.644	9.88E-16	0.0008	0.0010

Regression Equation of Bearing Vertical V-vibration at the Age ;

Bearing Vertical Vibration = 0.000893 x Working Age + 0.675644 mm./sec

Regression of horizontal H-vibration

Table 7-12: Summary Output (Horizontal H-Vibration)

Regression Statistics	
Multiple R	0.985963
R Square	0.972123
Adjusted R Square	0.970265
Standard Error	0.331023
Observations	17

Table 7-13: ANOVA (Horizontal H-Vibration)

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	#	57.31753	523.0835	4.48E-13
Residual	15	2	0.109576		
Total	16	#			

Table 7-14: Regression (Horizontal H-Vibration)

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.942256	0	6.772284	6.28E-06	0.645698	1.238813
Working Age (hrs)	0.000827	0	22.87102	4.48E-13	0.00075	0.000904

Regression Equation of Bearing Horizontal H-Vibration at the Age ;

Bearing Horizontal Vibration = 0.000827 x Working Age + 0.942256 m.m./sec

Table 7-15: Regression of Axial A-Vibration (Axial A-Vibration)

Regression Statistics	
Multiple R	0.873221
R Square	0.762515
Adjusted R Square	0.746683
Standard Error	0.771807
Observations	17

Table 7-16: ANOVA (axial A-vibration)

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	#	28.68942	48.16198	4.73E-06
Residual	15	9	0.595686		
Total	16	#			

Table 7-17: Regression (Axial A-Vibration)

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.77895	0	2.401185	0.029756	0.087503	1.470398
Working Age	0.000585	0	6.939883	4.73E-06	0.000405	0.000764

Regression Equation of Bearing Axial A-Vibration at the Age:

Bearing horizontal vibration = 0.000585 x Working Age + 0.77895 mm./sec

In practical we used the above three equation to predict V, H, and A vibration of bearing and set plan to replace the bearing prior to it fail. The equations were updated after each inspection completed. If we used 6 records of bearing vibration, the equation would be as follow;

Bearing vertical vibration = 0.000480 x Working Age + 0.96 mm./sec

Bearing horizontal vibration = 0.000662 x Working Age + 1.0314 mm./sec

Bearing axial vibration = 0.000331x Working Age + 1.115676 mm./sec

Table 7-18: Inspected Vibration Value Compared to Predicted Values

Working Age (hrs)	Vibration (mm./sec.)	Vpredicted	beta	intercept
0	1			
250	1.1			
500	1.1			
750	1.3			
1000	1.5			
1,750	1.8			
2,500	2.7	2.1600	0.0005	0.9600
3,250	3.8	3.0015	0.0007	0.8662
4000	4.5	4.0703	0.0008	0.7503
4,750	4.7	4.9517	0.0009	0.6957
5,500	5.5	5.4927	0.0009	0.7242

Table 7-18: Inspected Vibration Value Compared to Predicted Value (cont.)

Working Age (hrs)	Vibration (mm./sec.)	Vpredicted	beta	intercept
6000	5.8	5.9315	0.0009	0.7235
6,250	6.2	6.1041	0.0009	0.7353
6,375	6.4	6.2359	0.0009	0.7279
6,400	6.4	6.2918	0.0009	0.7174
6,525	6.5	6.4211	0.0009	0.7117
6,650	6.6	6.5466	0.0009	0.7079
6,775	6.8	6.6606	0.0009	0.7054
6,900	6.9	6.7921	0.0009	0.6994
6953	Replace			

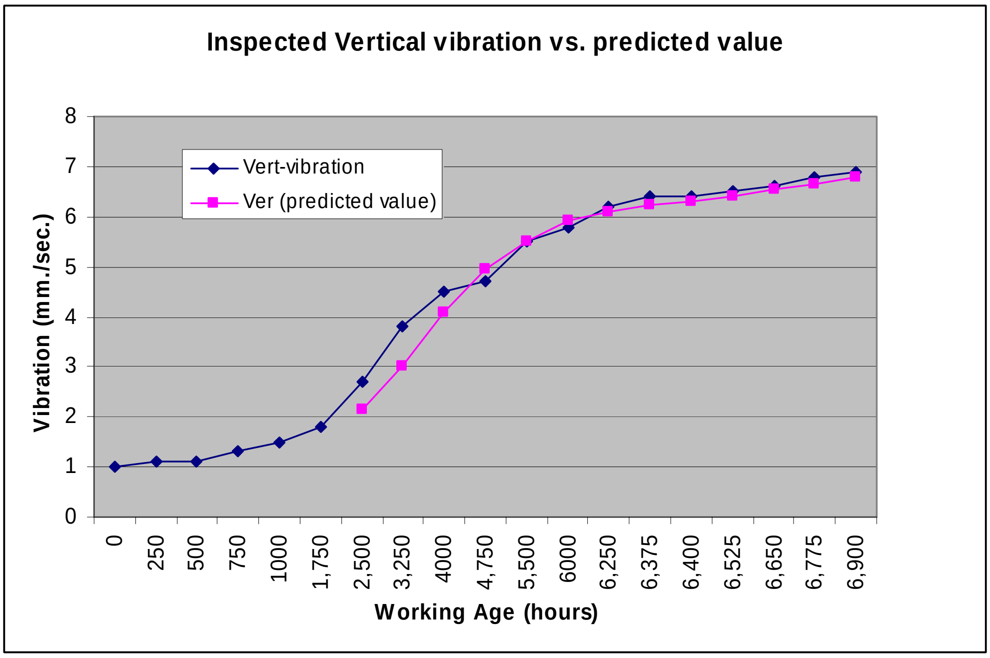

Figure 7-11: Inspected Vibration Value Compared to Predicted Value

By using CBM approach in maintenance policy, the company had never confronted the bearing failure as well as maintenance cost can be reduced significantly.

For further study, when the maintenance department collect enough the numbers of replacement together vibration dataset, we could adopt the Cox proportional hazards modeling (Cox Weibull PHM) which predict the hazard growth of the item used to desire the replacement decision making.

CHAPTER VIII
RESEARCH FINDINGS AND CONCLUSIONS

As one of the world class lean manufacturing strategies, TPM is well structured with eight fundamental development activities and data based approach (OEE) to improve both the effectiveness of any production system/process pertaining to everyone. Apparently, TPM implementation can succeed better and last long as compared to other isolated program because there is an ultimate change in people (knowledge, skills, and behavior) during the progress. However, the tremendous efforts required to make that change happened and last could not be underestimate. Although the 12 steps in TPM development programs have been settled and simplified by JIPM, most organizations implementing TPM on their own have never achieved the first time and for those managing to kick start do not achieve the expected and sustainable effectiveness improvement. Introducing and implementing TPM was different from a standard project, which normally has a starting, and an end that is rarely more than one year. Rather, TPM is a long-range living program which can take more than few years to implement and enjoy the lasting benefits when the whole organization has become strategy-oriented instead of evaluating one new program after another before implementing TPM thoroughly. Many recent studies revealed that TPM implementation leading to Lean transformation often confronts lots of obstacles that hindered the success expected by the executives and the investors. The examples of the obstacles were that: typically, people show strong resistance to change, many staff treat it just another program of the month without paying any focus and any doubt about the effectiveness, not sufficient resources (people, money, time, etc.) and assistance provided, insufficient understanding of the methodology and philosophy by middle management, and many people considered TPM activities as additional work/threat.

This study established the framework of Lean TPM for continuous process type using machines as the basis in the production line. In fact, the executives needed to develop the production line so that it would become Lean manufacturing type by starting the development of this production type with the application of TPM to improve OEE of the machines at the initial stage. This study also referred to TPM development process according to the procedure determined by Japan Institute of Plant Maintenance (JIPM) written by Tokutaro Suzuki (1994) in conjunction with the study of Chan et al. (2003), and Bamber et al. (1999). The findings of these studies were the additional suggestions from the original TPM implementation in Phase 1: Introduction-preparatory stage pertaining to the descriptions for the design of 9 recommended key success factors introduced by Chan et al. (2003), and Bamber et al. (1999) in order to guarantee the success of Lean TPM implementation. The basic instrument used in this regard was the creation of good attitudes among the employees towards their company by trying to respond to their actual needs since the response to their suggestions that corresponds with the fast business operation would help create more sense of participation among the employees. the study for the framework suggested that there should be preparation during the initial stage of Lean TPM implementation of the factory of which its procedure is shown below. The outcome of the implementation could enhance better effectiveness of value stream in the main production which had higher overall equipment effectiveness (OEE) as there was descriptions of some case study in Chapter V. In addition, the improvement reduced the eight major plant losses and increased overall plant effectiveness (OPE) from the original figure of 35.51% to 60.30% in different and suitable methods and approaches and Lean manufacturing was aimed to remove as the result found in chapter VI. It was found that the Lean TPM implementation in the company for this case study could reduce process lead time by 20% and inventory was reduced to 10%. Table 8-1 showed the comparison plant effectiveness and the OEE value, as well as its availability (A), performance rate (P), and quality rate (Q) components between before and after the Lean TPM focused improvement activities, displayed in the Table 8-2 and Table 8-3 below.

Table 8-1: Comparison of Plant Effectiveness Before vs. After Focused Improvement

No.	Items	Unit	Overall feature	
			Before improvement	After improvement
1.	Overall plant effectiveness	%	35.51	60.30
2.	Process lead time	days	52.32	42.24
3.	Raw material-Virgin Chips storage	Tons.	2,283	1,970
4.	Finish goods inventory	Tons.	804	909
5.	Work in process	Tons.	1,280	293
6.	Rework product outside factory	Tons.	335	154
7.	Average excess side trim sale	Tons/month	104	0
8.	Maintenance part inventory	million Bath	97	95.7

Table 8-2: Overall Equipment Effectiveness of 7 Production Line Processes (Before Improvement)

Process/Equipment	Max. Capacity (tons/hr.)	A	P	Q	OEE
Main Process BOPET-P1	1.50	93.21%	50.79%	96.08%	45.50%
BOPET Slitting P1	3.70	58.64%	49.74%	97.63%	28.48%
Main Process BOPET-P2	2.50	78.49%	71.98%	80.55%	45.50%
BOPET Slitting P2	6.30	65.73%	46.40%	95.09%	29.00%
BOPET Recycle Process	1.40	94.77%	69.58%	98.58%	65.00%
Main Process BOPP-B1	3.50	80.59%	58.24%	96.93%	45.50%
BOPP Slitting B1	9.50	77.70%	33.63%	95.81%	25.04%
Main Process BOPP-B2	3.50	74.52%	91.35%	95.07%	64.71%
BOPP Slitting B2	9.50	79.34%	35.53%	96.12%	27.09%
Main Process BOPP-B3	2.00	74.54%	91.35%	95.06%	64.73%
BOPP Slitting B3	9.50	78.77%	35.45%	96.80%	27.03%
Main Process BOPP-B4	0.85	75.36%	91.61%	95.14%	65.68%

Table 8-2: Overall Equipment Effectiveness of 7 Production Line Processes (Before Improvement) (cont.)

Process/Equipment	Max. Capacity (tons/hr.)	A	P	Q	OEE
BOPP Slitting B4	9.50	82.36%	37.44%	98.72%	30.44%
BOPP Recycle process	0.30	99.43%	76.05%	92.52%	69.96%
Main process BOPA N1	0.50	99.27%	78.82%	84.39%	66.02%
BOPP Slitting N1	1.00	77.57%	33.58%	98.48%	25.65%
BOPA Recycle Process	0.30	99.37%	71.63%	92.11%	65.56%
Metalizing Process M2	0.50	61.19%	49.63%	98.71%	29.97%

Table 8-3: Improvement Results of OEE of Main Equipments (After Improvement)

Process/Equipment	Max. Capacity (tons/hr.)	A	P	Q	OEE
Main Process BOPET-P1	1.50	93.35%	88.97%	98.24%	83.24%
BOPET Slitting P1	3.70	67.86%	60.20%	97.17%	39.69%
Main Process BOPET-P2	2.50	86.92%	93.74%	98.31%	80.10%
BOPET Slitting P2	6.30	82.86%	69.04%	98.39%	56.28%
BOPET Recycle Process	1.40	95.76%	89.38%	98.78%	84.54%
Main Process BOPP-B1	3.50	94.97%	78.60%	98.86%	73.80%
BOPP Slitting B1	9.50	88.56%	59.47%	98.37%	51.81%
Main Process BOPP-B2	3.50	86.46%	92.55%	97.72%	78.36%
BOPP Slitting B2	9.50	88.95%	64.96%	98.92%	57.16%
Main Process BOPP-B3	2.00	93.29%	93.95%	95.95%	84.10%
BOPP Slitting B3	9.50	81.38%	38.60%	96.97%	30.46%
Main Process BOPP-B4	0.85	82.73%	94.65%	96.50%	75.57%
BOPP Slitting B4	9.50	94.52%	89.86%	99.53%	84.54%
BOPP Recycle process	0.30	99.83%	91.15%	94.29%	85.80%
Main process BOPA N1	0.50	99.14%	82.69%	86.06%	70.54%
BOPP Slitting N1	1.00	93.40%	75.11%	99.57%	69.86%
BOPA Recycle Process	0.30	99.75%	94.06%	96.84%	90.87%
Metalizing Process M2	0.50	62.18%	43.09%	98.72%	26.45%

8.1 Framework for the Effective Lean TPM Implementation

In fact, after the improvement for some parts of Lean TPM, company's overall plant effectiveness was improved for double. Chronic losses such as quality defects due to deviation of process parameters were eliminated. Hereunder, the framework is proposed for phase 1-phase 3 Lean TPM implementation Main idea of the framework is to study the manufacturing contextual factors and the attitudes of employees on Lean TPM implementation. The company's executives would use the outcome of data surveyed to establish the particular policies and strategies to improve employees' participation for the activity. In fact, the framework would be elaborated as follows:

8.1.1 Field-Base Preliminary

To investigate the whole production process problems of the factory. Determine the current one batch continuous process value stream mapping (VSM) of each main process. The value stream or set of most efficient action to obtain specific product through the three critical management tasks of any business including problem-solving task, information management task and physical transformation task to cover since from raw material to delivered finished product in hand of customers. Gathering snapshot data such as inventory levels before each process, process cycle times (CTs), number of

workers, each equipment OEE, availability and changeover (CO) times. The time for one inventory triangle is calculated by normally dividing the inventory quantity into the daily customer requirements but in this case production rate is used instead of customer requirement rate.

8.1.2 Defining and Describing the Future State Map

To start while developing the current state map, where target areas for improvement start to show up. Inventory and lead time may be viewed as two related issues since the more inventory, the longer any item must wait for its turn and thus, the longer the lead time. In creating the ideal future state map we try to identify lean manufacturing tools to drive focused improving the process through TPM focused improvement pillar in conjunction with other pillars. In this step some of 22 manufacturing practices which are sub-components of four lean bundles will be evaluated and selected to implement but in this case study just needed to improve OEEs to 85%.

8.1.3 Describing Overall Plant Effectiveness

To calculate firstly eight major process losses by using data collecting in above to calculate eight losses component of each equipment bases on desired production schedule at desired equipment condition and capability. Summation of this desired state is 100% requirement. Normally the actual equipment effectiveness is not 100% so eight major process losses which are resulted from each equipment losses namely shutdown loss, Production adjustment loss, equipment failure loss, process failure losses, normal production loss, abnormal production losses, quality defect losses, and reprocessing losses Summation of each equipment results in overall eight major plant losses. Overall plant effectiveness is determined by value of 100% desired state minus overall eight major plant losses.

8.1.4 Implementation of Lean TPM Program

Lean TPM is implemented in four phases or stages with 12 steps as describe shortly below:

8.1.4.1 Phase 1-Introduction-Preparatory Stage

1) Step 1 - Introducing Lean TPM**:** The top person's declaration of the resolve to introduce Lean TPM. The declaration is made in an internal Lean TPM lecture meeting, and should be printed in an internal bulletin or newsletter.

2) Step 2 - Introduction Education and Campaign: For managerial staff: Staff of the same echelon are scheduled together for training and conducting slide-show meeting with general employees. Moreover it must understand the current situation.

First start model machine, criteria for model machine selection were developed if it is bottleneck process among the whole production line, unique machine in production with low OEE. Establishing project team organization, project-team activities and workshop small-group activities in eliminating major losses of selected model machine. Effective improvement procedure had been addressed in following portions.

The steering organization should carry out a situational analysis of the current level of TPM development; this can be done through established review techniques or using audit methodology. Using UTAUT and FFA to establish the effective Lean TPM implementation based on 9 recommended key success factors in this step, namely 1) The existing organization. 2) Measures of performance. 3) Alignment to company mission. 4) The involvement of people. 5) An implementation plan. 6) Knowledge and beliefs. 7) Time allocation for implementation. 8) Management commitment. 9) Motivation of management and workforce.

3) Step 3 - Formation of Lean TPM Promotion Organizations and Formal Organizational Models: To create a steering organization. A steering organization or committee, specialized subcommittees, promotion secretariat if not already in place should be created with the authority and responsibility to develop the Lean TPM program.

4) Step 4 - Setting of Basic TPM Principles and Targets: Benchmarks and targets; prediction of effects

5) Step 5 - Preparation of a Master Plan for Implementation of TPM: From preparation for introduction to undergoing examinations.

6) Step 6 - Commenmence the Lean TPM**:** To from preparation for introduction to undergoing examinations.

7) Step 7 - Establishment of a System for Improving: Improvement of production efficiency through 4 main activities comprising 1) Focused Improvement or Kobetsu –Kaizen**:** First start project-cross-functional-team activities and workshop small-group activities in eliminating major losses of selected significant machine, then establishing project team organization, major losses analysis and target setting, initial inspection, mapping out of losses and suitable improvement (Kaizen) technique such as setup time reduction or elf plan , evaluation of analysis and countermeasures, implementation of improvement (Kaizen), effect confirmation, recurrence prevention measurement, horizontal replication. 2) Jishu Hozen or

Autonomous Maintenance (AM): AM team implementation activities comprising AM Step 1-Initial Cleaning and Basic Equipment Conditions Establishment, AM Step 2-Countermeasures (for the causes of forced deterioration and improving hard to access areas, AM Step 3-Cleaning and Lubricating Standards, AM Step 4-Overall Inspection, AM Step 5-Autonomous Maintenance Standards, AM Step 6-Process Quality Assurance, and AM Step 7—Autonomous Supervisors. 3) Planned maintenance: To establish maintenance system encompasses all effective maintenance technology such Corrective maintenance, periodic maintenance, predictive maintenance. 4) Operation/maintenance skill development: Collective education of leaders and education concerning transmission of education to members

8.2 The Entire Preparation for Effective Lean TPM Implementation

What was significant to the success of the SGA activity was positive supporting and active participation provided by managers. In fact, helping to motivate employees, conducting inspections and evaluations, handing down general inspection knowledge, and conducting the effective analysis techniques studies are the executives' activities. This study suggested that during Lean TPM implementation, there should be the preparation activity with a purpose to create the understanding and good attitude among the employees towards Lean TPM implementation in Phase 1-Introduction-Preparatory Stage with Introduction Education and Campaign which consists of the following activities.

8.2.1 Activities to Promote Lean TPM Program

The role of senior executives was to establish basic Lean TPM policy and objectives in line with the company business policy. They must therefore always shows their strong and consistent involvement, and commitment in order to make the employees feel that their executives were serious for Lean TPM implementation including the following activities to prompt the employees' real willingness to participate in the Lean TPM.

8.2.1.1 Create a communication campaign and frequently reinforce the need to change

8.2.1.2 Establish the organization e.g. steering team/TPM coordinator/TPM office

8.2.1.3 Create a TPM objectives and goals and deployment through sponsor, owner, users and coach

8.2.1.4 Arrange for evaluation system for employees that reflect the outcome obtained from their Lean TPM implementation

8.2.1.5 Provide various necessities and resources (equipment, space, training, money, etc.)

8.2.1.6 Establish reward and recognition system

8.2.1.7 Provide a review on the implementation status regularly

8.2.1.8 Encourage the employees to participate in activities suggestions and response to them promptly if they are beneficial

8.2.2 Activities for Middle Executives and Supervisor Development (strong understanding TPM methodology & philosophy)

For middle executives' role, it is to shape the policy for their specific departments or divisions according to the companywide Lean TPM policy and goals. In order to guide the activities, the middle executives and supervisors themselves must participate directly in SGA through Autonomous Maintenance activity. Also they must make a decision to what losses to overcome via use of focused improvement activity and point appoint project teams. Conducted by middle executives and supervisors, the requirement for the leadership of effective Lean TPM were 1) consciously assuming leadership, 2) showing apprehension and assuming responsibility for SGA, 3) leadership for practice session, 4) actively observing and supporting small group activity, and 5) encouraging the small groups' members to keep their fresh and vigorous. The following topics are the list for the development of necessary knowledge and skill of middle executives and supervisors so as to be applied for increasing the effectiveness of Lean TPM implementation.

8.2.2.1 Role and Responsibility in Lean TPM Implementation

8.2.2.2 Ownership of Lean TPM Implementation

8.2.2.3 Understanding of AM Implementation, AM Stepwise Inspection and Evaluation

8.2.2.4 On The Job Training Skill

8.2.2.5 P-M Analysis Skill

8.2.2.6 Failure Analysis Skill

8.2.3 Activities on Employees Development

Regarding to the investigation the behavior in this research, it could be concluded that SGA with the high level of knowledge and skills on knowledge and skills shown below could be more able to improve OEE of the machines than that of the lower ones, whereas the group of the employees who had lower educational level would be more able to cooperate for the OEE improvement than that of the higher one. As a consequence, company's executives should promote the employees' knowledge, skills, and understanding through organizing the training and creating necessary understanding at the most level or at least between the range from 3.87 to 4.03 so as to improve the OEE of the machines to retain at least 85% as follows;

8.2.3.1 TPM Introduction and Group Function and Role

8.2.3.2 Understanding of AM Principle, AM Stepwise Inspection and Evaluation

8.2.3.3 Ownership of Lean TPM Implementation

8.2.3.4 Basic Mechanical Techniques

8.2.3.5 Basic Electrical Techniques

8.2.3.6 Mechanical Part Abnormality

8.2.3.7 Machine Losses

8.2.3.8 Human Growth Need Relate Basic Lean TPM

8.2.3.9 Basic Tools of SGA and Information Feed Back

8.2.3.10 Basic SGA management techniques and SGA activity

8.3 Suggestion for Further Research

During the Lean TPM implementation, although the company's executive realize that providing education and training on Lean TPM principle and related topics to all employees were very important, they could not develop the employees' knowledge and skills as expected. The researcher noticed that some employees were unable to attend every topics of the training due to the fact that they had to perform their main duties so they did not have time for the training. In this case, it was necessary to design the training system and develop the instructional media in order to increase the effectiveness until they were convinced that the employees had good knowledge on those topics promptly.

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APPENDICES

APPENDIX A

Table A-1: IOC Test Result of Proposed Questionnaire

Questionnaire Item	Judgment			IOC
	Expert #1	Expert #2	Expert #3	
PE1- TPM is useful for your job.	1	1	1	1.00
PE2-TPM is suitable for your job.	1	1	1	1.00
PE3-TPM implementation enables you to accomplish your tasks more efficiently.	0	1	1	0.67
PE4- TPM implementation enables your job to have higher quality.	1	1	1	1.00
PE5-TPM implementation enables you to have more production.	1	1	1	1.00
PE6-TPM implementing enables your chances of getting promotion in your carrier path.	0	1	1	0.67
EE1-You understand the TPM very well.	1	1	1	1.00
EE2-You are very clear about your role in TPM.	1	1	1	1.00
EE3-It is not difficult to perform the TPM if having better understanding.	1	1	1	1.00
EE4-It is easy for you to learn TPM	1	1	1	1.00
SI1-Your colleagues want you to participate in TPM activity.	1	1	1	1.00
SI2-If the majority of other work units has implemented TPM, you will follow it.	1	1	1	1.00
SI3-You are willing to implement the TPM if asked by your superior.	0	1	1	0.67

Table A-1: IOC Test Result of Proposed Questionnaire (cont.)

Questionnaire Item	Judgment			IOC
	Expert #1	Expert #2	Expert #3	
SI4-You are willing to implement the TPM it is the company policy which every staff must follow.	1	1	1	1.00
VO1-You are willing to implement the TPM though your superior does not ask you to do.	1	1	1	1.00
VO2-You are willing to implement the TPM though it is not related to your job.	1	1	1	1.00
BI1-You whole heartedly intend to implement the TPM according to the company's plan.	1	1	1	1.00
BI2-You whole heartedly intend to review the TPM activity according to the company's plan.	1	1	1	1.00
FC1-You have enough team and materials for well implementing TPM activity.	1	1	1	1.00
FC2-You can ask for advice and support from the TPM coordinator.	1	1	1	1.00
FC3-You can ask for advice and support from the TPM consultant.	1	1	1	1.00
FC4-The company has supplied enough material for TPM knowledge searching.	1	1	1	1.00
EX1-For how many years, have you had work experience?	1	1	1	1.00
EX2-You have had much experience in small group activities and creative activities.	1	1	1	1.00
EX3-You have had much experience in 5S activities.	1	1	1	1.00

Table A-1: IOC Test Result of Proposed Questionnaire (cont.)

Questionnaire Item	Judgment			IOC
	Expert #1	Expert #2	Expert #3	
EX4-You have had much experience in Kaizen suggestion activities.	1	1	1	1.00
EX5-You have much experience in TPM implementation.	1	1	1	1.00
KN1-What education level have you finished?	1	1	1	1.00
KN2-You have had basic knowledge in your machine structure very well.	1	1	1	1.00
KN3-You have known the seven fuguai very well and can be able to detect it.	1	1	1	1.00
KN4-You have known the seven machine loss very well and can be able to detect.	1	1	1	1.00
KN5-You have had good basic knowledge in TPM implementation.	1	1	1	1.00
KN6-You have had knowledge and understanding in doing pillar activities of TPM very well.	1	1	1	1.00
KN7-You have had knowledge necessary for doing TPM activities very well.	1	1	1	1.00
KN8-You have had knowledge and understanding in implementing small group activity very well.	1	1	1	1.00
KN9-You have had knowledge and experience in managing your jobs by your own-self.	1	1	1	1.00
TP1-In implementing the TPM, you do not reduce your significant role in your working line.	1	1	1	1.00

Table A-1: IOC Test Result of Proposed Questionnaire (cont.)

Questionnaire Item	Judgment			IOC
	Expert #1	Expert #2	Expert #3	
TP2-In doing TPM, there is no negative impact on your work.	1	1	1	1.00
CL1-You are satisfy with expressing your ability whenever you have opportunity.	1	1	1	1.00
CL2-You want your department to set its definite goals.	1	1	1	1.00
CL3-You want your department to evaluate your job outcome exactly against the set objectives.	1	1	1	1.00
CL4-You want your department to motivate how to choose work method that regularly increases its effectiveness.	1	1	1	1.00
CL5-You want the company to exactly divide the level of responsibility in organizing small group activities comprising the head and the members of small group.	1	1	1	1.00
BU1-On average you participate in training , meeting, and small group activity including TPM almost every time or every time.	1	1	1	1.00

Table A-2: Descriptive Statistics for Performance Expectancy (PE) Obtained from the Survey in the Company for the Case Study (n=138)

Questionnaire items	**1**	**2**	**3**	**4**	**5**	**Mean**	**Std. Dev.**
PE1- TPM is useful for your job.	3 (2.17%)	29 (21.01%)	85 (61.59%)	21 (15.22%)	0 (0%)	2.90	0.66
PE2-TPM is suitable for your job.	98 (71.01%)	40 (28.99%)	0 (0%)	0 (0%)	0 (0%)	1.29	0.46
PE3-TPM implementation enables you to accomplish your tasks more efficiently.	35 (25.36%)	75 (54.35%)	28 (20.29%)	0 (0%)	0 (0%)	1.95	0.68
PE4- TPM implementation enables your job to have higher quality.	1 (0.72%)	32 (23.19%)	78 (56.52%)	27 (19.57%)	0 (0%)	2.95	0.68
PE5-TPM implementation enables you to have more production.	39 (28.26%)	71 (51.45%)	28 (20.29%)	0 (0%)	0 (0%)	1.92	0.69
PE6-TPM implementing enables your chances of getting promotion in your carrier path.	89 (64.49%)	49 (35.51%)	0 (0%)	0 (0%)	0 (0%)	1.36	0.48

Table A-3: Descriptive Statistics for Effort Expectancy (EE) Obtained from the Survey in the Company for the Case Study (n=138)

Questionnaire items	1	2	3	4	5	Mean	Std. Dev.
EE1-You understand the TPM very well.	76 (55.07%)	62 (44.93%)	0 (0%)	0 (0%)	0 (0%)	1.45	0.50
EE2-You are very clear about your role in TPM.	11 (7.97%)	72 (52.17%)	55 (39.86%)	0 (0%)	0 (0%)	2.32	0.62
EE3-It is not difficult to perform the TPM if having better understanding.	125 (90.58%)	13 (9.42%)	0 (0%)	0 (0%)	0 (0%)	1.09	0.29
EE4-It is easy for you to learn TPM	118 (85.51%)	20 (14.49%)	0 (0%)	0 (0%)	0 (0%)	1.14	0.35

Table A-4: Descriptive Statistics for Social Influence (SI) Obtained from the Survey in the Company for the Case Study (n=138)

Questionnaire items	1	2	3	4	5	Mean	Std. Dev.
SI1-Your colleagues want you to participate in TPM activity.	72 (52.17%)	55 (39.86%)	11 (7.97%)	0 (0%)	0 (0%)	1.56	0.63
SI2-If the majority of other work units has implemented TPM, you will follow it.	2 (2.08%)	15 (15.63%)	32 (33.33%)	0 (0%)	0 (0%)	2.40	0.63
SI3-You are willing to implement the TPM if it is asked by your superior.	0 (0%)	66 (47.83%)	64 (46.38%)	8 (5.80%)	0 (0%)	2.58	0.60

Table A-4: Descriptive Statistics for Social Influence (SI) Obtained from the Survey in the Company for the Case Study (n=138) (cont.)

Questionnaire items	1	2	3	4	5	Mean	Std. Dev.
SI4-You are willing to implement the TPM if it is the company policy which every staff must follow.	7 (5.07%)	19 (13.77%)	54 (39.13%)	56 (40.58%)	2 (1.45%)	3.20	0.88

Table A-5: Descriptive Statistics for Voluntariness of Use (VO) Obtained from the Survey in the Company for the Case Study (n=96)

Questionnaire items	1	2	3	4	5	Mean	Std. Dev.
VO1-You are willing to implement the TPM though your superior does not ask you to do.	24 (17.39%)	39 (28.26%)	75 (54.35%)	0 (0%)	0 (0%)	2.37	0.76
VO2-You are willing to implement the TPM though it is not related to your job.	60 (43.48%)	65 (47.10%)	13 (9.42%)	0 (0%)	0 (0%)	1.66	0.64

Table A-6: Descriptive Statistics for Facilitating Conditions (FC) Obtained from the Survey in the Company for the Case Study (n=138)

Questionnaire items	1	2	3	4	5	Mean	Std. Dev.
FC1-You have enough team and materials for well implementing TPM activity.	24 (17.39%)	60 (43.48%)	54 (39.13%)	0 (0%)	0 (0%)	2.22	0.72
FC2-You can ask for advice and support from the TPM coordinator.	10 (7.25%)	86 (62.32%)	42 (30.43%)	0 (0%)	0 (0%)	2.23	0.57
FC3-You can ask for advice and support from the TPM consultant.	0 (0%)	17 (12.32%)	67 (48.55%)	52 (37.68%)	2 (1.45%)	3.28	0.69
FC4-The company has supplied enough material for TPM knowledge searching.	101 (73.19%)	37 (26.81%)	0 (0%)	0 (0%)	0 (0%)	1.27	0.44

Table A-7: Descriptive Statistics for Experience (EX) Obtained from the Survey in the Company for the Case Study (n=138)

Questionnaire items	1	2	3	4	5	Mean	Std. Dev.
EX1-For how many years, have you had work experience?	11 (7.97%)	4 (2.90%)	15 (10.87%)	8 (5.80%)	33 (23.91%)	6.34	3.58
EX2-You have had much experience in small group activities and creative activities.	13 (9.42%)	48 (34.78%)	77 (55.80%)	0 (0%)	0 (0%)	2.46	0.66
EX3-You have had much experience in 5S activities.	0 (0%)	18 (13.04%)	60 (43.48%)	60 (43.48%)	0 (0%)	3.30	0.69
EX4-You have had much experience in Kaizen suggestion activities.	12 (8.70%)	48 (34.78%)	78 (56.52%)	0 (0%)	0 (0%)	2.48	0.65
EX5-You have much experience in TPM implementation.	91 (65.94%)	47 (34.06%)	0 (0%)	0 (0%)	0 (0%)	1.34	0.48

Table A-8: Descriptive Statistics for Knowledge (KN) Obtained from the Survey in the Company for the Case Study (n=138)

Questionnaire items	1	2	3	4	5	Mean	Std. Dev.
KN1-What education level have you finished?	10 (7.25%)	22 (15.94%)	56 (40.58%)	38 (27.54%)	12 (8.70%)	3.14	1.03
KN2-You have had basic knowledge in your machine structure very well.	61 (44.20%)	67 (48.55%)	10 (7.25%)	0 (0%)	0 (0%)	1.63	0.63
KN3-You have known the seven fuguai very well and can be able to detect it.	12 (8.70%)	42 (30.43%)	70 (50.72%)	14 (10.14%)	0 (0%)	2.62	0.78
KN4-You have known the seven machine loss very well and can be able to detect.	67 (48.55%)	63 (45.65%)	8 (5.80%)	0 (0%)	0 (0%)	1.57	0.60
KN5-You have had good basic knowledge in TPM implementation.	78 (56.52%)	54 (39.13%)	6 (4.35%)	0 (0%)	0 (0%)	1.48	0.58
KN6-You have had knowledge and understanding in doing pillar activities of TPM very well.	13 (9.42%)	65 (47.10%)	60 (43.48%)	0 (0%)	0 (0%)	2.34	0.64
KN7-You have had knowledge necessary for doing TPM activities very well.	11 (7.97%)	53 (38.41%)	74 (53.62%)	0 (0%)	0 (0%)	2.46	0.64

Table A-8: Descriptive Statistics for Knowledge (KN) Obtained from the Survey in the Company for the Case Study (n=138) (cont.)

Questionnaire items	1	2	3	4	5	Mean	Std. Dev.
KN8-You have had knowledge and understanding in implementing small group activity very well.	29 (21.01%)	63 (45.65%)	46 (33.33%)	0 (0%)	0 (0%)	2.12	0.73
KN9-You have had knowledge and experience in managing your jobs by your own-self.	92 (66.67%)	38 (27.54%)	8 (5.80%)	0 (0%)	0 (0%)	1.39	0.60

Table A-9: Descriptive Statistics for Organization Culture (CL) Obtained from the Survey in the Company for the Case Study (n=138)

Questionnaire items	1	2	3	4	5	Mean	Std. Dev.
CL1-You are satisfy with expressing your ability whenever you have opportunity.	32 (23.19%)	73 (52.90%)	33 (23.91%)	0 (0%)	0 (0%)	2.01	0.69
CL2-You want your department to set its definite goals.	3 (2.17%)	24 (17.39%)	81 (58.70%)	30 (21.74%)	0 (0%)	3.00	0.69
CL3-You want your department to evaluate your job outcome exactly against the set objectives.	0 (0%)	2 (1.45%)	58 (42.03%)	76 (55.07%)	2 (1.45%)	3.57	0.55

Table A-9: Descriptive Statistics for Organization Culture (CL) Obtained from the Survey in the Company for the Case Study (n=138) (cont.)

Questionnaire items	1	2	3	4	5	Mean	Std. Dev.
CL4-You want your department to motivate how to choose work method that regularly increases its effectiveness.	89 (64.49%)	43 (31.16%)	6 (4.35%)	0 (0%)	0 (0%)	1.40	0.57
CL5-You want the company to exactly divide the level of responsibility in organizing small group activities comprising the head and the members of small group.	11 (7.97%)	47 (34.06%)	67 (48.55%)	13 (9.42%)	0 (0%)	2.59	0.77

Table A-10: Descriptive Statistics for Behavioral Intention (BI) Obtained from the Survey in the Company for the Case Study (n=138)

Questionnaire items	1	2	3	4	5	Mean	Std. Dev.
BI1-You whole heartedly intend to implement the TPM according to the company's plan.	27 (19.57%)	54 (39.13%)	57 (41.30%)	0 (0%)	0 (0%)	2.22	0.75
BI2-You whole heartedly intend to review the TPM activity according to the company's plan.	67 (48.55%)	55 (39.86%)	15 (10.87%)	1 (0.72%)	0 (0%)	1.64	0.70

Table A-11: Descriptive Statistics for Use Behavior (BU) Obtained from the Survey in the Company for the Case Study (n=138)

Questionnaire items	1	2	3	4	5	Mean	Std. Dev.
BU1-On average you participate in training, meeting, and small group activity including TPM almost every time or every time.	78 (56.52%)	52 (37.68%)	8 (5.80%)	0 (0%)	0 (0%)	1.49	0.61

Table A-12: Spearman's Correlation R (n=138) for the Company in this Case Study

	AGE	*PE*	*EE*	*SI*	*FC*	*VO*	*EX*	*KN*	*CL*	*BI*	*BU*
AGE	1										
PE	-0.7833	1									
EE	-0.7051	0.62737	1								
SI	-0.7322	0.70793	0.786872	1							
FC	-0.6522	0.62617	0.580756	0.62104	1						
VO	-0.8089	0.72917	0.840888	0.93358	0.65116	1					
EX	0.3753	-0.1086	-0.24784	-0.1296	-0.0867	-0.1917	1				
KN	-0.8381	0.79817	0.734693	0.82612	0.65072	0.88919	-0.1605	1			
CL	-0.8621	0.82034	0.752664	0.83742	0.64276	0.89697	-0.2069	0.90141	1		
BI	-0.8402	0.84467	0.799762	0.87461	0.69058	0.9156	-0.1705	0.88447	0.92127	1	
BU	-0.608	0.67773	0.656629	0.65746	0.71439	0.6999	-0.0651	0.66141	0.69164	0.75776	1

Table A-13: Force Field Analysis sheet (FFA)

FFA1-The reasons in making decision to have full participation.	**FFA2-The reason for unwillingness to participate with the activity.**
No.1 – You think that the customer needs the company to implement the TPM. ( )	No.11 – You do not know what usefulness it would make to the company. ( )
No.2- TPM implementation helps enhancing the company work's atmosphere. ( )	No.12 – You are afraid that you will be punished if you make something wrong. ( )
No.3 - TPM implementation helps reduce your job problems. ( )	No.13 – You feel that your superior or your executive do not encourage you to do the implementation. ( )
No.4 - TPM implementation helps you to progress in your job position. in your job. ( )	No.14 – You feel that if the system is better, you will lose importance in helping solve the factory's actual problem. ( )
No.5 - TPM implementation helps you work safely. ( )	No.15 You are afraid that the TPM implementation will make your subordinates to be better able to do the job, you may be fired. ( )
No. 6-TPM implementation helps the company under economic fluctuation and crises to maintain stability. ( )	No.16-If the equipment is good, you may lose opportunity to do an overtime job. ( )
No.7-TPM implementation helps widen your opportunity in fully expressing your ability. ( )	No.17-You feel that there is no use to participate in the implementation as it would support other department's job to be better. ( )

Table A-13: Force Field Analysis sheet (FFA) (cont.)

FFA1-The reasons in making decision to have full participation.	**FFA2-The reason for unwillingness to participate with the activity.**
No.8-TPM implementation helps enhance your potentiality. ( )	No.18-You do not know and do not understand of what implementation you should conduct. ( )
No.9 - TPM implementation helps you to manage your jobs more easily. ( )	No.19-Other ( )
No.10 - TPM implementation helps enhance your professional life quality. ( )	

Table A-14: Employees' Comments on Lean TPM Activities

No.	**Comment**
1.	Good finance makes quick Lean TPM.
2.	Full stomach and outstanding concrete job lead to success as the old saying "A military troop can move only by stomach"
3.	Cooperation leads towards a success
4.	Motivate employees to understand their work problem with an insight into it, ready for the correction and providing rewards to all concerned (better if small group)
5.	Good finance make job move
6.	There should be job alteration among different group for more understanding of the Lean TPM
7.	There should be more Lean TPM training so that the employees would have more understanding
8.	Giving more incentive for drafting work instruction as what is done with OPL
9.	Provide more Lean TPM activity in the department and allow the employees would participate more
10.	Encourage every department to cooperate in Lean TPM equally

Table A-14: Employees' Comments on Lean TPM Activities (cont.)

No.	Comment
11.	There should be the contest for Lean TPM activity board with the employees playing the role of judge. At the same time giving opportunity to all employees in taking part, the contest should be held for every step
12.	There should be Lean TPM activity board contest in which employees are judges
13.	The better system would remove the important in solving the existing problem
14.	There should be a provision of a calendar with the pictures of employees' Lean TPM small group activities
15.	There should be Lean TPM activity a bulletin board contest
16.	Ed and T should support those participating in Lean TPM activity more than usual and provide more for the material used in Lean TPM since it would not be successful without the Ed and T encouragement
17.	Higher payment should be made to those working more
18.	Since higher salary and higher bonus would make everything move fast
19.	What most of the employees needed the company's motivation in order to increase the morale among the employees
20.	The department head should participate more since the department administrator did not cooperate as much as it should be. There is a lack of material for administering the data couple with the lack of unity among the administration
21.	In regard to the employees' remuneration, the company should create motivation among the employees so that they would have willingness in doing their job
22.	The teaching was ineffective and not entire, Hence there should be special personnel who could give knowledge and advise so that they could come to the workplace for imparting the knowledge since the employees in production department did not have time to attend the training, or else there should an appointment of engineer to be responsible with this regard because the engineer had only their own limited area. When they attached the information on the board, no one understand its source and

Table A-14: Employees' Comments on Lean TPM Activities (cont.)

No.	Comment
23.	they care only for their duty. When having more work on Lean TPM , they found it was an added burden with the same payment "If you want anything you should give them first then the cooperating would be better"
24.	The employees found it was boring and even their routines still make them tired. Even the department head did not want to do it. They also found it boring and miserable.
25.	The executive should be more ready to do the work, not giving every job to the group.
26.	There was too much paper work, adding more burden to the employees, making them boring.
27.	The new department named TPM should be established so that it would collect and analyses the data, as well as providing the TPM implementation plan with department employees acting themselves as the raw data sources
28.	Although the Lean TPM was a good job, the employees found them boring particularly it paper work. However, they were willing to do (100%) practical activities.
29.	It should be understood that each employees had his or her own duty. So it was improbable to assign them with the whole system of work with high expectation.
30.	They did not want to do it because they had to write more within limited time. Each department was not still ready. There should be the training of employees by the more experience staffs acting as mentors so that it would be easier them to learn and understand Lean TPM activity quicker than reading WI. In this case writing WI may not be necessary.
31.	There should be more participation from every involved personnel.
32.	There was vague motivation from different work unit of the factory. The Lean TPM administration still relies on old, conventional policy

Table A-14: Employees' Comments on Lean TPM Activities (cont.)

No.	Comment
	without any development from its different sub-organization.The employees thought that why they should do it if there was no readiness in terms of cooperation from everyone involved. They were still in doubt about the readiness.

APPENDIX B

Table B-1: Record Data of Process Parameters Which Was Scaled Data-Pre-Processing

X_1:Thickness (micron)	X_2:Speed (mpm)	X_3:Nip Pressure	X_4:Nip Hardness	X_5: Tension	X_6:Chem pH	Output : QC Checked
1	2	3	2	3	2	OK
2	3	4	3	3	3	OK
2	3	4	3	4	3	OK
2	4	4	3	3	3	NO
1	4	3	2	3	2	NO
1	1	3	3	3	2	OK
2	3	4	3	3	3	OK
1	2	3	1	1	2	NO
2	3	5	3	3	3	NO
1	2	5	4	3	2	NO
2	3	4	5	3	3	NO
1	2	3	2	3	2	OK
2	3	4	3	5	3	NO
1	4	3	2	1	2	NO
2	3	4	3	3	3	OK
1	2	3	1	3	2	OK
1	2	3	2	3	2	OK
2	3	4	3	3	2	OK
1	2	5	2	3	2	NO
1	2	4	3	3	2	OK
2	3	4	5	3	4	NO
1	3	3	2	3	2	OK

Table B-1: Record Data of Process Parameters Which Was Scaled Data-Pre-Processing (cont.)

X_1:Thickness (micron)	X_2:Speed (mpm)	X_3:Nip Pressure	X_4:Nip Hardness	X_5: Tension	X_6:Chem pH	Output : QC Checked
1	1	3	2	3	2	OK
1	3	3	2	3	2	OK
1	2	2	2	3	2	OK
1	2	4	2	3	2	OK
1	2	3	1	3	2	OK
1	2	3	3	3	2	OK
1	2	3	2	2	2	OK
1	2	3	2	4	2	OK
1	2	3	2	3	1	OK
1	2	3	2	3	3	OK
1	1	2	1	3	2	OK
1	3	3	2	4	2	OK
1	2	2	3	4	2	OK
1	3	4	2	2	1	OK
1	2	3	1	2	3	OK
1	1	2	3	2	1	OK
1	2	3	1	2	3	OK
1	3	4	2	4	1	OK
1	2	3	1	4	1	OK
1	4	4	1	4	1	NO
1	2	2	3	4	2	OK
1	4	3	2	3	2	NO
1	1	1	2	3	2	NO
1	2	3	1	4	1	OK
1	4	5	2	3	2	NO
1	2	3	2	3	1	OK

Table B-1: Record Data of Process Parameters Which Was Scaled Data-Pre-Processing (cont.)

X_1:Thickness (micron)	X_2:Speed (mpm)	X_3:Nip Pressure	X_4:Nip Hardness	X_5: Tension	X_6:Chem pH	Output : QC Checked
1	3	5	4	3	2	NO
1	2	3	2	4	2	OK
1	1	3	4	5	1	NO
1	2	3	1	2	3	OK
1	2	2	3	4	2	OK
1	5	3	2	1	2	NO
1	1	3	5	5	2	NO
1	1	3	3	2	3	OK
1	3	3	1	1	4	NO
1	1	2	3	2	1	OK
1	4	3	4	4	5	NO
1	2	3	2	3	2	OK
1	3	2	2	2	2	OK
1	3	3	2	3	2	OK
1	3	3	2	3	2	OK
1	4	3	2	3	2	NO
1	2	4	3	3	2	OK
1	1	3	3	3	2	OK
1	3	3	2	3	2	OK
1	2	5	2	3	2	NO
1	2	3	2	4	2	OK
1	2	1	2	3	2	NO
1	3	3	2	3	2	OK
1	2	3	1	3	2	OK
1	2	3	2	2	2	OK
1	2	3	2	4	2	OK
1	2	3	2	3	1	OK
1	2	3	2	3	3	OK
2	3	4	3	3	3	OK
2	2	4	3	3	3	OK

Table B-1: Record Data of Process Parameters Which Was Scaled Data-Pre-Processing (cont.)

X_1:Thickness (micron)	X_2:Speed (mpm)	X_3:Nip Pressure	X_4:Nip Hardness	X_5: Tension	X_6:Chem pH	Output : QC Checked
2	3	4	3	3	1	NO
2	3	4	3	3	5	NO
2	4	4	3	3	3	OK
2	3	3	3	3	3	OK
2	2	2	2	3	3	NO
2	3	5	3	3	3	OK
2	3	4	2	3	3	OK
2	3	4	4	3	3	OK
2	3	4	3	2	3	OK
2	3	4	3	4	3	OK
2	3	4	3	3	2	OK
2	3	4	3	3	4	OK
2	1	4	3	3	3	NO
2	5	4	3	3	3	NO
2	2	4	3	3	3	OK
2	3	4	3	4	3	OK
2	2	4	3	3	3	OK
2	3	2	3	3	3	NO
2	3	4	1	3	3	NO
2	3	4	5	3	3	NO
2	3	4	3	1	3	NO
2	2	4	3	3	3	OK
2	3	4	3	5	3	NO
2	3	4	3	3	1	NO
2	3	4	3	3	3	OK

Table B-1: Record Data of Process Parameters Which Was Scaled Data-Pre-Processing (cont.)

X_1:Thickness (micron)	X_2:Speed (mpm)	X_3:Nip Pressure	X_4:Nip Hardness	X_5: Tension	X_6:Chem pH	Output : QC Checked
2	3	4	3	3	5	NO
2	3	4	3	3	3	OK
2	3	4	3	4	3	OK
2	1	3	3	3	3	NO
2	3	4	3	3	3	OK
2	5	4	4	3	3	NO
2	2	2	2	3	3	NO
2	3	5	3	3	3	OK
2	2	3	1	4	3	NO
2	3	4	4	3	3	OK
2	3	4	3	3	4	OK
2	4	5	5	2	4	NO
2	2	4	3	3	3	OK
2	3	3	4	1	4	NO
2	3	4	3	3	3	OK
2	3	3	3	3	3	OK
2	3	4	3	5	2	NO
2	3	4	3	3	3	OK
2	3	4	3	3	3	OK

Table B-2: Test for Predictors Selection

Classifier	MultilayerPerceptron -L 0.3 -M 0.2 -N 500 -V 0 -S ? -E 20 -H a					
Test options	Cross-validation Folds 12					
No. of Attributes	W/O	RMSE@seed					Avg. RMSE
		0	1	2	3	4	
7	none	0.2423	0.2598	0.2562	0.2636	0.2425	0.25288
6	thickness	0.303	0.2959	0.2966	0.2966	0.2954	0.2975
6	speed	0.3436	0.341	0.3601	0.3623	0.359	0.3532
6	pressure	0.3089	0.2985	0.2858	0.2956	0.2944	0.29664
6	hardness	0.3013	0.3134	0.3046	0.3136	0.3119	0.30896
6	tension	0.3387	0.3373	0.3314	0.338	0.3491	0.3389
6	Chem. ph	0.3093	0.2963	0.2828	0.2958	0.2949	0.29582

Table B-3: Optimal Numbers of Hidden Layer Node

Classifier	MultilayerPerceptron -L 0.3 -M 0.2 -N 500 -V 0 -S ? -E 20 -H ?					
Test options	Cross-validation Folds 12					
No. of Hidden Layer	RMSE@seed					Avg. RMSE
	0	1	2	3	4	
1	0.2994	0.2388	0.2578	0.2441	0.2326	0.25454
2	0.2791	0.2439	0.288	0.2581	0.2433	0.26248
3	0.2709	0.2344	0.2675	0.2477	0.2445	0.253
4	0.2492	0.258	0.2664	0.2407	0.2333	0.24952
5	0.2503	0.2529	0.2675	0.2416	0.2451	0.25148
6	0.2405	0.2598	0.2771	0.2611	0.2444	0.25658
7	0.2456	0.2627	0.2602	0.2625	0.2451	0.25522
8	0.2483	0.256	0.2743	0.2587	0.2457	0.2566
9	0.2499	0.254	0.2468	0.2582	0.2572	0.25322
10	0.2546	0.2523	0.2612	0.2435	0.244	0.25112
11	0.2477	0.2662	0.2446	0.2449	0.2459	0.24986
12	0.2473	0.2733	0.2461	0.2618	0.2513	0.25596
13	0.2473	0.2584	0.2627	0.2577	0.2484	0.2549
14	0.2423	0.2598	0.2562	0.2636	0.2425	0.25288

Table B-3: Optimal Numbers of Hidden Layer Node (cont.)

Classifier	MultilayerPerceptron -L 0.3 -M 0.2 -N 500 -V 0 -S ? -E 20 -H ?					
Test options	Cross-validation Folds 12					
No. of Hidden Layer	RMSE@seed					Avg. RMSE
	0	1	2	3	4	
15	0.25	0.2634	0.2663	0.2512	0.2583	0.25784
16	0.2508	0.2703	0.2656	0.2608	0.2384	0.25718
17	0.2484	0.2579	0.2622	0.266	0.2389	0.25468
18	0.243	0.2691	0.2736	0.245	0.2338	0.2529
19	0.2616	0.2587	0.2643	0.2626	0.2362	0.25668
20	0.2561	0.2644	0.2675	0.2593	0.2348	0.25642
21	0.2423	0.264	0.2643	0.2596	0.2534	0.25672
22	0.2549	0.2558	0.2655	0.258	0.2291	0.25266
23	0.2444	0.2603	0.2618	0.2635	0.2341	0.25282
24	0.2389	0.2571	0.2673	0.2519	0.2294	0.24892
25	0.2613	0.2564	0.2635	0.2442	0.2288	0.25084
26	0.269	0.2543	0.264	0.2524	0.2322	0.25438
27	0.2758	0.2642	0.2652	0.2496	0.2309	0.25714
28	0.2711	0.2569	0.2689	0.2483	0.2281	0.25466
29	0.2666	0.2401	0.2674	0.247	0.2299	0.2502
30	0.2797	0.2551	0.2742	0.2584	0.2297	0.25942

Table B-4: 12-Folds - Cross-Validation Training

Classifier	MultilayerPerceptron -L 0.3 -M 0.2 -N ? -V 0 -S ? -E 20 -H 24					
Test options	Cross-validation Folds 12					
No. of Learning Epochs	RMSE@seed					Avg. RMSE
	0	1	2	3	4	
1	0.4842	0.4857	0.4807	0.4783	0.4827	0.48232
100	0.2742	0.2599	0.2702	0.2487	0.2512	0.26084
200	0.2689	0.2601	0.2676	0.2502	0.2473	0.25882
300	0.2554	0.2586	0.2678	0.2508	0.2297	0.25246
400	0.2413	0.2577	0.2676	0.2514	0.2295	0.2495
500	0.2389	0.2571	0.2673	0.2519	0.2294	0.24892
600	0.2382	0.2565	0.2672	0.2523	0.2294	0.24872
700	0.2379	0.2561	0.2672	0.2527	0.2294	0.24866
800	0.2377	0.2558	0.2673	0.253	0.2294	0.24864
900	0.2376	0.2556	0.2673	0.2533	0.2294	0.24864
1000	0.2376	0.2554	0.2674	0.2536	0.2294	0.24868

Table B-5: Test for optimal Learning Rate and Momentum Rate

Classifier	MultilayerPerceptron -L ? -M ? -N 800 -V 0 -S ? -E 20 -H 24						
Test options	Cross-validation Folds 12						
No. of Learning Rate	No. of Momentum	RMSE@seed					Avg. RMSE
		0	1	2	3	4	
0.1	0.1	0.2831	0.2769	0.2702	0.2785	0.2305	0.26784
	0.2	0.2777	0.2764	0.2706	0.2759	0.2301	0.26614
	0.3	0.2779	0.2693	0.2712	0.2617	0.2304	0.2621
	0.4	0.2774	0.2662	0.2716	0.2654	0.2302	0.26216
	0.5	0.2732	0.2587	0.2871	0.2646	0.246	0.26592
	0.6	0.2436	0.2625	0.3001	0.2637	0.247	0.26338
	0.7	0.2374	0.2763	0.2939	0.2449	0.2564	0.26178
	0.8	0.2691	0.2698	0.2524	0.2598	0.2629	0.2628
	0.9	0.2431	0.2316	0.2425	0.2397	0.2377	0.23892

Table B-5: Test for optimal Learning Rate and Momentum Rate (cont.)

Classifier	MultilayerPerceptron -L ? -M ? -N 800 -V 0 -S ? -E 20 -H 24						
Test options	Cross-validation Folds 12						
No. of Learning Rate	No. of Momentum	RMSE@seed					Avg. RMSE
		0	1	2	3	4	
0.2	0.1	0.2704	0.2554	0.29	0.2592	0.2448	0.26396
	0.2	0.2663	0.2553	0.2882	0.2595	0.2456	0.26298
	0.3	0.261	0.2489	0.2922	0.26	0.2327	0.25896
	0.4	0.261	0.2629	0.2923	0.2507	0.2331	0.26
	0.5	0.2417	0.2683	0.2565	0.2592	0.2445	0.25404
	0.6	0.2384	0.2644	0.2569	0.2634	0.2608	0.2469
	0.7	0.5843	0.2591	0.2503	0.2394	0.2638	0.2384
	0.8	0.2381	0.2396	0.2421	0.2391	0.2434	0.24046
	0.9	0.2368	0.2406	0.2617	0.2625	0.2392	0.24816
	0.2	0.23	0.2391	0.2383	0.2379	0.2438	0.23782
0.3	0.1	0.2627	0.2543	0.2726	0.2538	0.2297	0.25462
	0.2	0.2377	0.2558	0.2673	0.253	0.2294	0.24864
	0.3	0.2464	0.2582	0.2517	0.2562	0.2327	0.24904
	0.4	0.2431	0.2569	0.2526	0.2575	0.253	0.25262
	0.5	0.2435	0.2428	0.2505	0.2471	0.2548	0.24774
	0.6	0.2418	0.235	0.254	0.244	0.2573	0.24642
	0.7	0.2353	0.237	0.246	0.2469	0.2399	0.24102
	0.8	0.2467	0.2537	0.2427	0.258	0.2324	0.2467
	0.9	0.283	0.2727	0.2636	0.2651	0.2526	0.2674
0.4	0.1	0.241	0.2558	0.2511	0.2562	0.2326	0.24734
	0.2	0.2422	0.2536	0.2549	0.2578	0.2485	0.2514
	0.3	0.2461	0.2432	0.2516	0.247	0.2486	0.2473
	0.4	0.2447	0.2489	0.2462	0.248	0.2515	0.24786
	0.5	0.2447	0.2432	0.2386	0.2413	0.2454	0.24264
	0.6	0.2374	0.2485	0.246	0.2364	0.2453	0.24272
	0.7	0.2327	0.251	0.2561	0.2426	0.236	0.24368
0.5	0.1	0.2394	0.2373	0.2494	0.2438	0.2499	0.24396
	0.2	0.2363	0.239	0.244	0.2444	0.2492	0.24258
	0.3	0.2451	0.2457	0.2458	0.2348	0.2405	0.24238
	0.4	0.2455	0.2342	0.2436	0.2351	0.2465	0.24098

Table B-5: Test for optimal Learning Rate and Momentum Rate (cont.)

Classifier	MultilayerPerceptron -L ? -M ? -N 800 -V 0 -S ? -E 20 -H 24						
Test options	Cross-validation Folds 12						
No. of Learning Rate	No. of Momentum	RMSE@seed					Avg. RMSE
		0	1	2	3	4	
0.5	0.5	0.2435	0.2403	0.2372	0.2341	0.2503	0.24108
	0.6	0.2299	0.2444	0.2599	0.2444	0.2402	0.24376
	0.7	0.2407	0.2488	0.26	0.2494	0.2314	0.24606
	0.8	0.2588	0.2586	0.2692	0.2551	0.257	0.25974
	0.9	0.3724	0.41	0.442	0.4115	0.3827	0.40372
0.6	0.1	0.24	0.2366	0.2441	0.2565	0.2368	0.2428
	0.2	0.235	0.2453	0.2488	0.2351	0.2452	0.24188
	0.3	0.2347	0.2331	0.2446	0.2383	0.2467	0.23948
	0.4	0.2441	0.2378	0.2393	0.2315	0.2507	0.24068
	0.5	0.2266	0.2386	0.2386	0.2347	0.2473	0.23716
	0.6	0.2335	0.2573	0.255	0.2419	0.2377	0.24508
	0.7	0.2618	0.2302	0.2569	0.2495	0.2276	0.2452
	0.8	0.2557	0.2673	0.3083	0.2541	0.2651	0.2701
	0.9	0.46	0.5179	0.4808	0.4119	0.4567	0.46546
0.7	0.1	0.2364	0.2251	0.2477	0.2349	0.2448	0.23778
	0.2	0.2377	0.2329	0.2387	0.2355	0.2483	0.23862
	0.3	0.23	0.238	0.2433	0.2335	0.2456	0.23808
	0.4	0.2316	0.237	0.2482	0.2297	0.2464	0.23858
	0.5	0.2253	0.2419	0.2595	0.2377	0.2338	0.23964
	0.6	0.2432	0.243	0.2644	0.2527	0.2299	0.24664
	0.7	0.2447	0.2606	0.2886	0.258	0.228	0.25598
	0.8	0.3178	0.297	0.3011	0.2607	0.2966	0.29464
	0.9	0.5092	0.538	0.5203	0.4762	0.4908	0.5069
0.8	0.1	0.2376	0.2244	0.2356	0.2351	0.2436	0.23526
	0.2	0.23	0.2391	0.2383	0.2379	0.2438	0.23782
	0.3	0.2277	0.2376	0.2451	0.2365	0.242	0.23778
	0.4	0.2279	0.2473	0.2522	0.2329	0.2384	0.23974
	0.5	0.2198	0.2326	0.2667	0.2424	0.2387	0.24004
	0.6	0.2428	0.2516	0.2662	0.232	0.2294	0.2444
	0.7	0.2438	0.2401	0.271	0.2613	0.239	0.25104

Table B-5: Test for optimal Learning Rate and Momentum Rate (cont.)

Classifier	MultilayerPerceptron -L ? -M ? -N 800 -V 0 -S ? -E 20 -H 24						
Test options	Cross-validation Folds 12						
No. of Learning Rate	No. of Momentum	RMSE@seed					Avg. RMSE
		0	1	2	3	4	
0.9	0.1	0.2389	0.2385	0.2359	0.2362	0.2455	0.239
	0.2	0.2378	0.2401	0.2443	0.2372	0.2391	0.2397
	0.3	0.2352	0.2443	0.2448	0.2378	0.2424	0.2409
	0.4	0.2315	0.2469	0.2566	0.2476	0.2337	0.24326
	0.5	0.2447	0.2379	0.2574	0.2434	0.2352	0.24372
	0.6	0.2671	0.238	0.25	0.2612	0.2372	0.2507
	0.7	0.2504	0.2816	0.3024	0.2757	0.248	0.27162
	0.8	0.4128	0.3775	0.3629	0.419	0.4221	0.39886
	0.9	0.5906	0.4896	0.582	0.5536	0.6234	0.56784

Table B-6 Pinning sparking parameters

DL1	DL2	DL3	BM1	BM2	BM3	DM1	DM2	T	H	SL	SC	HV	HC	SW	BT	HOS	VOS	HDS	VDS	S
4	4	4	7	4	2	2	4	1	9	9	10	7	5	7	9	8	3	6	4	OK
3	3	5	4	2	3	1	4	1	10	9	10	7	5	7	9	8	3	6	4	OK
6	3	1	3	2	1	2	5	9	3	9	10	7	5	7	9	8	3	6	4	OK
1	3	4	3	3	1	2	6	9	3	9	10	7	5	7	9	8	3	6	4	OK
4	1	3	2	4	3	2	5	8	3	9	10	7	6	5	2	8	5	6	7	FB
5	4	3	3	5	2	1	10	8	3	9	10	7	10	5	2	8	5	6	7	OK
10	10	10	2	3	5	1	2	8	2	9	10	7	10	5	2	8	5	6	7	PS
4	2	4	2	2	7	3	2	7	3	7	7	9	2	7	5	9	9	8	4	OK
3	2	4	2	1	5	2	2	7	2	7	7	9	2	7	5	9	9	8	4	OK
2	2	4	3	1	5	3	2	8	2	7	7	9	2	7	5	9	9	8	4	OK
2	2	3	3	2	6	3	6	8	1	7	7	9	2	7	5	9	9	8	4	OK
1	3	5	2	3	4	2	3	8	2	9	8	9	3	8	5	9	10	8	5	OK
3	3	4	1	3	4	1	1	9	2	9	8	9	3	8	5	9	10	8	5	PS
1	8	5	7	10	9	10	5	8	2	2	3	7	1	7	3	7	1	5	3	FB
8	7	3	10	8	10	7	6	8	1	2	3	7	1	7	3	7	1	5	3	OK
9	7	1	7	8	8	3	6	8	1	2	3	7	1	7	3	7	1	5	3	FB
7	5	5	7	6	8	5	5	8	1	2	3	7	4	9	4	7	1	6	8	OK
8	5	3	8	8	7	6	5	8	1	2	3	7	4	9	4	7	1	6	8	OK
6	6	4	8	6	8	5	4	7	2	2	3	7	4	9	4	7	1	6	8	OK
4	6	1	6	7	5	3	4	7	1	2	3	7	4	9	4	7	1	6	8	PS

BIOGRAPHY

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