A practical analysis of OEE

By

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TPM orients enterprises towards production excellence: A Practical Analysis of OEE

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Abstract

Purpose – The purpose of this paper is to review the literatures on Total Productive Maintenance (TPM) and to present an overview of TPM implementation practices initiated in a ‘connector’ manufacturer in China. It also examines the need to develop, practice and implement such maintenance campaign, which not only reduce unscheduled and scheduled failures in process but also decrease operation and maintenance costs.

Design/methodology/approach – A case-based approach in combination with scientific theory and standard tools, techniques and practices is used to discuss various issues related with TPM implementation in industry.

Findings – The findings indicate that TPM not only leads to increase in efficiency and effectiveness of manufacturing equipments measured in terms of OEE index by reducing the failure, time loss, and defects but also helps organization to improve morale of people and working environment significantly. The contributions of strategic TPM programs towards improving manufacturing competencies of the organizations have also been highlighted here.

Originality/value – The paper contains a comprehensive literature on the field of equipment maintenance and also presents an interesting investigation of TPM implementation issues which may be useful to researchers, maintenance professionals and other practitioners concerned with maintenance to understand the significance of TPM.

Key words: Total Productive Maintenance, Overall Equipment Effectiveness, Six Big Loss, Lean Production

Article type: Research paper
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1. Introduction

1.1 Background

In global manufacturing industries, drastic changes have taken place in the last three decades reflected in management approaches, product and process technologies, customer expectations, supplier relationships as well as competitive behavior (Ahuja et al. 2006). The global marketplace has witnessed an increased pressure from customers and competitors in manufacturing (David, 1995). Toyota initially put forward lean idea – lean production, just-in-time and pull management in order to meet higher demands from customers.

The rivalry among organizations has become into the competition of production behavior and system campaign. Entrepreneurs are striving for reaching the lowest prices for their products while reaping most benefits through focusing on production process optimization, improved equipment maintainability, supply chain integration, total quality management, overall equipment effectiveness, continuous innovation and improvement, morale and ergonomics promoted and customer satisfactions. The manufacturing industry has experienced an unprecedented degree of challenges for diverse product range with state-of-the-art product features while coupled with high quality, lower costs, and more effective, swifter research and development (R&D) (McKone and Wiess, 1998).

With the increased global competition, more and more enterprises shift their attentions from increasing efficiency by means of economies of scale to meeting market conditions in terms of flexibility, delivery performance and quality (Yamashina, 1995). Challenged by two levels, enterprises experience intense competition on the supply side and strong volatility in customer requirements on the demand side. To stay competitive, cost effective production has become a must-to-do.

Despite implementation of advanced manufacturing technologies and development of lean production, benefits from these programs have often been restricted due to unreliable or inflexible equipments and methods (Tajiri and Gotoh, 1992). Historically, the overall neglect of maintenance as a competitive strategy and a general lack of synergy between maintenance approaches and quality management has been observed (Wireman, 1990). As
a result, the inadequacies of the maintenance practices in the past, have adversely affected the organizational competitiveness thereby reducing the throughput and reliability of production facilities, leading to fast deteriorations in production facilities, lowering equipment availability due to excessive systematic downtime, lowering production quality, increasing inventory, thereby leading to unreliable delivery performance. A mass of capitals are tied up in the production and maintenance management to make enterprises stay at competitive disadvantages.

Effective and efficient maintenance not only helps to keep equipment/facility in good condition but also extends its life and improves availability and capacity. In another word, poorly maintained equipment/facility could lead to highly frequent failures, inadequate utilization resulting in production delays. Conventionally, most of companies adopted fire-fighting method called reactive maintenance for maintenance activities. Only as and when equipment/facility fails to perform, maintenances are carried out. In this way, not only down time stays increased but also the production is obstructed. With development of manufacturing pattern and increased competition, this approach has been substituted by proactive maintenance strategies. A preventive and predictive maintenance is to prevent sudden sporadic or chronic failures by proactive and aggressive attitude. Today, because of automation and large-scale mechanization, higher facility availability, better product quality and long equipment life cycle had assumed considerable significance. In order to meet the above challenges, adoption of a suitable maintenance strategy has become essential for organizations to survive. While these advanced maintenance strategies require greater commitments in terms of employees, resources, materials and integration, they are also expected to provide higher levels of equipment availability and plant performance (Ljungberg, 1998).

Historically, the evolution of maintenance has been traced in three-time perspectives:

1. Before 1950, global industries were not mechanized but manual in the most of jobs and equipments structures were simple and easy to operate. As a result, the task of maintenance was easy with no need of expertise. In addition, the cost of maintenance was very low. At that time, all of firms adopted the concept of ‘Fix it when it breaks’. However after World War II, with the fast development of industrial technologies and large scale industrialization in Europe and America as a result of which complex machines were evolved. Hence, Industrial maintenance required specialized knowledge and maintenance cost was much higher than before
In this case, equipment maintenance had to be fulfilled by special teams and experts (Wireman, 1990).

2. After 1950, the concept of preventive maintenance (PM) of ‘I operate – You fix’ was introduced. Preventive maintenance utilized Taylor principle that follows equipment’s friction theory and wear-out theory. With the increase of machines life, the failure rate can be expressed as a curve in three parts, which is depicted in the figure 1.

![Bath-tube Curve – Failure Rate](image1)

**Figure 1.** Bath-tube Curve – Failure Rate (Gao Fucheng, 1998)

The first part is a decreasing failure rate, called as early failures. In this period, the failure is primarily caused by incompatibility at each part of design, production and assembly etc. With the use of the machines, the failure rate will decrease through all parts going into optimal cooperative state.

The second part is a constant failure rate, also called as sporadic failures. The failure in this period is caused by the reasons of mishandling, negligence of operation, poor lubrication, inactive maintenance, inferior material, low workmanship and so on. The failure is random by these facts.

The last part is an increasing failure rate, known as wear-out failures. The spare parts of machines have been worn out after long years of use. The failure in this phase belongs to a phenomenon of deterioration (Telang, 1998).

3. Since the mid-1970s, the drastic changes in industry have been drawn attentions by many firms. Owing to improved automation and mechanization reliability and availability became more essential, conventional preventive maintenance failed to
fulfill the challenges brought about by modern, advanced manufacturing systems. In this event, the need to develop new maintenance management techniques was felt. Total Productive Maintenance (TPM) was put forward initially in Japan and subsequently was spread over universally.

TPM can be defined as a systematic work method aiming to develop disturbance free processes at lowest possible cost through the commitment of all co-workers. It has three basic natures: total effectiveness; total maintenance; total commitment. (Salonen, 2007)

During this time perspective, various maintenance approaches were introduced to meet and realize different maintenance effectiveness and strategy in different industries. Condition Based Maintenance (CBM), Reliability Centered Maintenance (RCM), Computerized Maintenance Management Systems (CMMS) evolved with passage of time and even now still play significant roles in modern manufacturing maintenance management (Mobley, 1990).

In summary, the evolution of maintenance concept is presented in brief in the following.

<table>
<thead>
<tr>
<th>Production Function</th>
<th>First Phase (before 1950)</th>
<th>Second Phase (1950-1975)</th>
<th>Third Phase (1975-2000 ....)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manpower</td>
<td>“Fix it when breaks”</td>
<td>“I operate – You Fix”</td>
<td>Automation and Globalization</td>
</tr>
<tr>
<td>Mechanics</td>
<td></td>
<td></td>
<td>Concepts such as outsourcing and information processing</td>
</tr>
<tr>
<td>Maintenance Function</td>
<td>Considered as necessary evil</td>
<td>Considered as a task of maintenance department</td>
<td>Realized maintenance not an isolated function. An integrated, external + internal partnerships</td>
</tr>
<tr>
<td>Maintenance Techniques</td>
<td>Corrective maintenance</td>
<td>Bath tub curve-based PM policy</td>
<td>CBM, TPM, RCM, CMMS</td>
</tr>
</tbody>
</table>

Table1. Evolution of maintenance concept (Shi and Zhao, 2000)

The overall goal of TPM is to improve overall equipment effectiveness (Sun et al. 2003). OEE provides an effective way of measuring and analyzing the efficiency of a single machine/equipment or an integrated manufacturing system. OEE is defined as the core
metric for measuring the success of TPM implementation program (Jeong and Phillips, 2001). OEE is calculated by obtaining the availability of the equipment, performance efficiency of the process and rate of quality products (Dal et al. 2000):

\[ \text{OEE} = \text{Availability (A)} \times \text{Performance efficiency (P)} \times \text{Rate of quality (Q)} \]

1.2 Problem definition

How to develop and implement effective and efficient TPM so as to improve industrial competitiveness, which not only reduces sudden sporadic failures in work shop but also reduces both operation and maintenance costs. Through the measure in terms of OEE index, the hidden problems would be exposed and resultant countermeasures can be executed based on TPM framework and practices.

1.3 Summary of contributions

This paper reviews a large number of theories and papers in this field and reveals the important issues in TPM including maintenance techniques, framework of TPM, OEE, and TPM implementation practices, barriers and success factors in TPM implementation. The paper presents an interesting investigation of TPM implementation process which may help the enterprises/practitioners to prepare their plants to adopt and implement effective and efficient TPM so as to improve competitiveness. In another hand, the paper is a good reference book to help those students and scholars who intend to cast a board view and investigations on TPM field.

This paper is organized as follows. Starting with introduction part where the global industrial background and evolution of maintenance management are discussed. In the following part of theory, sufficient literature review regarding the development of TPM and OEE are presented. This report also makes focus on the case study starting from depiction of company background to discussion of the procedure for detailed TPM implementation in the cell with greater emphasis on data collection and failure analysis. Sequentially, we demonstrate the tangible and intangible benefits reaped from the effective TPM implementation and recommendations for the company going to adapt and practice TPM. Finally, the results and conclusions are reached.
1.4 Related work

This paper is abundant in theories and approaches how to realize enterprise excellence by means of TPM development and implementation. A case study in company of ABC describes the application of TPM in real world where confronted with barriers and challenges, while eventually reaps huge benefits from OEE results compared with earlier one before TPM.

1.5 Delimitations

This paper is a research paper based on a case study of TPM research process in entity and all the data was provided by the company. Since the authors did not exactly join in the TPM program launch, we can only make the OEE analysis based on the collected data and analyze the effect of TPM. In this case, it is difficult for us to realize the factual problems and obstructs TPM group was confronted when they started the TPM implementation.

Since the authors did not participate in the whole process of TPM improvement, we can not exactly understand the data collection method, e.g. how to calculate the planned stop time and break time. So this paper will exclude the data collection process but focuses on the OEE calculation to see the effects of introducing TPM into the production line.

Also in the parts of TPM improvement, where contains much mechanical knowledge and theories related with inner reconfiguration of machine which is not in the professions for the authors, we will go through the improvement methods and actions but skip the mechanical design process.
2. Methodology

In this part, we will reveal the reasons why we choose TPM as our subject and explain the research model at length. This is research paper based on case study approach and reviews plenty of scientific theories concerned with maintenance management field from different authors’ views. We will use both quantitative methodologies and qualitative methodologies to gather information and make data analysis. We will also use some analytical approach to reveal the production excellence such as ABC analysis, fish-bone diagram and brain storm etc. Following is the research model of this paper.

![Research Model Diagram]
2.1 Choice of the topic

TPM is first introduced by Japan thirty years ago and is becoming more and more popular in the manufacturing industry all around the world. But so far only few companies are able to reap substantial benefits from success of good TPM implementation. The companies have to find their own way to implement and develop TPM to suit in their conditions. TPM is not merely a cookbook that can be followed at the same pattern by all firms. Hence, before introducing TPM, companies need to make a research on feasibility about the TPM campaign and target the effect of TPM improvement. In this respect, that is much of significance to study the TPM implementation in the real entity. We believe the headline “TPM orients enterprises towards production excellence” can be absorbing for both researchers and the practitioners. Followed by a successful case study, we tap into the TPM implementation methods and process by a prestigious company in China and see how the OEE has been improved by effective proposals and actions.

We gained many assistances and coordination from Ms. Shi Wenjun who is working in ABC, which has succeeded to introduce TPM to the manufacturing process last year. Ms Shi participated in the TPM improvement project and she provided us with the most real and primary information of the TPM project, which will greatly help us to accomplish the case study. With a view to protect the business secret of the company, we have agreement with ABC company that we are not allowed to disclose any hints of company in our paper. In this case, we keep ABC as company name.

ABC is a subsidiary company to XYZ group, which is the world’s leading manufacturer in IT connector industry. With growth of demands in the market, ABC had recognized the necessities and edges of TPM deployed throughout the production process. And indeed, ABC is prototype that actually applied TPM in the manufacturing process and harvested massive and solid proceeds from success of effective TPM implementation.

Thereby, it’s meaningful to introduce successful experience in TPM implementation from ABC in our research and hopefully it will help more enterprises to promote their competitiveness through improving efficiency and effectiveness of equipments.
2.2 literature study

In order to find the theoretical support of our topic, we read lots of books and literatures both in English and Chinese. The presentation material of “competitive production system” (Salonen, 2007) gave us great help in studying TPM and OEE. We also chose the definition and the theories from his presentation material as our main theoretical support.

After carefully studying and consideration, we decided to choose the following five theories to support our case study.

**Equipment management and equipment maintenance**

Equipment management and equipment maintenance define the TPM theoretical framework. TPM is a result evolved from initial equipment management and maintenance in a long historical period. Looking from the angle of equipment management, it covers the whole course from equipment’s design, selection, manufacturing, installation, usage, maintenance, repair, reconstruction, renewal up till its obsolescence. While, equipment maintenance has witnessed three time perspective historically, reactive maintenance, preventive maintenance, condition based maintenance, reliability centered maintenance and total productive maintenance.

**TPM and lean production**

Actually, TPM is one of tools among lean production framework, and both have same target to create disturbance free working environment and eliminate the wastes as far as possible. In our research, the TPM theoretical source primarily relies on lean’s mindset, e.g. 5S housekeeping principle, Kaizen (continuous improvement), visual management, Kanban production etc.

**5S**

5S is one foundation stone of TPM and also a very useful method to improve efficiency of equipment and morale. 5S can be used in all kinds of industries throughout the world.

**OEE**

OEE is without doubt a must-to-do in our paper, since it is an effective metric to evaluate the effect of TPM implementation. Meanwhile, the final goal of TPM is to improve the overall equipment effectiveness.
Six big losses

Six big losses are the key components of OEE. By means of observing the time loss, speed loss and quality loss, we can reach availability, performance rate and quality rate to calculate the OEE value. In addition, by analyzing six big losses, the root causes may be identified in the process and it is easier to find the prescription to remedy through scientific approaches, e.g. ABC analysis, fish-bone diagram and brain storming.

2.3 Research methodologies

The research methodologies described the method the authors used to collect data and gather information in this paper. It is always important to use the right method to gather different kind of information. (Fisher, 2004)

2.3.1 Quantitative methodology

Quantitative methodology is a research strategy that emphasizes quantification in the collecting data and the information analysis. It is focus on the relationship between theories and the research, which tested the theories in reality. (Bryman, 2004)

In this research, the authors used observation as our main quantitative methodologies. We took survey and questionnaire together as interviews, which we will explain later.

Observation – observation means the researcher watch and record the action of certain in a certain environment. (Fisher, 2004)

In this research the authors observed the production line of ABC and take some pictures of the machine and the signal control system. We also go through the process following with the operators to record the time lose. The methodology gave us a general picture of the production line situation.

2.3.2 Qualitative methodologies

Qualitative methodology is a research method that usually emphasizes words rather than quantification in collecting data and information analysis. It is focus on the generation of
the theories and finding the reality by interviews, participated observations and data analysis. (Bryman, 2004)

In this research, since we only do the case study about the TPM improvement process, which ABC has finished, we can’t participate in the project or make ethnographic study. So we can only use open interviews and statistical studied as our qualitative methodologies.

**Interviews** – good structured interviews can help the researchers collect information more efficiency. Open interviews can let researchers get much information in a long time, but the researchers need more time to pick up useful information from much useless information. (Fisher, 2004)

In this research we take open interviews in order to get as much information about the TPM project so as to enforce our case study.

Since we have a friend Ms. Shi Wenjun who works in ABC and also joined the ABC’s TPM project, we decided to make an interview with Ms Shi and get some information about ABC’s TPM process.

In the first interview, she introduced the ABC’s background and its business scope with some commercial and booklets concerning about the ABC’s operation situation, so that we got the general information about the possibility for ABC to try TPM at that time. She also brought us to the production line to let us know more about the process. She explained all the function of the equipment to us and showed the improved maintenance plan. The authors also take some pictures about the production line and the data control center. But she told us that we cannot put the pictures which concerning to the equipment and technology in this paper, instead we can only put some data table and design chart in the case study.

The authors asked Ms. Shi to provide the data of the production line’s operation, including the fore data before TPM project and the improved data. She said that the data is controlled by the manager and she need to discuss about it with the manager. So we appointed the next meet time.

Then the authors met Ms. Shi at her office for the second interview. This time Ms Shi provided the collected data of March, April and July 2008 of the production line. She explained that they can only provide these data for us to do the case study. According to the three months’ data we can get the picture of TPM improvement for ABC. She also
provided the TPM group’s work dairy and improvement plan and explained the work process very carefully in detail.

After reading and analyzing the data we got from Ms. Shi, the authors came back to ABC and met Ms. Shi together with ABC’s technician Mr. Wang. In this meeting we focused on asking questions about the improvement proposals of the production line. Since we have researched the data we got before, we found the big improvements in all aspects of OEE. So we need the information about how ABC successful to improve the OEE. Ms Shi and Mr Wang explained some kind of improvements in the machine design and the operation method. They also show the design map and brought us to the equipment to explain the function of the new design. The resource we got that day impressed us because they only make small changes to get big difference.

By three times interviews and several times telephone and E-mail contact, we got lots of important primary resource from ABC and we can start to do the case study based on the data.

**Data analysis** – this study is using some scientific method to do analysis with collected data to get the real meaning of the data and seek the potential evaluation of the information. (Fisher, 2004)

In this research we get the data from ABC and we use OEE calculation formation to do statistical study and find the bottleneck of the production line. We also use the statistical study to compare with different result to see the valuation of the improvement.
3. Theoretical framework

3.1 Equipment Management

Production equipment development is one of the main capabilities customers are seeking. Senior and advanced equipments/facilities not only can help to enhance operational achievements and also can improve ergonomics. Historically, the evolution of production equipments has experienced dramatic revolutions from initially hand-made along with monotonous machines operation, to semi-automatic mechanism and finally to intelligently computers-aided operational environment where a huge number of automatic equipments have been utilized such as robots. All these changes reveal the fact that enterprises have been seeking for continuously effective and efficient production modes to improve capabilities through the development of equipments/facilities. Meanwhile, some dangerous and humdrum jobs are replaced by robots as a result the working environments have been improved largely (James et al. 2004).

Thereby, equipment management as an independent discipline emerged as the times required and has been studied extensively by researchers. Equipment management has its research object of equipments, machines and tools, and has its objective of manufacturing operation excellence to reach the goal of possibly lowest equipment life-cycle expense and optimal equipment utilization by means of a number of theories and methodologies, for example, systematic engineering, value engineering and equipment abrasion theory, compensation theory, equipment reliability and maintenance theory, equipment monitoring and diagnosis approach. Equipment management covers the whole course from equipment’s design, selection, manufacturing, installation, usage, maintenance, repair, reconstruction, renewal up till its obsolescence (Li and Yang, 2000).

Equipment management plays a significant role in modern production management. Equipment management has been dependent and relevant to many sectors in an organization such as project division, quality control, manufacturing techniques, materials management, and financial department. Figure 2 reveals the position of equipment management in enterprise management.
Yield: the production task that is required. More efficiency of equipment capability, more output;
Quality: equipments help to improve product quality;
Cost: to lower the equipment maintenance cost is to reduce the total cost;
Delivery: less downtime and disturbance to ensure accurate delivery date;
Safety: good safety performance of equipment, less accidents at workshop, less pollution to environment;
Morale: better compatibility between humans and machines and less repairs of machines to improve operators’ positivity and enthusiasm;

In figure 2, equipments as a sort of capital inputs through vertical management binding together with humans and materials help firms to realize horizontal managements optimization in production management, quality control, cost management, delivery control, safety and pollution management, and morale improvement (Yu and Wang, 1998).

### 3.2 Equipment Maintenance

From the definition of maintenance, it is referred as ‘combination of all technical, administrative, and managerial actions during the life cycle of an item intended to retain it
in, or restore it to, a state in which it can perform the required function’ (Turbide, 1995). In modern production system, machines and equipments with automation by computers or robots aided have predominant places over hand-made era decades ago, which has determinant factor on industrial competitiveness in the markets. It has been revealed by below main five aspects (Cheng, 1999):

- The level and function of maintenance have direct impact on organizational planning, accurate delivery of orders, and balance of manufacturing process;
- The level and function of maintenance have direct impact on output and quality of products;
- The level and function of maintenance have direct impact on production cost;
- The level and function of maintenance have indirect impact on safety, working environment and pollutions;
- Equipments as a capitals input themselves in the enterprise account for more than half of overall capitals, hence the level and function of maintenance have also impact on the feasible allocation and use of capitals;

### 3.3 TPM

As introduced formerly in this paper, maintenance management has been witnessed in three-time frame. Before 1950, reactive maintenance was used broadly, ‘Fix it when it fails’. After 1950 till 1970s, preventive maintenance had been a main maintenance means that was adopted by most of manufacturing companies. From mid-1970, Japan initially introduced Total Productive Maintenance – TPM combined with domestic enterprises’ managerial experiences and reliability engineering theory with the goal to arrive zero loss and operation & maintenance (O&M) cost minimization.

TPM can be defined as a systematic work method aiming to develop disturbance free processes at lowest possible cost through the commitment of all co-workers (Salonen, 2007). TPM has unprecedented advantages over other maintenance methods as follows.

- Replace routine with development;
- Increased commitment from all co-workers;
- Continuous improvements;
- Foreseeable operations;
• Improved safety and environment;

TPM soon has been implemented and developed by many firms all over the world. The process of TPM implementation is divided into four phases: TPM preparation, TPM implementation, TPM evaluation and new goal.

At the stage of preparation, it includes management’s decision, education, organization and pilot, policy and goals, and a master plan (Chaneski, 2002). The most important aspect in this stage is that all employees have to attend the education and practices of TPM plan and comprehend adequately the top management’s policy and goal for TPM. The development and implementation of TPM must be promoted in its master plan.

At the course of implementation, it forms into two foundation stones, eight pillars of TPM, and one final goal. TPM implementation can be depicted like building up a house.

<table>
<thead>
<tr>
<th>Continuous Improvement</th>
<th>Autonomous Maintenance</th>
<th>Planned Maintenance</th>
<th>Education and Training</th>
<th>Early Equipment Management</th>
<th>Quality Maintenance</th>
<th>Effective Administration</th>
<th>Safety, Hygiene and Environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>5S guideline and practice</td>
<td>Cross-functional group activities</td>
<td></td>
<td></td>
<td></td>
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</table>

Table 2. 8 pillars of TPM (Liu, 2004)

1. Through continuous improvement and unanimous commitment of all employees, the radical causes and hidden problems would be found out in order to eliminate and minimize the six big losses and 16 main wastes (Liu, 2004).
2. The TPM team ought to teach operators to react on cause instead of result (Hutchins, 1998). In the long term, operators not only may conduct daily inspections
and low frequent controls, but also may perform maintenance tasks. By increased competency and understanding, the operators are able to eliminate minor stoppages, to prevent break-downs, to secure implemented improvements, to improve quality, safety, and environment. To reach this goal, it always costs many years in the company and is implemented through seven well-defined steps (Salonen, 2007).

- Basic cleaning and order;
- Counter measures at the problem source;
- Standards for cleaning and lubrication;
- General inspection training;
- Autonomous inspection;
- Organize the work environment;
- Autonomous maintenance;

At first two steps, they help operators to find defects and to understand the principles for improvements of the equipments. At the third and fourth steps, the operators have opportunities to understand the functions and structure of the equipments. At the fifth and sixth steps, the relations between maintenance and product quality can be revealed to the operators. The last step enhances the competence on repair skills.

3. By elaborate planned maintenance activities to improve maintenance effectiveness, TPM team establishes maintenance planning, maintenance control, spare parts control, and economy control. The implementation of planned maintenance parallel with activities of improving OEE such as corrective maintenance, preventive maintenance, condition-based maintenance lead to below results (Li, 2005).

- Increased Mean Time Between Failure (MTBF) and Mean Time Between Maintenance (MTBM);
- Decreased Mean Time To Repair (MTTR), Mean Waiting Time (MWT);
- Closer to 0-faults, 0-stops and 0-accidents;
MTBF is a major parameter to measure the breakdown and waiting time. MTBF = Total monitoring time – Total downtime of machines / times of breakdown of machines.

MTBF = \( T - (t_1 + t_2 + t_3 + t_4) / 4 \)

**Figure 3.** The calculations of MTBF (By authors)

MTTR and MWT are forms of downtime that obstruct OEE improvement. However, by means of effective planned maintenance approaches, such time can be saved largely. Accordingly, it’s also meaningful to observe and calculate them and minimize them (Jing, 2003).

4. Education and training is indispensable parts during project of implementation of TPM. Through learning and practices, the competence and skills of employees may be improved. At the same time, operators are provided with mindset of autonomous maintenance. Operators are not only workers that handle the machines as before but also good maintenance men that are able to monitor, setup, repair, and maintain the equipments and even to prevent the breakdown and accidents. Regular cross-functional activities and meetings are good ways to train the operators (Liu, 2004).

5. The final goal of early equipment management is to reach stable, full speed production at start-up and to meet the detailed requirements of the equipment as far as possible. The operators at work floor collect all information and data of operations and conditions of equipments and feedback to machines’ design and development department to decrease the R&D period and optimize design and manufacturing of equipments. The intended new equipments are aiming to be reliable and producing non defective products, easy to be mended and set up, and fast to start after set-up changes, easy to maintain, and fast to localize faults and repair, easy to clean, lubricate and be inspected, resource efficient and safe (Li and Guo, 2002).

6. The quality maintenance is a management and control of machines, methods, and materials (3M). The standard conditions of 3M must be set and consistent monitoring of 3M status must be performed to eliminate the abnormities, finally the
zero-defect goal can be reached (Cui, 2004). Quality maintenance can be performed in 17 steps as follows (Salonen, 2007):

- Control of quality standard and quality parameters;
- Localizing origin of quality defects;
- Choice of pilot equipment and defect for implementation of quality maintenance;
- Evaluate function, operating state and method for set-up change of equipment;
- Examine and restore the state of the equipment;
- Perform PM-analysis;
- Eliminate all defect creating factors;
- Define preferred state and optimize operating conditions and method for set-up change;
- Detect defects;
- Restore or improve;
- Evaluate standard values and which components to inspect;
- Determine the valid state for production of non-defective products;
- Reduce the number of inspection points;
- Define standard values for inspection points;
- Make a draft for a quality matrix;
- Discuss the content of the inspection standard;
- Evaluate and, if needed, change the standards and inspection points through trend analysis;

7. The aim of effective administration is to create effective administrative processes through reduced loss and waste, and also develop a work process that can handle changes. Through standardized administrative system, production efficiency and service quality will be better off, and even the reliability of information flow between each work station may be improved largely. The goal is that all efforts aim at value creating tasks from the customers’ point of view (Liu, 2004).

8. At last pillar, the employers must consider the measures how to improve working environment, regard the employees’ health, avoid the accidents, and decrease pollutions to protect the environments.

At the last two course of TPM, TPM group ought to evaluate the effect of improvement in the key production station that had been bottleneck to obstruct the effective production
for the entire production line by means of measuring the OEE index. Collecting all data before and after TPM implementation and analyze how much improved with respect to productivity, costs, quality, delivery precision, safety, commitment. TPM group also has to think about if there is possibility to improve again by next TPM campaign and how much for the new goal (Jing, 2003).

3.4 5S

5S originated from Japan and is one of foundation stone of TPM. In organizing workplace, a robust tool of housekeeping methodology of 5S is often used to reduce time wasted by looking for things, repairing the machines, changeover, and helps to decide what should be kept, where it should be kept, and how it should be stored. This method asserts it makes work easily to understand and act. 5S, standard work and TPM are the foundations for fast, flexible flow. 5S is learned from five Japanese words – Sorting, Straighten, Sweeping, Standardizing, and Sustaining (Wireman, 1990).

Sorting means everything has its own place (Nie et al. 2004). To separate the tools and materials that is used frequently from those that are used seldom, to store everything else or discard, which includes trashes, scraps, defects, unwanted tools, and obsolescent machines, is lucrative to enlarge the working area, decrease inventory, save capitals, improve the quality and enhance the productivity.

Straighten has its intent to arrange the tools, equipments and parts in a manner that promotes work flow. There are three points to be noticed.

- Don’t change frequently fixed sites, unless change promotes the work flow;
- Those tools, equipments and materials that are used more often should be placed closer to operators at their reaches, otherwise should be put beyond operators;
- Marking the tools, materials with different color or shapes in terms of their functions and purposes helps to be obtained easily and quickly;

Sweeping is a kind of systematic cleaning to keep the work shop clean as well as neat. The activity of sweeping is not an occasional one performed when the things get too messy, but is viewed as a part of daily work. Especially at the end of each shift, the work area must be cleaned up and everything ought to be restored to its place. This makes it easy for the operators at next shift to know what goes where to work at clean and neat area. And also this initiative must be sustained to the next.
Standardizing indicates a standardized and consistent work with a view to the activities of sorting, straighten, sweeping. At this premise, 5S can be initiated at a long run and reached anticipative goals and results.

Once 4S has been established, the good habits and behaviors must be maintained and reviewed. Sustaining is a key point in 5S initiatives to maintain the focus on this new way of operating and do not allow a gradual decline back to the old ways of operating.

An added sixth phase ‘Safety’ is sometimes executed. That ensures operators work at a secure and safe environment where less hazards and accidents occur. Nevertheless, some experts argue it’s unnecessary because if operators are working at 5S guideline, there certainly are no threats by the dangers resulted from inappropriate operating ways (Nie et al. 2004).

Sorting, straighten, sweeping, standardizing, and sustaining are not independent but correlative with center of sustaining that ensures other 4S operated in the correct fashion.

5S activities have been followed by many industries all over the world in virtue of many benefits and advantages, which reveals in eight big purposes (Xiao, 2003).

- Leave a good impression of clean and neat work shop for the customers;
- Save the cost in operation & maintenance (O&M), inventory, administration etc;
- Help to shorten the delivery time;
• Improve the safety coefficient at work floor;
• Boost the establishment of standardized work;
• Heighten the morale of employees;
• Decrease the waste;
• Improve quality of products and efficiency of production;

Thus it can be seen that 5S not only helps implementation and development of TPM and also itself is an effective approach to improve the productivity and capability for the manufacturers.

3.5 TPM and Lean Production, Just in Time (JIT)

Lean production is a phrase coined by Krafcik and used to describe what Toyota initially called the Toyota Production System (TPS). It was called “lean” because it used less when compared to mass production technique that initially was invented by Henry Ford at the early of last century, half the labor hours, half the factory space, half the tooling investment, and developed new products in half the time using half the engineering hours, while requiring under half the on-site inventory, producing fewer defects, and a greater variety of products (Kong et al. 2000). Lean production sometimes has another name called JIT production, which indicates to produce and deliver the correct products, quantity at correct places and at correct time with high quality and less costs.

TPS evaluates five key lean thinking, assess the value of customer; identify value stream; create flow; implement JIT; and seek perfection continuously (Qi, 2004). Rightly against these principles of lean thinking, toyota executed extensively lean production and manufacturing throughout worldwide Toyotas. As Toyota focused on improving its productivity and competitiveness, products value to customers, morale and motivation, lean can arrive to all of these goals.

However, to implement lean production based on a long-term concept and approach, for medium-sized firms, it needs at least 3-5 years to convert organizations into lean enterprises. Ohno confirmed that the Toyota Production System did not happen overnight but through a series of innovations spanning over 30 years (Tian, 2000). As lean production need to be improved and innovated continuously, more and more technologies and tools required in current lean methods. From the perspective of lean management, these tools play critical roles in implementation of lean production (John, 2004):
• Stable and standardized process: to reduce variation and create flexibility by improving the production process and product quality and to minimize changeover time, lead time, and waste on defects and surplus equipments;
• Visual Management: no problems are hidden to improve value added flow;
• Kaizen: continuous improvement on quality, cost, design and delivery, never satisfied;
• Kanban Process: using a card needed to be put in place;
• TPM: a systematic work method aiming to develop disturbance free processes at lowest possible cost through the commitment of all co-workers;
• Gemba: go and see by yourself to find the problems out;
• Five S principle: Sort, Straighten (orderliness), Shine (cleanliness), Standardize, and sustain;
• One-piece flow: a serial of process on one piece production including various operations in design, order taking and production, without interruptions, backflows or scrap;
• Flexible Staffing: to prevent unnecessary costs from arrangement of employees;
• Waste Elimination: in overproduction, processing, inventory, motion, transportation, waiting, repair/rejects;
• Just-in-time: to produce what customers want when they want it in the right price and volume with shortest lead time;
• Jidoka: to pay more attention to quality;
• Leveled production: Flexibility to make what the customer wants when they want it, reduced risk of unsold goods, balanced use of labor and machines, smoothed demand on upstream processes and the plant’s suppliers;
• Pull system: To avoid the overproduction;
• Strategic Alignment: more partnership than competitors.

Lean cannot work with isolated tools and it requires the need to concentrate on the whole value chain. Like Toyota production system to work effectively, it needs to be adopted in its entirety, not piecemeal. TPS is an interlocking set of three underlying elements; the philosophical underpinnings, the managerial culture and the technical tools.

Lean has four primary goals, zero inventory, high flexibility, zero defects, and waste elimination (Kong et al. 2000).
Inventory itself is a root of ‘evil’ that tied up with numerous capitals and spaces. The inventory can appear at upstream, downstream of production line and also between stations. The cause resulted into much inventory could be from machine breakdown, defects and scraps returning, imbalance among the operation stations etc (Tang and He, 2003).

Flexibility features in organization, staffing, and equipments to produce more varieties of products with less capitals input. Through scientific and effective measures of total quality management (TQM), the number of defects and scraps can be minimized (Sun et al. 2004). Once unqualified products detected, they have to be quickly returned to the production line for re-work. But this instance should be avoided through effective quality control system.

Toyota commits itself to eliminate muda (the Japanese word for waste) in lean environment. muda refers to any activity that is not value-adding. They are overproduction, inventory, repair/rejects, motion, processing, waiting, transport (Liker, 2004).

- Overproduction: the quantity of production overruns the requirement of orders, or production is prior to orders;
- Inventory: inventory refers to over-storage including materials, parts, work-in-process (WIP), finished products;

![Figure5. 7 Muda (By authors)]
• Repair: the time and cost wasted on repair defects and unqualified products, or reject the scraps;
• Motion: Muda of motion takes place in manufacturing when the arrangement of equipments, materials and operators are sub-optimized, which causes staffs to have to move further than necessary to carry out their work, or when assembly lines are unnecessarily long, causing them to break down or jam easily;
• Processing: inappropriate processing occurs in poor plant layout because preceding or subsequent operations are located far apart. Investing in smaller, more flexible equipments and work shop where possible; creating manufacturing cells; and combining steps will greatly reduce the muda of inappropriate processing;
• Transport: Transporting products between processes and stations is a cost itself which adds no value to the product. Excessive movement and handling cause damage and are an opportunity for quality to deteriorate;
• Waiting: the materials and products are not transferred from upstream stations, causing subsequent process idle and overstock WIP;

Generally speaking, muda of overproduction is a primary waste among 7 mudas (Crawford et al. 1988). It leads directly to increase of inventory, waiting, unnecessary motion and transport, tied up with capitals and spaces. Thereby, this muda should be solved firstly.

TPM as one of basic technical tools of Lean has similar goals with lean. Both are aiming to create a disturbance-free working scenario where makes the most of decreasing waiting time, defects and inventory. Therefore, TPM is an effective tool to implement lean production in industries (Zhao et al. 2000).

3.6 OEE & Six Big Losses

TPM is a people-centered, preventive maintenance management for maximizing equipment effectiveness and operation efficiency, which is committed by all departments and functions in the company (Jing, 2003). Through scientific calculation methodology module and accurate data acquisition recorded in e-files by computer, the effect of TPM implementation can be numerically measured by index of OEE metrics. OEE tells users the percentage of time that equipment, when running or required for production, is producing good-quality products at an acceptable rate (Jill, 2009). OEE is the product of three ratios, which is interpreted as the multiplication of availability rate, performance or production rate, and first-pass quality rate. OEE has four key purposes as follows (Salonen, 2007):
• Show the disturbances that reduces the productivity of the equipment;
• Show how effective the equipment is used by measuring loss factors;
• Show that improving actions are adequate;
• Aid in planning of resources and workload;

Among four purposes, the key essence of OEE is to help understand and identify disturbances and failures during the manufacturing process and to minimize the losses by means of effective TPM program. OEE can therefore be defined as a bottom-up approach where an integrated workforce strives to achieve overall equipment effectiveness by eliminating the six big losses (Nakajima, 1988). Nakajima defines these ‘six big losses’ as follows:

• Failures and break-downs;
• Set-up and adjustments;
• Idling and minor stoppages;
• Reduced speed;
• Defects and rework;
• Start-up losses;

Equipment failure/breakdown losses and set-up/adjustments both are considered as time losses. Failures and break-downs result from equipment malfunction, corrective maintenance and repair. While set-up time loss can be the reasons from downtime and defective products that interrupt the production rate at optimal state (Liu, 2004). Adjustment time losses can be viewed as changeover time when production of one item ends and the equipment or machine has to be adjusted to meet criteria of production of another item.

The both big losses are considered as time losses which can be used to calculate a value of availability of equipment.

Idling and minor stoppage losses result from a temporary malfunction or interruption, for instance, lack of materials and workforce, overproduction at downstream of production line, or when a machine is idling by other unexpected matters. Reduced speed losses refer to the difference between equipment pre-determinative or design speed and actual operating
speed. The causes for this time loss are wasted in changeover, set-up, decreased speed by defect observations etc (Cui, 2004).

The third and fourth big losses are counted as speed losses that can be used to calculate the performance rate of a machine, for example, the speed losses between actual operating rate and the optimum conditions.

Quality defects and rework are losses in quality caused by malfunctioning production equipment. Start-up loss occurs during the early stages of production from machine start up to stabilization.

The final two losses are considered as quality losses due to defects, the larger number of defects determines the lower quality rate.

OEE is measured in terms of these six big losses, which are essentially a function of the availability, performance rate and quality rate of the machine, production line, or factory, whichever is the focus of OEE application (Nakajima, 1988).

\[
OEE (\%) = \text{Availability (\%)} \times \text{Performance rate (\%)} \times \text{Quality rate (\%)}
\]

Availability is a percentage = Planned production time – Unplanned stop time / Planned production time. Unplanned stop time may be referred to the downtime from temporary machine malfunction, changeover/adjustment time, and unexpected maintenance time.

Performance rate = Bought cycle time x items produced / Available operative time, where bought cycle time is referred to the time that is used to produce each time.

Figure 6. The calculation of OEE (Salonen, 2007)
Quality rate = Items produced – defects / Items produced.

The total multiplication of three components by availability, performance rate and quality rate is ultimate value of OEE.

That is vital of importance to obtain accurate performance data to measure OEE figure. Record the actual time of each downtime and speed loss in the whole operative time by computerized data collection system. Note that each data loss for OEE must be recorded and collected when the machine is in the corresponding state – a collection of variables that contain necessary information to describe the system. Thereby, the boundary of each state must be clearly defined so as to obtain reliable data (Shi and Zhao, 2000).

After collection of all losses data, make a detailed analysis and study on these losses and disturbances and find out the root causes. A very powerful approach of fish bone diagram can be researched in many different aspects according to low productivity in a machine. Aiming at these causes, develop a plan and measurements to improve deficiency. Improved OEE can lead to below benefits (Dal et al. 2000).

- Less disturbances which in turn may lead to improved planning ability, reduced risk of quality problems, more time for developing work;
- Released capacity which in turn may lead to alternative to capacity investments, increased flexibility, decreased operative time, decreased number of equipments;

Nakajima (1988) suggested that ideal values for the OEE component measures are 90% up in availability, 95% up in performance efficiency, and 99% up in quality rate. Thus, the total value of OEE results in 85% which is benchmark OEE considered as world-class performance (Blanchard, 1997).

However, still many experts dedicated in lean production give blackballs against the three metrics of OEE calculation. The OEE calculation, by now well known, is availability rate times production or efficiency rate times quality rate. The first two components, availability rate and production rate, are in conflict with lean’s essence: Product or delivery just what the next process requires (Richard, 2007).
In Richard’s opinion, too much endeavors on improving availability of machine or equipment by fewer time loss on changeover, which will lead to longer production runs and more items produced than what next process needs. Thus, inventory occurs that is against lean.

Likewise, production rate seems the higher, the better. But in reality, the supervisors of production line press too much for higher productivity for their own motivations. They extend production time, put off the preventive maintenance and neglect the over-growth of inventory. All of these violate the central role of TPM and Lean.

While, OEE is a good beginning for many organizations to help themselves to find out where is the root causes for failures and losses. Furthermore, the value of OEE can help organizations to recognize the gap from benchmark criteria in the same industry, thereby to set a target to improve within TPM and Lean framework (Jill, 2009).

Meanwhile, we need to note that OEE is only part of the equation or simply a tool to analyze and diagnose causes and deficiency. It can be applied well or not applied well, which relies on how to actually use OEE to drive change in an organization in an effective manner.
4. Case study- A Practices of TPM

4.1 Background

4.1.1 Company introduction

XYZ GROUP is a leading IT component manufacturer with the main products of PC connectors, precise modules, hi-tech components and cables. It is one of the biggest PC connectors’ manufacturers in China for customers of APPLE, COMPAQ, INTEL, IBM, HP, DELL, CISCO, MOTOROLA, NOKIA and other digital products manufacturers. It boasts the turnover has over 4 billion dollars per year and the margin profit increasing rate is over 40%. It has internationally 48 R&D centers in Asia, America, and Europe, and more than 10 manufacturing bases all around the Asia mainly located in China and South-East Asia etc.

ABC is a subsidiary company of XYZ GROUP sit in Shanghai, which is our research subject of this paper. ABC was built up in 1993, and so far it has over 30,000 employees with the area of 2000 acre. It has become the production base of CCC (3C) connector of XYZ GROUP and one of the biggest PC connector manufacturers.

In the initial phase of business, the main product of ABC was D-SUB. The variety of product had characterized by monotony and the means of production was accomplished primarily by manual work. As a result, the productivity and requirement of quality was relatively low. At that time, ABC mainly adopted ‘mass production’ as strategic mode in order to meet the requirements of customers’ orders.

With the rapid development of IT industry, digital products and PC technology has become diverse, and the requirement of PC connecters has the attribute of multiplex and unique for different digital products. The increasing demands of PC connecters gave ABC the best chance to expand the production system. Hence, at this case it’s indispensable to replace the old manual equipments with new automatic equipments. In the subsequent 5 years, ABC succeeded in improving automation rate by over 70 percent by means of eliminating those torn-out manual tools and equipments and in substitute of automatic and semi-
automatic production facilities. The production system has also transit successfully from ‘mass production’ to ‘order-based production’.

4.1.2 Current production system

With the development of automation in production line, the company encountered new types of problems.

1. Since ABC adopted ‘order-based production’, and customers’ orders represented small volumes while with wide varieties of products. Therefore, it’s unavoidable that the frequent adjustments and changeover with the equipments and tools occur. It’s always a problem that defects continuously were yielded after the operators changed and adjusted the parts on the machines when the machines worked at optimal state. In another case, the machines were worn out soon due to intermittent changeover.

2. As far as changeover concerned, it’s a kind of waste of time itself that seriously affected equipment efficiency.

3. In the traditional maintenance system, only technical support department takes in charge of the regular maintenance and repair. The operators simply need to handle equipments without any knowledge and education of regular maintenance and equipment efficiency operations. That is a fact they cannot forecast when the machines breakdown and cannot find out the causes and roots of the problems. Once breakdown takes place, they have to stop the production line and look for technicians’ support, which as a result increases the downtime and repair time, and also reduce the OEE of the equipments.

4. Since the operators were short of equipments structural knowledge and maintenance skills, and plus ‘breakdown maintenance’ as a maintenance concept prevailed at early stage, more frequent bread down, longer repair time and higher repair cost obstructed the improvement of OEE. The entire production lines were trapped in the bottleneck situation realized by from top management to workshop workers in ABC.

4.1.3 A brief feasibility analysis of introducing TPM to ABC

1. **Necessity:** all of employees are aware of the truth that ABC lags behind those enterprises that adopt advanced equipment management methods. To stay competitive
in connector manufacturing markets, TPM is a prerequisite for ABC to improve current deficiency in equipment management.

2. **Possibility**: ABC has obtained the licenses of ISO9001 and ISO14000 for years. All employees from top down discipline themselves with quality management philosophy and are willing to attempt all advanced management concepts and methods to improve firm’s benefits.

3. **Advantages**: with the growth of the company, ABC has obvious advantage over independent R&D team of automatic machines inside the department. Except for some specialized equipments, all other equipments are designed, developed, produced, setup, tested, and maintained inside the company. The management team holds regular training courses for the operators at frontlines to acquaint themselves with equipment inner structures and master the knowledge of periodic maintenance on machines. Meanwhile, operators are able to feedback with deficiency of design to R&D team to improve machines’ capability.

4. **Forecast**: after implementing of TPM in ABC, tangible and intangible benefits can be achieved. The obvious benefits through TPM represent minimized breakdown, less downtime, less repair cost, less labor time and intensity, higher efficiency of production lines. While, intangible benefits bring about improving morale in the company, decreasing pollutions due to less repair and maintenance, and enhancing company’s reputation in the market due to high availability of orders and quality of products.

In the analysis of these facts, we believe that ABC is able to reap the benefits through reasonable and effective TPM deployment and implementation in the company. Only TPM can lead enterprise to a new epoch of success, otherwise ABC will be washed out by the rigid competitive system.

**4.2 Typical equipment introduction**

**4.2.1 Preparatory phase**

For a modern enterprise, the final goal is to maximize profitability, whose realization thereby relies on continuous improvement on OEE. Before implementing TPM in the organization, an experimental machine or station will be selected. Through the management method of OEE, find out and analyze the factors that have impacts on OEE
and then search for effective and scientific approaches and countermeasures to improve it. After typical equipment selected, ABC formed a specific TPM group comprising of operators, technicians, equipment experts, production supervisors and equipment designers, to participate in the TPM implementation project.

This TPM team masters a plan to implement and develop TPM as follows:

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>DESCRIPTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Choose experimental equipment</td>
<td>Choose the bottleneck equipment that obstructs the production process</td>
</tr>
<tr>
<td>Form a TPM group</td>
<td>Operators, technicians, equipment experts, production supervisors and equipment designers</td>
</tr>
<tr>
<td>6 big losses analysis</td>
<td>Data collection from operative workshop, including calendar working days, planned and unplanned downtime, CT, output and defects</td>
</tr>
<tr>
<td>Analyze each parameter of OEE, find problems</td>
<td>Approach of PM, Plato, Fish bone diagram, Cause-effects etc</td>
</tr>
<tr>
<td>Make improvement plan</td>
<td>Through autonomous maintenance, preventive maintenance plan etc</td>
</tr>
<tr>
<td>Implement TPM plan</td>
<td>Analyze the effect of improvement after TPM. Adjust the plan if necessary.</td>
</tr>
<tr>
<td>Calculate new OEE</td>
<td>Compare OEE to find how much improve</td>
</tr>
</tbody>
</table>

**Figure7.** Master plan of TPM (By authors)

TPM group chooses the experimental equipment that consists of several sub-stations for high-speed units input. All of products from this equipment will be flowed to other production lines for final assemble before output. The product is one of the key products in ABC, and a large number of orders received every month, which occupies full schedule of production. Once any kinds of downtime occur at this station, it will lead to stand-down for
the entire production lines, even delay of delivery for customers’ orders. Thereby, this equipment is key one among all in the manufacturing process and also bottleneck equipment that could obstruct the high equipment efficiency. It’s meaningful to analyze and research its OEE improvement.

Following is the picture of equipment:

![Picture of equipment](image)

**Figure 8.** The appearance of the equipment

### 4.2.2 Process description

TPM group performs data collection between 1\textsuperscript{st} March 2008 and 30\textsuperscript{th} April 2008. Each month has 28 calendar working days, two shifts per day, and 12 working hours per shift with 60minuters break time, meeting, and training.

The analysis of losses primarily encircles following four aspects:

a. Changeover and adjustment time;
   - Change among different spare parts (optional operations), e.g. hooks, plastics, cutters etc;
   - Change ports for various types of products;

b. Maintenance and breakdown time;

c. Lack of materials and defective materials;
d. Defects and scraps;

Below is the process map of port change:

![Figure 9. The process map of port-change (By authors)](image)

In this operation, the products will be categorized into two types, product without S-port and product with S-port. Normally, changing a port needs 4-6 minutes per roll, and we hereby take average time 5 minutes as port change time.

Products without S-port: the process to change ports for products without S-port needs to change three big ports (B-port) sequentially, each unit of product needs 8 B-port 1, 8 B-port 2 and 8 B-port 3. Each B-port 1 & 2 has 50,000 per roll, and B-port 3 has 30,000 per roll.

Product with S-port: this product not only needs to change three big ports (B-port), which are just the same as product without S-port in need of 8 B-port 1, 8 B-port 2 and 8 B-port 3, but also needs to change two S-ports and one blade. Each unit of product needs 2 S-port 1, 2 S-port 2 and 1 blade. Each S-port 1 and S-port 2 has 50,000 per roll and each blade has 30,000 per roll.

According to different type of products input, the operators need to change some tools and add some operations optionally. The above figure shows the operation options which the operations need to consider about when new product input.

4.3 Data collection and OEE analysis

4.3.1 Analysis of changeover time loss

Time loss of spare parts change (optional operations)
In March, the time loss of terminal change 771 minutes, in April 460 minutes;
In March, the time loss of cutter change 2460 minutes, in April 1500 minutes;

In March, the time loss of plastics replacement 404 minutes, in April 340 minutes;

In March, the time loss of hook change 470 minutes, in April 160 minutes;

In March, the time loss of blade change 150 minutes, in April 360 minutes;

The sum-up of time loss in spare parts change 4255 minutes in March and 2460 minutes as below table.

<table>
<thead>
<tr>
<th>Spare parts</th>
<th>March (min)</th>
<th>April (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>terminal</td>
<td>771</td>
<td>460</td>
</tr>
<tr>
<td>cutter</td>
<td>2460</td>
<td>1500</td>
</tr>
<tr>
<td>plastics</td>
<td>404</td>
<td>340</td>
</tr>
<tr>
<td>hooks</td>
<td>470</td>
<td>160</td>
</tr>
<tr>
<td>blade</td>
<td>150</td>
<td>360</td>
</tr>
<tr>
<td>In total</td>
<td>4255</td>
<td>2460</td>
</tr>
</tbody>
</table>

Table 4. Time loss of spare parts change in March and April

These data will be used later in calculating the OEE.
Time loss of changing ports for products without S-port and products with S-port

March

In March, the production line’s output is 1,313,960 pieces, which included 589,150 pieces without S-port products and 724,810 pieces with S-port products.

We can calculate the number of rolls of products without S-port in March:

The number of roll of B-port 1 & 2 is
\[
\frac{589150 \times 8 \times 2}{50000} = 189
\]
The number of roll of B-port 3 is
\[
\frac{589150 \times 8}{30000} = 157
\]
So the total number of roll of products without S-port is 189 + 157 = 346 rolls

We calculate the number of roll of products with S-port in March:

The number of roll of B-port 1 & 2 is
\[
\frac{724810 \times 8 \times 2}{50000} = 232
\]
The number of roll of B-port 3 is
\[
\frac{724810 \times 8}{30000} = 193
\]
The number of roll of S-port 1 & 2 is
\[
\frac{724810 \times 2 \times 2}{50000} = 58
\]
The number of roll of Blade is
\[
\frac{724810 \times 1}{30000} = 24
\]
So the total number of roll of products with S-port is 232 + 193 + 58 + 24 = 507 rolls

The total number of rolls changed in March is 346 + 507 = 853 rolls

The total time loss in changing port roll is 853 roll x 5min/roll = 4265 min

April

In April, the production line’s output is 1,507,292 pieces, which included 772,060 pieces without S-port products and 735,232pcs with S-port products.
Then in the same way, we calculate the number of rolls of products without S-port in April:

\[
\frac{772060 \times 8 \times 2}{50000} = 247
\]

The number of roll of B-port 1 & 2 is

\[
\frac{772060 \times 8}{30000} = 206
\]

The number of roll of B-port 3 is

So the total number of roll of products without S-port is 247 + 206 = 453 rolls

We calculate the number of rolls of products with S-port in April:

\[
\frac{735232 \times 8 \times 2}{50000} = 235
\]

The number of roll of B-port 1 & 2 is

\[
\frac{735232 \times 8}{30000} = 196
\]

The number of roll of B-port 3 is

\[
\frac{735232 \times 2 \times 2}{50000} = 59
\]

The number of roll of S-port 1 & 2 is

\[
\frac{735232 \times 1}{30000} = 25
\]

The number of roll of Blade is

So the total number of roll of products with S-port is 235 + 196 + 59 + 25 = 515 rolls

The total number of rolls changed in April is 453 + 515 = 968 rolls

The total time loss in changing port roll is 968 roll x 5min/roll = 4840 min

The following chart is the calculated data of time loss in changing ports.

<table>
<thead>
<tr>
<th>Port</th>
<th>March (roll)</th>
<th>April (roll)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>with S-port</td>
<td>without S-port</td>
</tr>
<tr>
<td>B-port 1</td>
<td>116</td>
<td>94.5</td>
</tr>
<tr>
<td>B-port 2</td>
<td>116</td>
<td>94.5</td>
</tr>
<tr>
<td>B-port 3</td>
<td>193</td>
<td>157</td>
</tr>
<tr>
<td>S-port 1</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>March (min)</td>
<td>April (min)</td>
</tr>
<tr>
<td>----------------</td>
<td>-------------</td>
<td>-------------</td>
</tr>
<tr>
<td>S-port 2</td>
<td>29</td>
<td>0</td>
</tr>
<tr>
<td>Blade</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>507</td>
<td>346</td>
</tr>
<tr>
<td>Time (min)</td>
<td>2535</td>
<td>1730</td>
</tr>
</tbody>
</table>

Table 5. The calculated data of time loss in changing ports

Time loss of unplanned maintenance and equipment breakdown

Due to some reasons of malfunction, equipment breakdown, maintenance, power-off and so on, the total downtime is 2100 minutes and in April is 2730 minutes in two shifts.

Time loss of lack of materials and defective materials

Statistically, in March such time loss is 3160 minutes and in April is 3415 minutes.

Finally, the total time loss in March is: $4255 + 4265 + 2100 + 3160 = 13780$ minutes

The total time loss in April is: $2460 + 4840 + 2730 + 3415 = 13445$ minutes

Figure 11. Histogram of total time loss in March and April
Defects and scraps

Among the total output of 1,313,960 pieces in March, defective products is 15,312 pieces. In April, the defective product is 16,583 pieces among total output of 1,507,292 pieces.

4.3.2 OEE calculation

The total calendar time = 28day x 24hour/day x 60min/hour = 40320 min

The scheduled down time = 28day x 2shifts/day x 60min/shift = 3360min

Based on above calculated data, the following is table of all statistics of OEE in March and April.

<table>
<thead>
<tr>
<th>Month</th>
<th>Total calendar time (min)</th>
<th>Scheduled downtime (min)</th>
<th>Unscheduled downtime (min)</th>
<th>Changeover time (min)</th>
<th>Cycle time (sec)</th>
<th>Output (pcs)</th>
<th>Defects (pcs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>40320</td>
<td>3360</td>
<td>5260</td>
<td>8520</td>
<td>0.9</td>
<td>1313960</td>
<td>15312</td>
</tr>
<tr>
<td>April</td>
<td>40320</td>
<td>3360</td>
<td>6145</td>
<td>7300</td>
<td>0.9</td>
<td>1507292</td>
<td>16583</td>
</tr>
</tbody>
</table>

Table 6. Statistics of OEE in March and April

The formula OEE = Availability x Performance x Quality

We will calculate the availability, performance and quality in March and April respectively.

March

Availability

Scheduled working time = total calendar time − scheduled downtime

= 40320 − 3360 = 36960min

Available operative time = scheduled working time − unscheduled downtime

− changeover time

= 36960 − 5260 − 8520 = 23180min

Availability = available operative time / scheduled working time x 100%
Performance

Performance = output x cycle time / available operative time x 100%

= 1313960 x 0.9 / 60 / 23180 x 100% = 85.03%

Quality

Quality = (output – defects) / output x 100%

= (1313960 – 15312) / 1313960 x 100% = 98.84%

OEE

Hereby, calculated OEE in March = 62.72% x 85.03% x 98.84% = 52.71%

April

Availability

Scheduled working time = total calendar time – scheduled downtime

= 40320 – 3360 = 36960min

Available operative time = scheduled working time – unscheduled downtime

– changeover time

= 36960 – 6145 – 7300 = 23515 min

Availability = available operative time / scheduled working time x 100%

= (23515 / 36960) x 100% = 63.62%

Performance

Performance = output x cycle time / available operative time x 100%

= 1507292 x 0.9 / 60 / 23515 x 100% = 96.15%

Quality

Quality = (output – defects) / output x 100%
\[
\frac{(1507292 - 16583)}{1507292} \times 100\% = 98.9\%
\]

**OEE**

Hereby, calculated OEE in April = 63.62\% \times 96.15\% \times 98.9\% = 60.5\%

### 4.4 Improvement proposal

From the calculation of OEE, the results both in March and April are not ideal and still have much space to improve. Moreover, the equipment effectiveness lags far behind those advanced enterprises in the same industry. In the survey of histogram of various types of time losses and statistics of OEE in March and April, the several causes that lead to low equipment efficiency are long changeover time, unplanned downtime, and defects. Among them, long changeover time on spare parts and ports changes represents extreme outstanding over other two.

#### 4.4.1 Changeover time loss analysis and improvement

In the time loss of changeover, there are two major time losses. One is time loss on changing spare parts, and another is on changing ports. This is affected by the different types of products in the process due to many varieties of models and specifications. The customers have specific requirements on different materials and shapes, which needs operators to change the key processing parts of equipment (ports, cutters, blades, plastics etc). Normally, such changes occur 2-3 times a day but sometimes 5-6 times. Looking into such time loss over a month period span, this is indeed a restrictive factor on OEE improvement.

In the investigation, each time when the manufacturing process needs to change spare parts, it is operators who notify machine technicians after the machine stops working. Once all technicians are busy with working on other equipments, then this process has to wait and gets into downtime. It is a kind of time loss. In addition, the parts needed to be changed have no obvious distinctions on the appearance, thereby that is a happening oftentimes that technicians change for wrong spare parts.

To reduce time loss on changing spare parts, TPM team suggests that operators must advise technicians to change spare parts 10 minuters before the machine stops, which can
leave enough time for technicians to plan the job. In addition, spare parts design department requires manufacturing department of spare parts to make different marks on the parts and also sort them out and put in each bin before taking them so that mistakes could be avoided by technicians. Moreover, TPM group also recommends technicians should teach operators basic skills and knowledge on how to change spare parts when they are changing for them. That could help in the future operators have abilities to change themselves.

The measures to reduce time loss on changing ports have also been studied by operators and engineers. They change the mode of current process of the equipment through reconfiguration of inner structure of equipment.

- The mode of changing ports before reconfiguration
  The equipment gives an alarm when the ports run out at the machines, then operators take out the fastening-ring, empty tray, and tape in the order. Load the filled tray, undrawn the tape and fasten the ring, the change costs 5-6minuters and even proficient operators needs 3-4minuters. Every month operators need to change approximate 800-900rolls, which is striking resulting in much time losses.

- The improved mode after reconfiguration
  When the alarm sounds, operators revolve the tray by 180 degree and load the refilled tray at another end and then activate the machine. After machine runs, operators take down the empty tray and load refilled tray to prepare for next change. Thus, the time on changing ports needs merely couples of seconds and it decreases the time in the large extent.

Figure 12. The overall appearance of equipment after configuration (ABC design drawing)
Above pictures are described after configuration. The machine designers changed the roller into a “T” type. The device can be turned $180^0$ from one side to another side. The advantage of this innovation is to keep machine running without breaks while operators can change ports easier and faster. All of the jobs could be finished in one minute without affecting manufacturing process. By this means, operation process can save approximate 4,000 minutes time loss per month.

4.4.2 Time loss by lack of materials and defective materials analysis and improvement

In case the downtime is resulted from machine problem itself, e.g. the materials not loaded timely, operators can identify the problem quickly by three-color lights on the machine and address it soon. However, if the interrupt of materials supply is from upstream of process, then the process has to be stopped until operators advise warehouse or production department to replenish immediately. In the investigation, many of downtime of equipment is from this reason. Considering the large size of the factory, the company introduces electronic KANBAN system with wireless signal transmission that can report the relevant staffs with problems and solve in a quick action.

The system covers two areas, one is only for the production area, and another is across all parts of the factory. When different problems occur in the production line, operators press the button at station, the light over the station will be turned on. Meanwhile, there is another light at the front of the production line will be turned on and one light at the back of the production line will flicker in green. That informs station supervisor and technicians have to come to the field to solve the emergencies immediately. In the event that the problems exceed the scope of their ability, the light at the back of the production line will be turned on and at the same second the signal of emergency is transmitted out. At one corner of the factory, a receiver has been installed and all signals will be processed by specialized computer that changes the signal into data and transfers to KANBAN system. Moreover, the computer will sort the data out and distribute to relevant staffs. Besides this, at production and technical department, warehousing department, quality control department installed an alarm respectively working on the problems from malfunction of equipments, interrupt of materials supply, and defects. The corresponding staffs must rush to the field of emergency to solve the problems according to the display of KANBAN and
light at the back of production line, in which means the downtime loss can be decreased greatly.

Above pictures are one segment cut off from KANBAN system, where tells at which station what problems happen at real time phase.

KANBAN system has below advantages:

- Wireless signal transmission to save cables and easy to maintain and manage;
- Working in the real-time phase, staffs are able to know the current situation at station;
- As evidence that records all downtime causes and time by malfunction, quality, and lack of materials which can be helpful for management to explore countermeasures;

4.4.3 Analysis of equipment malfunction and product quality improvement

Actually there exist many connections between malfunction of machine and defects explored from the investigation. For the product of connector, the cause of malfunction of
machines and defects can be many aspects. Below is the statistics and classification of different processes leading to defects and scraps.

According to Plato principle, it is obvious to find the key causes to defects are by wrong plug-in and broken ports. ABC forms Quality Improvement Team to find further out the root causes about these malfunction.

Through brain-storming activities, quality improvement team reveals the reasons by fish-bone diagram with pre-defined main factors.
In order to improve the quality of products, TPM group makes large number of parameter analysis, system tests, even through adjusting the inner design and configuration of machine to change the operation process. Hereby, we will not go further at this point but we will calculate new OEE after TPM implementation in ABC.

4.5 Result from TPM

After three month pilot of TPM implementation, we take month of July 2008 as data source for new OEE calculation.

The working time keeps the same. Each month has 28 calendar working days, two shifts per day, and 12 working hours per shift with 60minuters break time, meeting, and training.

The total output of July is 1,856,320 pieces, in which 395,620 pieces without S-port and 1,460,700 pieces with S-port. Among the output, defects are 6,350 pieces.

The time loss of changing spare parts is 2700minutes. The total number of rolls changed in July is $233 + 1024 = 1257$rolls. And time loss of changing ports including products without S-port and products with S-port is $1257 \times 0.9$ (because of re-configuration of inner machine,
the working time to change a roll reduced from previous 5minuters to 0.9minuter) = 1132minuters. The unscheduled downtime by malfunction and maintenance loss in July is 1600minuters and the time loss of lack of materials is 1900minuters.

We calculate the number of rolls of products without S-port in July:

$$\frac{395620 \times 8 \times 2}{50000} = 127$$

The number of rolls of B-port 1 & 2 is 127

The number of roll of B-port 3 is $$\frac{395620 \times 8}{30000} = 106$$

So the total number of rolls of products without S-port is 127 + 106 = 233 rolls

We calculate the number of rolls of products with S-port in July:

$$\frac{1460700 \times 8 \times 2}{50000} = 468$$

The number of rolls of B-port 1 & 2 is 468

The number of rolls of B-port 3 is $$\frac{1460700 \times 8}{30000} = 390$$

The number of rolls of S-port 1 & 2 is $$\frac{1460700 \times 2 \times 2}{50000} = 117$$

The number of rolls of Blade is $$\frac{1460700 \times 1}{30000} = 49$$

So the total number of rolls of products with S-port and Blade is 468 + 390 + 117 + 49 = 1024 rolls

The total number of rolls changed in July is 233 + 1024 = 1257 rolls

The total time loss of changing ports including products without S-port and products with S-port is 1257 roll x 0.9min/roll = 1132minuters

Based on above calculated data, the following is table of new statistics of OEE July.

<table>
<thead>
<tr>
<th>Month</th>
<th>Total calendar time (min)</th>
<th>Scheduled downtime (min)</th>
<th>Unscheduled downtime (min)</th>
<th>Changeover time (min)</th>
<th>Cycle time (sec)</th>
<th>Output (pcs)</th>
<th>Defects (pcs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>July</td>
<td>40320</td>
<td>3360</td>
<td>3500</td>
<td>3832</td>
<td>0.9</td>
<td>1856320</td>
<td>6350</td>
</tr>
</tbody>
</table>
Table 7. Statistics of OEE in July (ABC data)

**Availability**

Scheduled working time = total calendar working time – scheduled downtime

\[
= 40320 - 3360 = 36960 \text{ minutes}
\]

Available operative time = scheduled working time – unscheduled downtime – changeover time

\[
= 36960 - 3500 - 3832 = 29628 \text{ minutes}
\]

Availability = available operative time / scheduled working time x 100%

\[
= \left( \frac{29628}{36960} \right) \times 100\% = 80.16\%
\]

**Performance**

Performance = output x cycle time / available operative time x 100%

\[
= 1856320 \times 0.9 / 60 / 29628 \times 100\% = 93.98\%
\]

**Quality**

Quality = (output – defects) / output x 100%

\[
= \left( \frac{1856320 - 6350}{1856320} \right) \times 100\% = 99.66\%
\]

**OEE**

The final improved OEE in July = 80.16% x 93.98% x 99.66% = 75.08%

We can see that the OEE has been improved by 22% compared to 52.71% in March and by 15% compared to 60.5% in April. The TPM implementation in ABC has reaped substantial progresses and benefits. Not only has time loss decreased largely and equipment effectiveness improved significantly, but ergonomics has been promoted. Although this result has still too much to go toward TPM targets of zero loss, it is simply a first step of success. The TPM group has to consider what next step is for TPM campaign in the organization.
5. Conclusion and Discussion

It is notable to know the OEE merely is a tool to analyze and diagnose causes and deficiency, whereas regarding to how to improve the OEE which needs enterprises to take different measures suitable to themselves to improve the situation. Aiming at improving OEE, ABC adopts following holistic plans.

- All of production line supervisors and equipment technicians must make statistics of key equipment’s availability, performance and quality periodically and set up the goal of OEE to help equipment efficiency management;
- The operators and supervisors at frontline must record for each time of unplanned equipment maintenance, changeover and number of defects in ‘OEE data record table’;
- Equipment development department must analyze the OEE record data from frontline to calculate the OEE before comparing the result and goal of OEE;
- To those equipments whose OEE results are under goal, relevant supervisors must organize PM with operators to establish plan and monitor the progress of improvement plan. If the effects of improvement is not substantial, then re-establishment of plan has to be made in time;
- In the maintenance of equipments, the company set up ‘instructions of equipment maintenance’, ‘record of equipment regular maintenance’, ‘daily inspection table of equipment’, and ‘record of equipment preventive maintenance’;
- ABC has many training courses about the maintenance and management of equipments for the operators to help them get more knowledge and skills. Meanwhile, operators will join in the machine set-up by the help of machine designers and know the structure and working principle of machines, which is better for them for operate the machines in the future;
- To improve morale of employees, ABC organizes many activities implemented across the company. 7S (besides 5S described previously, ABC add Safety and Save) and continuous improvement (KAIZEN) make opportunities for employees to give valuable advices and approaches to improve the equipment efficiency, management effectiveness and productivity.
With the development of science and technology, the function of equipments has been featured in complicated and promoted. As a result, equipment management has been one of radical conditions to reach high productivity. Besides the proper operations on the machines, the ability of maintenance on machines needs to be improved gradually. The evolution of equipment management has been witnessed through phases of reactive maintenance, preventive maintenance, and TPM. Through over 30 years’ development, TPM has been accepted and adopted by many industries.

TPM utilizes the participation of all the employees to promote production equipment's availability, performance, quality, reliability, and safety. TPM makes efforts to excavate the “hidden capacity” of unreliable and ineffective equipments. TPM harnesses proactive and progressive maintenance theories and methodologies and demands the knowledge and cooperation of operators, equipment vendors, engineering, and mechanicians to optimize machine performance, thereby resulting in elimination of malfunctions, reduction of unscheduled and scheduled downtime, improved utilization, higher output, and better product quality. The key features of TPM are in the pursuits of economic efficiency or profitability, maintenance prevention, improving maintainability, the use of preventive maintenance, and total participation of all employees. The basic achievements of successful TPM implementation initiated in an organization include decreased operating costs, increased equipment life cycle and minimized overall maintenance costs. Thus TPM can be described as a well-set equipment-centered continuous improvement process that endeavors to optimize production excellence by identifying and eliminating equipment and production efficiency losses throughout the equipment life cycle through active participation of employees across all levels of the operational hierarchy. The following achievements gained from implementing TPM in contemporary manufacturing scenario:

- Overall equipment efficiency has been improved significantly to ensure the accurate delivery of orders and high product quality;
- Much saving in labor and materials costs, reduced the maintenance expenditure largely;
- Elimination of all wastes and losses, and realizing energy and resource economization;
- Making job easier and safer to promote the morale and ergonomics;
- Minimizing investments in new technologies and maximizing return on investment ROI;
• Realizing sustainable organizational growth and reinforcing enterprise’ culture and mindset;

Nowadays, many researchers and experts in manufacturing industries give TPM a new definition – Total Production Management which is a more advanced method and tool to realize production excellence. It is far more than focusing on constantly improve the effectiveness and efficiency of manufacturing equipments but established upon the workshop as background, people-centric through effective managerial approaches initiatives in 4M (Man, Material, Machine, Method) to produce high quality deliverables. Total production management may be the next production managerial tool after total productive maintenance.
6. Acknowledgements

First of all, we would like to express our sincere gratitude to our supervisor Mr. Antti Salonen for his instructive advices and patient guidance to help us accomplish thesis. He spent plenty of time and efforts to encourage us in different aspects.

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7. Reference


