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The Successful Implementation of TPM in Conjunction with EOM and 5S: A Case Presentation

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Abstract: Certainly, manufacturing plants are encountering resource constraints. Limited equipment resources require close attention to make them useful every moment. This demands a total participatory equipment maintenance environment. Total Productive Maintenance (TPM) philosophy demonstrates that potential ability. In conjunction with Ecology Oriented Management (EOM) and Japanese 5Ss housekeeping-norms, TPM can offer the successful achievement of total maintenance and pertinent productive goals. This study presents a case example on how a blend of these three concepts renders the highest effective potential in maintenance arena that can excel over maintenance goals. The methodology of this study is two fold: literature survey and case investigations in a large-scale company.

Key words: TPM, EOM, 5S, major losses, implementation, case studies

INTRODUCTION

Good maintenance is fundamental to a productive manufacturing system[1]. The main objective of maintenance is to reduce the adverse effects of breakdown and to maximize the availability of facilities at a minimum cost[2]. Modern manufacturing requires advanced technologies (AMTs) to bring about increasing automation and integration in manufacturing activities. Their installations and replacements are expensive and thus need intense attention. Therefore, the importance of a comprehensive and complementary maintenance system is now more felt than earlier.

Maintenance is a strategic area[3] that affects competitive edge. It is an inevitable function of manufacturing firms in the input side of a system. Good maintenance is a major contributor to the performance and profitability of manufacturing systems[4]. Towards integration of the various manufacturing functions in a coherent manner, proper maintenance has no exception. It protects the firm's investment[3], prolongs equipment life and can lead to substantial savings in capital investment[5]. However, any maintenance practices such as breakdown maintenance, preventive maintenance and condition-based maintenance in isolation cannot work well. Even, the Total Productive Maintenance (TPM) that started its journey in early 1970s from the house of Toyota in Japan with a success story, cannot meet all the major current demands. It can work well when it is a part of TQM or JIT system. Nevertheless, it cannot meet the demand of the sound protection of physical environment. Therefore, Ecology Oriented Management (EOM) or eco-efficient manufacturing system can be joined in order to make it more effective and efficient. Now the pertinent question is what should be the easy approach in implementing TPM and EOM? The Japanese 5S housekeeping practices can be brought into with this duo. All the three together can present a very appreciable blend of quality and people-oriented maintenance environment.

The success of this blend is now a proven reality! This was tested in a large Japanese company in Malaysia. It was proved that change is inviting if it is based on knowledge and handled by knowledge-workers. This study presents such a success story.

Equipment or plant maintenance function aims to optimizing the availability and reliability of production equipment and plant facilities and maintaining their operability at an acceptable cost level[4]. TPM is a production equipment maintenance philosophy and program that can be applied to enhance equipment effectiveness and maximize equipment output on a company wide basis[6]. It is a frame of a productive work environment where all employees of an organization via small group teamwork activities carry out the maintenance work. It works well in conjunction with 'no waste' and

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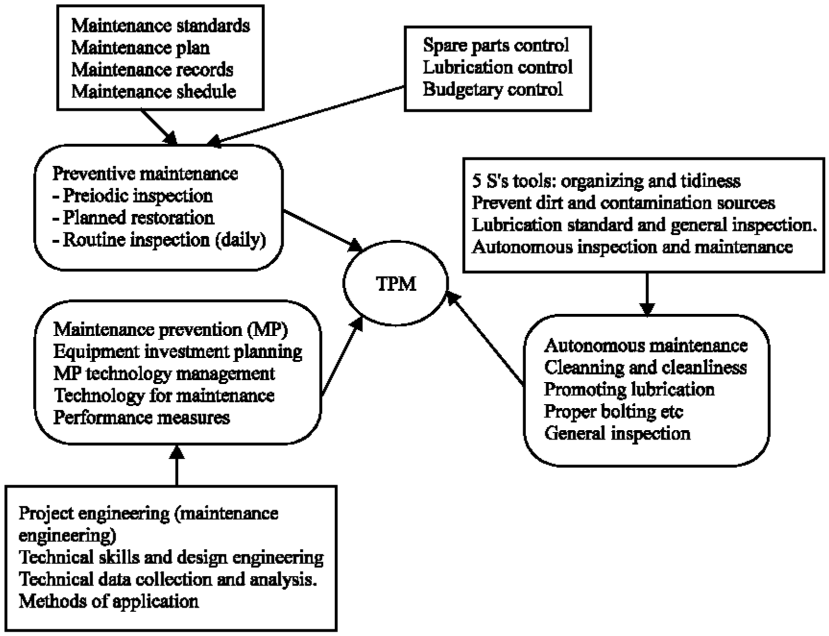

Fig. 1: TPM domains and functional areas

'zero defect' (JIT approach) philosophy or Total Quality Management (TQM). Nakajima[7] who is considered as the father of TPM has given the original approach of its application. A few more definitions of TPM are placed by a number of researchers[1,5,8,9]. Among them, Rhyne's [8] definition of TPM appears more detailed.

The word total means involvement of all production and maintenance individuals through teams. The meaning of the word productive is the complete state of production of goods and services that meet or exceed customers' expectations, where there is expected, no breakdown, no defect, no accident, minimum or no adjustments and minimum or zero minor stoppages. TPM's mission is thus directed towards elimination of equipment and plant maintenance. TPM is keeping the current plant and equipment at its highest productive level through cooperation of all areas of an organization[1]. Therefore, TPM system should be internally strong to integrate different departments where a set of working principles can be developed for improvement of the organization's performances, the major is the equipment improvement.

In many organizations, opportunities like brainpower, the problem solving abilities of the employees and a large portion of machine hours are underutilized or unused. An optimistic approach and work environment is needed to tap into those opportunities or resources. Through the commitment and participation of management and employees, that kind environment can be created. Appropriate implementation of this system (TPM) can offer tremendous potential in improving, not only the equipment efficiency and effectiveness, but as well as quality, flexibility and employee-work friendliness. The resulting effect can be quite remarkable for all parties-manufacturer, employees, customers and suppliers-better cost-control and thus reduced product's price and better assurance of delivery promises.

The domain of TPM can be viewed into three interrelated areas: preventive maintenance, predictive maintenance and autonomous maintenance (Fig. 1). Preventive maintenance is the process of performing activities on the equipment periodically to keep it on running. Predictive maintenance is the action of using data to determine potential failure time of a piece of equipment. The main features of TPM are 'total' employee participation, good equipment conditions and continuous improvement trend. It is proactive in nature.

Today, a manufacturing firm cannot alone work for its profitability. It has a great responsibility to social issues as well. World-people have been showing their conscious and serious concern for a living-friendly environment since mid 1980s. So, environmental orientation in designing production systems has become an important issue to the human society. It is pointed out by Minuro Yosinka of Japan, our forefathers and we have forgotten the elements of ecology and environment in pursuit of our technological goals. But times are changing and people are realizing that enough mistakes have already been done and the demand for production systems that are safe for the earth and environment is ever increasing.

A relatively new concept of productive management termed as ecology oriented manufacturing/management (EOM) can be applied to maximize contribution to the human society based on a strong sense of global justice. The outcomes of this could be a pollution free environment, cost-effective production, higher profitability, high quality product and better employee morale. It does not need to invest a huge amount of money to achieve these ends but can be brought about by better housekeeping. Eco-efficiency in general includes any measure or initiative undertaken by any production system that results both in reduced environmental impact and increased efficiency and resulting in cost savings for the company concerned[10]. Therefore, operations management based on ecology emphasis has a strong rationale. EOM is the concept of harmonization of ecology and economy. Eco-efficient manufacturing philosophy has been proposed to reduce the use of raw materials and costs of waste management; to create marketable by-products, new markets and increasing market shares, to conserve energy and water, reduce pollution and consent charges, reduce fees and penalties and to improve employees health and safety as well. Economically, any reduction in waste results in gain to the corporation. EOM also has an advantage of safeguarding a motherly nature. One of the major objectives of EOM is to attempting an increase of the yield rate. The theoretical target is 100%. This could be achieved through:

- The reduction of defective items, start-up loss, scraps, etc.
- Design for minimizing size of materials
- Procure right quality of raw materials and components
- Prefer in-house production of parts
- Make full use of recycled material
- Participatory design engineering
- Reduction and recycling of waste.

Productivity improvement can be achieved through effective and efficient utilization of the four 4 M resources (man, machine, material and method) instead of 3 M (man, material and method) in a non-TPM system. An organization can achieve total productivity improvement if it can achieve a balance in the areas of product quality, cost, due date delivery, safety and employees morale. Some of them are quite important to catch hold competitive advantages. To achieve the targets like the world-class product and society-friendly operation systems, the 21st century requires a human management which would be more environment-friendly and participative rather than authoritative. An understood EOM or eco-efficiency program can identify and exploit the market opportunities associated with good environmental practice. Firms can promote green products and able to find new business opportunities resulting from their efforts to solving pollution problems. These opportunities, if pursued properly, not only offset the costs of the programs, but also lead to increasing profit.

EOM is linked to the International Standards Organization (ISO) 14000 series as well. The ISO 14000 series defines and supports the application of environmental management systems (EMS). ISO14001 requires that an organization identify the environmental aspects of its activities, products or services that can control and over which it can be expected to have an influence, in order to determine those which have or can have significant impacts on the environment[10]. This standard is appropriate to most manufacturing situations. It has already become a necessary condition for many industrial operations in Western Europe and in North America[10]. ISO 14001 has its inherent control mechanism. It includes routine internal monitoring of environmental performances against the defined targets for improvement (internal auditing). So, the successful implementation of the EOM supports the obtaining of ISO 14001 standards through reduction of raw material usage and waste.

It is evident that both TPM and EOM essentially require total active participation of people. Those also require some understood and workable principles. The Japanese advocacy on good management is titled as the 5S rewarding principles. The five keys, popularly known as 5S's, come from the first five letters of the five Japanese terms. These terms/words are Seiri, Seiton, Seiso, Seiketsu and Shitsuke. In English, they are respectively, Organization, Neatness, Cleaning, Standardization and Discipline. Their messages are obviously universal. The ideas of 5S are simple and intuitively appealing. In any work environment there is something very fundamental and important. The Five key elements, the 5Ss, if properly conceived and followed, could be revolutionary towards greater productivity and quality in electronics, precision processing, fabrication, assembly, hospital and any other manufacturing and service industry.

Although the 5S activities sound to be very simple, in practice, to implement 5Ss, it requires perseverance and determination. They also require constant effort, ability to see what is important and paying attention to the details. One might be doing wrong by expecting dramatic results within a short period, but must see continuous improvement by applying them. They show results in

Appendix A: The 5Ss at a glance

5S Overview

5S theme	Meaning	Aims	Activities	Principles
Organization (Seiri)	Distinguish between the necessary and unnecessary and getting rid of what you do not need	Establish criteria and strict to eliminate the unnecessary. Practice stratification management to set priorities. Be able to deal with causes of filth.	Eliminate the unnecessary. Dealing with causes of filth. KAIZEN and standardization based on fundamentals.	Stratification management in dealing with the causes.
Neatness (Seiton)	Establish a neat layout so that you can always get just as much of what you need when you really need it.	A neat looking workplace. Efficient (including quality and safety) layout and placement. Raising productivity by eliminating the waste of looking for things.	Functional storage based upon 5W's and the 1H. Practice and competition in putting things away and getting them out. Neat workplace and equipment. Eliminating the waste of looking for things.	Functional storage and elimination need to look for things.
Cleaning (Seiso)	Eliminating trash, filth and foreign matter for a cleaner workplace. Cleaning as form of inspection.	A degree of cleanliness commensurate to your needs. Achieving zero grime and zero dirt. Finding minor problems with cleaning inspection.Understanding that cleanliness is inspection.	5S where it counts. More efficient cleaning. Cleaning and inspection equipment and tools.	Cleaning as inspection and degree of cleaning.
Standardization (Seiketsu)	Keeping things organized, neat and clean, even in personal and pollution related aspects.	Management standards for maintaining the 5Ss. Innovation visible management so that abnormalities show up.	Innovation visible management. Early detection and early action. Tools for maintaining standardization. Color-coding.	Visual management and 5S standardization.
Discipline (shitsuke)	Doing the right thing, first time, as a matter of course.	Full participation in developing good habits and workshops that follow rules. Communication and feedback as daily rules.	One-minute 5S! Communication and feedback. Individual responsibility. Practicing good habits.	Habit formation and a disciplined workplace.

Appendix B: A set of 5Ss activities

5S Elements	Typical activities
Organization (Seiri) Stratification management and dealing with causes.	1. Throw out the things you do not want. 2. Deal with the causes of dirt and leaks. 3. Housekeeping. 4. Treat defects and breakage. 5. Inspect covers and troughs to prevent leakage and scatter. 6. Clean the grounds. 7. Organize the warehouse. 8. Eliminate grime and burrs. 9. Eliminate oil pans.
Neatness (Seiton) Functional storage and eliminating the need to look for things.	1. Everything has a clearly designated place. 2. Thirty seconds storage and retrieval. 3. Filling standards. 4. Zooming and placement marks. 5. Eliminate lids and locks. 6. First in first out (FIFO). 7. Neat notice board. 8. Easy to read notices. 9. Straight lines and right angles. 10. Functional placement for materials, parts, cart shelves tools equipment and everything else.
Cleaning (Seiso) Cleaning as inspection and degrees of cleanliness.	1. Quick 5S drills. 2. Individual responsibility. 3. Make cleaning and inspection easier. 4. Sparkling clean campaigns. 5. Everybody is a janitor (priority 5S). 6. Perform cleaning, inspections and correct minor problems. 7. Clean even the places most people do not notice.
Standardization (Seiketsu) Visual management and 5S standardization	1. Okay marks. 2. Danger zones marked on meters. 3. Thermal labels. 4. Directional markings. 5. Belt size labels. 6. Open and shut directional labels. 7. Voltage labels. 8. Color-coded pipes. 9. Oil labels. 10. Warning colors. 11. Fire extinguisher signs. 12. Fool proofing. 13. Responsibility labels. 14. Wire management. 15. Inspection mark. 16. Precision maintenance labels. 17. Limit labels. 18. Color-coding. 19. Transparency. 20. Preventive noise and vibration. 21. I can do it blindfolded placement. 22. 5S calendars. 23. Park like plant layout.
Discipline (Shitsuke) Habit formation and a disciplined workplace.	1. All together cleaning. 2. Exercise time. 3. Pick up practice. 4. Wear your safety shoes. 5. Public space management. 6. Practice dealing with emergencies. 7. Individual responsibility. 8. Telephone and communication practice. 9. 5S manual. 10. Seeing is believing.

terms of more convenient work practices and less downtime, workers take pride in their work and reduced personal ego and less conflict. And they show results in terms of higher productivity and better quality because people who care about better work do a better job.

Some of the 5Ss practices can be done in isolation. But it is important to practice them all simultaneously and there should be a total company wide effort by everyone. To acquire all pervasive, fruitful and measurable results, the 5Ss have to be practiced at offices as well as at factories. Whatever be the management techniques are available for application; the 5Ss should be emphasized first. It is necessary to have a clean, well organized workplace or environment before making decisions on problems relating to quality, efficient material use, labor productivity, equipment productivity or staff morale. As is known that without having well defined and consistently followed operating procedures, it is impossible to tell whether one is doing the right thing or wrong. Similarly, without the 5Ss movement, none of the other campaigns and innovations that have been invented for better working conditions and superior products will remain less than of full avail.

The 5Ss are important for good management, especially for maintenance. A brief description on the meaning of 5Ss and how they affect the company's productivity is illustrated in this section. The Appendices A and B show 5Ss overview and activities in brief.

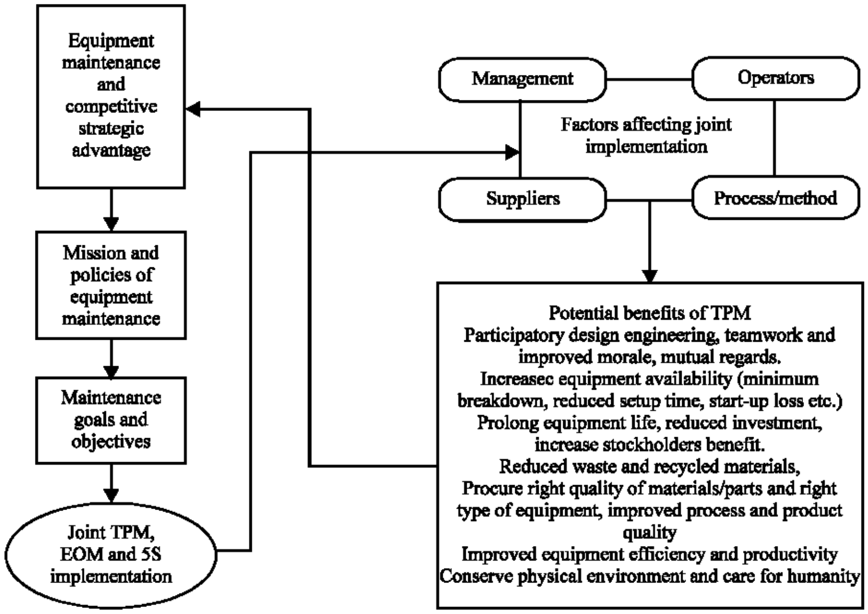

Fig. 2: Framework for successful implementation of TPM

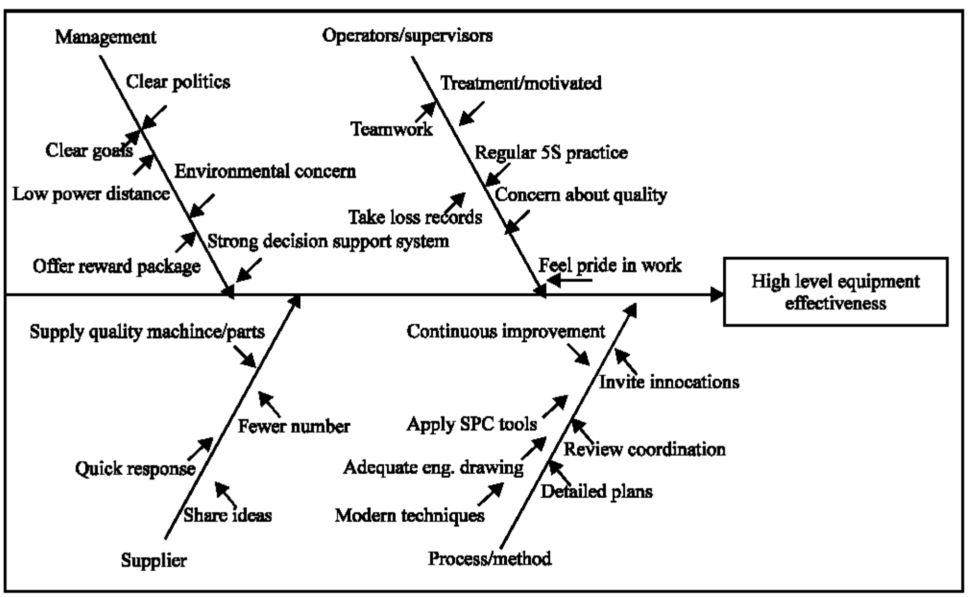

Fig. 3: Factors affecting good maintenance

Research framework and implementation methodology: Like other management systems, maintenance management has a few functional components. The five interrelated components of this are strategy and policy formulation, human dimensions, support mechanisms, use of tools and techniques and organization[11]. Well-defined goals, objectives and policies always guide people towards their ends. Compatibility between job and operator through training and education determines a continuously improving work environment. Support mechanism refers to information and communication, which is again a vital component. Without the application of proper methods and statistical and managerial tools and techniques, proper objective-oriented management cannot be established. A flat type organizational setup with adequate delegation of authority along the responsibility makes everything else lively and workable.

To implement TPM successfully, an organization must have a promotional structure, which is free from so-called bureaucracy. A well-drawn master plan is required to guide the consecutive activities. Four prominent factors are needed to take into consideration before embarking into TPM implementation. These are leading role of the top management, operators and supervisors skills, strong adherence to implementation (i.e., morale) and working conditions. The subject of behavioral science is an important element in the implementation of TPM. The top management involvement should come from the understanding that TPM can save millions. Therefore, they should take the lead to set the mission, basic goals and objectives, develop policies and procedures through the participation of workers and other concerned. As suppliers are important partners of the whole gamut of value chain, their involvement should be sought. So, together, all partners should create a corporate environment and frame a set of attitudes that would support the necessary changes (Fig. 2). Figure 3 expresses the detailed breakup of the pertinent factors affecting a successful maintenance program.

In TPM, the top management sets the major goals and policies and the operators via small groups function by setting their own objectives in line with the basic goals and policies. Thus there develops a top down goal setting by top management and bottom up objective determination atmosphere.

THE CASE PRESENTATION

About the company: The company where the combined concepts of the above three were put in trial was a worldwide reputed company in producing electrical and electronic products. It is a large company having business houses in many countries around the world. This case study was conducted in an organ of it in Malaysia. A few projects were undertaken in order to improve equipment and the direct labor productivities, which were found very appropriate in case of equipment/workstation's productivity enhancement. It was experienced from the previous data that in case of stiff competition in the market, productivity improvement was very much necessary for price competitiveness.

Problem faced: A unit of a big company had experienced that in its manufacturing processes waste of time for setup and adjustments of machines and breakdown etc. was quite high. There had been waste of materials and misuse of space and complaints of environmental degradation too. The overall productivity in the company was reportedly decreasing. The decline was occurred for those products, which have had high product values and were facing stiff competition in the market. Therefore, the necessity of productivity improvement as well of price competitiveness was felt very much. Further, the company was concerned about environmental degradation toward social justice, although its work didn't bring alarming hazards.

The company had currently been adopting ecology oriented management concept with the aim of achieving objectives like elimination of waste in any forms. But the success was cunning. An idea was underway of thinking that the capacity of equipment and workmanship of its operators could be notably enhanced. But the lack of solution ideas barred from availing the predicted gains.

Investigation noticed that the idea of formal small group activities was not introduced and although some people worked in groups but these groups were not integrated as part of the organizational structure and nor were these promoted with the total employee participation concept. Despite having a goal of absolute elimination of wastes and that was tuned among the middle level management, supervisors and foremen, the achievement was noticed not enough. As per people side, there was no total participative feeling. The technical skill development through planned training programs was found largely inadequate. Therefore, for instance, there were lack of record keeping and mode of proper analysis of lost time, material waste, etc. So, in the investigation and implementation of TPM, the authors faced numerous obstacles, which took the case study through a period of around two years.

Before implementation of the TPM system in conjunction with 5S and EOM, the equipment maintenance practices were not organized and productive maintenance was not in implementation. The overall scenario could be explained briefly, as:

- Machine keepers were not really aware of the importance and ways of proper equipment maintenance.
- Lack of skilled workers to introduce the concepts of TPM or 5S's, such as in standardization, documentation and proper recording in maintenance. These activities are essential features in preventive maintenance.
- The overall equipment effectiveness of the company in the beginning of the case studies was evaluated and from a scale in ascending order of proper maintenance level-1 through level-4, the rating of the company was put at level-1 (poor).

Appendix C: Major function involved in TPM development

Type	Phase 1	Phase 2	Phase 3	Phase 4
Preventive maintenance	Reduce variability of life span-restore neglected equipment Eliminate inferior equipment-adhere to condition of use	Lengthen life span-Correct design weakness Eliminate unexpected breakdowns-external repair and maintenance of equipment	Make occasional repair -project life span and plan periodic renovation Identify symptoms of deterioration	Predict life span-use equipment diagnostic techniques Do technical analysis of major breakdowns
Autonomous maintenance	a. Basic cleaning, b. address sources of problems, c. set cleaning and lubrication standards	d. general inspection of equipment	e. autonomous inspection	f. organization and orderliness, g. autonomous activities
Education and training	Basic training on cleanliness, use of nuts and bolts etc.	Training in handling keys and bearings, power transmission system, hydraulics pneumatics and sealing	Training in operations and maintenance methods: loss calculations	Training in analysis and evaluations
Startup maintenance and economic evaluation	Startup maintaining records	Functional analysis; cost reduction analysis; design standards	Maintenance prevention analysis: standardization of practices	Evaluate economic efficiency

- Breakdown losses-sporadic as well as chronic breakdowns were quite common with no proper analysis and data collection or data recording system. Low-level preventive maintenance and autonomous maintenance atmosphere.
- Setup and adjustment losses-work procedures were not organized as per requirement of 5S's and setup time varied widely.
- Speed losses-unstable operating conditions due to fluctuation in frequency and unidentified location of losses were prevalent.
- Idling and minor stoppage-losses from minor stoppages were as if unrecognized and unstable working conditions were persisted.
- Quality defect and startup losses-chronic quality defects were neglected.

However, the company's products were increasingly varied and they were highly demanding to the global market and to meet the situations it had to expand its capacity, both in terms of number of machines and operators. With a time span of six years, the number of machines rose from 6 to 59 and the number of operators from 16 to 51. So, the responsibility of operators had been increasing, naturally more of it in case of the skilled operators. With the rapid expansion of the firm's capacity but having greater proportion of unskilled or semi-skilled worker, the equipment related problems had been increasing too. The company management had felt the necessity of a breakthrough and decided to introduce the TPM methodology.

The means to achieve the goals: TPM aims at input side rather than output side. It aims at no maintenance goal. Therefore, there should be a master plan to apply the three components of TPM, namely, preventive maintenance, autonomous maintenance and maintenance prevention. A general master plan is depicted in Appendix C and the domain of Preventive Maintenance (PM) and Maintenance Prevention (MP) is shown in Fig. 1.

The concept of TPM was introduced here in conjunction with EOM and 5S systems, although its constituents, viz: preventive maintenance, autonomous maintenance and maintenance prevention were thus far not fully implemented. The authors have a firm conviction that Japanese working culture like sense of belongingness, perseverance and discipline has a great bearing on the successful implementation of TPM.

Before its introduction, as it is mentioned earlier, there were poor and haphazard recording of equipment losses. The introduction of TPM had begun here with the training programs chalked out for both supervisors as well as machine operators. Some section managers, supervisors and machine operators were sent in Japan to learn about implementation of TPM. The section manager and supervisors taught the machine keepers about the importance of loss time and their recording. One manager of the company who happened to be a member of 5S-implementation committee reported, it was a Herculean task to change the minds of machine keepers in a different work culture or a multi-cultured society than Japan to adopt this system. The equipment as one of the main contributors to a manufacturing organization and the six big losses associated with it were taught to all supervisors. The machine keepers thus learnt how to keep records of loss time data and they were assigned to keep record of loss time. In the first phase drastic improvement of loss time data recording was observed. However, they were poor to analyze data and locate the improvement activities. Most machine keepers were still ignorant about the existence of the six big losses and unaware of the importance of machine as a profit contributor.

Knowing their ignorance about the constituents of TPM, as mentioned earlier, the management took an initiative to construct a TPM implementation plan. The

Four Phase TPM plan was constructed; vis-à-vis, education and training programs were executed. The support of the machine suppliers was sought in imparting training programs.

The machine operators divided into skilled and semi-skilled categories. Operators experienced two years or above in machine handling and trained in Japan were put under the skilled category and the workers those having a technical qualification but less than two years experience fell under the semi-skilled category. The skilled workers ranged only about 25 to 35 per cent of the total machine keepers population and were responsible to upkeep his/her machine, guide and teach co-workers to do so, in addition to their own machines handling. They held the positions of shift leaders or general leaders and took care of production, quality, cost, safety, delivery date and morale. On an average, a skilled worker was responsible for 3.3 machines and an operator was handling 1.2 machines.

THE SIX BIG LOSSES

The six big losses are measured in terms of overall equipment effectiveness (OEE), which is a product of availability (A), performance rate (P) and quality rate (Q). The exact definition of OEE differs between applications and authors (Table 1). Nakajima[7] was the original author of OEE and De Groote[12] is one of several prominent ones.

The availability measures the total time that the system is not operating because of breakdown, set-up and adjustment and other stoppages. It indicates the ratio of actual operating time to the planned time available. The performance rate is the measure of the ratio of actual operating speed of the equipment (i.e. the ideal speed minus speed losses, minor stoppages and idling) and the ideal speed (based on the equipment capacity as initially designed). Nakajima[7] measures a fixed amount of output and in his definition (P) indicates the actual deviation in time from ideal cycle time. De Groote[12], on the other hand, focuses on a fixed time and calculates the deviation in production from planned. Both definitions measure the actual amount of production, but in somewhat different ways. The quality rate takes into consideration the quality losses (number of items rejected due to quality defects) that happen close to the equipment, not the quality losses that appear downstream. This is a very introspective approach. A wider definition of (Q) would be interesting, but would complicate the calculations and interpretations. It should be according to which process is to blame and this is not always easy to identify.

Owing to different definitions of OEE and other varying circumstances between companies, it is difficult to identify optimum OEE figures and to compare OEE between firms or shops. Some authors have tried to do it though; e.g. Raouf[14] asserted that under ideal conditions firms should have A >0.90, p>0.95 and Q >0.99. These figures would result in an OEE >0.84 for world-class firms and Nakajima considers this figure to be a good benchmark for a typical manufacturing capability. Kotze[15], on the other hand, argues that less than 0.50 OEE is rather more realistic. This figure corresponds to the summary of different OEE measurements presented by Ericsson[16] where, OEE varies between 0.30 and 0.80. These disparate figures indicate the difficulties of comparing OEE between processes.

In this case study, during the first phase, the lost time data was collected and put in a summarized form. However, those data were not classified into six categories and not yet was fully investigated. This time, the six big losses concept was introduced towards implementation of TPM. A few formats of data collection were introduced for a few machines. The total monthly loss for a particular machine was then summarized. Later the measuring indices in terms of production efficiency and machine efficiency were calculated. The production efficiency or operation efficiency and machine efficiency were measured by using the following formulas:

$$\text{Production efficiency} = \frac{\text{Total working time} - \text{total losses}}{\text{Total working time}} = \frac{T_w - T_1}{T_1}$$

$$\text{Machine efficiency} = \frac{\text{Total working time} - \text{losses due to reasons not related to m/c}}{\text{Total working time}}$$

Where losses not related to machine meant, if there was no order, no material and such other losses. The machine

Table 1: Definition of OEE variables

	Nakajima[7]	De Groote[12]
Availability (A)	Loading time-downtime	Planned production time-unplanned downtime
	Loading time	Planned production time
Performance (P)	Ideal cycle time x output	Actual amount of production
	Operating time	Planned amount of production
Quality	Input-volume of quality defects	Actual amount of production-non-accepted amount
(Q)	Input	Actual amount
OEE	(A) x (P) x (Q)	(A) x (P) x (Q)

Source: Jonson and Lesshmmar[13]

Appendix D: Five activities to uncover and address hidden defects

Maintain basic equipment conditions	Maintain operating standards	Restore deterioration	Improve design weakness	Prevent human error
Equipment cleaning- eliminates source of contamination. Tightening- prevent looseness. Lubrication- highlight lubrication points: improve methods of applying. Prepare cleaning and lubrication standards.	Set design capacity and load limiting values. Standardize operating conditions. Set and improve operating conditions for units and parts. Set and improve construction standards: installation, piping, wiring. Prevent dust and moisture in revolving and sliding parts. Set environmental conditions, dust, temperature, humidity, vibration and shock.	Detect and Predict Deterioration. Visually inspect items common to all units, expose deterioration. Prepare daily inspection standards. Part by part MTBF analysis: estimate lifetimes. Set limiting values for parts replacement. Prepare inspection, testing and parts replacement standards. Learn to interpret abnormal signals. Study deterioration prediction parameters and measurement methods. surface Establish Repair Method. Standardize disassembly; reassemble measurement and replacement methods. reduce stress. Standardize parts. Improve tools and apparatus and restrict to particular uses. Improve equipment structures for ease of repair. Set standards for spare parts storage.	Strengthen parts to extend lifetimes: mechanisms and structures, materials and shapes, dimensional accuracy, assembly accuracy, assembled parts strength, wear resistance, repair errors. roughness, capacity, etc. Take measures to Improve repair tools and Design safety relief against excess stress. Treat weak points to prevent overloading.	Prevent Mis-operation. Analyze causes of mis-operation. Improve design of control panels. Provide interlocks. Foolproof operations. Visually control equipment conditions. Standardize operating and adjustment methods. Prevent Repair Errors. Analyze causes of Improve confusing part shapes and fitting methods. apparatus. Simplify and standardize troubleshooting procedures (visual control for equipment conditions).

efficiency represents the Overall Equipment Effectiveness (OEE), because this efficiency had been computed by taking into consideration of machine loading time, standard machine speed and good (quality) production quantity. To monitor the six big losses, two data collection and analysis formats had been introduced. Through these formats, one could portray the monthly trend of a section's six big losses. The summary of these data enabled the management to truly understand the conditions of their equipment and the level a piece of equipment was being operated. Necessary steps were taken to eliminate/minimize the respective loss (es) through the autonomous small group activities.

The following few cases illustrate the actions taken to reduce the six major losses. Almost in every case, the relevant engineering drawing(s) was developed.

Elimination of equipment breakdown: Investigations revealed that from the point of overall equipment effectiveness, the firm's initial position was in poor state. Truly, there was no systematic preventive maintenance in practice. Sporadic and chronic breakdowns were quite common with no proper analysis and data collection or recording system. The autonomous management was not properly organized and equipment weaknesses were not well known. At this stage it was not possible to stop machine breakdown. Identification of defects towards breakdown was required first hand to eliminate them. Defects in a machine were physically and psychologically remained hidden. The five action plans was taken to uncover and eliminate hidden defects. These are summarized in Appendix D.

The five activities for zero breakdowns are not short-term programs and should not be implemented simultaneously. The program covers four phases, as is depicted in Appendix E. TPM covers four phases through the three main techniques, viz., preventive maintenance, autonomous maintenance and startup maintenance. By employing these three techniques, developed in four phases, a firm can eliminate the six big losses.

Reduction of setup and adjustment losses: The Japanese 5S actions, particularly, organization and tidiness, in association with EOM philosophy was adopted to eliminate redundant activities and to ease difficult jobs, so that the operator could use the saved time for productive purposes. To identify and then remove the setup and adjustment related problems, a number of projects were undertaken. A few of them are presented here.

Reduction of CNC turning machine cleaning time: Previously, the scrap was removed manually. A significant time was consumed in each removal before the next loading, which could be termed redundant. Now, a vacuum suction unit was introduced. Thus scrap-cleaning time could be reduced by around 10 min after each operation. The number of scrap removal per month was about 180 times. A total of nearing 30 h of time could be

Appendix E: Achieving Zero breakdowns in four phases

Phase 1	Phase 2	Phase 3	Phase 4
Stabilize mean time between failures	Lengthen equipment life	Periodically restore deterioration	Predict equipment life.
Restore unchecked deterioration.	Correct Design Weakness	Restore Deterioration at Regular Intervals	Predict Equipment Life Using Diagnostic Techniques
	Correct weakness in strength and precision.	Estimate life span of equipment	
Deal with visible defects.	Select parts conformable to operating conditions	Set standards for periodic inspection and testing Set standards for periodic parts replacement	Clarify and adhere to operating standards
Prevent accelerated deterioration.	Correct weaknesses to prevent overloading.	Improve maintainability	Perform Technical Analysis of Catastrophic Failures
Set basic equipment conditions.	Elimiate Sporadic Breakdowns Improve operating and maintenance skills	Use Senses to Detect Internal Deterioration	Analyze rupture facets Analyze material fatigue
	Prevent disoperation Prevent repair errors Restore external appearance of equipment.	Identify deterioration that gives warning signs Identify types of warning signs given Learn to detect warning signs	Analyze gear tooth flanks, etc. Take measures to extend equipment life Conduct periodic restoration based on predicted life

saved through this change. It increased the machine's efficiency by 6.25%. Further, it helped saving oil by recycling the oil back to the machine after removal of scrap. Also, it eased the work of machine keeper and improved the health of work environment, which eventually helped improve productivity.

Quick die changing by using rotating lifter: The number of die change per month was around 110 times and each change took away an average of 180 min. Now, an internal activity was converted into an external activity. Unlike the old lifter, the new lifter used a rotating table. With the new table, the machine operator could prepare the die for the next production in advance. Then he removed the old die, rotated the lifter and pushed the new die into the bolster of the press machine and continued with this die setting. With the implementation of this quick die changing, the die change time could be reduced by 5 min each time. After this change, the overall production efficiency improved by 1.9%. However, a continued effort should be given in pursuit to achieve the single-minute-exchange-of-die (SMED) level suggested by Shingo[17].

Semi-auto bobbin change: In this plant, some of the stamped parts were produced in the form of hoop and it was wound round the circular rings named bobbin. The quantity of products wound round the bobbin varied from product to product and during the continuous production periods these bobbins were removed and new one was fixed to the winder. Before the change, the press machine was stopped to change the bobbin. A semi-automatic bobbin-winding unit was devised through which a bobbin could be mounted on one side that glided right after the previous operation. The bobbin changing time could thus be reduced to 3.5 from 4.0 min. In a month, for around 880 bobbin changes, 7.33 h could be saved.

Reduction of scrap disposal time at a press: This is as if the JIT Kanban system. It involved placing a spare scrap container whenever the original one is removed for disposal. Ironically, in the conventional method, when a scrap container was removed for disposal the machine was left idle for some 15 min. Under the new system, about 3 min was required to remove the filled scrap container and replace that by another one. A lot of time was thus rescued. The total time saving from this project per month was computed to be nearing 60 h.

Gear changing for gear feeder press: Earlier, the practice was that the machine keeper had to stop the machine, dismantle the gear set, remove the gears from the attachment, fix a new gear set to the attachment and fixes it again to the machine. Meanwhile, the machine remained idle for long 30 min. Here, a spare attachment was introduced that enabled the machine keeper to prepare the next gear set, as different sets were required for different products. It took some 10 min to change the gear set under the new system. Because of the introduction of this new technique, the total savings of time per month was around 20 h.

Auto feeding of a part feeder to feed shaft of a milling machine: The milling process was the subsequent process after turning the job at CNC lathe station. Earlier, the shafts were feed manually via a hollow brass bar. Fixing a part feeder to the feed shaft of the machine made the change. The productivity of this station had been registered and improvement was reported to be around 10.8%. The cost of production came down by over two thousands unit of money per month in terms of the local currency.

Auto serration process at an auto lathe section: According to the process flow, some of the shafts after the turning and milling processes were serrated manually to produce the desired shape ordered by the customers. Previously, the serration process was done manually by means of a mini serration-punching machine. In order to improve it, incorporation of an auto-serration process within the milling machine eliminated the manual process. A tremendous productivity improvement was resulted on this particular part (around 75%).

With the implementation of the last two projects, the overall productivity of Auto Lathe section was increased by 23% and due to elimination of manual operation and increase of production rate, a monthly savings of around three thousands unit of money was reported. Through these changes, the company could withdraw the manual workers from these processes and assign them more productive work like process quality inspection and data analysis.

Reduction of Idling and minor losses: At this stage, the loss time figures for idling and minor stoppages were not computed because of its inability to compute the minor stoppage time, frequency of occurrence and the type of minor stoppages. However, from the information of production figures and Overall Equipment Effectiveness (OEE) an estimation of idling could be derived. In order to facilitate the analysis and encourage the collecting of relevant information, minor stoppage frequency at the auto lathe section was analyzed and came up with some interesting findings. As a single machine keeper was responsible to take care of a few machines, it was not possible to measure the minor stoppage time by the operator himself. The operator was not very sure when a machine actually stopped operating. To compute the minor stoppage, setup time or breakdown time, a device called hour-meter was suggested to install with the machine. This meter consists of two dials-one to record the operation time and the other to record the time the moment the machine stops. The unit of record time was second, which was assumed to be very useful in recording minor stop time. However, this meter was not installed yet. During the case study in the auto lathe section, data on frequency of occurrences of minor stoppages at secondary process, the milling operation, after the turning on the CNC lathe machine was collected for a month. The minor stops recognized were:

- Double feeding (occurred 180 times)
- Shaft out of position (occurred 808 times)
- Shaft stuck at part feeder (occurred 649 times)
- Shaft stuck at bar slot from part feeder (occurred 138 times)

The first project was undertaken to eliminate minor stop due to shaft out of position and double feeding. Upon analyzing the situation, it was found that a single improvement project could eliminate both the problems, i.e., to eliminate shaft out-position and double feeding problems. In this regard several drawings were prepared. One drawing was prepared to show the normal position of the feeding mechanism. The shaft from the part feeder was fed along the brass tube to a jig (say, jig-1) on the machine; once the shaft was on rest upon the jig-1, a pneumatic mechanism slides the shaft from the jig-1 onto a chunk from the milling process. The problem happened when the shaft didn't fall on the right direction onto the jig-1 or two shafts fall at the same time, resulting in blockage and thus causing the machine to come to a stop.

The improvement was performed through fabrication of another jig (say, jig-2) with a pneumatic drive in a transverse direction to the jig-1. The jig-2 moved into a position so that the shaft came to a rest on the right direction and after its right positioning, the pneumatic action pulled the jig-2 and the shaft fallen in the required direction onto jig-1, thus ensuring smooth operation. The project was considered as a big success since it was possible to eliminate the minor stops due to shaft out of position and the double feeding to zero. The minor stop time in this case on an average was about 0.5 min per stop and the probability of these kind of minor stops per month were around 2300 occurrences, causing a total loss time of 1150 min per month. Upon this project, the productivity improvement was noticed to be around 0.14%.

Reduction of speed losses: Three parameters were identified important to increasing speed of a CNC machine. These were feed rate, spindle revolution and tool, chuck and material movement time. Before the improvement program, the relationship between/among these parameters was not clear to the machine keepers. Generally, the machine keeper would use a fixed feed rate of 0.02 mm/rev and a cutting speed of 5000 rpm, irrespective of the type of product, process condition and type of cutting process or quality requirement. They were also not well versed in the most economical tool movement when constructing their NC programs.

Then the machine keepers were taught how to choose the feed rate, the cutting speed based on the cutting process, the material being used, the process and quality requirement. The use of the relevant charts was explained before them. With these improvement actions, 33% of cycle time improvement was noticed. The machine keepers were then taught how to make economical programs and determine most efficient cycle time. A simple job instruction format was developed for the machine keepers.

In another case, with the introduction of EOM concept, the firm began changing die design to cut down the processing time of stamping parts. It was an old die that could produce only one product per stamping. The die ran at a speed of 100 strokes per minute and thus was producing 100 pieces of a product in a minute. However, the new EOM dies was designed that could produce 200 units per minute with the concept of two-line in the same die. In another project in a switch terminal, the original design having the capacity of producing 4 pieces per stroke (2 lines x 2 pcs/stroke) was changed to 8 pieces per stroke (8 lines x 1 pc/stroke). This project increased the productivity to 100%. And it was a very successful project considering the high demand of the product orders placed by customers to the firm.

Reduction chronic quality defects: Solutions of quality problems were looked into by means of a cause-and-effect diagram. The major factors considered were man, machine, material, measurement and method. Of the 269 identified problems causing defects and lot rejection, 88 problems were due to equipment problem (both machines and dies) and the highest was man related problems-103 cases. The other problems were associated with method (41), material (22) and measurement (15). Of these so many problems, over 85% was found minor ones, which is in line with Juran's 80-20 coining.

This study preferred to analyze machine-quality problems. For this the analytical and deductive approaches presented were referred. The study couldn't finish in finding the chronic defects.

Material savings: In the firm's press unit, the equalizer cover pitch and width could reduce by 1 and 2 mm, respectively from corresponding 27 and 45 mm. The resultant yield improvement was about 7.9. Yield is defined, as the proportion of saleable products by weight compared with amount of raw materials required for producing it. The formula used to calculate yield is given below:

$$\text{Yield, } y = \{1-(R-Q)/Q\}\times 100$$

Where, R = actual material consumption during a period or to producing certain units of product; Q = material required (designed) to produce that quantity.

The company in its Ecology Oriented Management (EOM) campaign, requested all its units to improve the yield rate to 100%. In another case, yield improvement was achieved by 34.1%. This was resulted after reduction of pitch by 1.4 mm and width by 9 mm. The drastic reduction in width was possible by considering an overlap design, which was different from the previous one. Some other cases also noticed various levels of yield improvements. To calculate the yield rate for a particular product the formula is given below:
The weight of finished product and scrap,

$$m = \text{volume x density} = (w \times p \times t) \times (d/1000)\ g$$

Where, w is the width of the raw material in mm; p is the pitch in mm; t is the thickness in mm; d is the specific gravity of material.

The scrap weight, s = (m-z) g; z is the average weight of the finished product in gram.

Scrap as percentage of total weight = (s/m) x 100

So, the product yield rate,

$$y = (z/m) \times 100 = \{z/(z+s)\} \times 100$$

The value of z is more or less constant, so, y increases as s decreases. The scrap weight, s, could be reduced if either or all of w, p, or t could bring down.

Increasing labor productivity by reducing manual jobs: Labor productivity was measured by the production amount per direct staff per unit time. This was reportedly decreasing earlier. The decline was occurred for a particular model, which had high product value and was facing stiff competition in the market. Therefore, the necessity of productivity improvement as well as of price competitiveness was highly felt. With this in mind several productivity improvement projects were carried out. Auto feeding of shaft to secondary process machine by part feeder instead of previously used manual fed the productivity of auto lathe section increased by 10.8%. In another case at auto lathe section, some of the shaft after turning process and milling were serrated manually to produce the required shape given by customers. Prior to improvement, the serration process was not introduced within the automatic milling machine. The process was done manually by means of a mini serration-punching machine. Incorporating the serration process within the milling machine eliminated this manual process. The staff reduced with this implementation was 3 (one person per shift). The overall section's productivity was increased by over 10%. Further, human aspects like work friendliness, reward system, group activities and work environment were looked into.

CONCLUSIONS

The implementation of TPM in a comprehensive manner in conjunction with EOM and 5S's at a company derived numerous benefits which were closely related to the corporate goals and its Basic Business Principles (BBP). The major goals and BBP of the company were:

- To maintain profitability as an obligation to shareholders and development of society;
- Contribution towards society by supplying high quality products at reasonable cost and safeguarding the environment;
- Make-man-first-before-product-produce-caring employee development and their needs.

Should any manufacturing company which is innovative and capable of sustaining low operating costs, high quality, flexibility, faster response and increase productivity along with sustained physical environment; this set of goals might be seen. Therefore, any manufacturing firms can be benefited out of joint-effect of TPM, 5S's and EOM.

The benefits that were derived by the foretold case firm are:

- Profitability in terms of low operating costs and an environment friendly system were derived by the promotion of EOM. The TPM promoted in tandem with EOM encouraged workers to generate numerous projects that were not only environment friendly but also cost reducing and operator friendly. These projects attained increased productivities in equipment, labor, material use and thus the total productivity. In terms of ecology, the projects' reduced accidents, material wastage, time wastage and ease laborious jobs.
- Many equipment improvement projects were generated under EOM promotion activities. EOM defined equipment as the main contributor to a manufacturing firm which coincides with the objective of TPM. Thus it is simpler to obtain the goals of TPM if EOM activities are nursed.
- The 5S's keys along with TPM philosophy and EOM can create a total quality work environment. The 5S's bound activities can create a healthy working condition, which contribute towards high staff morale and prolong equipment life and its relation towards cost reduction. All these contribute towards productivity enhancement.
- The projects undertaken in this piece of case study generated positive outcomes in material savings and yield improvement, reduced setup and adjustment losses, reduced idling and minor losses, reduced speed losses, reduced quality defects and increased labor productivity. Those and other positive results could be evident in any manufacturing company under such circumstances mentioned in this study.

However, with the assistance of EOM and 5S's ideas, the implementation of TPM in the case firm is still incomplete-better say half-done. The organizational structure, for instance, has not been fully reshaped to accommodate small group activities. The training contents and programs are still inadequate and standardization and documentation of TPM activities are yet to be fully promoted. The monthly overall equipment effectiveness is yet to be fully analyzed and the relevant performance chart or loss charts are to be fully developed. Despite these inadequacies, the benefits of partial implementation of the system are quite evident. A fully developed system and its sustained continuous improvement culture would increase benefits in those and other areas. Further study could be conducted to ensure a full-blown TPM environment.

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