Research Paper Management

Maintenance to Total Productive Maintenance – a Journey of Transformation

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ABSTRACT

The aim of the authors is to highlight the birth of Total Productive Maintenance as an outcome of the industrial revolution. The paper begins with a description of the first and second industrial revolutions and the industrial practices followed. The different maintenance strategies – Breakdown, Preventive, Corrective, Predictive, and RCM and the part the industrial revolution played in development of these strategies are discussed next. It is then followed by a brief write-up on TPM. Finally the key concepts of TPM are highlighted.

KEYWORDS

1.0 Introduction

Total Productive Maintenance or popularly known as TPM is an offshoot of Industrialization. It is a technique being adopted by organizations to improve productivity and profitability. In order to learn more about TPM, we should go back a bit to the period which saw the birth of industries as a result of the industrial revolution. Industries are a part of our everyday life. We think, we touch, we see, we smell industrial products. Can we imagine life without utensils, refrigerators, computers, television sets, pens, books? All these are products of different types of industries. We are the consumers of these products and as consumers we have the right to demand quality products and an equal right to reject substandard products.

Let us take the case of a pen. Oxford dictionary defines pen as an instrument for writing or drawing with ink, typically consisting of a metal nib or ball, or a nylon tip fitted into a metal or plastic holder. By this definition we can see that a simple pen consists of multiple components. Have we wondered how a simple ballpoint pen is made? A ball point pen has on its tip a freely rotating ball secured in a socket with only a part of the ball exposed and the rest hidden inside the pen. The ball is continuously fed from the ink stored in the pen refill and once a person starts writing, the rolling action of the ball transfers the ink from the pen to the writing surface. The ink should not clog and should be free of particles. The ball which is the main element in the ballpoint pen is made of tungsten carbide and the pen holder is made of special thermosetting plastics. The manufacturing process of a ballpoint pen is intricate involving making ink, molding and constructing the ball and point, filling the ink and assembly of all the components.

The authors have touched upon the case of a ball point pen to highlight the fact that simple things require complex processes to manufacture. Any slip-up in any one of the manufacturing processes will result in a defective piece. Customers are choosy; they do not mind paying a slightly higher price for a better quality product and they will also not buy a product if they feel it is not value for their money. Brand name also makes a difference as customers associate brands with quality.

The point in discussing quality and brand name is to highlight the fact that for an industry or an organization however small to continue to attract customers, it should be able to produce quality goods and for this the processes involved should be running uninterrupted optimally without breakdowns and wastages. It is here that TPM plays a vital role. This paper will first touch upon the birth of different maintenance strategies as a prelude to TPM. For this it is important to discuss the industrial revolution and the part it played in development of these strategies. The emergence of TPM from the maintenance strategies will be taken up next followed by the key concepts of TPM.

2.0 Industrial Revolution

Industrial Revolution is the term given to the transformation of the British economy in the middle of the 18th century to the early periods of the 19th century from an agrarian nation to an economy led by industries and manufacturing processes. This is the 1st paradigm shift that gave a huge boost to the British economy. Let us go through the stages of Industrial Revolution:

2.1 Agricultural Revolution

An agrarian society is one in which the society depends on agriculture and farming as a means of growth and support for the economy. It was estimated that in Britain, nearly 70 to 75% of the population had their livelihood supported on agriculture in the beginning of the 18th century. People used to work in the fields and their farms, rear sheep and raise cattle and use the proceeds to sustain their livelihood. One very important point to note is that in Britain, the land in which the farmers tilled the soil was not their own but leased from the land owners. This land was handed over down the generations of farmers without the land owner interfering and it was assumed that the land would be under the hold of the farmers.

The implements used in agriculture during the agrarian period were very basic and rudimentary. Unlike today, there was no mechanization. Tilling was done manually using shovels, pick-axes and rakes. Sowing of seeds was done using the funnel tool. Irrigation was also manual by lifting water from wells by pulleys and transporting it to the field using cattle. Hence farmers were using tried and trusted methods without exploring better techniques which could have improved their yield. But then, there was no compelling need for them to increase their productivity.

All this changed when the farmers wanted to find out better ways of carrying out their activities and improving their efficiency. A spate of agricultural inventions like the mechanical seeder, horse drawn hoe and improved agricultural practices like crop rotation systems led to high yielding crops and increased land yield and productivity. As a result, more and more agricultural activities were being carried out by mechanized inventions progressively reducing the manpower required. In addition to this, land owners started claiming back their land through a series of parliamentary acts. These two factors resulted in farmers being out of work and led to exodus of people to the cities. It was in fact this agricultural revolution that was the catalyst for the Industrial Revolution. Readers have to keep in mind that the Industrial Revolution has never been seen from the perspective of TPM and there is a common thread of innovations and inventions and the desire to do things better which embraces the principles of TPM running right from the beginning of agricultural revolution to the present day innovations.

2.2 First Industrial Revolution

It was around this time that England experienced a population explosion partly due to the agricultural revolution resulting in an exponential growth in demand for manufactured goods and products. This demand along with the agricultural revolution fuelled the growth of industries. Manpower was available from the rural areas and England had abundant supply of raw materials like cotton and coal. To cater to the ever increasing demand of the population, innovative manufacturing methods sprang up. For example, cotton used to be spun and woven at homes manually by hand. But due to the time taken and limited amount of cloth being produced at a time, this system was unable to satisfy the needs of the people. To overcome this problem, spinning and weaving devices were invented which shot up the production of cotton garments multifold. This increased demand led to greater mechanization and more people were required to operate the machines leading to a spiraling cycle. Transportation of coal from mines which was being done manually by animals and people was upgraded to movement on rail carts. But the most significant advances were in the production of iron from iron ore and application of steam which drove the Industrial Revolution forward. Instead of mixing ore with charcoal in the blast furnaces, coal was being used due to the increased availability as a result of mechanization of coal mining and improved transportation leading to improvement in quality of iron produced. Steam was exploited as a source of power and played a vital role in industrialization in the form of the invention of steam engine which had infinite possibilities. Steam was used in coal mines (for pumping out water from mines), blast furnaces (for pumping air into furnaces for iron making), rolling mills (for producing finished iron), boilers and turbines (to generate power) and for rail transportation.

The authors do not plan to give a treatise on Industrial Revolution but to highlight the fact that the basic principles of TPM are not new but in existence right from the 18th century. Knowingly or unknowingly TPM was being embraced even though there might not be solid evidence to prove this. To reduce costs and to improve efficiency and productivity (prime concepts of TPM), machines were set up. Mechanization paved the way for faster production of goods. New methods were being tried out in order to produce more at a lower cost so that goods could be made available in abundance to meet the growing demand which in turn helped in the growth of the economy.

2.3 Second Industrial Revolution

The Industrial Revolution was followed by what was known as the Second Industrial Revolution or the Electric Revolution. This phase lasted from the early 19th century to the dawn of the 20th century. If coal, iron and steam were the catalysts for the first Industrial revolution electricity, steel, chemicals and the internal combustion engine were the main forces behind the second Industrial Revolution which was more pronounced in USA and Germany. Large areas began to get lighted up, electric motors and generators were built leading to great strides in fields of communication and transport thereby tremendously increasing industry output. Again as in the case of the agricultural and first Industrial revolutions, innovation was the key in the second Industrial Revolution. New concepts like assembly line and mass production were introduced in the second Industrial Revolution. People of one country could do business overseas with those of another country due to the telegraph and telephone network leading to expansion in industries.

The Industrial Revolution had a major negative impact. Even though industrial output increased, the living conditions of the ordinary workers had plummeted. The gap between the owners and the workers was widening. The owners got richer while the workers were not take care of. The working conditions were dreadful and appalling. The industry owners were neither concerned about the work place nor providing facilities to the workers which began to result in lower productivity and inferior product quality. Localities were highly polluted due to the constant emission of smoke and waste gases. This resulted in deterioration of work-life balance of the workers especially during the second Industrial Revolution.

3.0 Maintenance in Manufacturing

3.1 Breakdown Maintenance

The previous section on Industrial Revolution discussed how necessity and innovation formed the basis for invention of techniques to propel the setting up of industries and foster growth of production of goods and finished articles. People found out ways of doing things better and more efficiently with new machines resulting in tremendous increase in output. But this growth in output was accompanied by reverses in the quality of life of workers as much attention was not paid to the working culture. This in turn had an effect on quality of products. During the industrialization drive, owners were not concerned about the upkeep of the machines. They followed the policy of running the machines continuously and at over-capacity till they broke down and then maintenance was carried out to repair the machines. Hence it can be safely inferred that "Breakdown Maintenance" (also known as Reactive Maintenance) was the first type of maintenance to be introduced during the early 20th century. Wireman, 1990 defined Breakdown Maintenance as the maintenance strategy in which the repair is done after equipment failure / stoppage or upon occurrence of severe performance decline. Maintenance as an independent subject was not one of the focus areas during the Industrial Revolution. Another important feature was that even though mechanization was wholly adopted, the innovations came to a relative stand still in the early 20th century. The machines were simple and uncomplicated and there was no effort in trying to improve the design of equipments. The main disadvantages of Breakdown Maintenance were unplanned outages, excessive repair costs and requirement of major spares. As the maintenance of the equipment was deferred to the breakdown stage, any minor issues requiring replacement of a few components forced a major repair and overhaul job resulting in high repair spares replacement cost.

3.2 Preventive Maintenance

This state of affairs lasted till the 40s, when the 2nd paradigm shift took place. World War-2 altered the manufacturing scene and this time it was the US and not the British who was at the forefront. The US engaged in the war by deploying its arsenal of planes, ships, tanks and guns the manufacturing of which required continuous production lines and auxiliary manufacturing units. As they were to be used in war, the quality of these war equipments had to be of the highest standard as any malfunction could lead to a potential loss of lives. Each equipment contained numerous parts which were as complicated as the equipment itself and to produce these parts, auxiliary machines like grinding, drilling, turning and boring machines were required. To ensure that the machines run without breakdown, they were taken out of service at scheduled intervals and maintenance jobs like lubrication, cleaning, oil and belt replacement, replacing filters etc were

carried out. When the war ended, the Americans continued using this maintenance concept in industries and manufacturing. They realized that it is more economical to replace a part at scheduled intervals rather than waiting for the part to result in equipment breakdown and then replacing it as part of Breakdown Maintenance. This type of maintenance was defined as "Preventive Maintenance" (also known as Time-Driven Maintenance) and it resulted in lowering productivity losses. The main advantage of Preventive Maintenance was that by carrying out scheduled maintenance activities at pre-defined intervals, the maintenance team could also determine whether a particular component had worn out and required replacement. Ahuja and Khamba, 2008 has stated that Preventive Maintenance relies on the estimated probability that the equipment will break down or experience deterioration in performance in the specified interval and the preventive work undertaken may include equipment lubrication, cleaning, parts replacement, tightening and adjustment.

3.3 Predictive Maintenance

Preventive Maintenance was indeed a huge step forward from Breakdown Maintenance but still involved unnecessary repair costs. Parts listed down in the scheduled maintenance program for replacement may actually not require to be replaced. This necessitated development of "Predictive Maintenance" (also known as Condition Based Maintenance) program where-in the health of the equipments is monitored either on-line continuously or at regular intervals. R. Keith Mobley, 2002 defined Predictive Maintenance as a condition driven program that uses the actual operating condition of plant equipment and systems to optimize total plant operation. Brian Thorpe, 2008 says that the technique of Predictive Maintenance was in use in a limited way during the 1940s and the 50s when railroad companies and jet aircraft industries in the US were carrying out lubricant and oil analysis but it really took off in the late 1970s and the early 80s when handheld battery operated on-line vibration analyzers where used by industries to detect different modes of failures in machines. Predictive Maintenance involves techniques like vibration analysis, thermal radiography, on-line monitoring of process parameters, oil and lubricant analysis to detect the health of equipment and to determine when the equipment will fail. For example, vibration readings of motors can indicate among other things whether the motor is installed properly on its footing, whether the rotor is inserted properly inside the stator or whether the bearings are to be replaced or greased. By carrying out these measurements, failure of motors say due to seizure of bearings can be avoided. A successful maintenance program is one in which Predictive Maintenance techniques are used in conjunction with Preventive Maintenance. The cost of practicing both the techniques is justified as failure of equipment can lead to loses in millions of dollars if the equipment failure leads to shut down of the plant.

3.4 Corrective Maintenance

Preventive Maintenance schedules literally led to another form of maintenance called "Corrective Maintenance" in which the maintenance engineer would correct or set right the equipment by identifying and rectifying the fault in the equipment. Corrective maintenance action should be initiated on the occurrence of symptoms of impending failure which can be found out during Preventive Maintenance checks. To make the issue clear, suppose we have a PM schedule for motors which says that preventive maintenance has to be carried out every 6 months. One of the checklist points in the activity list would be to check the tightness of power cables of the motor. Now, assume that during tightness checks we find heating marks on the cable lugs and damage to cable insulation due to heating. This heating could be due to a variety of reasons- inappropriate size of lugs, lugs not crimped properly, poor quality of lugs etc. This problem if left unattended can lead to flashover in the motor terminals. It is during this stage of preventive maintenance that corrective actions like replacing lug with correct size of lug or proper crimping of cables should be carried out and this corrective action should be carried out on all motors. Ahuja and Khamba, 2008 has rightly stated that corrective maintenance improves equipment reliability, maintainability and safety, reduces deterioration and failures and aims at maintenance-free equipment.

3.5 Reliability Centered Maintenance

When Preventive, Corrective and Predictive Maintenance programs were being used as standards in industry, another form of maintenance program emerged in the late 1970s. In December, 1978 F. Stanley Nowlan and Howard F. Heap introduced the concept of "Reliability Centered Maintenance" or simply known as RCM in industries. Bill Keeter and Doug Plucknette, 2008 stated that the primary goal of Reliability-Centered Maintenance (RCM) should be to insure that the right maintenance activity is performed at the right time with the right people, and that the equipment is operated in a way that maximizes its opportunity to achieve a reliability level that is consistent with the safety, environmental, operational, and profit goals of the organization and this is achieved by addressing the basic causes of system failures and ensuring that there are organizational activities designed to prevent them, predict them, or mitigate the business impact of the functional failures associated with them. In RCM we first identify what is the performance expected from the equipment. This is then followed by preparing an exhaustive list of historical failures and probable failures that can happen in the future along with analysis on how these failures have occurred and recommendations to prevent these failures. The third step is to identify the effects of these failures and the consequences that they have on the equipment or the plant in which the equipment operates. Based on the severity, the consequences are prioritized. The final step is to device an action plan to prevent the failures starting from the failure which has the most critical consequence. The action plan may involve design modification, replacement of components or increasing the frequency of preventive or predictive maintenance. RCM is an on-going concept and implementation of the same requires committed top management support and willingness on part of the employees to go through the process. It is again pertinent to note here that RCM is not a stand-alone concept but has to be coordinated along with Preventive, Corrective and Predictive Maintenance programs.

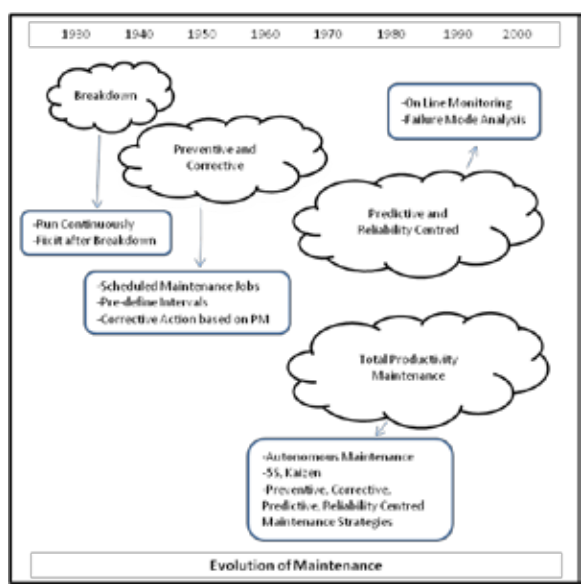

Figure-1

4.0 Emergence of Total Productive Maintenance

Before moving on to TPM, we should discuss two strategies that were instrumental in the emergence of TPM - Total Quality Management (TQM) and Productive Maintenance.

4.1 Total Quality Management

TQM is a concept aimed at exceeding customer's expectations with respect to the service or product offered by the organ-

ization. Even though it is simple, applying TQM in practice requires commitment of the top management and the employees of the organization. There are realms of papers and publications devoted exclusively to TPM but in this paper, the authors will touch upon the basics as a prelude to TPM.

Quality inspection has been in existence during the 1940s but it was basically a program involving statistical sampling of products and checking for quality with respect to the production line. The emphasis was only on production and not on the organization as a whole. Inspectors used to inspect the products and the production line and on finding any quality deviations would make the necessary adjustments in the production process i.e. quality issues were attended only after defects were identified. It was the Japanese in the second half of the 20th century who shook the industry by exporting low priced high quality goods. They were able to do this by incorporating organization wide quality systems designed to prevent production of poor quality products. Instead of looking for defects only in the finished goods, focused attention was given to the entire process of production from the design stage, production and right up to the finished goods. By doing so, any issues or problems which could have led to poor quality goods would have been identified and rectified early in the production line thereby reducing costs.

TQM forms a vital part of TPM. Hence it is wise to discuss the significant aspects of TQM before moving on to TPM. The main focus of TQM is on customers. Over the ages, customer acceptance (produce whatever you want; the customer will accept it) has given way to customer satisfaction which has now grown to customer delight. No longer is satisfaction an acceptable word, the competition is so fierce that the customers demand more. To keep up with the customer demand, the organization has to continuously focus on product quality by paying attention to the process quality. Any problem which can affect the quality of the product is to be identified proactively in the process line and the source of the problem is to be found out and rectified. The major advantage of this over the traditional method of finding defects in the finished products is in the tremendous cost savings that can be achieved by not having to rework the process. All of this is not possible without the active involvement and total commitment of the management and employees of the organization. Readers will notice that involvement and commitment are two words which are used continuously with reference to TQM and TPM as these two words are the key to successful implementation of TQM and TPM. Employees are the drivers of TQM, they are the ones who have their eyes and ears on the process and on the ground realities and hence can detect abnormalities. If employees are drivers, management is the driving force behind these drivers by motivating and cajoling the employees of the organization. Management's task is to instill in the employees sense of awareness and confidence in dealing with problems and to guide them in learning new techniques to find solution to these problems.

4.2 Defect Identification / Data Collection

One important technique used to prevent problems is to effect small improvements on a continuous basis rather than once-in-a-while big-bang reforms. Employees are encouraged and trained to get acquainted with the production process, look for defects and areas for improvement and to act to get rid of the defects. This is a never ending non-stop endeavor in pursuit of a defect-free process resulting in high quality products (This concept will again be talked about during our discussion on TPM). In addition to the technical details of the process or production line, employees are also trained to identify defects using specific tools like the Cause and Effect Diagram, Checklists, Flow Charts, Pareto analysis etc. We will discuss in brief some of the commonly used techniques.

1. Checklist is a common and simple tool used to determine the frequency of different discrete data categories. In Figure-2, the checklist shows the frequency of defects in production of dining tables.

2. Cause and Effect Diagrams popularly known as Fish Bone diagrams helps in identifying the causes for a particular problem. The head of the diagram indicates the problem; the bones indicate the major category of causes and the ribs the specific causes under each major category. By this method we exhaustively list down all the possible causes that can lead to the problem. Referring to Figure-2, the different causes for dining table to deviate from specifications are listed down under Materials, Machine, Manpower and Process.

3. A Process Flow Chart consists of rectangles, circles, arrows and other symbols connected by arrows showing the sequence of steps in any process. Each symbol signifies a particular activity. Flowcharts help to analyze the process and detect areas for improvement. A typical Flowchart showing shifting of a motor (bearings of which are replaced) to field is depicted below:

Date:	25.05.2012						
Process:	Replace Bearings of Spare Motor in Stores and Shift to Field						
Location:	Stores to Field						
Event Description	Symbol					Time (in Min)	Distance (in Mtrs)
Proceed to Stores		X				5	2500
Wait at Stores			X			10	
Lift and Shift Motor on to Truck	X					25	
Transport Motor to Workshop		X				5	1500
Wait for Personnel			X			15	
Draw Motor Bearings from Stores	X					15	
Inspect Bearings				X		5	
Replace Bearings in Motor	X					360	
Wait for Power Supply Source to be free			X			15	
Run Motor to check for Vibration	X					30	
Place Motor in Delivery Area					X		
Wait for Crane			X			20	
Shift Motor to Field		X				15	7500
Install Motor on Base	X					60	
Terminate Power Cables	X					30	
Wait for Operations Personnel			X			10	
Run the Motor	x					5	
						625	11500

Summary		Number of Steps	Time (in Min)	Distance (in Mtrs)
Operation		7	525	
Transport		3	25	11500
Delay		5	70	
Inspect		1	5	
Store		1		
			625	

4. The **Pareto Analysis** follows the 80-20 principle which states that majority of the problems (read 80%) are caused by a few major causes (read 20%). It is ability of the work force to detect these major causes that will help in alleviating the quality problems. The Pareto Chart reveals that the major cause of the dining table to deviate from specifications is "Parts Not as per Specification".

5. Bar Charts consist of rectangular bars the height of which represents the value of the concerned variable. The bar chart can be developed from a checklist with the Y axis showing the frequency of the different discrete data categories.

6. Scatter Diagrams or Plots are used to plot pairs of variables to determine relationship between the variables. The independent variable is drawn on the X axis while the dependent variable on the Y axis. By looking at the plots, it can be determined whether any relationship exists between the variables. For example, the scatter plot shown in Figure-2 depicts the relationship between Daily Sales of cold drink versus Mean Daily Temperature

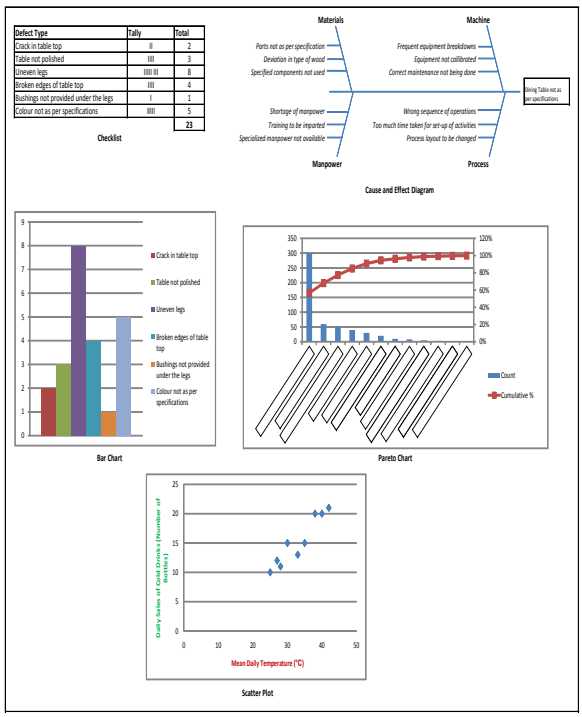

Figure-2

The preceding paragraphs were devoted to the process and not much focus was given to the product. In fact the process is an offshoot of the product design. Any process can be developed only if the product requirements are clearly spelt out. Two or more companies may have the same type of product with similar specifications, but it is the company which pays more attention to both the product and process design that can capture the customer. TQM uses a technique known as Quality Function Deployment (QFD) which translates customer requirements to improvements in product design. We will not be going in depth about QFD as it is a subject in itself but it will suffice to say that the technique takes into consideration the customer requirements, the relative importance of the requirements, defining the product characteristics, comparing the customer requirements with the characteristics and comparing the company's product in terms of the characteristics with its competitors. The bottom line is that the product has to be defined carefully vis-à-vis the customer requirements and then the finished product has to be analyzed with respect to customer feedback and the competitors using QFD to effect improvements in the process to upgrade the product.

We have talked about Process and Product but we still have to talk about Suppliers. Without good quality raw materials (the starting point of any process), a company cannot maintain defect free process and produce quality products. There are several ways to ensure quality raw materials like inspection during delivery, ensuring the supplier follows quality management programs, carrying an audit of the supplier or stationing company's representative at supplier's works. Majority of the companies have shifted from the traditional practice of inspection to complete involvement in the suppliers manufacturing system to ensure quality products are delivered without rejection.

4.3 Productive Maintenance

TQM was practiced along with another approach - Productive Maintenance which is the strategy of improving productivity of the equipment by reducing costs over the entire life cycle at each stage right from design, manufacture, operation and maintenance and by following Preventive, Predictive and Corrective maintenance strategies. What this means is that the organization uses all the methods at its disposal to improve equipment productivity whether carrying out design modification or running the equipment at its optimal capacity or by scheduling preventive maintenance specific to the equipment. There are many parallels between TQM and Productive Maintenance. All aspects of TQM are relevant to Productive Maintenance. Productive Maintenance combines TQM philosophy with the maintenance strategies (Preventive, Predictive and Corrective) of maintaining the equipments to reduce costs.

Now that we have talked about maintenance strategies, TQM and Productive Maintenance it is time to move on to TPM. The 1st paradigm shift in maintenance happened in Britain, the 2nd paradigm shift in the USA and now was the time for the 3rd paradigm shift which was to take place in Japan. A small revolution was brewing in Japan in the manufacturing field to reduce costs and at the same time to improve efficiency, reliability and quality. The Japanese had been using the American concept of Preventive Maintenance since the 1950s but due to automation and the increased complexity of the equipments and machines, was encountering high costs as a result of increase in maintenance force to maintain the equipments. To alleviate this problem, they started looking at ways to reduce costs and hit upon the idea of expanding the domain of work of the Operations team. Nippondenso, an automotive component manufacturer in 1960 was the first Japanese organization to radically change its work culture by asking its operators to do the simple routine maintenance of its machines. Thus was born the culture of "Total Productive Maintenance" commonly known as TPM. The main emphasis in TPM is to persuade the operating personnel to carry out the regular daily maintenance while the maintenance crew would carry out specialized maintenance, upgrades and modification jobs to minimize failures thereby increasing machine availability, reducing costs and improving profitability of the organization (Prasanth et al. 2013).

5.0 Key Concepts of Total Productive Maintenance

Let us look at the main concepts behind TPM. Experts in TPM talk in terms of pillars of TPM. In this paper we deviate a bit in the sense that we touch upon all the key concepts without using the "pillar" phrase.

5.1 Top Management Commitment

In the preceding paragraphs, we talked about Productive Maintenance as the culture of improving productivity over the entire life cycle of the equipment. This concept is extended to TPM in a way that the onus for improving productivity now does not rest with the maintenance group alone but also with the operating personnel. The whole organization right from the top management to the lowermost worker level across all streams of discipline is involved in TPM. Hence the word "Total" is added to Productive Maintenance. The thrust for TPM is given by the top management whose unconditional support and whole-hearted participation is crucial for TPM to be successful. TPM requires companywide awareness and is to be treated as an independent discipline with dedicated staff members for its successful implementation. Both the management and the employees should be prepared to put in their unstinted effort and long term commitment.

5.2 Goals and Targets

For TPM to be successful, the employees must have a clear goal explicitly and precisely stated in numbers and figures. Identification of specific, deliverable, measurable and quantifiable goals and targets is an important element of TPM. Employees should be aware of what the organization wants to achieve. Parameters on which results are to be measured are to be clearly defined. For example: Reduce manufacturing costs by 25% or Obtain 90% overall equipment effectiveness. Once the numbers are clear, the organization is geared up to face the challenges all out to deliver the goals and to do this, it needs a roadmap showing the direction to proceed. The roadmap starts from the top management who would provide organizational level goals. These goals will be specific at the level of the organization like: Reduce Fuel and Loss by 1%. The organizational goals will then have to be broken down to departmental specific goals. The job of Technical Services is to prescribe and issue standards and operating procedures to

bring down the fuel and loss. Operating team will have to follow these procedures and report any deviations in terms of the process back to the Technical Services team. Maintenance will have to ensure that the necessary design modifications are carried out so that the equipments are run more efficiently. Hence it can be seen that the goals can be attained only by a sustained team effort.

5.3 Teams

TPM can be accomplished only through team work. Self-directed trained teams and sub-teams are formed comprising of employees from different departments to get a wide array of view points and solutions to tackle issues. As these teams are trained in the design, operation and maintenance of the equipments under their control, they get a holistic view of the equipment with emphasis on the importance of interdependence of the various parts of the equipment. Self directed teams function without managerial supervision but they are empowered by the management to take decisions related to the work they are involved in. The members of the team are accountable for their actions and have a common understanding of what to achieve. Each member uses his or her expertise in achieving the team goal. The team defines its goals based on the organizational goals and hence directly or indirectly influences the organizational goals. Setting a goal independent of directives of the organization is meaningless as the ultimate aim of the team is to achieve the targets set by the management.

5.4 "5S"

Having identified their area of work, the first set of activities that the teams must do in TPM is to follow a set of actions grouped under what is called as 5S which is basically a method for work place organization. The five words under 5S are Japanese words starting with the letter S:

1. Sieri / Sort: Being systematic or removing the clutter by sorting out the required items as critical / not critical and required / not required from the items present in the workplace

2. Seiton / Set-in-order: Systematically arranging the required items at their designated places so that they can be easily accessed

3. Seiso / Shine: Cleaning the workplace and keeping it spic and span

4. Seiketsu / Standardize: Implementing and maintaining standards for orderliness in the work place, environment and equipments

5. Shitsuke / Sustain: Having self-discipline and commitment to practice 5S as a way of life

It can be easily seen why the above activities are essential whether or not an organization practices TPM. These activities which are crucial for TPM need not be confined to TPM alone. Organizations who have not implemented TPM should implement the 5S activities to improve their efficiency and productivity. What these activities imbibe in an organization is a disciplined approach to work practices. Disarray at work place is a major impediment to get work started. Employees get motivated to work by cleaning the work place and systematically sorting out and arranging the required critical items. The motivation to continue to do work comes from following standards and having the will power and strength of mind to keep practicing the 5S activities.

5.5 Kaizen

Let us discuss another practice integral to TPM which we have touched upon briefly in our discussions on TQM. Kaizen is the Japanese name given to the practice of carrying out small improvements on a regular basis and to continue to do better through learning, training and problem solving. The Japanese believed that everyone should continuously strive to attain perfection by improving upon their performance. They advocated the principle of detecting defects, however minor, then acting upon them and continue to find out other defects. By doing so, employees can recognize and eliminate waste resulting in improvement in productivity and efficiency and reduction in production costs. According to the Kaizen concept, an organization will always have problems and it is up to the workforce right from the top management to the worker level as a team to challenge the state of affairs and work ceaselessly to mitigate the problems. Two widely used techniques used in the Kaizen approach are:

1. PDCA cycle: Plan-Do-Check-Act cycle is a very straight forward but an important technique used in ferreting out defects. The first step in the cycle is to make a thorough evaluation of the current methods, practices and procedures followed and to identify the problems. A "plan" for mitigating these problems is developed. The second step is to carry out the plan i.e. "do" the job. When the job is being done all the parameters will be recorded and documented. The third step is to evaluate and study the documented records to "check" whether the action that was initiated has alleviated the problem. If successful, the fourth step of "act" will be put in place. This is nothing but revising the standards and work instruction manual to effect the changes in procedure so that the problem does not repeat again. This cycle will be followed by PDCA cycle for another problem and so on. Standards are kept revising to prevent repeat of occurrence of the problems.

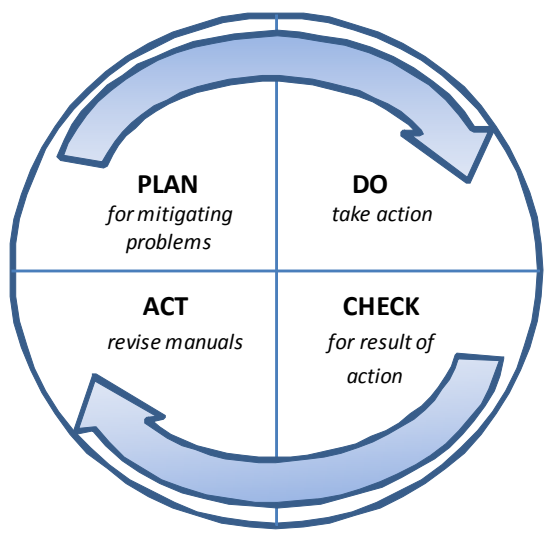

Figure-3

2. Benchmarking: This is the practice of comparing the organization's work practices against practices followed in best-in-class organizations. By setting the practices of the benchmark companies as the standard, organizations can learn to do things better and aim to continually improve their practices by finding out what these companies did to reach their world class status. It is worthwhile for organizations to emulate the best-in-class practices. Benchmarking need not be limited to the companies in the same industry as the organization as the practices followed by the organization might be followed by a totally different industry. The bottom line is that organizations carry out benchmarking to learn and adopt new practices to continuously improve upon their performance.

5.6 Losses and OEE

In TPM, we talk about productivity which is the measure of efficiency of production and is equal to output divided by input. Similarly equipment efficiency shows how efficient equipment is in running at its designed output. In an ideal world, productivity and efficiency would be 100% but in real life we

have losses, scrap and waste. Loss equals money lost and the endeavor of any organization is to reduce losses. There are around 16 losses identified in TPM out of which 6 major losses are as given under

• Down Time Losses consisting of Breakdown and Set-up and Adjustment losses. The losses are termed down-time because these losses prevent equipment from running its intended duration.

1. Breakdown Losses occur as a result of failure of equipment or reduced functioning of equipment below the normal level. This may be due to unanticipated equipment breakdown or unplanned maintenance or even due to sudden failure of a component of the equipment.
2. Set-up and Adjustment Losses are due to changeover in set-up of the production line to produce a different type of equipment. The losses can also be due to material shortage or unavailability of operator to activate and maintain the production line.

• Speed Losses are so called as these losses prevent the process from running at its ideal cycle rate i.e. its name plate capacity. The two types of speed losses are

3. Reduced Speed Losses result from running the process under the name plate or design capacity
4. Idling and Minor Stoppage Losses which occur due to short duration shortages as a result of temporary malfunctions blockages, jamming etc in the production line and which typically does not require intervention of maintenance personnel for rectification.

• Defect or Quality Losses arise when the produced output does not conform to quality standards and specifications. The two types of defect losses are

5. Process Defects due to faulty equipments in the production line leading to defective quality products and increase in scrap and rework.
6. Reduced Yield Losses arising in the production line during the early stages and start-up.

We can now calculate a number known as the "Overall Equipment Effectiveness" in terms of availability, performance and rate of quality products. In this respect we have to define a few terms:

• Availability Rate is defined in terms of the time the equipment is actually running (Operating Time) versus the time it should have been running (Planned Production Time). From the Planned Production Time, if we deduct the Down Time Losses (Breakdown + Set-up and Adjustment losses), we get the Operating Time. Hence

Availability Rate (A) = Operating Time / Planned Production Time

• Performance Rate is a measure of how the equipment is performing. Cycle Time is the time taken to produce one piece. Performance rate is defined as the Ideal Cycle Time divided by the Actual Cycle Time. Ideal Cycle Time is the theoretical minimum time to produce on piece while Actual Cycle Time is the time actually taken to produce one piece and is calculated by dividing the Operating Time by the actual number of processed pieces. Hence

Performance Rate (P) = Ideal (Design) Cycle Time / Actual Cycle Time
= Ideal Cycle Time / {Operating Time / Actual Processed Pieces}
= {Ideal Cycle Time x Actual Processed Pieces} / Operating Time
We can calculate Performance Rate by making use of Net Operating Time which is defined as Operating Time minus Speed Losses.

Performance Rate (P) = Net Operating Time / Operating Time
If you see both the definitions of Performance Rate, you will notice that both are one and the same. This is because the "actual processed pieces" is a direct function of the capacity at which the equipment is run (speed of the machine) and the duration for which the equipment is stopped for minor stoppages.

• Quality Rate is the ratio of good pieces out of the total number of pieces. Hence

Quality Rate (Q) = {(Ideal Cycle Time x Actual Processed Pieces) - (Ideal Cycle Time x Scrap Pieces)} / (Ideal Cycle Time x Actual Processed Pieces)

We can calculate Quality Rate in a second way by making use of Fully Productive Time defined as Net Operating Time minus Defect or Quality Losses

Quality Rate (Q) = Fully Productive Time / Net Operating Time
Here also both the definitions of Quality rate are the same. The Fully Productive Time is time taken for manufacture of quality goods after removing the scrap goods.

Overall Equipment Effectiveness is measure of how much planned production time is fully used or how efficiently a machine is running. The beauty of OEE is that it combines maintenance, operations and quality management to calculate a ratio which will help the organization in taking decisions to reduce losses and drive productivity.

OEE = Availability Rate x Performance Rate x Quality Rate
OEE = (Op Time / Planned Production Time) x (Net Op Time / Op Time) x (Fully Productive Time / Net Op Tim)
OEE = Fully Productive Time / Planned Production Time

The above concepts are shown in a diagrammatic representation given below:

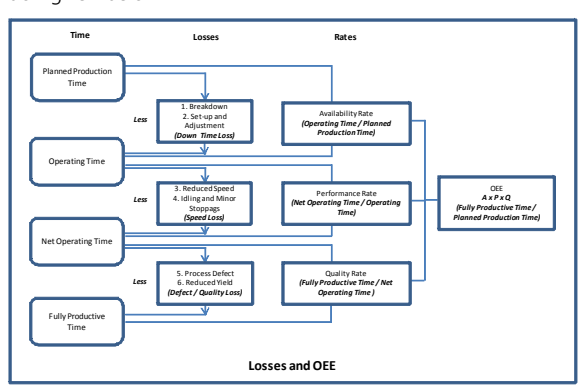

Figure-4

5.7 Autonomous Maintenance
In TPM, the regular maintenance of equipments like cleaning, replacing oil, greasing and lubricating is carried out by the operating personnel while the maintenance group will be actively involved in the more complex task of developing maintenance programs and schedules, equipment design modifications and carrying out reliability focused maintenance for maintaining the health and ensuring maximum availability of equipments. This is known as autonomous maintenance. Kulkarni and Dabade, 2013 stresses on the perspective that being more inclusive, TPM makes use of the operator's relationship with the machine for routine and simple maintenance activities and also includes input from managers, engineers and QC experts as well. What this means is that being near the equipments through the day, it is easy for the operator to carry out the regular maintenance jobs as he is more familiar with the

equipments than his maintenance counterpart. The jobs required to be carried out by the operations team is not complex; it includes activities like

1. Cleaning the equipment and its surrounding by removing unwanted materials and debris
2. Regularly maintaining equipment cleanliness
3. Identifying sources of contamination and defects
4. Rectifying and preventing normal defects instead of depending on maintenance
5. Conducting regular inspection
6. Carrying out lubrication and greasing of the equipment
7. Checking carefully using the operator' senses to detect any minor issues which otherwise would have gone undetected

5.8 Maintenance Strategies

The operations team having taken care of the routine maintenance, it is the job of the maintenance team to carry out scheduled maintenance practices as per the strategies chosen. All the maintenance programs (with the exception of Breakdown Maintenance) that were discussed earlier in this paper are employed in TPM. Organizations follow a combination of Preventive, Predictive, Corrective and Reliability Centered Maintenance strategies. These programs are carried out in response to the OEE number. Lower the OEE number, greater emphasis to be placed on the maintenance programs. As OEE gives us the productive time equipment is run, an organization should use an optimal combination of the maintenance strategies to reduce breakdowns and to improve the equipment availability and efficiency. The organization in addition to the maintenance plans should simultaneously focus on the product quality using the TQM approach by using specific tools like QFD.

5.9 Training and Education

The success of TPM implementation is directly dependent on the competency, skill, aptitude and proficiency of the organizational work force. Organizations opting for TPM should be willing to invest in training and imparting education to the employees. Suzuki. T, 1994 has impressed upon the fact that an organization should identify the specific knowledge, skills and management abilities that it wants its employees to have and then design suitable training to develop these skills. Management has to carry out gap analysis of the employees to determine what more is required to upgrade the present competency to that required for TPM. It then has to identify the training needs of the employees based on the gap analysis, develop suitable training programs, execute the programs and finally evaluate the employees to determine whether the training was successful in imparting the required knowledge. In addition to the technical training, management should also impart behavioral training to transform the mindset of the employees from their traditional concepts of operation and maintenance to the revolutionary concepts of TPM. Education and Training form two major foundation stones of TPM.

5.10 Safety, Health and Environment

Another major foundation stone is Safety, Health and Environment. By implementing TPM, one major outcome is the reduction of accidents by practicing 5S and the mandatory maintenance practices. Technical and behavioral training programs are complemented by safety training where the employees are trained on material handling, managing emergencies and usage of Personal Protective Equipments (PEE) like safety shoes, helmets, ear plugs etc. Executing TPM will result in safe working environment, safe machines and a major drop in accidents. Operators are trained to carryout routine maintenance activities while the maintenance group is given advanced courses in equipment maintenance. A very important offshoot of TPM is the reduction in environmental pollution levels. During the age of breakdown maintenance, attention was not paid to the environmental aspects. Oil and lubricant spillage was tolerated, emissions were not checked, noise level not monitored and leakages were not attended. These had an adverse impact on the environment. With the advent of TPM, environmental issues were being addressed at the design stage itself with the intention of lowering the environmental pollution. Maintenance schedules were tightened to prevent leakages and advanced monitoring systems were installed.

5.11 Office TPM

For TPM to be successful, the administrative support function should be in place. "Office TPM" is the application of TPM principles in the organization's administrative function and it ensures that the function provides an all round support to the manufacturing process. Some of the major departments in the administrative function include Human Resources, Information System, Purchase, Marketing, Corporate Communication and Finance departments. Human Resource ensures that the required qualified manpower for TPM implementation is in place. It is the job of Finance to take care of salaries and remuneration. Purchase department makes sure that raw materials are available on time for the production process while the Marketing department undertakes responsibility of finding customer for the product. By putting Office TPM in place, some of the changes that take place in the administrative support function are given below:

1. Systematic arrangement of work flow in the administrative departments and better utilization of work place
2. Fixing responsibility for each category of work like salaries, leave entry, computerization etc.
3. Increased flexibility to attend to requirements of manufacturing process
4. Reduction of inventory costs as the Purchase and Marketing departments are in sync with the production line
5. Repetition in work is avoided as all the employees are clear of their role
6. Reduction in equipment breakdowns and in complaints pertaining to administrative functions
7. Reduction in office overheads like electricity, water, communications, janitorial, advertising expenses etc.
8. Computerization ensures that the process parameters are available on-line thereby ensuring quick corrective response for any malfunction

5.12 Work Culture

To facilitate the concepts discussed in the previous paragraphs, it is essential that the organization should undergo a transformation in its work culture. The cultural, social and organizational barriers must be brought down. Management and employees must learn to trust each other. Ideas should flow freely both horizontally and vertically in an organization. There should be voluntary exchange of data and information among the departments to generate new ideas. As Mohamed Ben-Daya et al., 2009 says the biggest challenge before any management is to be able to make radical transformation in an organization's culture for ensuring overall employee participation towards manufacturing performance improvement through TPM initiatives. Employees must view themselves working for the organization and not for the department. It is the task of the management to align employees to the organization's vision and goals. Organizational work culture is always resistant to change and it is this resistance that the management must overcome. In the present system of operating a plant, the operations group does not consider routine maintenance jobs as part of its portfolio. How many times have we heard in organizations – "This is not my job. I will not do the maintenance, it is your job". It is this thinking that has to be transformed in TPM. The work culture has to undergo an attitude reform so as to alter the organization's outlook from a departmental view point to an organizational view point.

6.0 Wrapping it all up and the Journey Ahead

We had embarked on a journey right from the 18th century when people used carry out simple menial farming jobs to sustain their livelihood till the present age where-in sophisticated tools, and systems are being used for improving productivity. The period from the 18th to the 20th century witnessed the industrial revolutions and advent of mechanization, electric power, assembly line and mass productions in order to meet increased demand. New practices and techniques have

evolved to enhance process efficiency. Simultaneously quality grew in importance leading to quality management programs and improved and innovative maintenance techniques. Total Productive Maintenance led to a revolutionary change in work culture to enhance output and its efficiency.

For all the benefits associated with TPM, industries have found it very hard to implement the same, the primary reason being the inability to grasp the concepts of TPM fully and the long term commitment required on part of the management for successful implementation. Resources have to be committed and the organization has to adapt itself to the prerequisites required for implementing TPM. There needs to be a radical change in the outlook of the organization and it should view the expenses spend on TPM as an investment which will yield profits in a couple of years. To move ahead in the competitive environment, organizations have to embrace TPM as an important tool to boost productivity, efficiency and ultimately profitability.

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