ACTION PLANS FOR IMPLEMENTATION OF TOTAL PRODUCTIVE MAINTENANCE

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ABSTRACT

Maintenance is an inevitable function in manufacturing plants. Manufacturing plants are exposed to newer and rapidly changing paradigms. Today, a productive maintenance strategy and programs have utmost importance in order to discover the useable but hidden resources in an organization. A well-conceived action plan is a pre-requisite to unearth those potential treasures. This paper presents a brief action plan for implementation of total productive maintenance (TPM). From an empirical study, conducted by these authors, it is revealed that demanding quality in maintenance practices is still a far cry. Lack of understanding of the method and implementation guidelines appear to be the major factors responsible for this state. Therefore, it is strongly felt that TPM deserves more attention both in practices and research.

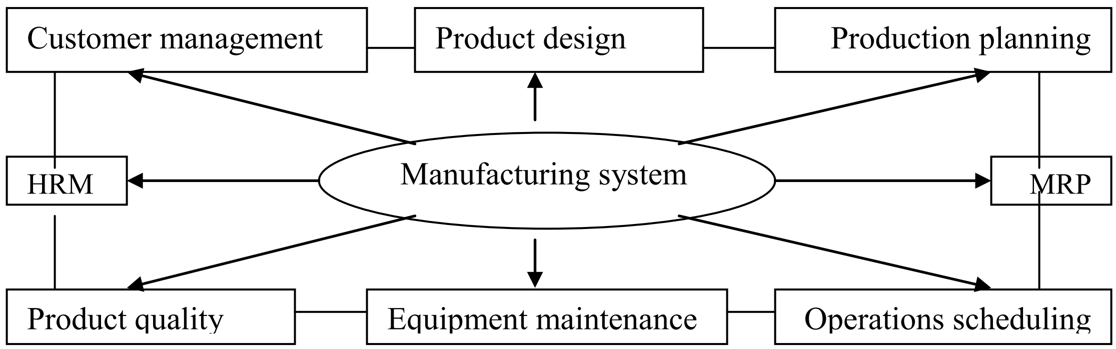
Keywords: TPM, Major losses, implementation, action plans

1. INTRODUCTION

Generally speaking, the objective of equipment maintenance is to reduce the adverse effects of breakdown and to maximize the availability of facilities at a minimum cost (Lofsten, 1999). But maintenance is often considered as a secondary process in firms and the management has a view that it is as if a *curse* and its costs cannot be controlled. Traditionally, maintenance is seen as a necessary evil, not a means to reduce costs (Paz and Leigh, 1994), and it is an inevitable cost center. The cost of traditional maintenance is obviously very high that consumes a significant part of the operating budget of an organization with heavy investments in plant, machinery and equipment (Cross, 1988; Dekker, 1996). The estimated cost of maintenance ranges between 15 and 40 per cent of production costs (Dunn, 1987) with an average of 28 percent (Mobley, 1990). Understandably, conventional maintenance accrue high costs but its efficiency is low (Sheu and Krajewski, 1994).

Maintenance is an indispensable function of a manufacturing plant (Figure 1), and it is the major contributor to the performance and profitability of manufacturing systems (Kutucuglu *et al*., 2001). Its importance is increasing (Maggard and Rhyne, 1992) as there is an increasing trend towards automation and integration of manufacturing system i.e., installation of advanced manufacturing technology (AMT) (*viz*. CIM, FMS). These modern technologies are sophisticated in nature and costly to avail. But as a manufacturing system is required to be profitable, cost-effective, flexible, speedy and productive enough to promise quick delivery of customized products *vis-à-vis* employee and environment friendly, the role of AMTs is vital. In such backdrops, proper maintenance of equipment/machinery deserves intense attention. Good maintenance is fundamental to a productive manufacturing (Besterfield *et al*., 1999) to discover a lot of potential working hours (expands capacity) and to save a lot of money (cost reduction). To stay competitive in the prevailing and increasing global market productive maintenance a strategic issue. In manufacturing, the general understanding should be that profitability begins from good machines/equipment conditions.

Good maintenance can be ensured by incorporating the philosophy and principles of total productive maintenance (TPM) in organizational practices. This will benefit the extension of working life of a machine, ease regular smooth handling and functioning, reduce/eliminate a number of equipment bound losses and enhance operators' morale. Not only in equipment maintenance, can the entire plant be maintained in a continually improving environment under TPM. Further, TPM can be implemented as a complementary to any other modern production management techniques, *viz*. TQM or lean production (JIT).



HRM = human resources management; MRP = material resources planning.

Figure 1: Manufacturing functional areas

However, the nature and extent of maintenance function may greatly vary from firm to firm, even equipment to equipment. Therefore, a set of action plans may not be suitable for all organizations. The action plans suggested here should be regarded as general guidelines and could be adapted as per the demand of an organization.

2. LITERATURE SURVEY

Over the last few decades and even today, manufacturing machines/equipment has been largely maintained after a reported breakdown – the traditional form of repair. External maintenance crops are hired to repair a machine that often face tight work schedules. They are engaged to do the repair work after an occurrence while the production line had to put off. This is too costly as it often causes delivery slippage and affects the product quality. The cost of manufacturing is often on the rise under this environment. Certainly, it diminishes workers' morale.

Now, the relatively *new* philosophy in this area is termed as Total Productive Maintenance (TPM). It logically assumes that in many opportunities or brainpower and problem-solving abilities of the employees (human treasure/capability) are under utilized or unused. The scenario in case of equipment might be similar. TPM is to tap into those opportunities or resources. TPM is thus always an optimistic approach as it aims to solve problems through the participation of employees. Appropriate implementation of total productive maintenance (TPM) offers tremendous potential in improving, not only the equipment efficiency and effectiveness, but in areas of quality, flexibility and employee-work friendliness as well. Besterfield *et al*., (1999) wrote, "TPM is keeping the current plant and equipment at its highest productive level through cooperation of all areas of an organization". The TPM philosophy is that each piece of equipment is giving some signals before it comes to a halt. Now, if the equipment user (worker) is skilled enough to receive and interpret the signal(s), the unintended downtime of equipment could be avoided or kept to a minimum. For this the worker has to be well conversant with his equipment/machine and should be authorized to exercise some power to take the necessary actions. Another idea is that if the equipment is used in a clean and tidy condition, what is really easy to maintain, a lot of maintenance works can be prevented.

The domain of TPM is viewed into three interrelated areas: preventive maintenance, predictive maintenance, and autonomous maintenance. Preventive maintenance is the process of periodically performing activities on the equipment 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, in quest of continuous improvement and good equipment conditions. TPM actions are proactive in nature. Therefore, a TPM organization cannot be a traditional one with application of *just in case* (JIC) traditional action. TPM implementation brings new ways of thinking, idea generation, communication, and work environment. It requires horizontal type of organizational structure armed with a few authority levels instead of conventional vertical type having too many authorities.

For the successful implementation of TPM, the Japanese 5S housekeeping principles, *seiri, seiton, seiso, seiketsu,* and *shitsuke* are very useful. In English, they are organization, neatness, cleaning, standardization, and discipline respectively. Their messages are universal. They epitomize good habit, good attitude, and disciplined work environment. In any available management techniques (viz. TQM, *Kaizen*, JIT), the 5Ss principles could be prescribed. Without the 5Ss movement, none of the other campaigns and innovations that have been invented for better working conditions and superior products will be less than very good avail. However, to implement 5Ss, it requires perseverance and determination. A detailed description of 5Ss is beyond the scope of this paper. A brief description on the 5S activities and how they affect the company's productivity is given in Table 1.

The 5S activities should be encouraged among equipment operators through *small group activities* by ascertaining their total participation instead of frequent directives from the management. The question of autonomous management thus arises. Without 5S activities, TPM structural plan cannot be carried out properly. A plan of *5 minutes equipment 5S* or *10 minutes 5S* may be recommended. Hopefully, such activities would help develop the feeling of autonomous management among workers, and management could spend more time on other important issues.

Manufacturers should intuitively know the TPM philosophy. But lack of understanding and action plans impedes them incorporating this into their practices. This is revealed from several studies (Ahmed and Masjuki, 2001; Paz and Leigh, 1994). So, this paper attempts to draw a set of general action areas for better maintenance function. However, the TPM is not a matter of 'quick-fix'. It takes time to cater the full benefit, depending on the size of organization, style of current management, and complexity of equipment handling.

Table 1: 5S typical activities

The 5S ACTIVITIES		
Theme	**Typical activities**	**Typical activities**
Organization (Seiri) Stratification management in dealing with the 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. Organize the warehouse 7. Eliminate grime and burrs. 8. Eliminate oil pans.
Neatness (Seiton) Functional storage and elimination need	1. Everything has a clearly designed place. 2. Thirty second storage and retrieval. 3. Filing standards	6. First in first out. 7. Neat practice board 8. Easy to read notice

to look for things.	4. Zoning and placement marks. 5. Eliminate lids and locks.	9. Straight lines and right angles 10. Functional placement for materials, parts, cart, shelves, tools, equipment, and everything.
Cleanliness (Seiso) Cleaning as inspection and degree 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. Color coded pipes 7. Oil labels. 8. Warning colors 9. Open and shut directional labels. 10. Voltage labels. 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. Preventing noise and vibration. 21. 'I can do it blindfolded' placement. 22. 5S cleanliness. 23. Park-like plant layout.
Discipline (Shitsuke) Habit formation and a discipline 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.

3. IMPLEMENTATION OF TPM

In a non-TPM organization, a lot of changes are invited in order to have a full-blown TPM system. So, it cannot be attained overnight. Depending on the size of the organization in terms of number of equipment, complexity of equipment handling, and availability of skilled manpower, it takes 1-3 years to create a 'total' TPM organization. However, a strategic plan is required for its proper implementation. The major elements of its implementation in order are the understanding and development of awareness about TPM, identification and classification of problems, development of human resources and formation of small groups, collection of data on losses and flow of information, identification of engineering methods for their minimization, implementation of those methods and evaluation by statistical analysis and interpretation, documentation, and measures for further improvement. The major functions involved in development of a TPM system are listed in Table 2.

Table 2: 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 & lubrication standards	d. general inspection of equipment	e. autonomous inspection	f. organization & orderliness, g. autonomous activities
Education & training	Basic training on cleanliness, use of nuts & bolts etc.	Training in handling keys & bearings, power transmission system, hydraulics pneumatics & sealing	Training in operations and maintenance methods: loss calculations	Training in analysis and evaluations
Startup	Startup maintaining	Functional analysis; cost	Maintenance prevention	Evaluate economic

maintenance & economic evaluation	records	reduction analysis; design standards	analysis: standardization of practices	efficiency

Maintenance plans for different terms (short, medium and long) can cover these phases. Large-scale revamping, overhauling of specific machine, and re-engineering type of maintenance activities could be put under long-term planning. In case of short-term plan, starting from daily maintenance work, it could be annual plan in question. Based on an annual plan, month-wise and weekly maintenance plans could be prepared in advance. For example, maintaining equipment reliability over its predicted lifetime from installation to scraping may be brought under the annual plan. However, prevention of breakdowns and improvement of functionality could be placed within the monthly plan. Different activities can be grouped in order to ease work assignment to an individual or a team. Activities, like cleanliness and discipline should be followed everyday.

The style of management: traditional vs. current need

TPM system cannot work within a framework of traditional bureaucratic style of management. Traditional "I operate and you fix" maintenance strategy invites external repair crews to bring back the machine in operative condition after its breakdown. The communication channel is one directional from the management to employees. Delegation of authority through small groups that would commensurate with the desired responsibilities is an important bearing for a TPM type management. The conventional can be replaced by "I operate and I repair" style which is exhibited (Figures 2). A typical division of responsibilities of different tires of management is also shown in a pyramidal diagram (Figure 3). An example of breaking up of various stages of planning is exhibited in Figure 4.

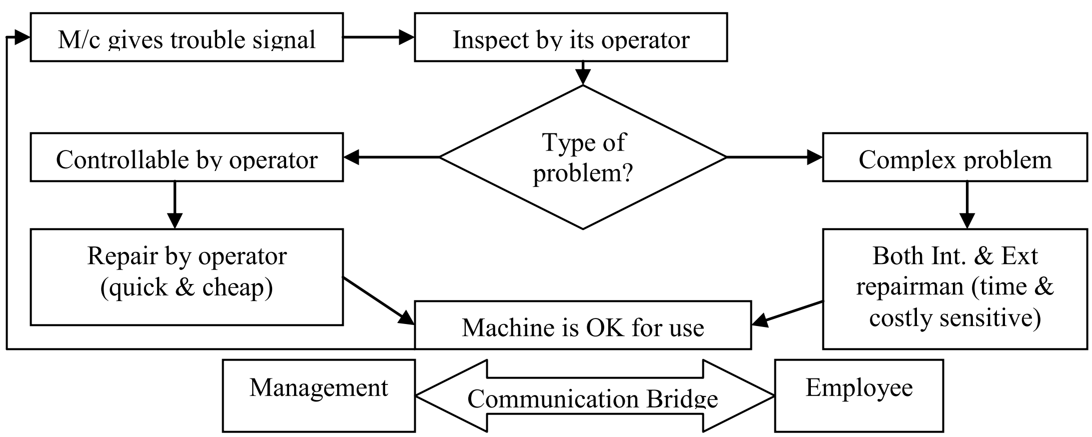


Figure 2: "I operate and I fix" confidence strategy and both way communications (suggested model)

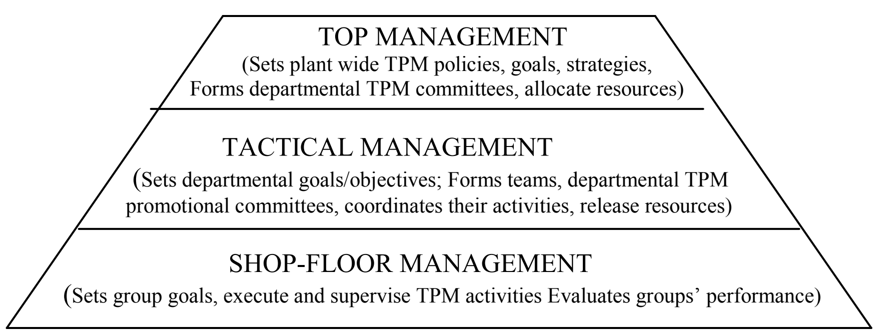


Figure 3: TPM Management responsibilities

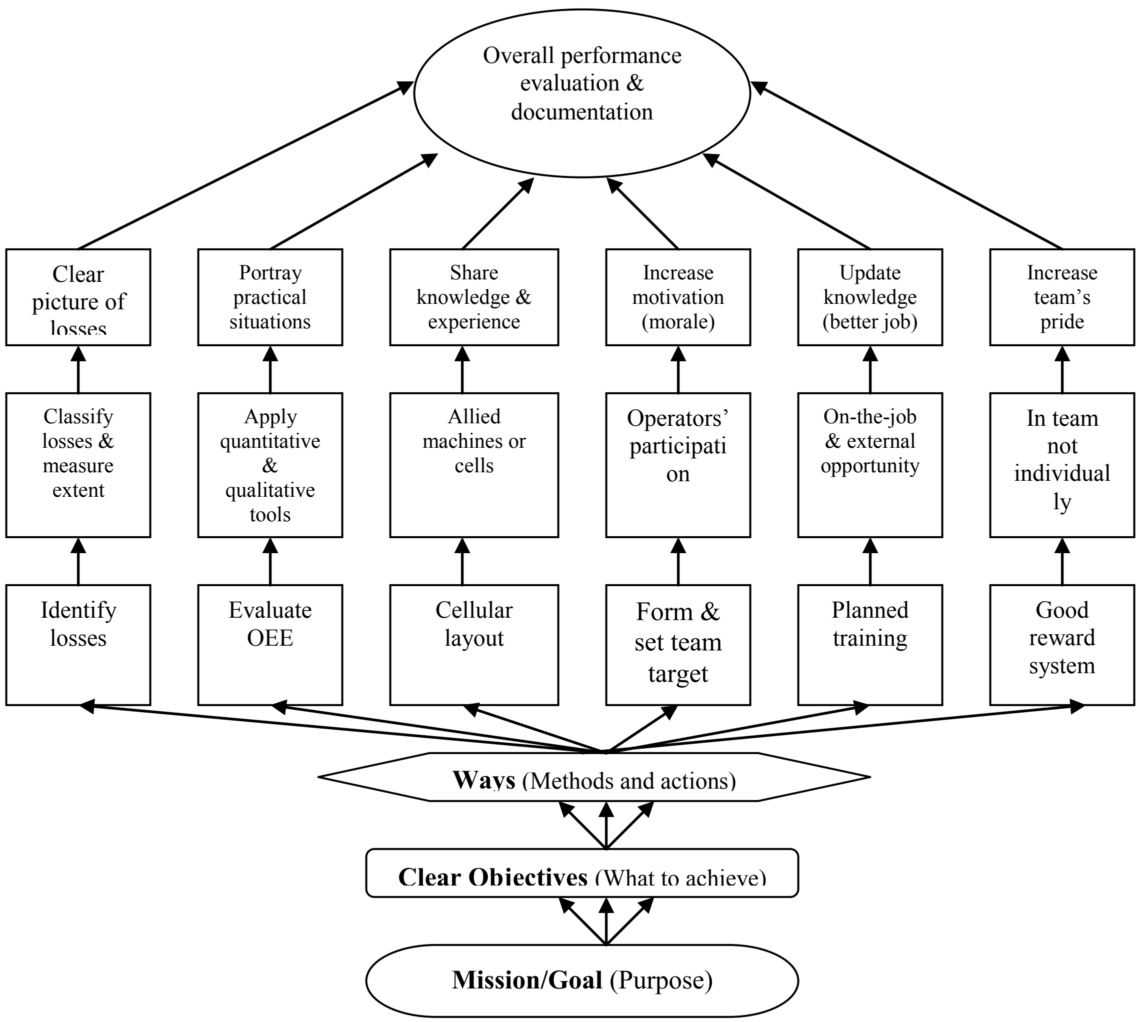


Figure 4: A systematic approach - condensed tree diagram

Small group activities and maintenance skill development

In TPM environment, productive maintenance could be achieved through skilled small groups by self-participatory management. The small group idea could be taken as the unique feature of TPM. These small groups should be integrated within the organizational structure to enhance productive maintenance activities within the corporate policy (Odaka, 1975). Japanese institute of plant maintenance (JIPM) promotes use of these small groups as autonomous groups. Small group activities are combined effects of American formal ZD (zero defects) and Japanese informal QCC (quality control circle) developed by Ishikawa (1985).

The small group activities could be very fruitful if the group goal(s) is accommodated within the company goal(s). Small group promotes itself and satisfies company goals as well as individual employee needs through concerted efforts. Behavioral scientist Rensis Likert (1961) divided management into "participative management" where attempt is made to improve both business results (profit, sales, etc.) and working conditions (human factors), and "authoritarian management" where business factors (product variables) are much cared and human factors are almost ignored. Likert branded the former companies as high producing ones and the other group as low producing companies. Participative management resembles management theory developed by Douglas McGregor's Theory-Y having paid some consideration to Maslow's need hierarchy. Respect for workers and company structure that supports employees help develop autonomous workers and create a psychological environment that encourages small group activities which functions well for a long time (Ouichi, 1981; Likert, 1961). For, TPM to succeed, it is necessary to have personnel with strong maintenance and equipment related skills. Operators, production front-line workers must become intimately acquainted with their own equipment and develop the practical expertise and the skills necessary to operate as well as maintain the equipment.

Though, operators handle many different types of equipment, comfortably, all equipment are made up of certain common parts or system elements; pneumatics, hydraulics, drive system, lubricating system, electrical system, basic components – bolts, nuts, keys, etc. So, all operators must be skillful in basic machine maintenance. Table 3 is an example of basic machine maintenance training program. Table 4 illustrates how it can be promoted as small group activities in four stages.

Table 3: Basic machine maintenance course

Basic Machine Maintenance Course		
Unit and Topic	Method	Contents (3 days per unit)
1 BOLTS AND NUTS	Lecture; practice on the shop floor	Opening remarks 1. Orientation, 2. How to read drawings, 3. Machines and materials, 4. Bolts and nuts, 5. Material and tightening torque 6. Unit review and comprehension test
2. KEYS AND BEARINGS	Lecture; practice on shop floor	1. Review unit 1 and answer questions, 2. Orientation, 3. Fits and tolerances, 4. Types of keys, 5. Bearings, 6. Lubrication, 7. Unit review and comprehensive test.
3. POWER TRANSMISSIONS (GEARS, BELTS AND CHAINS)	Lecturer; practice on the shop floor.	1. Review unit 2 and answer questions, 2. Orientation, 3. Gears, 4. V-belts, 5. Chains 6. Aligning and centering, 7. Unit review and comprehensive test.
4. HYDRAULICS, PNEUMATICS, AND SEALING	Lecture; practice on the shop floor	1. Review unit 3 and answer questions, 2. Orientation, 3. Hydraulics, 4. Pneumatics, 5. Sealing, 6. Cutaway models 7. Unit review and comprehensive test, 8. Presentation of cutaway models, 9. Closing remarks.

Table 4: Stages in developing individual skills to promote small group activities

Four stages in promoting small group activities				
Contents	STAGE 1 Self development	STAGE 2 Improvement activities	STAGE 3 Problem solving	STAGE 4 Autonomous maintenance
SUMMAERY	Studying techniques and becoming self-motivated	Proposing improvements through group activities and experiencing the satisfaction of achieving targets	Targeting problems that concern the organization and solving them through group activity.	Consistently matching small group targets with those of the organization and managing work autonomously.
MAIN FEATURES	Targets of interest to group members, but often unrelated to those of the organization. Group activities considered separate from work. Groups left alone by top management. Group activities struggle to take off.	Small group targets and organizational targets do not always match, improvement activity is central. Relation between group activity and work not well understood by the top management. Leadership and teamwork not always effective.	Small group targets and organizational targets match. Group activities are accepted as part of work, but some top managers do not understand them properly. Effective leadership and teamwork.	Small group targets are high and match those of the organization. Group activities are considered part of work, and the top management provides active guidance. Supervisor leadership and teamwork.

The essence of small group is brightly evidenced if the following points are kept in mind and addressed:

- Workers are the leading players – they must understand this and adhere to the concept of autonomous management;
- Motivation of small group – recognition of their work, allowing participation in setting and achieving goals, acting on suggestion from operators.
- Role of top-level management – developing able and self-managed personnel; developing adequate training: human growth needs, group function, technical education; favorable participative work environment.

Maintenance records and cost elements

Documentation is an important function of the proper maintenance management. It is not a denting task to maintain computerized records against each equipment or type of actions. Good maintenance record does reveal the quality of maintenance practices. Therefore, the activities carried out and the performance achieved should be recorded quickly. Those pieces of information could be retrieved and incorporated in subsequent maintenance plans. Deming's plan-do-check-act (PDCA) technique may be used to review the maintenance performance level continuously.

Table 5: Classification of maintenance costs

Cost center	**Description**	**Remark**
General material costs	Raw materials (steel, etc.), cotton waste, rubber, paint, seals, cleaning fluid, and miscellaneous materials costs.	
Costs for spares	Costs generated when new parts/components are made or purchased and issued for use.	
Jigs and other toll costs	Costs incur out of jigs, fixtures, and other tools.	
Maintenance labor costs	Inspection, adjustment, repair, parts replacement, and other labor costs.	
Lubrication costs	Lubricating oil, hydraulic fluids, etc.	
Commissioning costs	Costs out of repairing design weakness and breakdowns in newly-installed equipment. Such problems often occur during the commissioning phase due to problems running in process or lack of familiarity of operators and maintenance operators and other related staff.	These costs are essentially different from normal repair costs. So, identify them separately as commissioning costs.
Parts/equipment repair, restoration and overhaul costs	Costs of processing parts for reuse, e.g., replacing rubber linings, overlying, machining, and welding.	Salvage parts or equipment.
Maintainability improvement costs	Costs of accident prevention, lifetime extension, reduction of breakdown, and other improvement for maintenance purposes.	Reduces the overall costs.

4. PROGRAMS FOR IMPROVEMENT OF EQUIPMENT CONDITIONS

Like creation of 'family of products' in a flexible manufacturing system (FMS), TPM system groups so-called infinite elements of maintenance losses into just six "BIG losses". These are namely startup losses, breakdown losses, setup and adjustment losses, speed losses, quality defects, and idling and minor stoppages. The loss types, their major characteristics, and intended goals of maintenance are depicted in Table 6.

Table 6: The Six Major Losses and their Characteristics

Loss Type	Characteristics	Goal	Remarks

Breakdown loss	Time & quality losses. Reduce productivity & increase defective products. Sporadic & chronic losses. Chronic breakdown takes longer time to eliminate and amounts to a large percentage of total losses. Difficult to eliminate – need detailed analysis.	Eliminate	Reduce to zero for all equipment. Change the belief that breakdown is inevitable.
Setup & adjustment loss	Results in downtime and quality defects. Internal setup time & external setup time. Apply "single minute setup" (setup's less than 10 minutes) philosophy.	Minimize	Reduce internal setup time by changing internal action to external action.
Speed loss	Difference between equipment designed speed and actual operating speed. This constitutes a large obstacle to equipment effectiveness.	Eliminate	Achieve designed speed.
Start up loss	Yield losses that occur during the early stages of production, from machine start up to stabilization. Depends on processing condition, machine maintenance level, jigs and dies, and operator's skill, etc.	Minimize	Improve product and process design. Reduce learning time.
Quality defects	Caused by malfunction of equipment. Sporadic and chronic defects.	Eliminate	Acceptable to 100-30 PPM.
Idling & minor stoppages	Temporary malfunction or idling of equipment. Severe effect on unmanned equipment such as robots, automated assemblers, conveyors, and so on.	Eliminate	Reduce to zero for all machines.

In other words to maximize the equipment effectiveness so that each piece of equipment can be operated to its fullest potential and maintained at that level, a productive environment, called total productive maintenance (TPM) is the right option. Human workers and machinery should both function steadily under optimal conditions with zero breakdowns and zero defect philosophy in minds.

a. Towards Zero Breakdowns

Identification of defects and their root causes are required first-hand to eliminate them. Defects in a machine can be physically and psychologically hidden. The five action plans are recommended to uncover and eliminate any hidden defects. These are summarized in Table 7.

Table 7: Action plans to uncover and eliminate hidden defects

1	2	3	4	5
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. *Establish Repair Method.* Standardize disassembly; reassemble measurement, and replacement methods. 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, surface roughness, capacity, etc. Take measures to reduce stress. Design safety relief against excess stress. Treat weak points to prevent overloading.	*Prevent Disoperation*. Analyze causes of disoperation. Improve design of control panels. Provide interlocks. Foolproof operations. Visually control equipment conditions. Standardize operating and adjustment methods. *Prevent Repair Errors*. Analyze causes of repair errors. Improve confusing part shapes and fitting methods. Improve repair tools and apparatus. Simplify and standardize troubleshooting procedures (visual control for equipment conditions).

The five activities for zero breakdowns are not about the short-term programs and should not be attempted simultaneously. The program covers four phases, as depicted in Table 8. TPM covers four phases through the three main techniques, viz., preventive maintenance, autonomous maintenance, and startup maintenance. Deployment of these three techniques in four phases can eliminate the six big losses.

Table 8: 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. Deal with visible defects. Prevent accelerated deterioration. Set basic equipment conditions.	CORRECT DESIGN WEAKNESS Correct weakness in strength and precision. Select parts conformable to operating conditions Correct weaknesses to prevent overloading. ELIMIATE SPORADIC BREAKDOWNS Improve operating and maintenance skills Prevent disoperation Prevent repair errors Restore external appearance of equipment.	RESTORE DETERIORATION AT REGULAR INTERVALS Estimate life span of equipment Set standards for periodic inspection and testing Set standards for periodic parts replacement Improve maintainability USE SENSES TO DETECT INTERNAL DETERIORATION Identify deterioration that gives warning signs Identify types of warning signs given Learn to detect warning signs	PREDICT EQUIPMENT LIFE USING DIAGNOSTIC TECHNIQUES Clarify and adhere to operating standards PERFORM TECHNICAL ANALYSIS OF CATASTROPHIC FAILURES Analyze rupture facets Analyze material fatigue Analyze gear tooth flanks, etc. Take measures to extend equipment life Conduct periodic restoration based on predicted life

b. Reduction of setup time and number of adjustments

Setup and adjustment cannot be avoided. However, reduction of this can be done easily. It ought to be performed quickly and correctly. Single minute exchange of die (SMED) was proposed by Shingo (1985), and it has proved to be achievable (Toyota's single digit drive), which means a setup could be finished within a single digit time (SDT), i.e., in less than 10 minutes.

How could one achieve this SMED level? It requires careful examination of setup activities, available or possible alternatives, and inquisitiveness for continuous improvement. That means a systematic planning and course of actions is the pre-requisite for minimization of setup and adjustment time.

What to do towards that end? Well, find what setup and adjustment activities could be performed if the machine is still busy in doing the operation of the previous job and for what other setup and adjustment activities, the machine must be kept shut down. The former activities are called external setup activities and later are termed as internal activities. Preparation of jigs, dies, tools, work benches, preheating, sub-assembly for the next item or storage area for the items to be removed from the current operation, for instance, could be done in advance to reduce the setup time. But, replacing dies or jigs, centering and adjusting the new job couldn't be done without stopping the machine. A traditional operator, for example, searches a missing part or tool essentially by stopping a machine operation. A traditional system may be characterized by the followings:

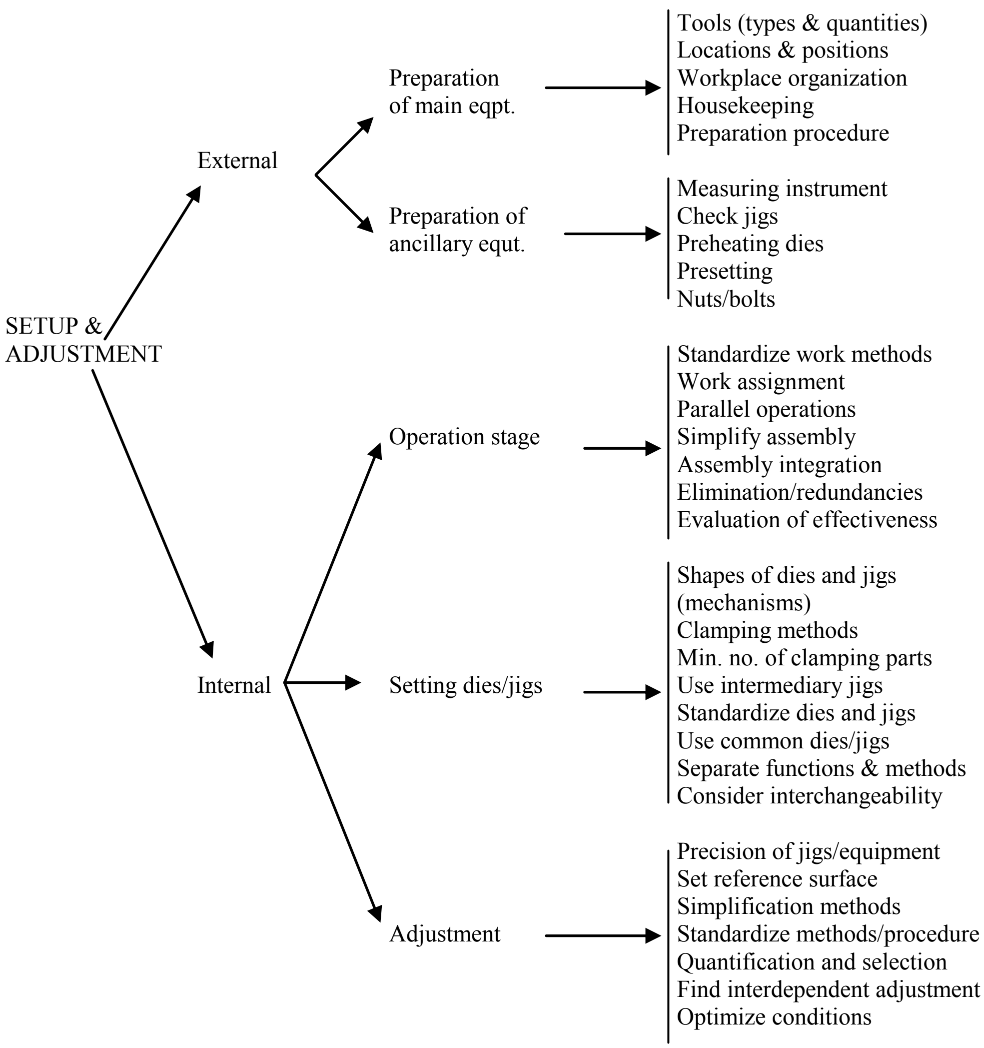
- Accumulation of errors: in positioning, centering, measuring, timing, and balancing;
- Lack of standards and rigidity;
- Lack of appropriate measuring methods and instruments;

- Lack of work analysis and improper work methods; and
- Unavoidable adjustments.

External setup activities are essentially preparatory to work elements for internal setup and adjustment, and an objective oriented observer (TPM operator/analyst) fills all missing links in advance. Summarily, a TPM practitioner asks such questions:

- What preparations (dies, jigs, tools, nuts, bolts, workbenches, etc.) could be taken beforehand-both types and quantities;
- Where should things are placed before a setup and after removal of an item and how these be transported;
- What changes or innovations could be incorporated in the process or system; and
- How to evaluate one's own performance and apply the findings.

A short list of setup and adjustment improvement areas and activities, and a summary of the steps of improvement of setup and adjustment under TPM are given below (Figures 5 & 6):



Objectives: Don't search while doing internal setup & adjustment
Don't move, eliminate redundancies, and inculcate basic operations
Avoid adjustments

Figure 5: Setup and adjustment improvement areas and activities

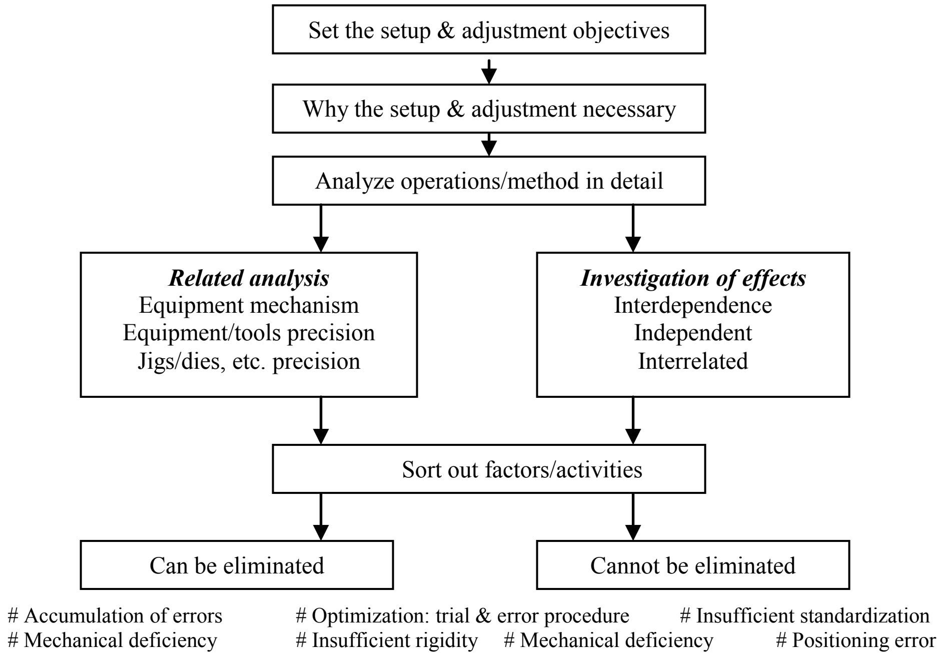


Figure 6: Analysis of setup and adjustment process

c. Approaches to improving in idling and minor stoppages

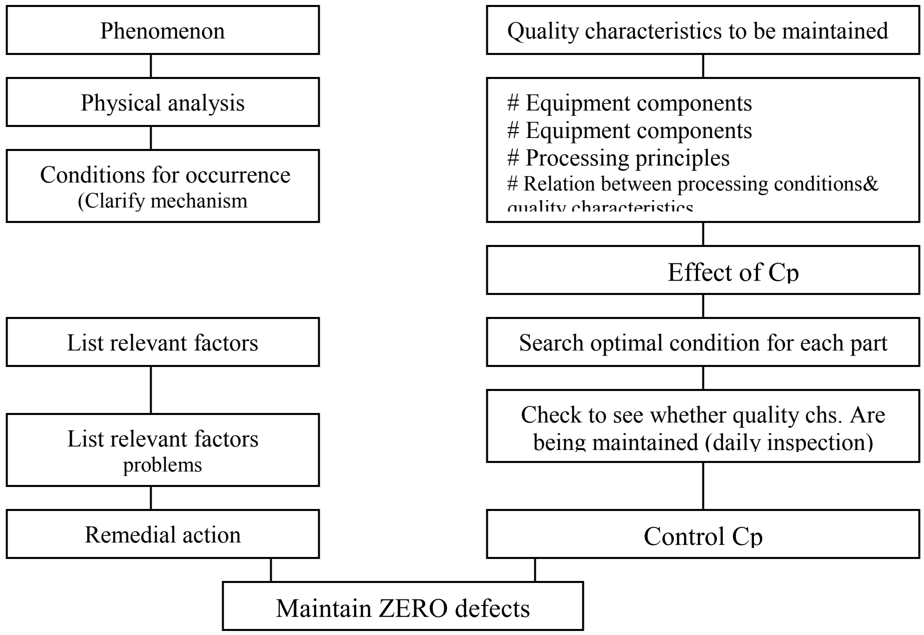
A six steps approach is shown in Table 9 to handle idling and minor stoppage losses. A systematic and analytic approach towards identifying and solving problems related to these problems is required.

Table 9: Six-step approach in handling idling & minor stoppages

Elements	Improvement	Where to improve
Reliability of use	1. Correct minor defects	# External appearance (surface damage, wear and tear, etc.) # Dimensions accuracy (precision, clearance) # Actuation (play, eccentricity, etc.)
Reliability of use	2. Apply basic principles of shop floor operations	2# Cleaning (dirt, play) # Lubrication (dirt, play, etc.) # Nuts and bolts (loose)
Reliability of use	3. Adhere to basic work procedures and standards	3# Correct manipulations # Setup (adjustment methods, setting) # Observations of equipment (methods of detecting abnormalities)
Reliability of use and equipment fabrication	4. Identify optimal conditions	4# Installation conditions (angle, position, resonance, compressed air pressure, degree of vacuum, vibration, amplitude, etc.) # Processing conditions (optimum feed rate, etc.)
Reliability of use and equipment fabrication	5. Identify required conditions	5# Limits of required precision (parts precision, assembly precision) # Conditions of use (optimal range of use)
Inherent reliability	6. Investigate design weakness	6# Designs conformable to shape of parts (shape design changes) # Selection of parts (change resulting from material quality/function) # Consideration of mechanisms and systems

d. Reduction of quality defects

Restored back to the *status quo* is the remedy of the sporadic type of quality defects, for instance, by replacing a worn part or toll. This is simpler than correcting the chronic defects as later requires some breakthrough solutions, may be by having new technology or changing the work method or production process. That is, by embarking on removal of chronic defects, the uncontrollable factors of the existing system are brought to controllable ones. This is relatively a costly or denting task. So, to attack the chronic defects, one has to apply both analytical and deductive approaches. The summary of these concepts is placed in Figure 7.



Analytical approach: reduce chronic defects. Deductive approach: maintain quality. Characteristics: prevent sporadic defects.

Figure 7: Analytical and Deductive Approaches

e. Minimization of speed losses

A designed speed may need to change and redesigned (standardized) based on the product characteristics or the nature of the process. Thus the speed loss can be minimized. To set the appropriate machine speeds or increasing speeds, causes that impede should be examined first and determined if they correspond to any of the items below:

- During the engineering stage if any defects left unresolved due to insufficient debugging;
- Defects in equipment mechanisms or systems;
- Inadequate daily precision; or
- Insufficient precision, etc.

After locating the causes, measures can be devised to correct them. A systematic improvement activity for increasing speed is outlined in Table 10.

Table 10: Strategies for maintaining or increasing machine speed

Find the current level	Speed; Bottleneck processes; Downtime and frequency of stoppages Conditions producing defects
Check difference between this and specification	Check the machine catalogue and find specifications; Locate difference between standard and current speed; Check speed ranges for different materials
Investigate past records	What about the increasing speed earlier? Types of problems faced and measures taken; Trend in speed variation and defect ratios over time Differences in similar equipment

Determine if processing theories or principles permit change	Problems related to processing theories and principles Processing and machining conditions
Identify mechanism	Mechanisms characteristics; Load ratio and rated output; Investigate stresses Revolving parts and their specifications
Analyze present situation	Cycle time per process; Loss or idling time; Process performance index, C_p or C_{pk} value; Precision of parts; Use of five senses
List problems and predict problems, and controllable factors	List problems and identify conditions that should exist; Compare with optimal conditions; Problems with mechanism or precision; Problems related to processing theories and principles ; Mechanical problems; Assignable quality control factors
Take corrective action against predictable problems	Compare those factors with present situation; Take necessary actions
Perform test runs	Operate machine to remove some major problems; Take feedback
Confirm phenomenon	Is it mechanical?; Or, quality?; Change in C_p or C_{pk} value and effects
Review analysis of phenomena and cause-and-effect relationships and carry out activities	Physical analysis of phenomena; Conditions producing phenomena Related causes
Perform pilot runs	Standardize some solutions; Implement those solutions
Monitor and keep records	Take feedback over time and monitor; Maintain records

5. CONCLUSION

To succeed, good planning is over half done! This is very true in case of equipment maintenance that stands in input side of a manufacturing system. In this age of agile manufacturing, a system is required to be 'always ready'. Therefore, a productive and organization wide equipment management policy and plans deserve utmost attention. This paper has given a few planning guidelines in order for a manufacturing firm to enjoin a value adding and encouraging equipment maintenance environment. Based on those exemplified plans, a firm can generate its own working plans and programs according to its suitability.

To be sure that a TPM system is being really implemented, active participation of the 'knowledge workers' is a must. A pool of knowledge workers could be developed if visionary training programs are introduced. The structure of the organization is required to be updated in sustained manner to accommodate those knowledge workers so that they can apply their wisdom in exercising decision-making, and play roles in decision implementations. The role of currently available technology in comparison to the ones of state-of-the-art in nature from the understanding that technology is the master key for accomplishing the economic agenda that should be duly assessed.

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