



**TOTAL PRODUCTIVE MAINTENANCE "TPM"
IN THE POWER INDUSTRY:
THE CASE OF SITRA POWER AND WATER
PLANT IN BAHRAIN**

BY

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ABSTRACT

This study researches in details the maintenance management systems that are applied in the industry. It clarifies their functions by identifying their basic elements. These functions are not different than the functions of management in general, i.e. planning, organizing, directing and controlling. The research identifies the relationship between the maintenance management systems and the plant's life cycle, product output and safety of equipment. The study researches the historical progress of the maintenance management systems from the primitive operate – to – failure maintenance to the latest extensive and complicated maintenance systems.

The study extensively researches the Total Productive Maintenance approach "TPM", which remarkably identifies what is called the era of Productive Maintenance. Total Productive Maintenance aims at maximizing equipment effectiveness through the entire life of the equipment. Like Total Quality Control, TPM involves every one in all departments and at all levels; It motivates people for plant maintenance through small-groups and voluntary activities, and involves such basic elements as developing a maintenance system, education in basic housekeeping, problem solving skills, and activities to achieve zero breakdowns. Top management is also involved to design a system that recognizes and rewards everyone's ability and responsibility for TPM. This approach was first started and flourished in Japan and then migrated to the west and the USA. It succeeded in changing the shop floors of industry to a highly remarkable quality production through effective maintenance.

The research presents a case study for a successful TPM implementation at a sugar manufacturing company in Japan. The case study discusses why the company implemented the TPM, what are the objectives and what

improvement is achieved after the implementation. The results and benefits of the TPM implementation on the total plant output are presented. This manufacturing company was awarded the Productive Maintenance Prize, class I in May 1984.

Sitra Power and Water Plant "SPWP" in Bahrain, in 1996, embarked on the implementation of TPM on pilot plants selected for the application. The aim was to create a model of high maintenance effectiveness through TPM for future plant-wide application. SPWP has always looked for ways and means to improve the production efficiency through the application of new production management systems. The study looks into the details of the TPM implementation at SPWP to assess its real practices and the climate conditions surrounding it. It concentrates on the various factors that may affect TPM success at SPWP. These factors are the introduction program and TPM awareness, the education and training, the TPM organization, the small groups activities, the culture of SPWP, the motivation of employees and the dedication and sustained support of the higher management.

The research analysis results are presented in the conclusions, which basically list the reasons behind why TPM at SPWP does not achieve the expected success. The research concludes that the culture at SPWP is not adapted and changed for the TPM approach. While TPM relies on total integration and total participation, the employees at SPWP conventionally believe in separation between the maintenance and operations departments which depends on the concept "you fix, I operate". Instead of being homogeneous with other plant activities, the TPM at SPWP disturbs the normal maintenance work duties and reduces the maintenance effectiveness.

Although TPM shows a partial success in one pilot plant, it did not bring an improvement on the total plant production. The study at the end came up with some recommendations in order to put the TPM implementation process at SPWP back on track.

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CHAPTER ONE

INTRODUCTION

Maintenance plays an important role in the usefulness life of the industrial plants. A company objective might be expressed as being to maximize life cycle profitability within the constraints imposed by the need for safe operation. The useful life begins when the plant comes into use and continues until the plant is disposed of being. Being the longest and the profit-making period of the plant life cycle, the useful life has been for a long time the focus point in terms of plant maintenance. The new trend of considering profitability of the plant is on the life cycle bases. Investment in the plant occurs from its conception to its commissioning and perhaps into the early years of its operation. It is that the specification for new plant includes reliability and maintainability requirements in addition to performance, capital cost and safety requirements.

At the design and the installation stages, maintainability continues to be an important consideration. Clearly, the best time to influence maintenance and unavailability costs is before plant comes into use. To keep the plant operating at a desired level of output and safety, maintenance need to be perfumed in order to replace short life components or some higher level assemblies to which the component belong or some time do the necessary adjustments for plant equipment to return them to their required performance. For this to be conducted in the most economic way a maintenance strategy is required which is concerned with identifying the items of the plant that require maintenance, and the most appropriate maintenance procedure to be applied.

There are many approaches, techniques and philosophies available for the choice of the plant's managers. One of the major recent approaches in maintenance is the *Total Productive Maintenance* "TPM". The Concept of *Total Productive Maintenance* is simple. TPM seeks a company wide approach towards achieving a standard performance in production, in terms of the overall effectiveness of equipment, machines and processes, which is truly world class. It does not, however rest at that point, but strives for continuous improvement aimed at achieving and sustaining flawless operation.

TPM is based on teamwork and provides a method for the achievement of world-class level of overall equipment effectiveness through people and not through technology or systems alone. It was first introduced in Japan in the early 70's and became a nationwide - adopted approach in the manufacturing and process industries. It has gained a big interest in the west and is now adopted by many European and American leading companies in manufacturing and process industries.

1.1 OBJECTIVES OF THE STUDY

The main objective of the study is to carry out a comprehensive analysis about the Total Productive Maintenance as applied in the industrial nations like Japan, USA and Europe and to compare its application at a non-industrial nation. For this purpose two case studies are taken. One in a sugar manufacturing company in Japan, and the other at Sitra Power and Water Plant in Bahrain, where the research study is conducted. The objectives of the study can be summarized as follows:

1. To review the maintenance management systems that are existing and applied in the manufacturing and utility industry setting the bases for the Total Productive Maintenance approach.

2. To carry out a comprehensive literature review and analysis of the Total Productive Maintenance Approach.
3. To present a case study on the TPM implementation in a manufacturing plant in Japan as a model of a successful TPM implementation in an industrial country.
4. TO conduct a research on TPM implementation on trial pilot sub-plants at Sitra Power and Water Plant "SPWP" in Bahrain to assess its achievements in a different culture outside the industrial countries like Japan, USA and Western Europe. The research explores the factors that may affect the TPM success at SPWP in order to reach concluding results and to come up with recommendations.
5. To come up with conclusions about TPM implementation and recommendations for future applications.

1.2 ORGANIZATION OF THE STUDY

The study is organized into six chapters. The first chapter is an introduction to *Maintenance Management Systems* and. The objective and the organization of the study are outlined in this chapter.

Chapter two is literatures review of maintenance management systems functions and their objectives. The chapter reviews the maintenance management as a field of interest. It also introduces briefly the birth of the Total Productive Maintenance "TPM" as an approach for equipment maintenance.

Chapter three is devoted to explore the TPM, its history and how it was introduced first in Japan to changed the phase of the industry and to keep the Japanese into the competitive edge of maintenance quality.

The chapter explores the concept of TPM, the techniques utilized and its simple differences to other systems.

Chapter four is a case study of TPM implementation in a Japanese sugar manufacturing company and an implementation on a pilot scheme at Sitra Power and Water Plant "SPWP" in Bahrain.

Chapter five discusses the research Methodology used into this study. The empirical research work is based on questionnaire results to evaluate the effectiveness of various aspects of the TPM at SPWP. The chapter discusses the research assumptions, the sample selection, the data gathering procedure and the questionnaire design. It also contains the discussion of the results. The results of the questionnaire are analyzed and discussed in detail. The questionnaire results are tabulated in order to make the analysis easier.

The conclusions, which are drawn from the findings and analysis of the results, are presented in chapter six. Based on the conclusions and the information obtained from the analysis a number of recommendations are made.

1.3 LIMITATIONS OF THE STUDY

The study aims at researching the TPM practices at SPWP to come up with some conclusions about the actual situation of the TPM and the obstacles that hinders its success at SPWP. The research does not analyze each pilot plant under TPM scheme separately to find out the conditions and factors behind its successful or failure of application, which are pertinent to that plant. For this purpose, the questionnaire requires further adaptation. The pilot plants contain several sub-plants that can be a subject of focus, but this study is not concerned to do particular analysis for each of those sub plants. The TPM activities and performance of those sub-plants can be researched individually rather

than in integration with others. For a very extensive study of the TPM results and benefits it is required to collect accurate performance measurements indicators, but what makes the assessment and analysis so difficult is that SPWP does not apply all the TPM and other maintenance performance measurements.

SUMMARY

Maintenance plays an important role in the usefulness life of the industrial plants. A company objective might be expressed as being to maximize life cycle profitability within the constraints imposed by the need for safe operation. The useful life begins when the plant comes into use and continues until the plant is disposed of being. There are many approaches, techniques and philosophies of maintenance management systems available for the choice of the plant's managers. One of the major recent approaches in maintenance is the *Total Productive Maintenance* "TPM".

CHAPTER TWO

LITERATURE REVIEW

2.1 The Function of Maintenance

Maintenance is a combination of actions carried out to return an item to or restore it to an acceptable condition (Kelly, 1984). He regarded the function of maintenance as: to use the maintenance resources to inspect, repair, replace adjust or modify the parts of the plant. A plant could vary from a chemical plant on the one hand to a power Plant generating electricity on the other. In either case the plant performs the overall production function. The Production function is usually measured by the output of the plant over some production period, e.g. tons of chemicals per week (Hibi, 1977). In order for any plant to function it is necessary to perform maintenance. The situation of the plant or some major critical part of it, has been represented by Tanaka (1990), to be in one of the following states:

- ❑ Production: only "on-line" maintenance can be carried out.
- ❑ Dead time: Not required by production e.g. weekends: This is called a maintenance window where off-line maintenance will not incur production losses.
- ❑ Production Outage: e.g. stock shortage. These are also maintenance window but are usually shorter and more difficult to schedule.
- ❑ Shutdown: Taken out of Production, by agreement, for maintenance.
- ❑ Emergency Maintenance: Failed unexpectedly and maintenance is being carried out under emergency conditions since production loss is being incurred (unplanned maintenance).
- ❑ Waiting for Maintenance: Failed unexpectedly but waiting resources. A production loss is being incurred.

Mcleary & Narashimahn (1985), present the difficult situation for maintenance where a plant is multi-product, each of predictable but fluctuating demand with little output stock and no excess capacity. The sales/production policy is to manufacture on demand. This situation provides windows that are schedulable only in the short term. Shutdown maintenance is necessary, but not always carried out where these windows are unable to satisfy the time needed for maintenance.

The sales/production relationship has a considerable influence on maintenance function and needs to be studied in detail in any analysis of the maintenance strategy. It has already been pointed out that the dependency of life cycle profitability on availability and hence on maintenance has greatly increased. This is more apparent when plants are large and sophisticated. For example, in the process and power generation industries large, or single-stream, plants have replaced the previous many smaller plants in the drive for economy of production. As a result high plant availability has become vital to profitability. This has been demonstrated by Holroyd (1967), who studied the effect of the delays in plant start-up and low availability on return of investment. He concluded that, while commissioning delays cannot be ignored, availability levels, which are dependant on maintenance, have a far greater effect on rate of return.

The combined effect of maintenance costs and unavailability costs on life-cycle profitability is well illustrated by Riddll (1980), from the batch processing chemical industry. He showed that over 15 years period, the maintenance costs and the unavailability cost equaled the capital and operational cost.

2.2 A methodology for understanding the industrial maintenance management function

To understand the functions of maintenance management systems, it is required to identify its elements. The functions of the maintenance management systems are based on the basic functions of management i.e. planning, organizing, directing and controlling. Riddll (1980), defined the function of a maintenance department is that it is concerned with providing and controlling the reliability of the plant.

The function of the maintenance system, and the ways in which this might be affected by the dynamic relationship between that system and the production system, need to be clearly understood. From this, a definition of the maintenance objective that is compatible with the definitions of the corporate and the production objectives can be identified. Riddll then expressed a general departmental maintenance objective as it is: "To achieve the agreed plant operating pattern, product quality, within the accepted plant condition and safety standards, and at optimum resource cost".

Forecasting the way in which the plant is to be used, the likely rate of equipment wear and the safety requirements can identify the life plan. According to Harvey (1979), the maintenance life plan has a strong influence on the level and nature of the maintenance workload (preventive, corrective and modification work), which in conjunction with the plant layout has a considerable influence on the nature of the maintenance organization.

The primary task of the maintenance organization is to match resources (men, spares, tools and information) to the maintenance workload. The objective of such a matching is to achieve the agreed plant output at optimum resource costs, which is restatement of the maintenance objective. In order to achieve this optimum task, the organizational design needs to maximize trade force performance, which itself is a function of trade force utilization and motivation, of

spares, tools and information availability and of work planning efficiency (Kelly, 1994).

Mayers (1982), discussed the maintenance organization. The first element in the design of maintenance organization is the maintenance resource structure, which is the geographical location of the men, spares, tools and information, their function, composition, size and logistics. In practice the objective of a design or modification of a resource structure will need to be defined for each situation and will most likely be expressed as being 'to achieve the best resource utilization for a desired resource response and work quality'.

The second element in the design of a maintenance organization is the formation of a maintenance management decision-making structure-the maintenance administrative structure. This can be considered as a structure of work roles, ranked by authority and responsibility, for deciding what, when and how maintenance work should be carried out.

The third element in the design of maintenance organization is the formation of the work planning system, which defines the way in which the maintenance work is planned, scheduled, allocated and controlled. The design of this system should aim to get the right balance between the cost of planning the resources and the savings in the direct and indirect maintenance costs that result from use of such resources.

As control is one of the basic management elements it is quite applicable to maintenance management. Kelly (1984), explained that a maintenance control system is to ensure that the maintenance organization system is working towards the set objective and to provide corrective action as it is not, e.g. to change the life plan.

There are three principle mechanisms of maintenance control:

- (i) Control of "maintenance productivity", ensuring that the budgeted levels of maintenance effort are being sustained and that plant output factors are achieved.
- (II) Control of "maintenance effectiveness", ensuring that the expected long and short term plant reliability is being achieved and hence controlling failure levels and safety. Is the life plan being carried out? Is the life plan effective in controlling reliability?
- (III) Control of "maintenance organizational efficiency", monitoring the efficiency of labor, spares and tool usage.

It can be seen that some form of documentation is needed to assist in the operation of all the elements of maintenance management. Maintenance documentation includes any document, catalogue, manual, drawing or computer software or file that contains information that might be required to facilitate maintenance work. The function of a maintenance documentation system is to provide a formal system for the collection, storage, interrogation, analysis, and reporting of maintenance information.

2.3 THE FUNCTION AND STRUCTURE OF INDUSTRIAL PLANT

One way of regarding any plant is as a hierarchy of parts ranked according to their functional importance. Such way of visualizing a plant is called modeling. To understand plant modeling, Kelly (1994), represented the plant hierarchy as shown in Fig 2.1.

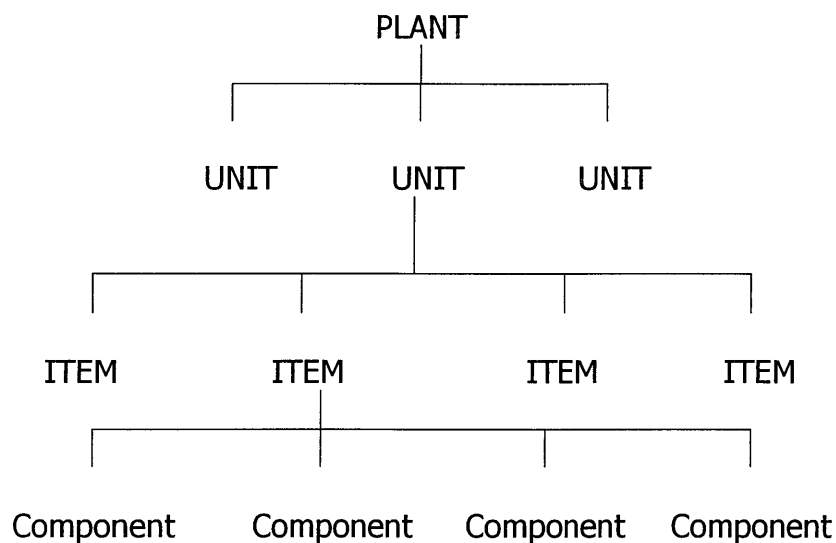


Figure (2.1) Industrial plant modeling inclined

- A unit performs major plant functions and is replaceable as a whole e.g. a batch chemical reactor.
- An item performs major unit functions and is the lowest level of plant that can be directly and easily repaired or replaced e.g. a gearbox or a motor.
- A component is the lowest replacement part of a plant e.g. gear or shaft bearing.

For replacement of the plant or units of plant the higher management takes the decision, but for the replacement of items and components the lower maintenance management level normally takes the decision.

This kind of modeling Kelly said is particularly important when setting up the equipment inventory, usually based around the unit and more importantly to identify the maintenance causing items and components of the unit.

Maintenance is generated from component level. When a component is unable to perform its designated function according to some predetermined condition, it can be said to have failed. The loss of the function could be contained at unit level (at least for a period) or have consequences at plant level, depending on the design of the plant, e.g. on the amount of inter-stage storage or redundancy. The loss of function could also have safety or product quality consequences (LIN & Titmuss, 1995).

Many of the constituent components of a plant will have been designed, for technological and economic reasons, with a useful life greater than the longest plant production cycle, but less than the plant itself. In most cases such short life components will have been identified at the design stage and made easily replaceable at component level without affecting plant availability or safety (Iserman & Freyermuth, 1992).

2.4 THE NEED FOR MAINTENANCE STRATEGY

To keep a plant operating at a desired level of output and safety, maintenance needs to be performed in order to replace short life components or some higher-level assemblies to which the components belong. Kathleen, Eisenhardt & Donald (2001) argued, that strategy arises from focusing on key strategic processes and developing simple rules that shape the process. Corder (1975) said, maintenance strategy is concerned with identifying the components/items of the plant which require maintenance, determining the most appropriate maintenance procedure e.g. should we repair or replace the part? should we do this before or after failure?. Finally it is concerned with

listing the procedures in the form of a schedule for the plant (a guideline) and determining the organization to carry out this work.

The establishment of such a strategy is a complex problem involving numerous interrelated decisions. In general the main task associated with each decision (and therefore with the strategy) is the determination of the optimum type and level of maintenance action. What is meant by optimum can only be determined after understanding the maintenance objective. Vanvliet & Devries (1998), argued that in general the maintenance strategy is not concerned directly with the "capital replacement decisions" for units and large sections of plant. Such decisions are considered as part of the corporate strategy.

2.5 ESTABLISHING MAINTENANCE OBJECTIVES

The maintenance objective is the starting point of the strategic maintenance management process. One of the main reasons for wanting a maintenance objective is to assist maintenance management in setting a maintenance strategy. These statements beg the following questions: What is a maintenance objective? How to establish a maintenance objective?" And How to use maintenance objectives?

Idhamer (1979) explained that in theory the objective maintenance might be considered as being concerned with achieving the best balance between the allocation of maintenance resources and the achievement of the plant output factors. In practice the establishment of maintenance objective is more complex than this. It usually involves the users/owners/safety department specifying what they want from the plant in negotiation with the maintenance department. Only then can the maintenance department decide how best to maintain the plant. Factors that should be included in a maintenance objective are short listed by Bagadia (1992), when talking about maintenance resources and that they are used to ensure that the plant achieves its design life, that safety standards are achieved, that plant output

required by production policy is met, and that energy use and raw material consumption are optimized. It is important to elaborate the relation of each factor.

a) RESOURCES OF MAINTENANCE VS. PLANT LIFE

Nillson (1982), when talking about life cycle costing elaborated the relationship between maintenance resources and plant life. He said, "A proportion of the maintenance resources is necessarily devoted to ensuring that major plant units and, indeed the whole plant itself, survives up to or beyond its design operating-life. Failure to ensure this will mean a corresponding loss of the company's capital assets. Such maintenance is usually of a "protective" nature (e.g. corrosion protection of structural units) but can also involve major part replacement".

It is often difficult to establish the relation ship between the level of maintenance and the life of a plant although it is obvious that negligence can cause repaired deterioration. Fox (1995), argued that the best way of incorporating this into the objective is establishing "standards of plant condition" necessary to see the plant through to its expected life. Such standards may be reviewed periodically (to take into consideration such factors as obsolescence and age) compared to the actual standard of plant condition (a plant condition audit) before deciding on the level of maintenance necessary to correct the situation. While it is unlikely that the standards of condition will change over the life of a plant, the level of maintenance necessary to achieve these standards will increase with plant age.

b) MAINTENANCE RESOURCES VS. PLANT SAFETY

One of the functions of maintenance is to ensure that plant is maintained in such a way that it can be regarded as safe. There are numerous maintenance requirements, expressed in national

legislation or in recommended standards or codes of practice, for ensuring that safety standards for specific types of plant (e.g. pressure vessels) are achieved. For many other items of plant the safety standards will have to be set within the company because of the difficulties of quantifying safety and establishing a relationship between levels of maintenance and safety (Lin & Titmuss, 1995).

c) MAINTENANCE RESOURCES VS. PRODUCT OUTPUT

In order to discuss this relationship it is necessary to discuss what product output means. In the case of a power and water Plant, product output means megawatts of electricity generated and desalinated water produced at some stated product quality respectively. It is what makes profit for the company or the organization.

Olivier (1992), discussed the relationship between maintenance resources and output, saying that in most situations the relationship between product either unknown or has considerable uncertainty attached to it. An added complication is that in large complex multi-product plants such a relationship does not mean much when applied to the plant as a whole. In such situations it is not just the level of resource used that is important-but where it is applied.

2.6 MAINTENANCE PROCEDURES

The maintenance can be carried out to prevent failure or as a result of failure. The following are the procedure that are widely used in maintenance and are applicable for a particular item. Such procedures are almost found in every text that discusses the maintenance management policies and strategies.

a) Operate-To-Failure

Upshall (1994) defines Operate-To-Failure maintenance as: no action is taken to detect the failure. The corrective work occurs with random incidence and with little or no warning. This is mostly used where the consequences of failure are negligible or at least less expensive than any other alternative. In some situations the operate-to-failure might be the only action possible (perhaps in the short term). Eg. Solid-state electronic items. In other situations failure of an item might have no effect on output for some known (or predictable) time, in such cases corrective maintenance guidelines are an essential part of the strategy i.e. planning effort to ensure correct spares holding, repair methods etc, this is a form of planned corrective maintenance (lees, 1980)

b) Fixed Time Maintenance

They are first-line maintenance actions that are carried out at regular intervals, or after a fixed cumulative output, fixed number of cycles of operation, etc. this includes item replacement, item repair and major strip-down for inspection. This procedure is only effective where:

- The failure of the item is clearly time-dependent
Obviously, the more the "failure predictability" the easier it is to identify the optimum maintenance timing.

- The statistics of failure are known from the manufacturer's manuals or from maintenance history.

According to pantaloon (1992), fixed time maintenance is a far more difficult procedure to justify with complex replaceable items because of the high cost of maintenance action and less failure predictability. In such cases an alternative procedure is often sought e.g. condition-based maintenance.

Fixed-time maintenance is usually an appropriate procedure for simple replaceable items. Examples might be:

- The group replacement of identical simple items e.g. light bulbs in commercial buildings.
- The group replacement of dissimilar simple items as in "periodic services" of large complex industrial plants.

Another application of fixed-time-maintenance is the complete shutdown of large plants e.g. large electricity generating unit boiler/turbine/alternator etc. However the main reason is ensuring that the large resource requirement can be met at a particular time.

c) Condition-Based Maintenance

This is an attractive concept. Its approach is that the proper time for performing maintenance ought to be determinable by monitoring the condition and/or the performance, provided that a monitorable parameter of deterioration can be found. According to Newport (2000) the probabilistic element in failure predications is reduced or, indeed, almost eliminated, the life of the item maximized and the effect of failure minimized. One of the major benefits of this policy is that the resulting corrective maintenance can, in most cases, be scheduled in the short term without

production loss. It is a particularly useful technique where the item exhibits little failure predictability and fixed time maintenance is not effective. There are many monitoring techniques that can be used for both condition checking and trend monitoring.

d) Design-Out Maintenance

By contrast with the above procedures, which aim to minimize the effect of failure, design-out maintenance aims to eliminate the cause of maintenance. Clearly, this is an engineering design problem but it is often part of the maintenance department's responsibility.

According to Bendall (1999), Design-Out maintenance is appropriate for items of high maintenance cost where such costs arise either because of poor maintenance, poor design or operation outside design specification. In many cases design-out is aimed at items that were not expected to require maintenance. Therefore, such a policy can only be implemented effectively if an information system exists which facilitates the identification of such items.

2.7 ESTABLISHING THE BEST PROCEDURE FOR AN ITEM

To establish the best procedure in a particular situation for a particular item of plant, figure 2.2 of Kelly (1994) and Kelly (1984) is a flow chart that can be easily followed. The chart incorporates the use of failure characteristics to assist in determining the effective procedures. The identification of the most desirable of these is then based on a "least cost life cycle" criterion, subject to safety constraints

2.8 MEASUREMENT OF MAINTENANCE PERFORMANCE

Measurement of maintenance performance is aimed at expressing in value terms the results of maintenance performance and also at increasing the productivity of plant maintenance service. Measurement of maintenance performance is indispensable to effective plant maintenance.

Commenting on the importance of performance measurement, Schuleh (1961) wrote on the importance of result management: "You cannot have a "results" accountability without measurement! The time and effort spent to get even an estimated measurement, a crude measurement, or an over-all measurement is well worthwhile to provide a basis for tying in accountability. Frequently men will say that certain activities are not measurable. In our opinion, if they are not measurable (either short-range or long-range), the chances are very little to measure, and it is highly questionable whether the job is necessary. In the end every function must in some way show a result which will favorably affect the objectives of the enterprise".

In his "Managing for Results", Drucker (1964) Stated: "responsibility for achieving results becomes clear only when assignments specify what sort of economic results should be achieved where and how soon. If it is to be a real assignment, there has to be a deadline; work without deadlines is not work assigned but work toyed with, thus stressing the importance of the measurement of economic performance in every job done in a business enterprise".

Hibi (1977) emphasized that maintenance performance measurement be ultimately carried out integrally and pecuniarily. The reason for this is that the comparison and evaluation of the various necessary elements should be determined by using a common factor, that is, pecuniary value. Maintenance performance measurement will reveal,

for example, how much repair material was used for which equipment, how many man-hours were required for the actual maintenance work, including inspection, adjustment, repair and replacement. Furthermore, various other information such as the number of cases of equipment failure, hours lost as a result of the stopping of equipment, the number of cases in which certain processes were delayed due to lack of spare parts in the stock and decrease in production because of lack of reserve equipments, are obtained on a monthly basis. All of this information must be used for improvement. Some of the information may be used in connection with the changes of work procedure for the following month, and some may be used as feedback material for designing new equipment.

2.8.1 METHODS OF MEASUREMENTS

It is outside the scope of this research to list all the methods utilized in maintenance performance and to explain them in detail. However it is quite useful to list some of those methods.

a) Nippon Denso Method

Nippon Denso Co., Ltd., which manufactures exclusively electric accessory parts for automobiles, is an excellent company, which enjoys a good reputation in Japan because its plants are implementing productive maintenance activities. The company has developed a well-studied evaluation scale for PM performance. Table 2.1 is a summary of the major factors as given in Takada (1990).

Items	Factors	Point (1)	Weight (2)	Result (1) x (2)	Calculation formula of factors
Planned Maintenance Work ratio			0.3		$\frac{\text{PM(Hr)} + \text{CM(Hr)}}{\text{Total maintenance work time}} \times 100$
Net maintenance Work ratio			0.1		$\frac{\text{PM} + \text{CM} + \text{BM (Hr)}}{\text{Total working time of maintenance men}} \times 100$
Equipment shutdown intensity ratio			0.3		$\frac{\text{Down time from shutdown}}{\text{Active time}} \times 100$
Equipment Shutdown Ratio			0.2		$\frac{\text{Number of shutdowns}}{\text{Active time}} \times 100$
Production Interference Ratio			0.1		$\frac{\text{Production interfered time}}{\text{Planned operating time}} \times 100$
Total			1.0		

TABLE 2.1 Overall Point System for Maintenance Performance Measurement

b) Due Pont Method

According to Luck (1956) the Due Pont Method of measuring maintenance performance have the following special features.

- (I) The maintenance department makes periodic self-evaluations to detect its own administrative weaknesses. The emphasis is on discovering room for further improvements.
- (II) Evaluation of maintenance performance is carried out by means of a graphic rating method predicated on four major functions and sixteen sub-factors.
- (III) Evaluation of each of the four major functions is made on a separate graph, with the rating given by one of the following six scores:
 - E: Excellent
 - G: Good
 - +A: Above average
 - A: Average
 - A: Below average
 - P: PoorFinally, these tow major functions are combined on the graph to obtain the overall rating at one of the above six levels.

c) Progressive Multi – Aspect Comparison Method

As extensively explained by Priel (1962), the method is an individual measuring method predicated on twenty elements broken down into several categories from the viewpoint of Maintenance effectiveness, Amount of maintenance and Cost of maintenance. He extensively elaborated the twenty formulas used and the way they are applied.

d) *The Hibi Method*

The earlier mentioned methods are considered to be conventional methods of measurement. The most important feature that distinguishes the Hibi Maintenance System from the conventional individual factors method is that it measures maintenance performance from the standpoint of integrated evaluation, while the latter provides only fragmentary and quantitative measurements. This system is also unique in that its computation formulas employ latest-point-in-time benchmarks, so achievements can always be assessed in the most recent frame of reference, thus enabling the results to be utilized not only for equipment maintenance, but also for general management purposes. Its basic concept is best explained by Hibi (1977).

In the past, repair cost control appears to have had minimization of repair expenses as its sole objective. Since the basic concern of a business enterprise is to earn as much profit as possible, any amount of repair expenses is justified so long as it assures profits that more than compensate for it. Conversely, any reduction in repair cost would be meaningless if it were offset by production decreases due to increased failures, supplies costs, or inferior product quality. In order to ascertain whether repair expenses are effectively used or not, examination must be made to see how repair costs and the total loss in production, supplies, quality, etc., compare with the benchmarks, and how this total is changing from one year to another. (Where the operational ratio is changed from year to year, such total figures cannot be used immediately for annual comparison). These total figures must be obtained by adding up the values of all the factors involved expressed in monetary units. The relationship of these additions forms the basis of integrated maintenance performance measurement.

Based on the line of thinking discussed in the preceding section, a conceptual formula for integrated maintenance performance measurement is given as follows:

$$\text{Efficiency} = \frac{\text{(Total repair cost)} + \text{(Total amount of production losses, yield ratio, supplies, energy, quality, etc. resulting from shut-down by failure or malfunction)}}{\text{(Total value of control scale)}}$$

In the Formula the numerator items are self explanatory, but the control scale given as the denominator must appropriately be chosen from among the scales that exhibit a high degree of correlation with repair cost and shut-down losses by failure, so maintenance performance measurements may be expressed as a value per unit of control scale.

2.9 MAINTENANCE MANAGEMENT IN JAPAN

Japan is one of the world's leading industrial nations, despite the fact it has no industrial resources produced in it. According to Takada (1990), one of the main reasons for Japan success is credited to the development in maintenance systems and technology in parallel with that of production and equipment technologies. This section outlines the course of progress Japan plant maintenance management systems and technology have gone through.

a) THE BREAKDOWN MAINTENANCE AGE

According to Kawasaki (1990), before 1950 Japanese industries had been relying on the Breakdown maintenance approach (BM) i.e. production units are repaired only after they have failed. Talking

about steel manufacturing plant condition he said, "At the initial stage of the plant operation, poor manufacturing and erection and inexperienced operation caused so frequent breakages to the point there was no time to cope with the troubles. Thus, the degradation of the equipment became worse in proportion to the output of production volume and failure frequency, which increased difficulties in maintaining the designed performance of the plant and the equipment.

b) THE PREVENTIVE MAINTENANCE AGE

In 1950 a U.S. style preventive maintenance system has made its way through major manufacturing industries in Japan in line with the rapid growth and expansion of its economy (Takada, 1990).

As the production capacity became larger by riding on the wave of the economic revival from the production reopening after World War II, the degradation of equipment became extremely worse because of insufficient maintenance and very hard usage of equipment during the War, and then the frequent failures and the long period stoppage due to repair caused difficulties in maintaining the plant and the equipment functions, which brought about serious situations such as degrading of product quality and delay of delivery time. As result, the rate of operation was considerably low.

For the above reasons Kawasaki (1990) said that the "Preventive Maintenance System was introduced to:

- 1) Prevent the progress of equipment degradation,
- 2) Measure or predict the equipment degradation (predictive) and
- 3) Restore, equipment healthy condition.

With the introduction of this system the Maintenance Department having all responsibilities and rights on the equipment maintenance

became independent from the Production Department. This independence greatly changed the maintenance system. The people concerned seriously studied how the plant maintenance was managed to eliminate the repeated failures, to shorten shut down time to repair and to prevent the failure of the equipment in order to make the operation of the plant stable and to improve its productivity.

According to O'Shima (1990) preventive maintenance system resulted in increase of reliability and availability of the plant, and that stability of product quality, etc. was improved remarkably. At this age efforts have also been directed at corrective maintenance aiming to lengthen the service life of equipment, enhance their reliability, facilitate repair works, improve tools and also the method of their use, improve the durability of equipment corresponding to changes in production conditions, etc. However preventive maintenance after being developed raised several concerns over the years.

- 1) Increase of the maintenance cost rate vs. production cost.
- 2) Increase of the stock of spare parts and materials due to putting too much importance on failure prevention.
- 3) Increase of the rate of labor cost vs. maintenance cost due to the increase of maintenance group members in number and a tendency that the increased cost was becoming a fixed cost.

c) THE PRODUCTIVE MAINTENANCE AGE

In order to eliminate the concerns that have come from extensive preventive maintenance, a new maintenance system has emerged in the 1960's. The new system is based on integration of all available procedures in one system. This procedure integration was best shown by Takada (1990), in Fig 2.3 and it aims at the following.

- 1) Economizing in the Maintenance Department organization.
- 2) Reduce the fluctuation of required manpower for repair.
- 3) In-house efficiency in using spare parts and material.
- 4) Preventing maintenance.
- 5) To minimize the sum of the total cost of maintenance plus that of machine loss in order to have the optimum maintenance.
- 6) Reliability

Aiming at maximizing equipment effectiveness the concept of Production Maintenance was developed further, where a new approach emerged and promoted through small group activities involving everybody in the organization called "Total Productive Maintenance (TPM)".

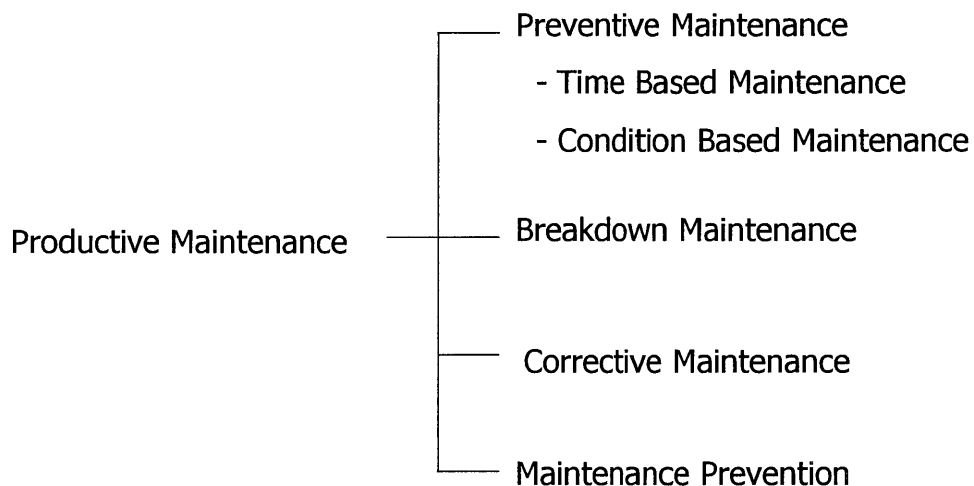


Fig. 2.3 Productive Maintenance Constituents

SUMMARY

Maintenance is a combination of actions carried out to return an item to or restore it to an acceptable condition. The function of maintenance is to use the maintenance resources to inspect, repair, replace adjust or modify the parts of the plant. In order for any plant to function it is necessary to perform maintenance. The maintenance objective is the starting point of the strategic maintenance management process. One of the main reasons for wanting a maintenance objective is to assist maintenance management in setting a maintenance strategy. These statements beg the following questions: What is a maintenance objective? How to establish a maintenance objective?" And How to use maintenance objectives? Maintenance went through deferent stages of development: the breakdown, the preventive, the condition-based and the productive maintenance age.

CHAPTER THREE

TOTAL PRODUCTIVE MAINTENANCE "TPM"

After World War II, Japanese industries determined that to compete successfully in the world market they had to improve the quality of their products. To do so, they imported management and manufacturing techniques from the United States and adapted them to their circumstances. Subsequently, their products became known throughout the world for their superior quality, focusing world attention on Japanese-style management techniques.

The Japanese have a knack for turning good ideas into enormously successful practices. Norman Bodeck the president of Productivity, Inc. said in his forward to the book of Nakajima (1988): "Many Japanese companies applied the ideas of Deming, Juran, and Crosby in innovative day-to-day management and improvement activities to achieve model quality control systems and unparalleled quality records. Similarly, Seiichi Nakajima introduced American maintenance practices in Japan then, in the early 1970s, he combined those ideas with the concepts of total quality control and total employee involvement to develop "Total Productive Maintenance", a system that is revolutionizing plant maintenance around the world".

The father of Total Productive Maintenance (TPM) was seiichi Nakajima, who pioneered the approach in Japan and exerted a major influence over the economic progress made by Japanese manufacturers from the late 1970's. Nothing can identify Mr. Seiichi Nakajima better than his words, which at the same time states the History of maintenance in Japan. He said "I began studying American preventive maintenance (PM) in 1950 and first visited the United Sates in 1962. Every year since then I have visited American and European manufacturers to study their manufacturing facilities and learn more about their PM systems. Based on my observations, I developed total

productive maintenance (TPM) and introduced it in Japan in 1971. In September 1987 I led a Japanese maintenance study mission to the United States. During the two-week stay, our team made presentations on TPM at several companies and at the Fourth International Maintenance Conference in Cincinnati, sponsored by the Institute of Industrial Engineers. After we completed the study mission, I left the group to speak in Pittsburgh at a TPM Executive Conference organized by Edward H. Harlmann, president of H.B. Maynard Management Institute. More than 150 executives from 80 companies attended those two conferences. I was impressed by the obvious enthusiasm for TPM in the United States and by the number of people eager to learn how to implement it in their companies." (Nakajima, 1988).

3.1 WHAT IS TPM?

The achievement of world class manufacturing performance is essential if companies are to survive against international competition. One vital ingredient of this is highly reliable and consistently operated machines, equipment and processes. It is perhaps worth reminding ourselves that these machines, equipment and processes together with their operators and maintainers are the only direct wealth creators in a manufacturing plant; all other functions such as sales, marketing, design, production control and finance either feed off them or support them. To build a consistent and sustainable competitive advantage it is essential that the man/machine interface is maximized and that all associated sources of waste are eliminated.

Total productive maintenance is based on teamwork and provides a method for the achievement of world-class levels of overall equipment effectiveness through people and not through technology or systems alone (Willmott, 1990). According to Nakajima (1988), total productive maintenance (TPM) is productive maintenance carried out by all employees through Small Group Activities. Like Total Quality Control "TQC", which is company wide total quality control, TPM is equipment maintenance performed on a company wide basis. According to Suzuki

(1994), the term TPM was defined in 1971 by the Japan Institute of Plant Maintenance (JIPM) characterized by the following five goals:

1. Maximize equipment effectiveness (improve overall efficiency).
2. Develop a system of productive maintenance for the life of the equipment.
3. Involve all departments that plan, design, use, or maintain equipment in implementing TPM (engineering and design, production, and maintenance).
4. Actively involve all employees-from top management to shop floor workers.
5. Promote TPM through motivation management: autonomous small group activities.

The word "Total" in *Total Productive Maintenance* has three meaning related to three important features of TPM according to Nakajima (1989):

- Total effectiveness: pursuit of economic efficiency or profitability.
- Total PM: maintenance prevention and activity to improve maintainability as well as preventive maintenance.
- Total participation: autonomous maintenance by operators and small group activities in every department and at every level.

The last concept, total participation, which includes autonomous maintenance by operators and small group activities, is unique to TPM. In American-style, maintenance department is generally responsible for carrying out PM. This reflects the concept of division of labor, an important feature of American labor unions. Japanese-style TPM, on the other hand, relies on everyone's participation, particularly autonomous maintenance by operators, (Wireman, 1991).

3.2 THE RELATIONSHIP BETWEEN TPM AND TEROTECHNOLOGY

To the extent that TPM focuses on reducing life cycle costs, it has features in common with the concepts of Terotechnology, developed in the United Kingdom. According to Harvey & Eastern (1979), Terotechnology is a term coined in the United Kingdom in 1970. It combines management, financial, engineering, and other practices with physical assets to achieve economic life cycle costs (LCC). It is concerned with the specification and design for reliability and maintainability of plant machinery and structures; with their installation; commissioning, maintenance, modification, and replacement; and with feedback of information on design, performance, and costs. Focusing only on equipment, TPM has the same goal as terotechnology i.e. economic life cycle cost (Nakajima 1989). Terotechnology involves the equipment supplier, engineering firms, and the equipment user. TPM on the other hand, is practiced only by the equipment user.

The United States Department of Defense first articulated the concept of economic life cycle cost in 1965, when it issued MIL-STD-785 the standard of "Reliability Programs for Systems and Equipment", which mandated the integration of reliability engineering activities with traditional engineering activities in design, development, and production to eliminate potential reliability problems at the earliest and cheapest stages in the development cycle. Since 1976, the department has based its procurement contracts for weapons and other large-scale systems on LCC (Riddell 1980).

3.3 EQUIPMENT EFFECTIVENESS

The equipment effectiveness is a major target of the TPM program. According to Shingo (1985), Equipment effectiveness is a measure of the value added to production through equipment. Simply stated, added value is the difference between the sales revenue and the cost of resources (material and labor) used to produce a product. TPM maximizes equipment effectiveness through two types of activities:

- Quantitative: increasing the equipment's total availability and improving its productivity within a given period of operating time.
- Qualitative: reducing the number of defective products, stabilizing, and improving quality.

The goal of TPM is to increase equipment effectiveness so that each piece of equipment can be operated to its full potential and maintained at that level. Human workers and machinery should both function steadily under optimal conditions with zero breakdowns and zero defects. Although approaching zero defects is difficult, but according to Nakajima (1988) believing that zero defects can be achieved is an important pre-requisite for the success of TPM. Nakajima (1989), addressed the difficulties inherent in maximizing equipment effectiveness by listing the six big losses which are very famous in the language of TPM and plant maintenance management in general.

1) BREAKDOWN LOSSES

Two types of loss are caused by breakdowns: *time losses*, when productivity is reduced, and *quantity losses*, caused by defective products. The non-frequent breakdowns of equipment failures are usually obvious and easy to correct. Frequent or chronic minor breakdowns, on the other hand, are often ignored or neglected after

repeated attempts to cure them. Because breakdowns account for a large percentage of total losses the company invest a great deal of time and effort searching for ways to avoid them. Eliminating them is extremely difficult.

To maximize equipment effectiveness, however, all breakdowns must be reduced to zero. This is actually possible without much effort or investment, although some investment may be necessary in the beginning. First, however, the conventional philosophy of breakdown maintenance, the belief that breakdowns are inevitable, must be changed.

2) SETUP AND ADJUSTMENT LOSSES

Losses during setup and adjustment result from downtime and defective products that occur when production of one item ends and the equipment is adjusted to meet the requirements of another item. This type of loss is not very much applicable in the power and water industry except for some auxiliary sub-plants within the main plant.

In the manufacturing industries according to Suzuki (1994) many companies are now working to achieve single-minute setups (under 10 minutes). Working from an industrial engineering perspective, setup time can be reduced considerably by making a clear distinction between internal setup time (operations that must be performed while the machine is down) and external setup time (operations that can be performed while the machine is still running) and by reducing internal setup time.

3) IDLING AND MINOR STOPPAGE LOSSES

A minor stoppage occurs when production is interrupted by a temporary malfunction or when a machine is idling. For example, from a decrease in the frequency of the electricity grid might cause

the Generator breaker to open, casing steam or gas turbine to idle; at other times a sensor alerted by high temperature inlet to the turbine shut down the turbine totally. These types of temporary stoppage clearly differ from a breakdown. Normal production is restored by simply removing the cause and resetting the equipment. Zero minor stoppages is an essential condition for unmanned production. If minor stoppages are to be reduced, operating conditions must be closely observed and all slight defects must be eliminated (wireman 1991).

4) REDUCED SPEED LOSSES

Reduced speed losses refer to the difference between equipment design speed and actual operating speed. Speed losses are typically overlooked in equipment operation, although they constitute a large obstacle to equipment effectiveness and should be studied carefully. The goal must be to eliminate the gap between design speed and actual speed. It should be noted that word speed is a general term in manufacturing equivalent to capacity or capability in terms of power or water production.

Equipment may be run at less than ideal or design speed for a variety of reasons: mechanical problems and defective quality, a history of past problems, or fear of abusing or the equipment. Often, the optimal speed is simply not known. On the other hand, deliberately increasing the operating speed actually contributes to problem solving by revealing latent defects in equipment conditions.

5) QUALITY DEFECTS AND REWORK

Quality defects in process and rework are losses in quality caused by malfunctioning production equipment. In general, sporadic defects are easily and promptly corrected by returning equipment conditions to normal. These defects include sudden increases in the quantity of

defect, or other dramatic phenomena, like fluctuation of the voltage or frequency in the power output from the generator terminals. Reducing chronic quality defects, like reducing chronic breakdowns, requires thorough investigation and innovative remedial action. The conditions surrounding and causing the defect must be assessed and control limits evaluated. Complete elimination of defects is, as always, the main goal.

6) STARTUP LOSSES

Startup losses are losses that occur during the early stages of production – from machine startup to stabilization. The volume of losses varies with the degree of stability of processing conditions i.e. maintenance level of equipment, operators, technical skills. In practice, the volume is surprisingly high. A steam Turbine machine start-up time may vary from minutes to several hours until proper and stable condition is reached and the machine is connected to the grid.

To eliminate the six big losses, there must be an extensive program to tackle each and every type of loss. A proper training shall be given to employees in order to enable them to take the appropriate action applicable to each type. Table 3.1 sets out the improvement goals for the six big losses.

Type of Loss	Goal	Explanation
1. Breakdown losses	0	Reduce to zero for all equipment
2. Setup and adjustment losses	Minimize	Reduce setups to less than specified limit
3. Speed losses	0	Bring actual operation speed up to design speed: then make improvements to exceed design speed
4. Idling and minor Stoppage losses	0	Reduce to zero for all equipment
5. Quality defect And rework losses	0	Extremely slight occurrences acceptable
6. Startup losses	Minimize	

TABLE 3.1 IMPROVEMENT GOALS FOR CHRONIC LOSSES

3.4 AUTONOMOUS MAINTENANCE

Ideally, whoever operates equipment should maintain it, and originally, these two functions were combined. Gradually, the maintenance and production functions were separated as equipment became more sophisticated and as plant perceptive maintenance "PM" was widely adopted. The production department concentrated on plant output responding to the demands of increased production, while maintenance departments gradually assumed responsibility for almost all maintenance functions. This bipolar specialization continues today.

As Suzuki (1994) noted that companies are increasingly under pressure to boost competitiveness and reduce costs. Today, many managers are keenly aware that a decisive factor in increasing competitiveness is more efficient equipment utilization. Maintenance performed by equipment operators, or autonomous maintenance, can contribute significantly to equipment effectiveness. At the heart of autonomous maintenance is deterioration prevention, which has been neglected in most factories until recently.

Efficient production depends on both production and maintenance activities, but the relationship between operators and maintenance personnel is often somewhat not favorable. No matter how hard maintenance personnel work, they can make little progress in maintenance and equipment improvement as long as the operator's attitude toward maintenance is "I operate you fix". If, on the other hand, operators can participate in the maintenance function by becoming responsible for the prevention of deterioration, maintenance targets are more likely to be achieved, this cooperative effort allows maintenance personnel to focus their energies on tasks requiring their own technical expertise, it represents the first step toward more efficient maintenance.

Efficient production depends on both production and maintenance activities. The two departments must do more than share the responsibility for equipment. Nakajima (1989) identified the task for both the departments as follows.

A) MAINTENANCE TASK ALLOCATION

Two types of activities are required to increase equipment effectiveness:

1. Maintenance activities prevent breakdowns and repair ailing equipment. They occur in a cycle consisting of normal operation combined with preventive maintenance (i.e., daily, periodic, and predictive maintenance) and corrective maintenance.
2. Improvement activities extend equipment life, reduce the time required to perform maintenance, and make maintenance unnecessary. Reliability and maintainability improvement, maintenance prevention, and maintenance-free design are all maintenance improvement activities.

b) PRODUCTION DEPARTMENT TASKS ALLOCATION

According to Nakajima (1989), The production department must carry out the following three deterioration-prevention activities:

1. Deterioration Prevention:

- ◆ Operate equipment correctly.
- ◆ Maintain basic equipment conditions (cleaning, lubrication, bolting).
- ◆ Make adequate adjustments (mainly during operation and setup).
- ◆ Record data on breakdowns and other malfunctions.
- ◆ Collaborate with maintenance department to study and implement improvements.

2. Deterioration Measurement (using the five senses):

- ◆ Conduct daily inspections.
- ◆ Conduct certain periodic inspections.

3. Equipment Restoration:

- ◆ Make minor repairs (simple parts replacement and temporary repairs).
- ◆ Report promptly and accurately on breakdowns and other
- ◆ Assist in repairing sporadic breakdowns.

These activities, particularly maintaining basic equipment conditions (cleaning, lubrication, bolting) and daily inspection, help prevent deterioration but cannot be addressed adequately by the maintenance staff alone. They are most effectively handled by those closest to the equipment (the operators).

One of the first and crucial steps towards TPM's autonomous maintenance comes from the application of the five S's, which are central to all the Japanese methods.

- ◆ **Seiri** organization
- ◆ **Seiton** orderliness
- ◆ **Seiso** cleaning (the act of)
- ◆ **Seiketsu** cleanliness (the state of)
- ◆ **Shitsuke** discipline (the practice of)

In English-speaking countries an alternative to the five S's is the more easily remembered CAN-DO. The philosophy is exactly the same (Willmott, 1994).

- ◆ **Cleanliness**
- ◆ **Arrangement**
- ◆ **Neatness**
- ◆ **Discipline**
- ◆ **Order.**

The 5 Ss are basic principles of operation management. Because some factories do them very superficially according to Nakajima (1988), JIPM recommends that companies wishing to avoid superficial autonomous maintenance adopt a seven-step approach that includes progressive mastery of each of the 5 S's. Table (3.2) outlines the seven-step method developed by JIPM consultant Goto Fumio.

Step	Activities
1. Initial cleaning	Clean to eliminate dust and dirt mainly on the body of the equipment: lubricate and tighten; discover problems and correct them
2. Countermeasures at the source of problems	Prevent cause of dust, dirt and scattering; improve parts that are hard to clean and lubricate; reduce time required for cleaning and lubricating
3. Cleaning and lubrication standards	Establish standards that reduce time spent in cleaning, Lubricating and tightening (specify daily and periodic tasks)
4. General inspection	Instruction follows the inspection manual; circle members discover and correct minor equipment defects
5. Autonomous Inspection	Develop and use autonomous inspection check sheet
6. Orderliness and tidiness	Standardize individual workplace control categories; thoroughly systemize maintenance control ◆ inspection standards for cleaning and lubricating ◆ cleaning and lubricating standards in the workplace ◆ standards for recording data ◆ standards for parts and tools maintenance
7. Full autonomous maintenance	Develop company policy and goals further; increase regularity of improvement activities Record MTBF analysis results and design countermeasures accordingly

Table 3.2 Example Of The Seven Steps for Developing Autonomous Maintenance

3.5 TPM VS. PREVENTIVE MAINTENANCE

As defined earlier preventive maintenance is periodic inspection to detect conditions that might cause breakdowns, production stoppages, or detrimental loss of function combined with maintenance to eliminate, control, or reverse such conditions in their early stages. In other words, preventive maintenance is the rapid detection and treatment of equipment abnormalities before they cause defects or losses. It is preventive medicine for equipment. Preventive maintenance consists of two basic activities: (1) periodic inspection and (2) planned restoration of deterioration based on the results of inspections. Daily routine maintenance to prevent deterioration is usually considered a part of preventive maintenance as well.

TPM integrates the short and long term planned maintenance activities conducted by the maintenance department in autonomous activities where operation and maintenance department are inseparable. The planned preventive maintenance activities includes: Setting maintenance standards, preparing and executing maintenance plans, keeping maintenance records, and carrying out scheduled equipment restoration activities. It covers subsystems such as spare parts control, lubrication control, and control of maintenance budgets. It also includes diagnostic techniques for predictive maintenance, which aims.

- To reduce breakdowns and accidents caused by equipment
- To increase operating times and production
- To reduce maintenance times and costs
- To increase the quality of products and services

According to Nakajima (1988) the planned maintenance alone cannot eliminate breakdowns, which is an objective for TPM. This idea is better explained using the "life span characteristic curve, Figure 3.1. When equipment is new, there is a high failure rate (early failure period), which eventually drops and levels off. Then the failure rate

stabilizes at a certain level for a long period of time (accidental failure period). Finally, as equipment approaches the end of its useful life, the failure rate increases once again (wear-out failure period).

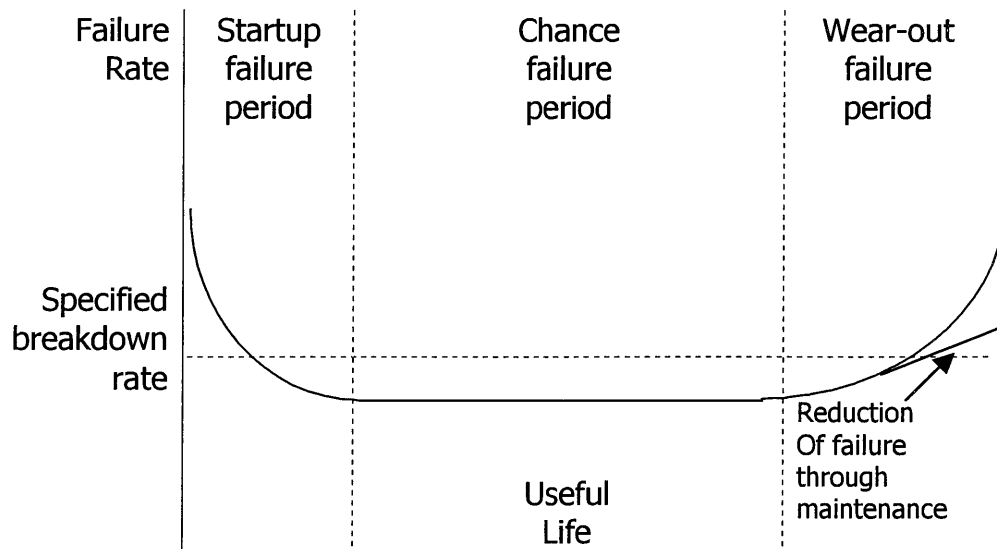
To achieve successful results each type of breakdown must be treated by different countermeasures. Causes of early period failure are design and manufacturing errors. To combat them, the design department must conduct test runs at the earliest stage. Furthermore, startup or corrective maintenance must be pursued to discover and treat weaknesses in design and manufacturing.

Accidental failures are caused primarily by operation errors, so the most effective countermeasure is to ensure that operators use equipment properly.

Wear-out failures are due to the limited natural life span of equipment parts. Equipment life can be extended by preventive maintenance and by corrective maintenance (through changes in design). This will reduce the wear-out failure rate.

Maintenance prevention is an effective countermeasure for all three types of breakdowns. A "maintenance-free" equipment design must be incorporated at the planning / design stage to prevent early period, accidental, and wear-out failures.

When the life cycle of equipment is considered in this manner, it becomes obvious that preventive maintenance alone cannot eliminate breakdowns. The success of TPM depends upon the cooperation of all departments. Maintenance as well as design/planning and operations departments should be involved in the elimination of breakdowns.



Category	Startup failure	Chance failure	Wear-out failure
Cause	Design / manufacturing errors	Operational errors	Wear-out
Counter-measures	Trial runs at acceptance and startup control	Proper Operation	Preventive and corrective maintenance
	Maintenance Prevention		

Figure 3.1 lifespan characteristics and breakdown countermeasures

3.6 WHAT IS MAINTENANCE PREVENTION?

Equipment management can be roughly divided into project engineering and maintenance engineering. Maintenance prevention (MP) is a significant aspect of project engineering that serves as the interface between project and maintenance engineering. According to Gasden & Galpin (1999), the goal of maintenance prevention activities is to reduce maintenance costs and deterioration losses in new equipment by considering past maintenance data and the latest technology when designing for higher reliability, maintainability, operability, safety, and other requirements. In other words, it means designing and installing equipment that will be easy to maintain and operate.

Maintenance prevention activities are conducted during equipment design, fabrication, installation, test run and commissioning. They include debugging at each stage (detecting and correcting errors and malfunctions). These activities are intended to reduce the period between design and stable operation and to assure efficient progress through this period with minimum labor and without imbalance in the workload. They are also intended to ensure that equipment is designed to perform at high levels of reliability, maintainability, economy, operability, and safety, and to achieve these aims within the restrictions set out at the equipment investment planning stage.

Willmott (1994) stressed that there is an extraordinarily powerful commercial advantage to a company when this vital pillar and principle of TPM can be mobilized and used to maximum effect. Designers, engineers, technologists, procurement, finance, operations and maintenance will then work as essential partners in the drive to improve the company's overall equipment effectiveness by eliminating many of the reasons for poor maintainability, operability and reliability at source (i.e. at the equipment design, engineering and procurement stage).

Suzuki (1994) indicated that to achieve the aims of MP, the engineering and design engineers responsible for equipment development must be highly skilled. They must also make full use of all available technical data, combining the application of this data with technology based on in-house research and development. This technical data includes operation and maintenance records, records of improvements to existing equipment, equipment development and modification records, outside technical data, records of past MP activities, and design standards and checklists based on these data. Analyzing and applying this information should lead to new equipment that requires less maintenance and produces higher quality products.

3.7 MEASURING TPM EFFECTIVENESS

According to Nakajima (1989) TPM effectiveness is measured for two reasons: to help establish priorities for improvement projects and to accurately and fairly reflect their results. Effectiveness measurement reveals the fruits of the daily efforts, isolates points that must be focused on, and helps to plan countermeasures. To implement TPM effectively, it is essential to know which areas in the plant are experiencing problems and what those problems are. This requires indices that show, accurately and continuously, where improvement is currently needed and what kind of results can be expected. Such indices focus improvement activities by pinpointing their most important aspects. They facilitate prompt identification and response to change and more accurate judgments, and they help promote more efficient TPM activities. The results of TPM activities are also measured using indices that show, accurately and fairly, the relative effectiveness of activities and improvement measures in the different plants or divisions.

According to Hibi (1997) Close monitoring at all levels helps maintain and improve results and promotes the development of more effective countermeasures (where no positive results are being produced). It

also helps to understand and prevent sudden drops in effectiveness. The following are the most commonly used measures for the TPM, which are extracted from the following references Nakajima (1989), Hibi (1977) and Suzuki (1994).

MEASURING EQUIPMENT EFFECTIVENESS

The overall equipment effectiveness has three factors: availability (operating rate), performance rate, and quality rate.

Overall Equipment Effectiveness

Overall equipment effectiveness is calculated from the formula.

Overall equipment effectiveness = availability x performance rate x quality rate

This is extremely useful as an overall indicator of factory or equipment performance.

Availability (Operating Rate)

$$\text{Availability} = \frac{\text{Loading time} - \text{downtime}}{\text{Loading time}} \times 100$$

(Downtime includes time for setup, adjustments, changing tools, breakdowns, and other stoppages). Operating rates can also be calculated for individual types of stoppage using the above formula.

Performance Rate

Performance rate = net operating rate x operating speed rate.

$$= \frac{\text{Output} \times \text{actual cycle time}}{\text{Loading time} - \text{downtime}} = \frac{\text{Ideal cycle time}}{\text{Actual cycle time}}$$

Quality Rate

$$\text{Quality rate} = \frac{\text{Input} - (\text{quality defects} + \text{startup defects} + \text{rework})}{\text{Input}}$$

Unit Setup Time

$$\text{Unit setup time} = \frac{\text{Total setup time}}{\text{Total setup operations}}$$

Reliability and Maintainability Indices

The following measurements are often used to classify and manage breakdowns as priority items:

Reliability Indices

$$\text{MTBF} = \frac{\text{Total stoppages}}{\text{Loading time}} \times 100$$

$$\text{Failure frequency rate} = \frac{\text{Total stoppages time}}{\text{Total stoppages}}$$

Maintainability Indicators

$$\text{MTTR (mean time to repair)} = \frac{\text{Total stoppages}}{\text{Loading time}} \times 100$$

$$\text{Failure rate} = \frac{\text{Total stoppages time}}{\text{Loading time}}$$

Measuring the Efficiency of Maintenance Activities

Indices for measuring the efficiency of the maintenance department differ depending on the type of maintenance work being done and how it is organized. They must address the following general questions:

- To what extent is the work proceeding according to plan?
- To what extent is the work helping to raise operating rates and product quality?
- Is the work being done using the most economical and effective methods?

BM (Breakdown Maintenance) Rate

$$\text{BM rate} = \frac{\text{BM jobs}}{\text{Total maintenance jobs}} \times 100$$

(Total maintenance jobs = total work done on sporadic breakdowns (BM), maintainability improvement (MI), and planned (preventive) maintenance (PM)).

BM Man-hour Rate

$$\text{BM man-hour rate} = \frac{\text{BM man-hours}}{\text{total maintenance man-hours}}$$

3.8 TPM SMALL GROUP ACTIVITIES "SGA"

A unique feature of TPM is its promotional structure of overlapping small groups, integrating organizational and small group improvement activity. According to Hirato & Ueda (1975) Japanese-style small group activities began with the quality control circle, introduced in 1962. The American concept of zero defects (ZD), which is an individual rather than a group activity, became popular three years later. NEC, the first Japanese firm to implement it, combined this individual improvement activity with the Japanese-style quality control (QC) circle to form ZD group activities.

According to Nakajima (1989) QC circles began as study groups to teach quality control techniques to shop-floor supervisors and evolved into problem solving small groups for a larger segment of the worker population. Circles are organized by subject or theme to deal with specific problems within the larger total quality control (TQC) program. Formed by workers, they are independent of the existing organizational structure. Participation is voluntary. In terms of organizational theory, they are informal organizations.

ZD groups, on the other hand, began in the United States at Martin Marietta as a means of involving all employees, individually, in solving the problem of delayed delivery. The Japanese imported the concept and incorporated it in their small group activities. Japanese ZD groups participate in management-based activities to solve problems of concern to the company and to work toward company goals. Accordingly it can be envisaged that TPM small group activities are based on the ZD model and built into the organizational framework. Small groups function at every level and across divisions to accomplish company objectives. TPM promotes autonomous maintenance by operators through small group activity. In TPM, the typically management-directed activities of equipment cleaning, lubrication, bolting, inspection, and so on, are performed autonomously as small group activities.

According to authors Hirato and Ueda (1975) the small group "promotes itself and satisfies company goals as well as individual employee needs through concrete activities. Teams called "circles" or "groups" set goals compatible with the larger goals of the company and achieve them through group cooperation or teamwork. This enhances company business results and promotes activities that satisfy both individual employee needs (self-satisfaction, success, motivation) and the needs of the organization. TPM small group activities are representative of this type.

Japanese base their insistence on small group activity on the behavioral scientist Likert (1961), who compared companies and factories that had high productivity with those that had low productivity. Likert argues that participative management is ideal because it encourages confidence among employees and promotes consistently high productivity. Authoritarian management, on the other hand, encourages submission based on fear among employees. Consequently, even if higher productivity can be achieved for a short

time, low employee morale will eventually lead to a decline in productivity.

In all small group activities workers are the leading players. In other words, those who do the work take responsibility for it rather than simply following orders and doing enough to earn their pay. Each worker manages his own work autonomously, striving for better and better results. Simply requiring operators to lubricate, clean, tighten, and inspect their machines as part of TPM will have little effect unless operators believe that they are in fact responsible for looking after their own machines.

While workers themselves must play a leading role, at the same time managers must play a large part by working to keep employees motivated. According to Nakajima (1988) there are four important factors in motivating small group activities:

- Recognizing the importance of the work
- Setting and achieving goals
- Acting on workers' suggestions
- Rewarding workers' efforts

3.9 DATA COLLECTION AND ANALYSIS IN TPM

A great deal of data can be collected in plants. Data and subsequent evaluation form the basis for actions and decisions. The following list the data collection classification of purposes, and the data analysis methods and techniques.

a) DATA COLLECTION

The data can be classified according to the various purposes they are collected for. A list of purposes is given by Ishikawa, (1985).

1) Data to assist in understanding the actual situation

These data are collected to check the extent of the dispersion in part sizes coming from a machining process, or to examine the percentage of defective parts contained in lots received.

2) Data for analysis

Analytical data may be used, for example, in examining the relationship between a defect and its cause. Data are collected by examining past results and making new tests. In this case, various statistical methods are used to obtain correct information.

3) Data for process control

After investigating product quality, this kind of data can be used to determine whether or not the manufacturing process is normal.

4) Regulating data

This is the type of data used, for example, as basis for raising or lowering the temperature of an electric furnace so that a standardized temperature level may be maintained.

5) Acceptance or rejection data

This form of data is used for approving or rejecting parts and products after inspection. There are two methods: total inspection and sampling.

b) ANALYSIS OF DATA

After data are collected, they are analyzed, and information is extracted through the use of statistical methods. Therefore, data should be collected and organized in such a way as to simplify later analysis. The following are some Data analysis techniques, which are widely used by the small groups in TPM. They are the same techniques used by the QC circle as part of the Quality Control tools. Such techniques shall be known by the QC circle leaders and if possible by all members as well.

1. Histograms
2. Cause – and – effect diagram (CE diagram)
3. Check Sheets
4. Pareto diagram
5. Graphs
6. Control Charts
7. Scatter diagram
8. Binomial probability paper
9. Sampling

3.10 TPM VS. KAIZEN

According to IMAI (1986) KAIZEN strategy is the single most important concept in Japanese management and the key to Japanese competitive success. KAIZEN laterally means improvement, but it actually means ongoing improvement involving everyone i.e. top management, managers, and workers In Japan, many systems have been developed to make management and workers KAIZEN conscious.

Underlying the KAIZEN strategy is the recognition that management must seek to satisfy the customer and serve customer need if it is to stay in business and make a profit. Improvements in such areas as quality, cost, and scheduling (meeting volume and delivery requirements) are essential. KAIZEN is a customer-driven strategy for improvement. In KAIZEN, it is assumed that all activities should eventually lead to increased customer satisfaction.

The implications of TQC or CWQC (Company-Wide Quality Control) in Japan have been that these concepts have helped Japanese companies generate a process-oriented way of thinking and develop strategies that assure continuous improvement involving people at all levels of the organizational hierarchy. The message of the KAIZEN strategy is that not a day should go by without some kind of improvement being made somewhere in the company.

What is improvement? Improvement can be broken down between KAIZEN and innovation. KAIZEN signifies small improvements made in the status quo as a result of ongoing efforts. Innovation involves a drastic improvement in the status quo as a result of a large investment in new technology and/or equipment. Figure 3.2 shows the breakdown among maintenance, KAIZEN, and innovation as perceived by Japanese management.

On the other hand, most Western managers' perceptions of job functions are as shown in Figure 3.3. There is little room in Western management for the KAIZEN concept. It is very clear that as a philosophy KAIZEN is the power behind making contentious improvement, which is a pillar concept in TPM.

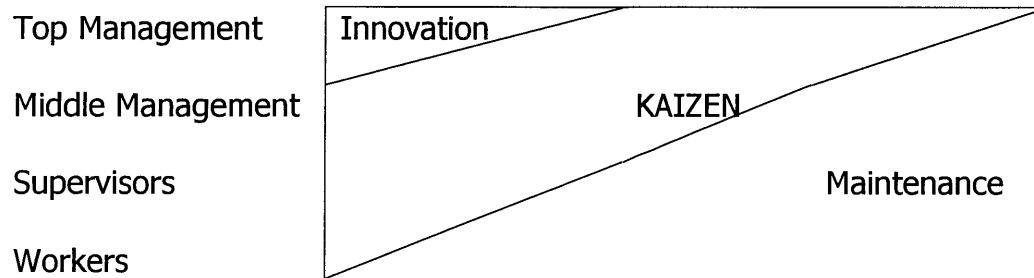


FIGURE 3.2 Japanese perceptions of job functions (2)

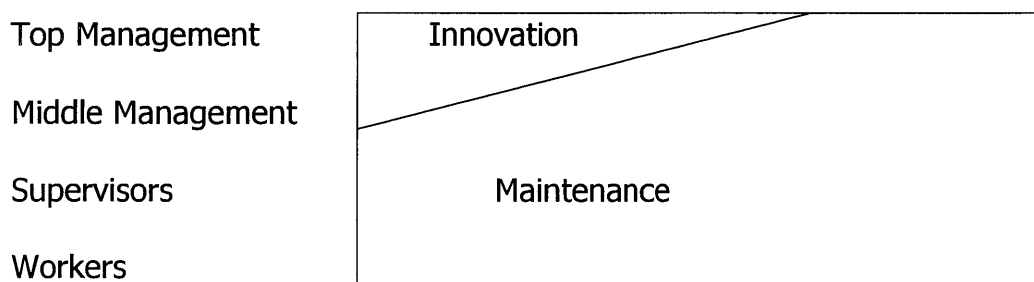


FIGURE 3.3 Western perceptions of job functions

SUMMARY

TPM was defined in 1971 by the Japan Institute of Plant Maintenance (JIPM) as to be characterized by the following five goals:

1. Maximize equipment effectiveness (improve overall efficiency).
2. Develop a system of productive maintenance for the life of the equipment.
3. Involve all departments that plan, design, use, or maintain equipment in implementing TPM (engineering and design, production, and maintenance).
4. Actively involve all employees-from top management to shop floor workers.
5. Promote TPM through motivation management: autonomous small group activities.

TPM integrates the short and long term planned maintenance activities conducted by the maintenance department in autonomous activities where operation and maintenance department are inseparable. A unique feature of TPM is its promotional structure of overlapping small groups, integrating organizational and small group improvement activity. Another feature of TPM is KAIZEN which is the single most important concept in Japanese management and the key to Japanese competitive success. KAIZEN laterally means improvement, but it actually means ongoing improvement involving everyone i.e. top management, managers, and workers In Japan, many systems have been developed to make management and workers KAIZEN conscious.

CHAPTER FOUR

TPM IMPLEMENTATION

While the western notions and Japan are very different in culture, the fundamentals of using production equipment are exactly the same. TPM has spread so rapidly through the Japanese industry since its introduction in 1971. The Western companies started introducing the TPM since the mid eighties by tailoring it to suit their differing culture and industrial type.

This chapter presents two TPM implementation cases. One is for a sugar manufacturing company in Japan which I visited in 1993 and had the opportunity to explore their success story of TPM implementation. The other is for Sitra Power and Water Plant in Bahrain where TPM was introduced in 1976 on a pilot plant.

4.1 THE CASE OF NISHI NIHON SUGAR MFG. CO., LTD., JAPAN

This plant was established in 1904 as Dai Sugar Plant, and in 1983 made a new start as a joint venture company manufacturing refined sugar for Dai-Nippon Sugar Mfg. Co., Ltd. and Meiji Sugar Mfg. Co., Ltd. Because the sugar industry was becoming very competitive, the company decided to promote a movement for "efficiency improvement by all employees" as its means for survival, and the "Total productive maintenance" was introduced as its core activities in May 1984. The program was developed based on "autonomous maintenance activities" and "specific improvement activities", which resulted in the company was awarded the Productive Maintenance Prize, Class I for the year of 1987 (Yamaguchi, 1990).

According to the company's annual report (1991), the some outline of the company is as follows.

Location: Kitakyushu City, Japan

Capitalization: ¥1,000,000,000 - (Share holders)

¥500,000,000 – (Dai-Nippon Sugar Mfg. Co., Ltd.)

¥500,000,000 – (Meiji Sugar Mfg. Co., Ltd.)

Annual output: 107,700 tons, approx. ¥21,000,000,000 –
(In the fiscal year 1989)

Employees: 88 [Male: 82, female: 6]

Plant production: 450 tons/day

The investment on plant and equipment was in the midst of the structural recession and excessive competition, tended to place importance on instrumentation for automation as the means of cutting down the number of personnel. While the mechanical equipment was becoming old, and the production was supported by the limited number of staff the equipment was almost being left un-maintained. This has resulted in occurrences of failure in the equipment, leaving the operators at the site busy trying to cope with plant troubles with no enough time to work out solutions and analysis of failures or improvement of the equipment.

In processing industry where long-term continuous operation is imperative, any accident and failure during operation causes entire process shutdown, causing a huge amount of loss. Therefore, it was essential to establish a system and organization to assure equipment maintenance during operation. The autonomous maintenance activities were decided to be carried out as a first priority. The aim was to establish an autonomous management system for the equipment as well as to make a creative and active organization through small group activities.

As for the development of autonomous maintenance activities in the company, a development program had been worked out on phases putting emphasis on how many types of equipment could be taken within a specified period of time. Figure 4.1 is a flow chart for TPM implementation targeting the promotion of autonomous maintenance and aiming at minimizing failures of equipment by early discovery of abnormalities and prevention of deterioration through carrying out the simple activities of cleaning, inspection and lubrication as well as periodical replacement of parts of which are within the scope of autonomous maintenance (Yamaguchi, 1990).

An example of improvement through autonomous maintenance needs to be given to understand the results in amore clear way. This has been recorded in a lecture given by the maintenance manager during a visit to the company. The example is about stopping the sugar leakage from the automatic filter. The company was facing a problem of liquid sugar was leaking from all of the ten filtering units which makes the machines and the floor dirty. Since the filters are of rotating type, there has been too much leakage from the gland, which resulted in frequent replacement of packing and loss of production.

Grasping and Analyzing the Conditions

The leakage of liquid sugar was found to be due to the gland of the shaft getting un-tight because the shaft diameter was as large as 242 mm and its run-out deformed the packing. The liquid sugar flows out through the clearance between the packing and the shaft. The problem is worsened by the rotation of the shaft, which caused the wearing in the packing. The leakage amount of liquid sugar was averaged at 72 liter per hour per unit, but it some times reaches to a maximum of 180 l/hr, which makes the annual leakage approximately 4400 M³.

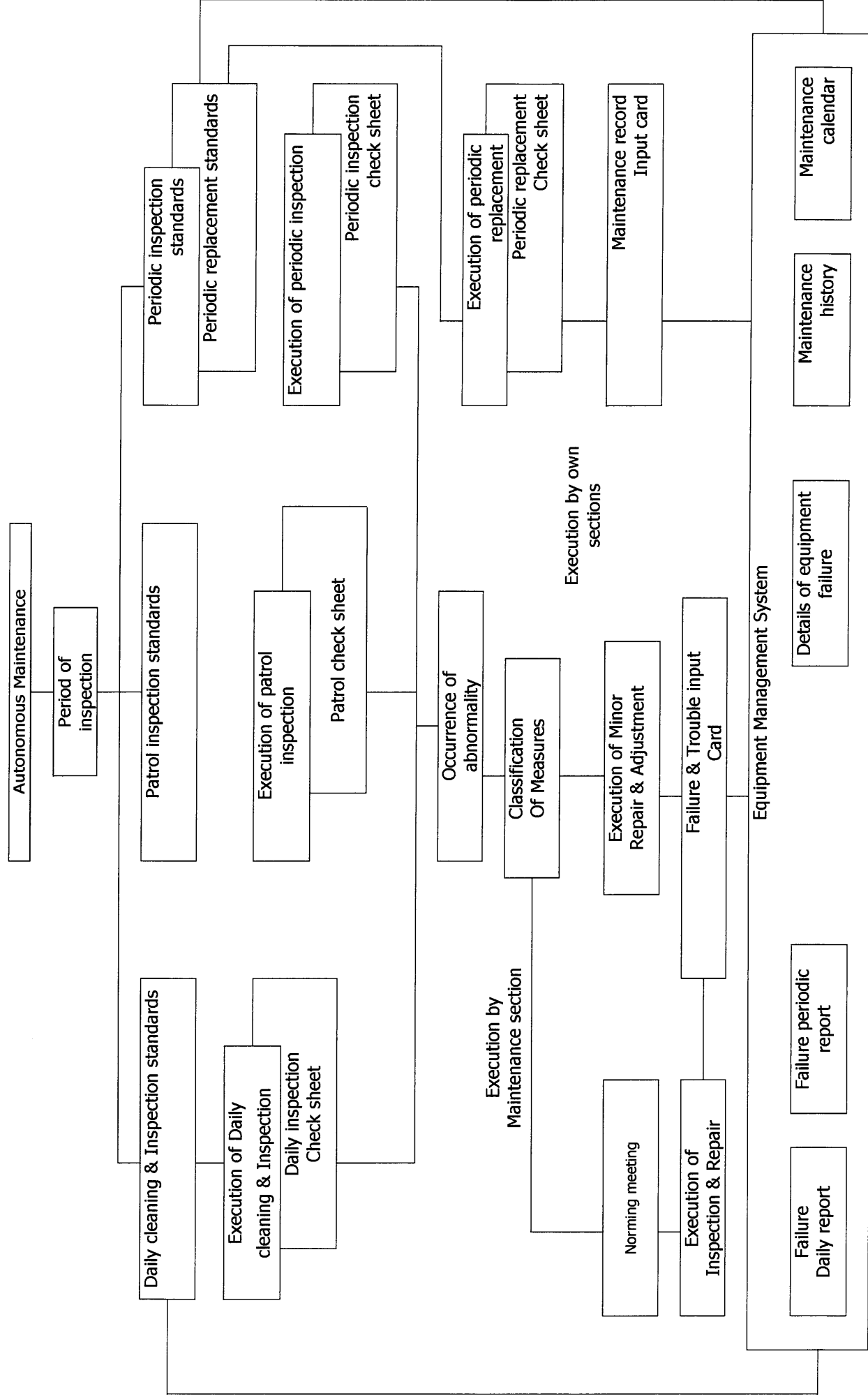


Fig 4.1 Flow Chart for Autonomous Maintenance

(Source: Nishi Nihon Sugar MFG. Co. Ltd.)

Details of the Improvements

The problem was studied by the autonomous small groups and rectified through by the Alignment of the Shaft of the Filters and improving the adjusting bolt of the supporting guide rollers for the rotating shaft to facilitate the adjustment and centering. A graduation plate was installed for visual control, so that any one could perform the work according to the standard. The filters were of revolving type, supposedly, for the purpose of better filtration. But it was doubted whether the system was really effective or not. By repeated tests related it was proven that the rotation had nothing to do with better filtration, hence the automatic sequence was revised to rotate the filter only during the cleaning and pre-coating processes and to stop the rotation during the filtering and passing of the liquid. This has resulted in the prevention of leakage from the gland and also in energy conservation (Yamaguchi, 1989).

Results of Improvements

- (1) The Effect of Minimizing Leakage on availability is shown in table 4.1

	Before the Improvement	After the Improvement	Reduction Ratio
Minimization of leakage of liquid sugar	4400 m ³ /year	15 m ³ /year	99.7%
Minimization of cleaning time	90 min./unit-man	20 min./unit-man	78.0%
Frequency of packing changed	4 times / year	0.5 time / Year	87.5%

Table 4.1 Effect of minimizing liquid sugar leakage on availability

(2) Effect On Energy Saving

- Electric power saved by: 1,800 KWH/year
Minimizing the leakage
- Electric power saved by: 28,400 KWH/year
Stopping the rotation

(3) Indirect Benefits

The fact that improvement idea overcame the problem and changed the concept that "a filter has to rotate", a great accomplishment was attained, which activated the small group activities to achieve more results. Standardized work was established by looking with the eyes, control of the alignment and adjustment of the rotating shaft.

RESULTS OF TPM

1. Improvement in productivity is shown in figure 4.2.
2. Reduction in total number of failures is shown in figure 4.3.

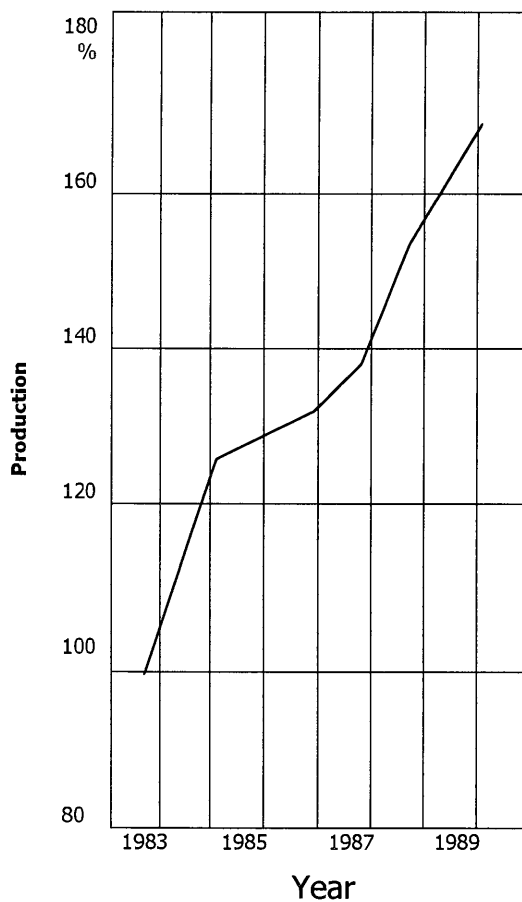


Figure 4.2 improvement in productivity

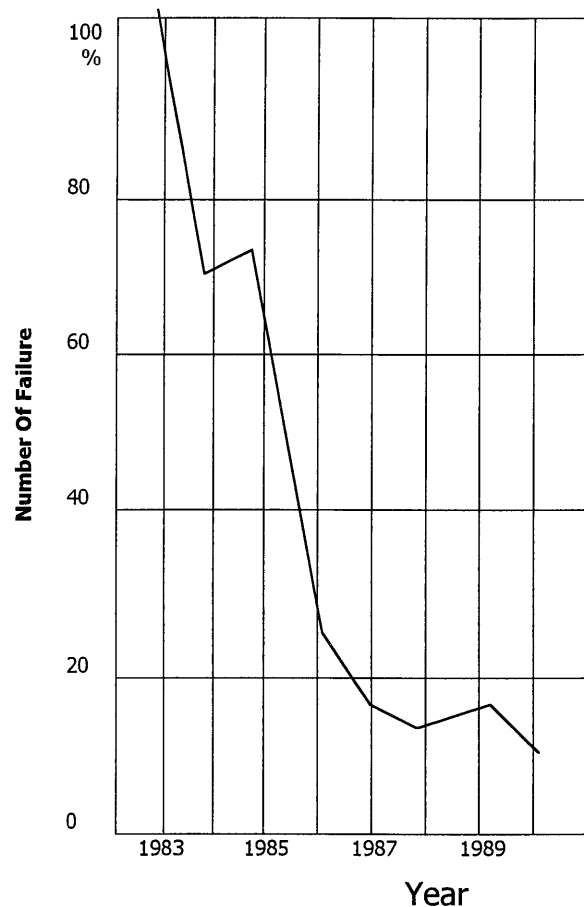


Figure 4.3 Reduction In number Of Failure

3. The confidence that "Anything can be achieved by challenge" was created through the processes of problem solving techniques.
4. Employee's Observation and sensitivity to defects were greatly improved together with being problem conscious.
5. The establishment of small group activities resulted in workshops becoming bright and clean, good teamwork and high morale of employees.
6. TPM brought about true communication among employees and enabled them to work systematically.

4.2 TPM INTRODUCTION AT SITRA POWER & WATER PLANT IN BAHRAIN

Sitra Power and Water Plant is a co-generation plant owned by the Government of Bahrain and built in three phases. Phase I plant was commissioned in 1975/1977 while phase II and III were commissioned in 1985 and 1986 respectively. Phase I of the Sitra Power and Water Plant was built to meet the country's ever growing needs for electrical power and good quality drinking water. It consisted of four gas fire water tube boilers of "Waagner Biro" manufacture, each rated to produce 57.5 kg/s of steam at 43.2 bar g at 481° C and supplying four 30 MW "Franco-Tosi" steam turbine units. The total installed steam raising capacity provided was significantly in excess of the maximum turbine and distiller load installed under Phase I to allow for future plant expansion by the installation of additional distiller units (El-Saie, 1986).

The Plant was operated in its Phase I configuration from commissioning through to 1986 in a base load mode, governed by the requirements of the water and electrical network. In 1985 one co-generation, stand alone unit, identified as Phase II of the Sitra Power

and Water Plant was commissioned. Phase II co-generation plant comprises one dual fuel "ABB" Type 9 gas turbine producing 24.20 MW and 23.70 MW at 50°C ambient temperature when firing natural gas and liquid fuel respectively. Connected to the gas turbine flue gas discharge is one waste heat recovery boiler of "Macchi" manufacture, producing 22.2 kg/s of steam at 14 bar g and 215 °C and supplying part of the steam requirements for one "Italmimpianti" 22,880 m³/day multi stage flash (MSF) desalination unit. The remaining steam requirement is produced from a 45.8 kg/s dual fuel fired water tube pressurized "TITAN M" package auxiliary boiler connected to the waste heat recovery boiler common steam header. Phase II plant is designed to utilize its own gas reducing station, liquid fuel supply system, seawater intake, seachlor plant etc (Fichtner, 1997).

In 1986, and as part of the desalination sector expansion plan, Phase-III was commissioned comprising of three identical MSF units, each of a 5 MGD capacity when operated at 90°C Top Brine Temperature (TBT). Each is also designed to produce about 6.8 MGD when operated at a TBT of 110 °C. At present, the installed plant capacity at Sitra Power and Water Plant is 125 MW of electrical power and 25 MGD of water when operated at 90 °C TBT, or up to 30 MGD when operated at 110 °C TBT (Fichtner, 1989).

According to the approved organization's chart of SPWP the total approved staffs of Sitra Power & Water Plant are 446 persons, out of which 210 employees are working in the maintenance section, representing 47% of the total staff organization. They are distributed among three maintenance sections as follow.

- 125 employees, in the mechanical maintenance section.
- 43 employees in the electrical maintenance section.
- 42 employees in the instrument maintenance section.

Sitra Power & Water Plant is operated as a base load Plant. A base load Plant means it is continuously operated at its design or maximum load.

Because Sitra is a major water desalination Plant and that desalinated water is a scarce commodity in Bahrain and is required throughout the year, SPWP is always kept on its maximum load to meet the water demand of the country. The power generation is also kept on its maximum because it is the requirement of the process to meet the water desalination.

It is the Ministry of Electricity & Water's policy to reduce the quantity of water consumed from the underground wells. For this purpose the Ministry limited the total water consumption in Bahrain to 72 million imperial gallons per day, while the total water desalination is 35 million gallons per day at its best before the introduction of Hidd Power & Water Plant. The Ministry has an ambitious plan to reach total dependence on desalinated water by the year 2006 with a total capacity of 90 million imperial gallons per day (Fichtner, 1997).

SPWP to be the major water producing Plant in Bahrain and it always has high attention from the Ministry's higher management. Its maintenance management system is well established since the early eighties. The maintenance policy at SPWP focuses on carrying out maintenance work to support the Production Directorate's functions for a safe, reliable and economic supply of Water and Electricity to meet the demand of Bahrain. According to Ibrahim (2000), This has reflected in setting management activities to target the following:

1. Workplace health and safety.
2. On going development and continuous improvement of plant and work management plans.
3. Support of training and development initiatives aimed at Bahranization and promotion of learning culture.
4. Proper financial planing and control.

The maintenance management objective at SPWP has always been to maximize water and electricity production in a safe and cost effective manner. To meet the short and long term goals, SPWP utilized the full

potential and values of its employees with a lot of effort for efficient use of resources. The objectives and setting of goals and targets of the maintenance department is reviewed annually and agreed with the Plant manager, Head of maintenance division, Head of operation division, senior planning engineer and the admin officer. The following are the key areas of emphasis.

- Power and Water Production requirement.
- Availability targets.
- Thermal efficiency targets.
- Reliability targets.
- Employee relations and training targets.

This agreement is then taken by to the maintenance division where it is translated into working procedures where, a commitment of the following takes place (Ibrahim, 2000).

- Plant management plans.
- Working management plans.
- Performance indicators to monitor and report the progress.

a) PLANT MANAGEMENT PLANS

According to Ibrahim (2000), an individual plant strategy or engineering plan is prepared for each clearly defined plant area. The plan is a single document or parts thereof that can give a concise picture regarding plant status and future direction. The respective Senior Maintenance Engineers assume responsibility for engineering plans prepared under their engineering discipline. The plans contain and consider the following points as a minimum:

- Plant overhaul, preventative, corrective and predictive maintenance philosophies.
- The requirements of plant/workplace health and safety.
- Life plans.
- Statutory/insurance requirements.

- Plant modifications and projects.
- Remnant life assessment or continuous life assessment philosophies.
- Manufacturers/OEM's recommendations.
- Local experience/history.
- Spares policy and coverage of insurance and consumable spares.

The plans take account of successful strategies and plans implemented to date (bottom up) as well as an approach based on future issues and plant requirements (top down).

b) WORK MANAGEMENT PLANS

The work management strategies complement the Plant Management or Engineering Plans and transfer the needs of the plant into long and short-term work management plans. They are prepared for each section within the Maintenance Division on a function or plant based group as appropriate. These plans are reviewed regularly and approved by the Head of Maintenance. Responsible officers are nominated by the Head of Maintenance in consultation with Senior Maintenance Engineers to develop work management plans. These may be part of existing committee structures (Al-Mulla, 2000). The plans contain and consider the following:

- i. Feedback mechanisms on the effectiveness of the engineering plans
- ii. Training and development plans to suit plant as well as personal development needs
- iii. Work patterns
- iv. Resourcing structures and job organization
- v. Use of contractors
- vi. Job design
- vii. Workplace health and safety

- viii. Scheduling, planning and allocation of work
- ix. Job roles and responsibilities
- x. Employee relations

c) *PERFORMANCE INDICATORS*

Both plant and work management strategies and their respective plans are monitored by the Planning Section, who assumes the role of an independent auditor for the Maintenance Division as well as a service to the Plant and Work Management Groups. It also has a dual report function reporting to the Manager on Management Information Systems. To this end some of the indicators support the overall section objectives, and others support performance indicators at all levels of the Maintenance Division. Typical high-level indicators are listed as follows. These are amended to support Plant objectives and strategies agreed each year (Al-Mulla, 2000).

- *Plant*
 - Actual plant production / forecast
 - Actual plant availability / forecast
 - Actual plant reliability / forecast
- *Percentages*
 - preventative maintenance
 - corrective maintenance
 - Predictive maintenance
 - Planned outages vs. unplanned outages
 - Thermal efficiency / forecast
- *Health & Safety*
 - Number of loss time accidents
 - Number of safety incidents reported and completed
- *Employee relations*
 - Percentage overtime against normal hours
 - Training commitment by hours / Section
 - Approved leave scheduled (by Section)
 - Number of correctors per month (by Section)
 - Number of callouts per month (by Section)

- *Work performance*

Number of jobs in backlog per Section

Maintenance backlog in hours per Section

Maintenance works completed in hours by –

- Preventive maintenance
- Corrective maintenance
- Predictive maintenance

Modifications approved (by Section)

Modifications outstanding (by Section)

Number of reworked jobs

- *Plant overhauls*

Plant and non-plant details to be specified depending on work performed.

- *Financial performance*

Actual financial performance / forecast budget by Chapter, by Section & by Division.

The functional structures at SPWP exist for normal production based maintenance and for project-based maintenance e.g. overhauls and outages (see figure 4.4 and 4.5). The structures are flat, and according to Al-Alawi (2000), they are aimed at providing the following characteristics:

- a. Maximizing the use of available expertise by defining roles and responsibilities.
- b. Reducing the number of reporting levels.
- c. Improving upward and downward communication.
- d. Encouraging sideward communication and team building.
- e. Exposing employees to different facets of the organization in order to improve their appreciation of the business.

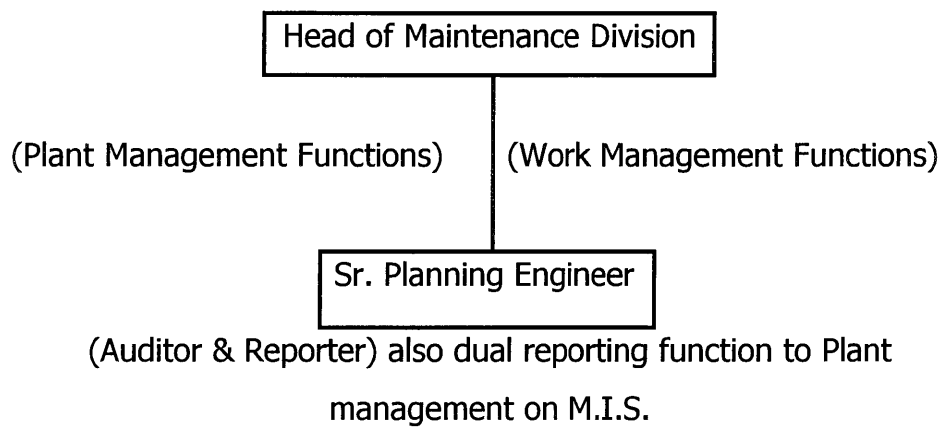


Figure 4.4 Maintenance production structure

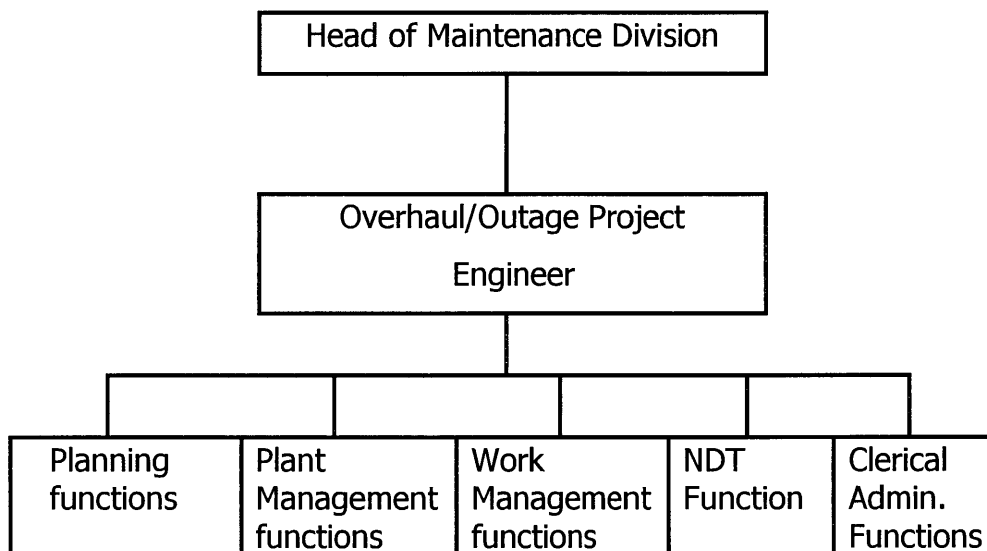


Figure 4.5 Maintenance functional structures

SPWP phase (I) is at the end of its design life. A typical design life is in the range of 20 to 25 years. As the Plant gets older and older the degradation of equipment become greater and hence their reliability decreases. This puts an increased pressure on the Plant management to find the means and ways to keep the production of the plant at a level that meets the national demand of electricity and water. Tables 4.2 and 4.3 show degradation of equipment performance at two consecutive years (SPWP's annual report, 2000).

The maintenance activities increase proportionally to the equipment degradation. The Plant's management is continuously improving on its maintenance techniques and management systems to coup with the production demand. Better team working between maintenance and operations is needed to solve ongoing plant problems, which are not necessarily related to machinery breakdown. Plant responsibility and accountability by both maintenance and process operators are needed. Process operators for example are totally flexible across the plant without responsibility for equipment. The likely benefit of a proactive maintenance is needed. For the above reasons and Observing the significant costs of maintenance activities and the economic benefit to be gained from higher process and equipment availability and reliability, in 1996 SPWP embarked on the application of the TPM on a pilot scheme in order to increase the plant equipment Reliability and availability and to make the most effective utilization of the available resources. The scheme was implemented on the following sub plants.

- The Sea Water Intake System
- The Chlorination plant
- Phase II plant which comprises
 - Phase II gas reducing station.
 - GT-5 gas turbine.
 - One heat recovery boiler.
 - One Auxiliary boiler.
 - One Desalination Unit

ITEM	UNIT	JAN – DEC.		Variation % with Last Year
		2000	1999	
		ACTUAL	ACTUAL	
<u>T/A1 – T/A4</u>				
Power Generation	GWH	754.923	750.789	-0.547
Availability	%	88.04	87.13	-0.91
F.O.R.	%	0.29	0.28	-0.01
M.O.R.	%	0.18	0.34	-0.16
P.O.F.	%	11.55	12.32	-0.77
Efficiency (U.S.O.)	%	38.10	41.32	-3.22
Average Load	MW	24.4	24.59	-0.778
<u>G.T.5</u>				
Power Generation	GWH	137.553	207.556	-50.891
Availability	%	62.52	93.99	-31.47
F.O.R.	%	0.50	-	+0.50
M.O.R.	%	2.71	0.03	+2.68
P.O.F.	%	35.42	5.98	+29.44
Efficiency (U.S.O.)	%	40.08	40.32	-0.24
Average Load	MW	25.04	25.2	-0.638
<u>ALL TURBINES</u>				
Power Generation	GWH	892.476	958.345	-7.38
Units Sent Out (USO)	GWH	867.249	932.093	-7.476
Aux. Power Consumption	%	2.827	2.739	+3.112
Availability	%	82.94	88.5	-5.56
F.O.R.	%	0.32	0.22	+0.10
M.O.R.	%	0.57	0.28	+0.29
P.O.F.	%	16.32	11.05	+5.27
Efficiency (U.S.O.)	%	38.40	41.09	-2.69
Specific Gas Consumption	M ³ /KWH	0.298	0.279	+6.375

F.O.R. – Forced outage rate, M.O.R. – Maintenance outage rate, P.O.F. – Planned outage factor

Table 4.2: Turbines performance
(source: SPWP's annual report, 2000)

ITEM	UNIT	JAN – DEC.		Variation % with Last Year
		2000	1999	
		ACTUAL	ACTUAL	
<u>DISTILLERS 1A & 1B</u>				
Water Production	MM ³	3.496	4.454	-27.402
Availability	%	51.36	68.14	-16.78
F.O.R.	%	23.64	6.41	+17.23
M.O.R.	%	3.87	1.43	+2.44
P.O.F.	%	30.68	26.2	+4.48
<u>DISTILLERS 2, 3 & 4</u>				
Water Production	MM ³	24.615	26.696	-8.454
Availability	%	86.47	89.48	-3.01
F.O.R.	%	1.76	0.37	+1.39
M.O.R.	%	0.40	0.81	-0.41
P.O.F.	%	11.64	7.72	+3.92
<u>DISTILLERS 5</u>				
Water Production	MM ³	7.238	7.239	-0.152
Availability	%	90.68	86.54	+4.14
F.O.R.	%	0.20	0.21	-0.01
M.O.R.	%	-	0.63	00.63
P.O.F.	%	9.14	12.73	-3.59
<u>ALL DISTILLERS</u>				
Gross Water Production	MM ³	35.340	38.390	-8.63
Net Water Production	MM ³	35.050	38.065	-8.602
Overall Output Factor	%	105.82	108.04	-2.097
Overall Production Ratio	L/M ³ GAS	93.81	91.3	+2.51
Overall Availability	%	75.46	82.74	-7.28
F.O.R.	%	7.49	2.07	-5.42
M.O.R.	%	1.13	0.95	+0.18
P.O.F.	%	17.57	14.72	+2.85
Total Water Supplied to WSD	MM ³	34.895	37.918	-8.663
Plant Make up	MM ³	0.290	0.324	-11.724

F.O.R. – Forced outage rate, M.O.R. – Maintenance outage rate, P.O.F. – Planned outage factor

Table 4.3: Distillers performance

(source: SPWP's annual report, 2000)

The scheme is quite ambitious and in order to help the employees to introduce TPM principles, philosophy and practicalities a structured step-by-step procedure is developed and is based on the following:

1. Initial general TPM awareness sessions for senior management, supervision and employee representatives. This is to get "buy-in" and initial commitment from the key influencers.
2. A short, sharp scoping study to determine how TPM can be tailored to suit the Plant situation.
3. Mobilization to agree to commitment, delivery, site awareness and detailed training for the TPM pilot and subsequent site-wide implementation.
4. Creation of the TPM organization.
5. Plant specific TPM awareness for all employees directly or indirectly involved in TPM.
6. Forming the small groups.
7. A comprehensive and practical four – day TPM facilitator and supervising training course.
8. Development of an autonomous maintenance programme by the small groups.
9. Conduct training to improve operation and maintenance leaders.
10. Continuous improvement of implementation.

To develop autonomous maintenance, the Small Group staffs are left to develop and improve their operation and maintenance skills by their own. This is achieved by adopting a non-authoritarian of management in relation to the TPM organization. It has to be emphasized that the management support is required at all times which is a key point in the success of TPM.

The Small Groups or "Quality Circles " teams of TPM are made up of one team leader, three to four team members and one TPM facilitator. The members of the circle are from deferent disciplines that are related to the operation and maintenance of the concerned sub-plant. The disciplines of the members are normally as follows:

- Mechanical Maintenance Section
- Electrical Maintenance Section
- Instrumentation and Control Maintenance Section
- The Operation Section
- The Chemical Section
- The Planning Section
- And some times the administration section

The team members are trained on the TPM quality circle techniques. The techniques are very simple but are very effective in terms of data collection, equipment's status identification and problem solving. The team members concentrate on the problems that hinder their pilot plants and utilize systematic methods of problem identification as normally used in QC circles. As there are many quality control techniques used by the Quality Circle Groups the Small Groups of SPWP uses the most appropriate techniques that are more suitable to the process they are dealing with. It is left to the members to decide the methods of data collection and techniques of compilation, organizing and analysis. The Pareto diagram, cause and effect diagram and correlation charts are extensively used. Figures 4.6 and 4.7 are some examples extracted from a real problem solving at SPWP.

Within one and a half year the number of quality circles grew from 2 to 5 groups. The groups have activities distributed among the sub-pilot plants they are responsible for. They conduct the quality circle sessions normally within the normal duty hours during the day shift when the maintenance staffs are available.

The operators gradually started to do the minor maintenance work (cleaning, lubrication, filling, painting, minor adjustment and simple equipment overhaul). To encourage them further they are allowed to participate in the major plant overhauls when it is on a long planned maintenance outage instead of letting them idle while the plant is not operating.

The performance indicators are exercised by some group of the QC circles, while some others continue to use the existing plant maintenance and production performance indicators. Table 4.4, 4.5 and 4.6 show the performance indicators for the pilot plants under TPM implementation at the beginning of TPM introduction and at the year 2000.

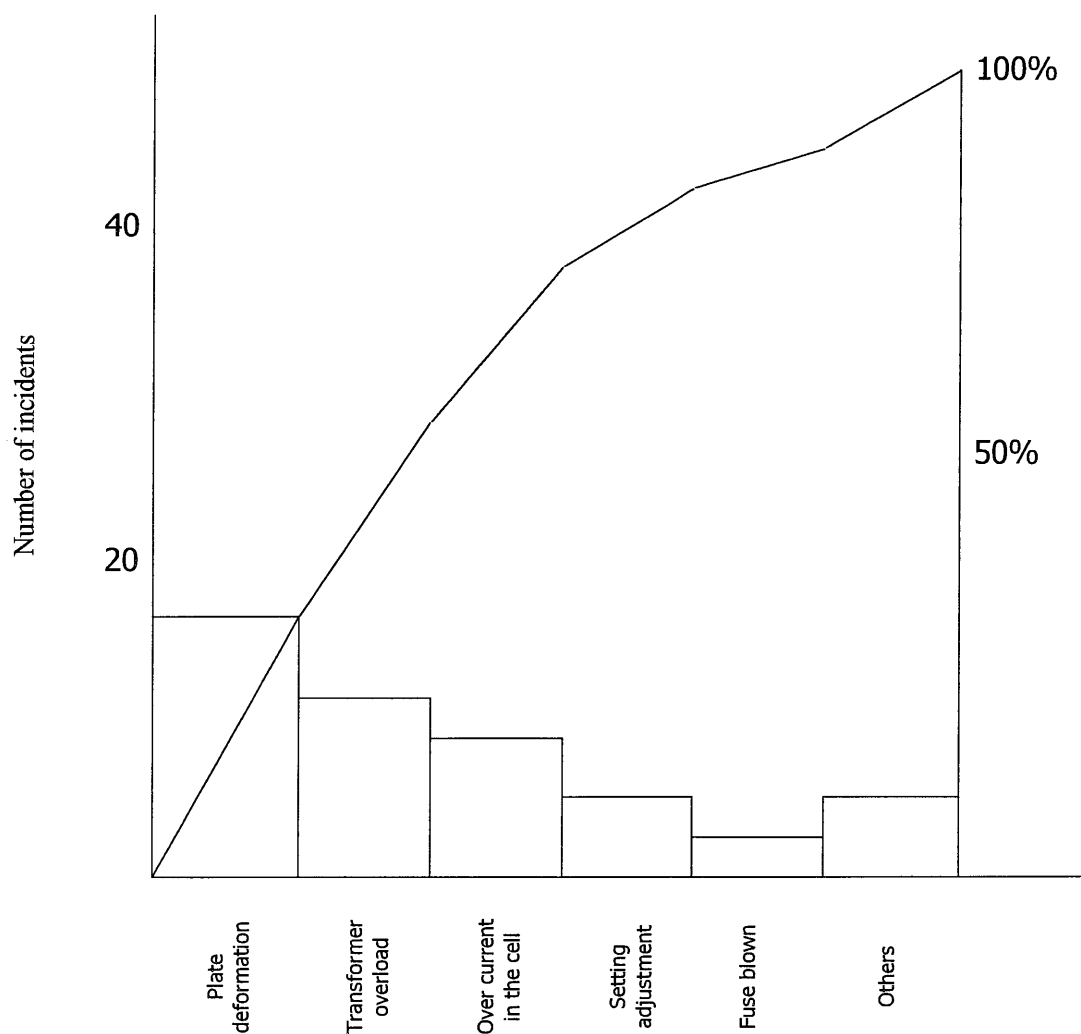


Fig. 4.6 Pareto diagram for the electrochlorinator unit no. 1 in the sea chlorination plant

(Source: SPWP's TPM activities, Planning Section's records,)

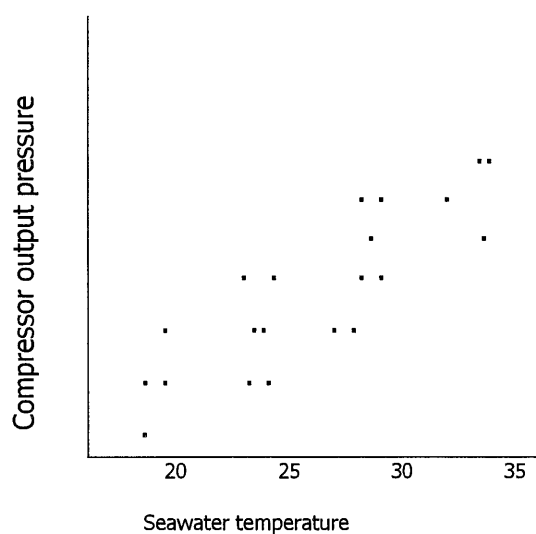


Figure 4.7 Correlation chart for Phase II Instrument Air Compressor

(Source: SPWP's TPM activities, Planning Section's records,)

Indicator		1996	1997	1998	1999	2000
FOR %	Target	.1	.1	.1	.1	.1
	Actual	20	10.4	.35	.09	.09
MOR	Target	.1	.1	.1	.1	.1
	Actual	6.6	6.0	4.0	.1	.2
Availability	Target	90-100	90-100	90-100	90-100	90-100
	Actual	78	88	95	96	98.8
Overall plant effectiveness	Target	80-90	80-90	80-90	80-90	80-90
	Actual	68	75	85	88	90

Table 4.4 Performance Indicators of the Seawater Chlorination Plant

(Source: SPWP's TPM activities, Planning Section's records,)

Indicator		1999	2000
FOR %	Target	.1	.1
	Actual	3	2
MOR	Target	.1	.1
	Actual	5	5
Availability	Target	90-100	90-100
	Actual	85	86

Table 4.5 Performance indicators of the Seawater intake system

(Source: SPWP's TPM activities, Planning Section's records,)

		GT-5	DISTILLER 5	Aux BLR	HRB
PARMTR	YEAR	ACTUAL	ACTUAL	ACTUAL	ACTUAL
GEN. MW OR MM ³	96	197.209	6.669		
	97	217.961	8.288		
	98	155.34	6.245		
	99	207.556	7.239		
	2000	137.553	7.228		
F.O.R %					
	96	0.39	0.71	0.75	1.49
	97	0.05	0.71	0.14	0.1
	98	3.93	0.75	0.59	0.82
	99	-	0.21	0.35	0.07
	2000	0.5	0.2	0.18	0.77
M.O.R %					
	96	0.1	0	0.33	0
	97	0	1.33	0.95	2.43
	98	0.68	0.95	0.92	0.82
	99	0.03	0.63	0.56	0.64
	2000	2.71	0	0	0
AVAIL %					
	96	89.58	84.25	83.25	86.27
	97	98.99	98.51	98.92	96.47
	98	70.99	77.32	77.56	54.66
	99	93.99	86.54	86.5	86.66
	2000	62.52	90.68	90.8	59.34

Table 4.6 Performance Indicators of Phase II Plant

(Source: SPWP's TPM activities, Planning Section's records,)

SUMMARY

Nishi Nihon Sugar Manufacturing Company was established in 1904 as Dai Sugar Plant, and in 1983 made a new start as a joint venture company manufacturing refined sugar for Dai-Nippon Sugar Mfg. Co., Ltd. and Meiji Sugar Mfg. Co., Ltd. Because the sugar industry was becoming very competitive, the company decided to promote a movement for "efficiency improvement by all employees" as its means for survival, and the "Total productive maintenance" was introduced as its core activities in May 1984. The program was developed based on "autonomous maintenance activities" and "specific improvement activities", which resulted in the company was awarded the Productive Maintenance Prize, Class I for the year of 1987 (Yamaguchi, 1990).

Sitra Power and Water Plant is a co-generation plant owned by the Government of Bahrain and built in three phases. Phase I plant was commissioned in 1975/1977 while phase II and III were commissioned in 1985 and 1986 respectively. In 1996 SPWP embarked on the application of the TPM on a pilot scheme in order to increase the plant equipment Reliability and availability and to make the most effective utilization of the available resources.

CHAPTER FIVE

RESEARCH METHODOLOGY AND RESULTS ANALYSIS

5.1 RESEARCH METHODOLOGY

a) RESEARCH ASSUMPTIONS

The TPM implementation at SPWP is not the only implementation for a TPM outside the industrial nations. The system proved its success in the USA and Western Europe as the literatures suggest. It flourished in Japan since the beginning of the seventies and is considered one of the factors for the success of the Japanese industry. The TPM is not implemented in just some sectors of the manufacturing industry but also in other sectors like the services sector, hence the two cases' studies were taken from two different types of industry.

To the best of my knowledge, the TPM is not implemented anywhere in Bahrain. A survey conducted on the industry in Bahrain revealed that none of the big companies are implementing the TPM approach in their maintenance activities hence this study assumes that SPWP is the only industrial organization in Bahrain that implements TPM on a pilot plant. In most of the industry, conventional maintenance management systems are applied, which are based on the Plant Preventive Maintenance "PPM".

When this research was conducted at SPWP, it was assumed that the staffs that participated in answering the questionnaires are all familiar with TPM applications. This does not necessarily mean that they are directly participating in TPM activities. Based on this assumption the outcome of the questionnaire is considered as an accurate representation of the TPM status at SPWP. Finally it is assumed that

TPM maintenance cost is outside the scope of this research simply because the data about it is not available at SPWP.

b) SAMPLE SELECTION AND DATA COLLECTION

As mentioned earlier, Bahrain industry was surveyed for the application of TPM. The survey revealed that TPM is not introduced in Bahrain. The research is narrowed down to the case study of Sitra Power and Water Plant.

The method used in the sample selection is judgmental sampling. It is a non-probability sampling technique in which the sample is selected based on an expert or experienced researcher judgment about some appropriate characteristics required of the sample member (Zikmund, 1991). Being an ex-employee of SPWP and having knowledge about the plant structure, the maintenances organization, and the employees' experience, judgment of the sample selection can be fairly taken. It is of paramount importance to the study that the respondents are familiar with the issue and in an educational and experience status to give more accurate responses. Because of the small size of SPWP population a quota for employees' categories is applied. A classing of population by pertinent properties, determines desired proportion of sample from each class. The purpose of quota sampling is to ensure that the various subgroups in a population are represented on pertinent sample characteristics to the exact extent that the investigators desire (Zikmund, 1991).

In total 42 questionnaires were distributed to the staffs of SPWP. The sample quota distributed as follows: Seven Engineer of different categories and experience, 30 technicians of different disciplines in both maintenance and operation departments. The emphasis on technicians was for two reasons. The first is that they are the most participants in the TPM activities. The second is that they are

knowledgeable enough to give accurate responses. Because fitters are not highly qualified as technicians, only five have been selected but they were of good knowledge about TPM and plant maintenance.

The respondents were asked to answer both parts of the questionnaire. All the 42 questionnaires were received back from the respondents and all were accounted for. Many of the questionnaires were answered with the help of interviews, which aim at making sure, that the responses are accurately represented and that all of the questions and statements are attended to.

c) THE RESEARCH PROCEDURE AND THE QUESTIONNAIRE DESIGN

The research is conducted via a questionnaire that aims at exploring the status of the TPM implementation at SPWP, by getting the staffs attitudes, through sets of questions. This method is considered to be the quickest, the most efficient and accurate mean of assessing the information about the population attitudes (Zikmund, 1991). To reduce the survey error the questionnaire was first tested on a small sample and was further tuned later on. The questionnaire consists of two parts, part one and part two, which are organized as follows:

Part one consists of 6 questions about the population samples status and categorization. It is based on the simple attitude scaling whereby the respondents either agree or disagree with the written statement (Zikmund, 1991). While part two consists of 33 statements to measure the population sample's attitude towards TPM at SPWP, which consequentially reflect the TPM status at SPWP. The following are the concepts that are addressed by this part.

Statements 1 to 5 address the TPM introduction program and awareness. Statements 6 to 10 addresses education and training on TPM and how efficient they are at SPWP. Statements 11 to 15 address

the TPM organization at SPWP. Statements 16 to 21 address the Small Group Activities "SGA" and the effectiveness of its practices at SPWP. Statements 22 to 26 address the culture of SPWP and its effect on TPM implementation. Statements 27 to 30 address the motivation towards TPM at SPWP. Statements 31 to 33 address SPWP management dedication and support to TPM.

Part two is a summated rating method based on the Likert scale. The respondents indicate their attitudes by checking how strongly they agree or disagree with the written statements. There are five alternatives to choose from: strongly disagree, disagree, uncertain, agree or strongly which are scored by assigning a weight to each category for analytical purposes, according to the intervals SD= -2, D= -1, U= 0, A= +1 and SA= +2.

5.2 THE FINDINGS

All the 42 questionnaires delivered to the selected sample were received and accounted for and all of them were answered in full. There weren't much ambiguity with the questionnaire as it has already been checked and tested for clarity by a number of experienced engineers prior to its distributions. A number of respondents contacted for clarification by telephone during their response recording. Additionally the respondents were personally interviewed when the questionnaires were submitted to ensure that the intended attitude of the respondents is what was recorded.

The answers of the respondents (total 42) and the results obtained from the questionnaires are tabulated below, for both parts one and two. The answers to part one, the general questions, are tabulated in tables 5.1 which indicates the rank of the respondent, his or her year of experience at SPWP, the section they work for, whether he or she a member of the "Quality Circle" or not, How long the person is a member and the pilot plant he or she works on.

The rest of the results are tabulated in two formats. The first format (table 5.2) lists the number of respondents to each statement of Part Two tabulated in accordance with the scale of satisfaction to the statement, the resultant mean and the resultant standard deviation. The other format lists the respondents' attitudes ranked according to the popularity of the written statement i.e. the statement with the more positive mean, showing the mean and the standard deviation, thus reflecting the actual status of the particular section of the questionnaire.

		NO. of Respondents	%
1. Rank	Engineers	7	16.6
	Technicians	30	71.4
	Fitters	5	11.9
Years of Experience	1 – 5 year	1	2.4
	6 – 10	8	19
	11 – 15	15	35.7
	> 15	18	42.8
Section	Operations	9	21.4
	Maintenance	24	57.1
	Planning	3	7.1
	Chemical	4	9.5
	Others	2	4.8
Quality Circle	Member	19	45.2
	Non Member	23	54.7
	1 Year	4	9.5
	2 Years	5	11.9
	3 Years	8	19
	> 3 Years	2	4.8
Pilot Plant	Sea Water Intake System	5	11.9
	The Chlorination Plant	5	11.9
	Phase II Plant	9	21.4

Table 5.1 Answers to the general questions

STATEMENT	SD	D	U	A	SA	MEAN	STANDARD DEVIATION
Q1	0	5	4	12	21	1.17	1.0340
Q2	1	5	15	21	0	.33	.7861
Q3	3	6	19	14	0	.05	.8821
Q4	0	0	8	24	9	.98	.7153
Q5	0	10	23	14	5	.57	.7034
Q6	2	5	21	9	0	-0.12	.8025
Q7	4	4	15	15	3	0.19	1.0647
Q8	0	6	5	27	6	0.83	.7938
Q9	1	6	13	22	0	.33	.8165
Q10	0	17	8	23	5	0.64	.8785
Q11	1	5	12	11	1	-0.14	.9258
Q12	5	14	5	22	5	.40	1.2109
Q13	1	5	11	13	3	.07	1.215
Q14	1	17	10	21	5	.57	.9408
Q15	2	5	12	10	1	-0.21	.9509
Q16	0	5	10	23	4	.62	.8250
Q17	0	13	27	10	0	0.12	.5927
Q18	0	4	16	11	2	0.05	.8821
Q19	0	4	12	21	5	0.64	0.821
Q20	0	6	13	22	3	0.57	0.7696
Q21	1	14	4	20	11	0.81	1.0647
Q22	0	6	21	7	0	-0.17	0.6955
Q23	18	14	4	4	0	-1.14	.9518
Q24	2	16	6	23	4	0.48	1.0415
Q25	10	7	9	7	3	-0.48	1.2344
Q26	16	13	8	1	0	-1.14	0.8136
Q27	14	17	0	3	0	-1.19	0.7726
Q28	0	0	16	24	2	0.67	0.5703
Q29	0	5	27	10	0	0.12	.5927
Q30	2	12	20	7	1	-0.17	0.8530
Q31	9	19	5	8	1	-0.64	1.1004
Q32	2	8	18	13	1	0.07	.8942
Q33	2	13	15	12	0	-0.12	0.8890

Table (5.2) Answers to analytical Question (Q1 – Q33)

5.3 DISCUSSIONS OF THE RESULTS

The following subsections discuss in detail the findings and the respondent attitudes to the written statements pertaining to the practices of the TPM at SPWP. The questionnaire is designed in such a way to reflect the result of the following concepts.

1. TPM introduction programme and TPM awareness at SPWP.
2. Education and training on TPM.
3. The TPM organization.
4. The Small Group Activities SGA and practices.
5. The cultural effect.
6. The motivation towards TPM.
7. SPWP management support.

In the following tables, the statements are tabulated rank-wise in descending order to reflect the most effectively applied function according to the calculated mean of the Likert scale. The calculated mean indicates the degree of agreement or disagreement of the respondent, with the written statement, which is representative of the status of TPM program at SPWP. The standard deviation is also calculated for each statement to measure the dispersion of responses to each statement.

5.3.1 TPM INTRODUCTION PROGRAM AND AWARENESS

Table 5.3 summarizes the Result of statements 1-5 of the questionnaire in relation to the introduction program of TPM at SPWP and the staffs' awareness.

Mean	Standard Deviation	Rank	Statement
1.17	1.0340	1	Q1 - The TPM pre- campaign was very effective. Every body was aware of TPM before it was introduced.
.98	.7153	2	Q4 - The participation in the TPM kick-off meeting was large
.57	.7034	3	Q5 - The TPM concepts, goals, expected benefits and the reasons of implementation are clearly understood.
.33	.7861	4	Q2 - The implementation plan was discussed with all the staff before the introduction of TPM. It was discussed with me in the section.
.05	.8821	5	Q3 - My views and comments about TPM implementation were taken into consideration. Modification to the plan was carried out based on my suggestions.

Table 5.3 TPM introduction program and awareness

The TPM introduction program was effective and has been appreciated by all the station staffs. Before TPM is introduced a very extensive campaign was made and communicated to the staffs of SPWP at every level especially in the management and staff meetings for a period of 3 months. The TPM was officially introduced in the kick off meeting, which was attended, by most of the SPWP staffs. As per the result of table 6.3 there should have been more involvement of the plant staffs in the process of making the TPM program. This is very important for the success of any new management system to be introduces for the first time. In the beginning and before the actual

implementation it was not very clear to the staff the reasons behind the TPM introduction. A mean value of 0.57 to Q5 does not indicate strongly that the benefits, goals and concepts of TPM are clear in the mind of the staff at the pre-introduction campaign stage.

5.3.2 EDUCATION AND TRAINING

Table 5.4 summarizes the result of statements 6-10 of the questionnaire in relation to the education and training campaign for TPM at SPWP the statements are listed ranked according to the mean value strength.

Mean	Standard Deviation	Rank	Statement
0.83	0.7938	1	Q8 - Team members are experienced and knowledgeable about plant equipment.
0.64	.8785	2	Q10 - The operators who participate in Autonomous maintenance are capable of carrying the minor maintenance duties.
0.33	.8165	3	Q9 - On-the-job skill training is being sufficiently conducted.
0.19	1.0647	4	Q7 - The team leaders and facilitators are capable of leading the small groups and directing their activities.
-0.12	0.8025	5	Q6 - There has been sufficient refreshment training to let the techniques and procedures of TPM always remembered.

Table 5.4 TPM education and training at SPWP

The results of the statement above indicate that the degree of training, education and on-job-training are not sufficient. Although there are training programs but they are average. This can be inferred from statements Q6 and Q7 where their mean results are -1.012 and 0.19 respectively. There have been initial training sessions for the Quality Circle teams, but some continuous refreshment training is a must and shall be conducted regularly. SPWP TPM program lacks such training as the results indicate. The members of the groups who conduct quality circle activities frequently change, hence they need to be trained, while the old members need to be refreshed about the TPM techniques to make sure these techniques are understood, carried out and implemented properly.

The result of statement 7 (mean = 0.19) indicates that the skills of the team leaders of the TPM SGA need to be improved. They are the key persons who can make the SGA succeed or fail. Any deficiency in their capability to lead the groups will directly reflect on the outcome of their team.

It is inferred from the outcome of statements 8 and 10 with mean values of 0.83 and 0.64 respectively that there is no lack of experience and knowledge of the maintenance staffs and operators with respect to the maintenance activities and the know how of equipment, but they need to be more trained in the TPM practices and techniques.

5.3.3 TPM ORGANIZATION OF SPWP

Table 5.5 summarizes the result of statements 11 to 15 of the questionnaire related to the TPM organization of SPWP.

Mean	Standard Deviation	Rank	Statement
.57	0.9408	1	Q14 - The pilot plants TPM organization is disturbing the normal activities of the section.
0.40	1.2109	2	Q12 - The TPM Small Groups are will integrated within the organization structure.
0.07	1.0215	3	Q13 - All the sections of the plant are participating in the TPM program.
-0.14	0.9258	4	Q11 - The TPM steering committee is very efficient as a driving force behind TPM.
-0.21	0.9509	5	Q15 - Other sections related to maintenance, like Planning and Stores sections, are dedicated to serve the TPM goals.

Table 5.5 TPM Organization of SPWP

From the above table it is inferable that the TPM organization in SPWP is not well coherent with the formal organization. Statement

14 with a mean value of 0.57 indicates that the SGA on pilot plants are not going smoothly with other maintenance activities of the rest

of the plant. It seems that the normal maintenance activities are somehow hampered by the introduction of the TPM. This is not a good sign because the TPM is considered to be part of the formal organization. Its activities shall improve the effectiveness of the staffs and their utilization. Statement 12 although shows some integration of the SGA within the plant organization but with a mean of 0.40 and standard deviation of 1.2109 the result cannot be strongly considered.

From the results of Q13 and Q15 with means of 0.07 and -0.21 respectively it is clear that the various sections are not geared in a manner to help the TPM implementation. In TPM, total means total participation. Cooperation and dedication of other departments are essential.

TPM steering committee, which is the drive behind TPM program, is not effective in its task. This can be inferred from the results of Q11 (mean = -0.14).

5.3.4 SMALL GROUP ACTIVITIES (SGA)

Table 5.6 shows the results of the statements 16 to 21 in relation to the SGA at SPWP.

Mean	Standard Deviation	Rank	Statement
0.81	1.0647	1	Q21 - The operators are performing autonomous maintenance effectively.
0.64	0.8211	2	Q19 - The suggestion system in the meetings is very active.
0.62	0.8250	3	Q16 - With the introduction of the small group activities, the communication between the various sections has improved.
0.57	.7696	4	Q20 - The discussions in Small Groups meetings are always fruitful. The brain storming process is always effective.
0.12	0.5927	5	Q17 - The small groups at Sitra are very organized.
0.05	0.8821	6	Q18 - The groups conduct their meetings regularly and always on time.

Table 5.6 Small Group Activities at SPWP

The statement Q21 (mean of 0.81) shows enthusiasm of the operators to do autonomous maintenance activities. This is quite expected, because operators think that maintenance is more skilful job. After a long period serving as operators they feel motivated to do some maintenance work when the situation permits. In SPWP they find it an opportunity when the TPM was introduced.

The meetings of the SGA appear to be quite active. Q19 (mean 0.64) suggests that there are many suggestions and proposals. The discussions in the meetings are satisfactory and directed in the right

way. Members seem to be enthusiastic about putting forward their suggestions, ideas and modifications of plant equipment to eliminate defects and improve reliability. The groups do not meet at regular bases and need to be more organized as inferred from Q18 (mean = 0.05). Because the SGA members are from different sections the SGA meeting marginally improved the communication between the various sections, which can be inferred from Q16 results (mean = 0.62).

5.3.5 CULTURE AT SPWP

Table 5.7 shows the results of the statements 22 to 26 of the questionnaire in relation to the industrial culture of SPWP, and its effect on the TPM activities.

Mean	Standard Deviation	Rank	Statement
0.48	1.0415	1	Q24 - The actions of cleaning, organizing and other 5 S's activities are effectively conducted.
-0.17	.6955	2	Q22 - The participation in the Small Groups is voluntarily and not by appointment.
-0.48	1.2344	3	Q25 - I feel owning the plant more than before. I am responsible for its availability, reliability and safety.
-1.14	0.8136	4	Q26 - Operators and maintenance staffs highly cooperate with each others
-1.14	0.9518	5	Q23 - The participants in the Small Groups stay after the duty hours to participate in the discussions without additional pay.

Table 5.7 Culture at SPWP

The results of the above table show negative culture with respect to the TPM at SPWP. Essential to TPM that SGA teams are voluntarily formed. The participants of SPWP Small Groups are most of the time appointed by the section head. Leaders are also appointed. Normally they are senior technicians from different sections. The above is inferred from Q22 that has a mean of 0.17. It is also known from the brief interviews with the respondents at the time of receiving the responses. The SGA meetings are suppose to be conducted outside the duty hours to reduce the-effect on the workloads. At SPWP the SGA meetings are conducted in the duty hours only. This can be inferred from statement 23 (mean = -1.14). This is why other maintenance activities are disturbed, which has been already inferred from statement No. 14 of section 5.5. Statement 26 (mean = -1.14) suggests that in SPWP the concept of segregation between operation and maintenance is still in the mind of the staff, the concept of (I operate, you fix). The operators and maintenance staffs if they do not cooperate, TPM cannot be effective. Some incidents have been reported about some maintenance staffs not allowing the operators to work on the equipment maintenance during plant outages.

Feeling the ownership of plant is a resultant of effective TPM which seems to be not the case at SPWP as inferred from statement No. 25. As earlier interred, it is confirmed by statement Q24 (mean = 0.48), that some operators enthusiast to do autonomous maintenance by conducting the 5 S's activities i.e. cleaning, organizing, putting in order, keeping clean and discipline.

5.3.6 MOTIVATION TOWARDS TPM AT SPWP

Table 5.8 shows the results of statements 27 to 30 of the questionnaire in relation to the motivation of SPWP towards the TPM program.

Mean	Standard Deviation	Rank	Statement
0.67	0.5703	1	Q28 - Successful suggestions and achievements are rewarded by appreciation letters.
0.12	0.5927	2	Q29 - There are so many suggestions in the TPM activities to the point they become difficult to manage
-0.17	0.8530	3	Q30 - There are many staffs who want to participate in the TPM activities.
-1.19	0.7726	4	Q27 - Successful suggestions and achievements are rewarded by monetary means.

Table 5.8 Motivation towards TPM at SPWP

Suggestions, proposals and achievements are rewarded by appreciation letters, but not with monetary means, this is clear from statement Q27 and 28 results with mean values of -1.19 and 0.67 respectively. Despite the appreciation letters being the mean of reward, it does not increase the staff's motivation towards TPM activities. This is clear in the result of statements Q29 and Q30 where their means values are -0.17 and -1.19 respectively. If participation is kept voluntarily, there will be few staffs willing to join the TPM activities.

5.3.7 MANAGEMENT SUPPORT

Table 5.9 shows the results of the statements 31 to 33 of the questionnaire in relation to the SPWP management of TPM program.

Mean	Standard Deviation	Rank	Statement
0.07	.8942	1	Q32 - Modification proposals generated by TPM are always accepted for implementation by the higher management.
-0.12	.8890	2	Q33 - Necessary funds to implement modification have always been provided.
-0.64	1.1004	3	Q31 - The plant's higher management fully supports the TPM activities.

Table 5.9 SPWP management support to TPM

Although the SPWP Management has accepted to implement the TPM program it does not have the total dedication to support the TPM activities. This can be inferred from statement 31 (mean = – 0.64. This can also be inferred from the results of statements 32 and 33 where their mean values are 0.07 and –0.12 respectively. The management supports improving the plant reliability by introducing more modifications but does not provide the necessary funds to execute them.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

As with most good practices, there is nothing particularly earth shattering about TPM. The essence lies in the ability to focus the concepts and principles on the reality of the actual day-to-day situation. This means getting the climate right through front-line teamwork, aiming for motivation and ownership of the condition and productivity of equipment when it is up and running, rather than the 'I operate, you fix' traditional approach. This is easily said, but is potentially difficult to implement unless TPM is both localized and tailored to the specific industry and local plant environment and business drivers (uptime versus downtime, output production, safety considerations, job flexibilities and so on) and of course the essential cultural and attitudinal perspectives. According to Williams (1992), TPM is essentially about new ways of working, effective and cooperative methods of doing essential asset care tasks and equipment related problem resolution. This is achieved by improving the flexibility and interaction of maintenance and production, supported by excellent management, supervision and engineers plus systems documentation, procedures, training, quality and team leading within an environment where safety is paramount.

TPM experiences in a wide range of industries confirm that it is essential to put hands on the issues before you can start to formulate a realistic programme of TPM-driven improvement with associated training, awareness and development. There is only one way to put hands on the issues, and that is to see and feel them at first hand.

SPWP developed a structured step-by-step approach to the implementation of TPM. Over a period of approximately 4 years of implementation, the TPM program did not show the expected success as it does in the industrialized nations like Japan, the USA and Western Europe, where 30% of equipment effectiveness improvement is within reach from the first year of implementation. Some success however is noticed in one of the selected pilot plants.

The research is aimed at putting hands on the reality of TPM at Sitra Power and Water Plant. The conclusions reached from the survey results may be summarized as follows:

1. The TPM pre-implementation campaign at SPWP was conducted in a fairly effective manner where every body was aware of the new maintenance management approach, which will be adopted. The program was discussed with the plant's employees for further improvements
2. The TPM is a total productive maintenance approach. It means total participation involving every body. Comments of individuals should be seriously taken into consideration. SPWP staffs are not fully satisfied about the process of participation in the introduction program preparation. This can impact advocating to TPM.
3. TPM activities aim at reaching zero-defect equipment. To reach this status or near to this status it requires creation of maintenance prevention "MP" organization with a high level of education and training to turn equipment operators into maintenance technicians. The TPM education and on-job-training program at SPWP is not sufficient to raise the level of operators to work as maintenance technicians. Team leaders and facilitator need more specific TPM training and other management

techniques like conducting meetings, brainstorming and leadership. Moreover the training of TPM needs to be adapted to suit the level and requirements of the power and water generation environment. It is argued by Jankowicz (2000), that much contemporary discussion about organizational learning is unfocused and unproductive because it fails to distinguish between learning and adaptation, the later being the chief characteristic of any learning organization.

4. Because the TPM SGA members are changing from time to time, It is required to conduct continuous training and refreshing courses to update the memory of the members. SPWP does not conduct refreshing training. It was rather left to the new comer to learn from the rest of the members. This leads to a negative impact on the group member's effectiveness and at the end at the maintenance effectiveness.
5. The operators of SPWP do not lack the knowledge of equipment. They are well experienced with them and know properly how they should be operated. At SPWP the operators need more training on the maintenance skills and TPM techniques in order to perform very effectively.
6. A maintenance organization can be considered as being made up of three necessary and inter-related components, the resources, administration and work planning and control system. Resources at SPWP are not well utilized to conduct the TPM activities of the pilot plant effectively without affecting the other maintenance activities. The hierarchy of authority and responsibility for taking TPM decisions are restricted by the existing system. Other sections that are directly supporting the TPM maintenance activities like Stores and Planning sections are not providing the required support for an effective work planning and control.

7. The TPM steering committee at SPWP is not effective. The committee is not assuming its role in keeping the TPM program on track. As a steering body it shall review the TPM activities and practices, assess the outcome of such activities and do the necessary to correct deviations.
8. The most outstanding feature of TPM is the Small Group Activities "SGA" and its structure of overlapping groups integrating organization and small groups improvement activity. The SGA's at SPWP are not overlapped because they are mainly in one hierarchy level of the organization structure. This is a big drawback, which indicate that links between the higher management and other levels of management are cut. This leads to wasting the time of the group members in doing activities that may not be approved for implementation.
9. The staffs of SPWP are able to generate ideas for improving equipment reliability and effectiveness because of their vast experience and knowledge about their machines. This does not necessary mean that such ideas are implemented.
10. The introduction of TPM at SPWP positively improves the communication between the various sections that are directly related to the maintenance and operation. This is due to the Small Groups having at least one member from each section. Very often interdepartmental problems are solved in the group's meetings.
11. Although TPM is a maintenance department initiative, on the contrary it is driven by production, which puts operations and maintenance as equal partners. It is no longer appropriate to

say, "I operate, you fix". The culture of SPWP is not yet changed. There are barriers between the operations and the maintenance departments that need to be eliminated.

12. The participation in TPM activities is voluntarily, where staffs themselves form the groups in the workshops and higher levels. This is not the case at SPWP. Appointments are found necessary in order to formulate the SGA groups.
13. TPM when applied successfully leads to employees being more responsible and accountable. This is not strongly felt in SPWP staffs..
14. The cultural difference between the industrial nations like Japan and the western Countries is a factor in the success of the TPM implementation at any organization. Cleanliness, order dedication, quality etc. is a style of life that is not being felt at SPWP.
15. The system of SPWP does not permit freely rewarding the staffs with the proper means. Monetary rewards are some times a must to motivate staff to encourage effective participation. Appreciation letters some times are not the proper mean to motivate employees for better outcome, which is the case at SPWP.
16. SPWP staffs are not motivated towards TPM activities. As a public sector, SPWP imposes so many restrictions on the management, which prevent motivating the staff. Bureaucratic laws that are not easy to change in some situations govern the system. The rules are strict, rigid and centrally imposed.
17. Financial Constraints affect directly the activities of TPM at SPWP. It is one of the major factors affecting TPM effectiveness. TPM

cannot be achieved without acting on modifying design shortfalls. Extensive maintenance activities in the beginning of the implementation are necessary. If the modification proposals generated in the SGA are not executed then TPM value is defeated.

18. For TPM to be successful there should be a consistent dedication of the higher management. The higher management of SPWP does not have the full dedication to support the TPM program. They might have been motivated at the beginning of the introduction, but at a later stage the support has diminished.

6.2 RECOMMENDATIONS

The following recommendations are deduced from the review of the related literature and the empirical research work:

1. For TPM to succeed there must be total commitment of the management. According to Willmott (1994), There must be 100% commitment from the top of the organization linked to total sustained consistency in the application of the TPM Commandments. The top management of the Ministry shall be involved to have their commitment and consistent dedication.
2. SPWP should put some milestones for the TPM achievement and should continuously look at TPM results. They should set three to five years milestone showing how it is intended to implement TPM as part of the ministry's or plant's future vision. TPM is not a program, which has a starting and finishing point. It is a process, a process of continuous improvement.

3. TPM shall be recognized as a practical application of "Total Quality" and hence world class performance. TPM shall aim at improving the overall effectiveness of the equipment through people and effective teamwork, rather than just a system.
4. Improvements in equipment performance and people's attitude and behavior will not be achieved without training. SPWP needs to pay attention to the TPM training and techniques, even if it is an expensive process. Supervisors and middle managers must be involved in the training process. They are often the most difficult to convince that empowerment of the people is a good thing.
5. SPWP should select an area for a pilot project, preferably a notorious trouble spot where the benefits can easily be measured and will be obvious to all. The project will be most effective in an area where attitudes are also already reasonably positive. Distracting the TPM effort in the beginning on 3 different pilot projects is not a good idea.
6. The middle managers and supervisors role is to link the overlapping TPM Small Groups. As discussed in the conclusions, this is an important factor in the successful TPM development program. According to Fujikoshi (1990), The requirements for effective TPM leadership by managers and supervisors include (1) consciously assuming leadership, (2) showing concern and assuming responsibility for circle activities, (3) leading practice sessions, (4) actively observing and supporting circle activities, and (5) encouraging circle members to keep their circle fresh and vigorous. SPWP TPM activities are deprived from the role of the middle managers (engineers and Senior Engineers).

7. Efforts shall be exerted to change the culture at SPWP towards the concept of TPM. There shall be no barriers between maintenance and operations departments. Operators and maintenance technicians shall work together as one team to achieve world-class maintenance. Operator's involvements in the maintenance activities during the outage programs drastically improve the total plant staff effectiveness and reduce the cost of maintenance.
8. An effort should always be made to coordinate scheduling of maintenance operations with production scheduling. Integration will be enhanced when production systems such as Water and Electricity generation and resources planning automatically identify windows of opportunity for performing maintenance work.
9. Spare parts management and inventory control present challenge to the TPM and must receive their share of attention. According to Raynes (1996), non-technical management and staff frequently seem to think that if an item in the maintenance stores has not moved for two years, it should not be there. This approach simply does not apply necessarily in the maintenance field, and it is this aspect of materials control in maintenance that differs so significantly from the requirements of ordinary shops.

The principle to always bear in mind is that, it is not the regular turnover of inventory that is important in maintenance store Keeping. It is the paramount requirement of having a vital spare part available in stock which, if it were not available, could cost the company in downtime losses many times its purchase price and cost of possession, and possible cause consequential late deliveries of production to the customers, or unacceptable social costs.

10. As a recommendation for a future research work in the TPM management field the cost of implementation may be studied so that a cost comparison can be made between the initial cost of TPM maintenance over a period of time until sustained TPM activities are fully established and the system fully regularized.
11. Future research work may survey Bahrain industry to see if TPM is applied in other companies and how successful it is. The study shall research the elements of success, isolating out and emphasizing on the culture.
12. Another topic for further research would be to complement comprehensive study on the effect of TPM on the cost of maintenance in comparison to production and operational costs. By doing this the organization will be able to assert positively whether their maintenance management strategies of TPM approach are cost effective or not.

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APPENDIX

TOTAL PRODUCTIVE MAINTENANCE IMPLEMENTATION AT SITRA POWER & WATER PLANT

This questionnaire is developed as part of a Bahrain University study of the applied "Total Productive Maintenance" and its application in the power industry and specifically to the case of Sitra Power and Water Plant in Bahrain.

The results of the questionnaire will not be used for any other purpose than the intended study and will not be published in any other form.

You are requested kindly to answer the questionnaire fully. If any question is not understood, please feel free to contact the undersigned.

Thank you for responding

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THE QUESTIONNAIRE

PART 1

General Questions

Please answer the following questions

1. Rank.

a) Engineer ☐ b) Technician ☐ c) Fitter ☐

2. Years of Experience at Sitra Plant.

a) 1-5 ☐ b) 6-10 ☐
c) 11-15 ☐ d) more than 15 ☐

3. Which section do you work for?

- ☐ Operations
- ☐ Maintenance
- ☐ Planning
- ☐ Chemical
- ☐ Others

4. Are you a member of the Quality Circles "small groups"?

a) Yes ☐ b) No ☐

If the answer to Q.4 is yes,

4.a) How long have you been involved with the small Group activities?

a) 1 year ☐ b) 2 years ☐
c) 3 years ☐ d) more than 3 years ☐

4.b) Which pilot plant are you involved with?

- ☐ Sea Water Intake System.
- ☐ The Chlorination Plant.
- ☐ Phase II Plant.

PART TWO

Analytical questions

Please circle the numbers, which represent the degree of agreement or disagreement with the written statement about the Total Productive Maintenance at Sitra Power and Water Plant as applied in the pilot plants. Numbers 1-5 represents the following:

Strongly Disagree (1)	Disagree (2)	Uncertain (3)	Agree (4)	Strongly Agree (5)
-----------------------------	-----------------	------------------	--------------	--------------------------

Introduction program and awareness

- | | | | | | | |
|----|---|---|---|---|---|---|
| 1. | The TPM pre- campaign was very effective. Every body was aware of TPM before it was introduced. | 1 | 2 | 3 | 4 | 5 |
| 2. | The implementation plan was discussed with all the staff before the introduction of TPM. It was discussed with me in the section. | 1 | 2 | 3 | 4 | 5 |
| 3. | My views and comments about TPM implementation were taken into consideration. Modification to the plan was carried out based on my suggestions. | 1 | 2 | 3 | 4 | 5 |
| 4. | The participation in the TPM kick-off meeting was large | 1 | 2 | 3 | 4 | 5 |
| 5. | The TPM concepts, goals, expected benefits and the reasons of implementation are clearly understood. | 1 | 2 | 3 | 4 | 5 |

Education And Training

- | | | | | | | |
|-----|---|---|---|---|---|---|
| 6. | There has been sufficient refreshment training to let the techniques and procedures of TPM always remembered. | 1 | 2 | 3 | 4 | 5 |
| 7. | The team leaders and facilitators are capable of leading the small groups and directing their activities. | 1 | 2 | 3 | 4 | 5 |
| 8. | Team members are experienced and knowledgeable about plant equipment. | 1 | 2 | 3 | 4 | 5 |
| 9. | On- the- job skill training is being sufficiently conducted. | 1 | 2 | 3 | 4 | 5 |
| 10. | The operators who participate in Autonomous maintenance are capable of carrying the minor maintenance duties. | 1 | 2 | 3 | 4 | 5 |

Organization

- | | | | | | | |
|-----|---|---|---|---|---|---|
| 11. | The TPM steering committee is very efficient as a driving force behind TPM. | 1 | 2 | 3 | 4 | 5 |
| 12. | The TPM Small Groups are will integrated within the organization structure. | 1 | 2 | 3 | 4 | 5 |
| 13. | All the sections of the plant are participating in the TPM program. | 1 | 2 | 3 | 4 | 5 |
| 14. | The pilot plants TPM organization is disturbing the normal activities of the section. | 1 | 2 | 3 | 4 | 5 |
| 15. | Other sections related to maintenance like Planning and Stores sections are dedicated to serve the TPM goals. | 1 | 2 | 3 | 4 | 5 |

Small Group Activity

- | | | | | | | |
|-----|--|---|---|---|---|---|
| 16. | With the introduction of the small group activities the communication between the various sections has improved. | 1 | 2 | 3 | 4 | 5 |
| 17. | The small groups at Sitra are very organized. | 1 | 2 | 3 | 4 | 5 |
| 18. | The groups conduct their meetings regularly and always on time. | 1 | 2 | 3 | 4 | 5 |
| 19. | The suggestion system in the meetings is very active. | 1 | 2 | 3 | 4 | 5 |
| 20. | The discussions in Small Groups meetings are always fruitful. The brain storming process is always effective. | 1 | 2 | 3 | 4 | 5 |
| 21. | The operators are performing autonomous maintenance effectively. | 1 | 2 | 3 | 4 | 5 |

Culture

- | | | | | | | |
|-----|--|---|---|---|---|---|
| 22. | The participation in the Small Groups is voluntarily and not by appointment. | 1 | 2 | 3 | 4 | 5 |
| 23. | The participants in the Small Groups stay after the duty hours to participate in the discussions without additional pay. | 1 | 2 | 3 | 4 | 5 |
| 24. | The actions of cleaning, organizing and other 5 S's activities are effectively conducted. | 1 | 2 | 3 | 4 | 5 |

- | | | |
|-----|--|-----------|
| 25. | I feel owning the plant more than before. I am responsible for its availability, reliability and safety. | 1 2 3 4 5 |
| 26. | Operators and maintenance staffs highly cooperate with each others | |

Motivation

- | | | |
|-----|--|-----------|
| 27. | Successful suggestions and achievements are rewarded by monetary means. | 1 2 3 4 5 |
| 28. | Successful suggestions and achievements are rewarded by appreciation letters. | 1 2 3 4 5 |
| 29. | There are so many suggestions in the TPM activities to the point they become difficult to manage | 1 2 3 4 5 |
| 30. | There are many staffs who want to participate in the TPM activities. | 1 2 3 4 5 |

Management Support

- | | | |
|-----|--|-----------|
| 31. | The plant's higher management fully supports the TPM activities. | 1 2 3 4 5 |
| 32. | Modification proposals generated by TPM are always accepted for implementation by the higher management. | 1 2 3 4 5 |
| 33. | Necessary funds to implement modification have always been provided. | 1 2 3 4 5 |