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Maintenance Productivity and Performance Measurement

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2.1 Introduction

Maintenance productivity is one of the most important issues which govern the economics of production activities. However, productivity is often relegated to second rank, and ignored or neglected by those who influence production processes (Singh *et al.* 2000). Productivity in a narrow sense has been measured for several years (Andersen and Fagerhaug, 2007). Since maintenance activities are multi-disciplinary in nature with a large number of inputs and outputs, the performance of maintenance productivity needs to be measured and considered holistically with an integrated approach. With increasing awareness that maintenance creates added value to the business process; organizations are treating maintenance as an integral part of their business (Liyanage and Kumar, 2003). For many asset-intensive industries, the maintenance costs are a significant portion of the operational cost. Maintenance expenditure accounts for 20–50 % of the production cost for the mining industry depending on the level of mechanization. In larger companies, reducing maintenance expenditure by $1 million contributes as much to profits as increasing sales by $3 million (Wireman, 2007). The amount spent on the maintenance budget for Europe is around 1500 billion euros per year (Altmannshopfer, 2006) and for Sweden 20 billion euros per year (Ahlmann, 2002). In open cut mining, the loss of revenue resulting from a typical dragline being out of action is US $ 0.5–1.0 million per day, and the loss of revenue from a 747 Boeing plane being out of action is roughly US $ 0.5 million per day (Murthy *et al.* 2002). Therefore, the importance of maintenance productivity is understood more and more by the management of the companies.

There are several examples when lack of necessary and correct maintenance activities have resulted in disasters and accidents with extensive losses, like; Bhopal, Piper Alpha, space shuttle Columbia, power outages in New York, UK and Italy, during 2003. From asset management and changes in legal environment, the asset managers are likely to be charged with “corporate killing” due to changes in the legal environment for the future actions or omissions of the maintenance efforts (Mather, 2005). BP refinery in US paid a US $21m fine and spent US $1b for repairs for an explosion at Texas City refinery, killing 15 and injured about 500 persons, making it the deadliest refinery accident (Bream, 2006). Prevention of such an accident could have enhanced BP's image besides saving a billion US $. The measurement of maintenance performance has essentially become an essential element of strategic thinking for service and manufacturing industry. Due to outsourcing, separation of asset owners and asset managers, and complex accountability for the asset management, the measurement of asset maintenance performance and its continuous control and evaluation is becoming critical. As a result of the dramatic change in the use of technology, there is a growing reliance on software and professionals from other functional areas, for making or managing decisions on asset management and maintenance. Therefore, the performance of the maintenance process is critical for the long term value creation and economic viability of many industries. It is important that the performance of the maintenance process be measured, so that it can be controlled and monitored for taking appropriate and corrective actions to minimize and mitigate risks in the area of safety, meet societal responsibilities and enhance the effectiveness and efficiency of the asset maintained. A measure commonly used by industries is the maintenance performance for measuring the maintenance productivity.

In general, productivity is defined as the ratio of the output to input of a production system. The output of the production system is the products or services delivered while the input consists of various resources like the labour, materials, tools, plant and equipment, and others, used for producing the products or services. With a given input if more outputs of products or services can be produced, then higher productivity efficiency is achieved. Efficiency is doing the things right or it is the measure of the relationship of outputs to inputs and is usually expressed as a ratio. These measures can be expressed in terms of actual expenditure of resources as compared to expected expenditure of resources. They can also be expressed as the expenditure of resources for a given output. Effectiveness is doing the right things and measures the output conformance to specified characteristics.

Productivity is a combined measure for effectiveness and efficiency, *i.e.,* a productive organization is both effective and efficient. Measurement of productivity needs to consider various inputs and outputs of the products or services produced to be adequate and appropriate. Improvement in maintenance productivity can be achieved through reduction in maintenance materials as well as reductions in projects, outages and overhaul savings (Wireman, 2007). Production and service systems are heavily affected by their respective maintenance productivity. Maintenance systems operate in parallel to production systems to keep them serviceable and safe to operate at minimum cost. One way to reduce the operation cost and production cost is to optimize utilization of maintenance resources (Duffuaa and Al-Sultan, 1997), which enhances maintenance productivity. In order to measure the effectiveness of any maintenance system, we need to measure its productivity and identify the areas where improvements can be made (Raouf and Ben-Daya, 1995). Therefore, measuring maintenance productivity performance is critical for any production and operational company in order to measure, monitor, control and take appropriate and timely decisions. Since the cost of maintenance for different industries is substantial as compared to the operational cost, more and more organizations are focussed to measure the performance of maintenance productivity.

The content of the chapter is as follows. After an introduction in Section 2.1, Section 2.2 discusses the performance measurement and maintenance productivity. In Section 2.3, maintenance performance and some of the important measures are explained. Section 2.4 deals with measurement of maintenance productivity performance and various factors and issues like MPI and MPM system. In Section 2.5, MPI standards and MPIs as in use at different industries are given followed by concluding remarks at Section 2.6.

2.2 Performance Measurement and Maintenance Productivity

Management needs information of maintenance performance for planning and controlling the maintenance process. The information needs to focus on the effectiveness and efficiency of the maintenance process, its activities, organization, cooperation and coordination with other units of the organization. Performance measurement (PM) has caught the imagination and involvement of researchers and managers from the industry alike, since the 1990s. With fast changes taking place in business and industry, the PM concepts and frameworks of past are outdated today, as they need to be modified as *per* today's requirements. Some of the concepts used in defining maintenance metrics are unclear regarding what to measure, how to communicate maintenance performance across the organization, aligning maintenance performance with objectives and strategies (Murthy *et al.* 2002). This essentially requires cascading down the corporate objectives into measurable targets up to shop floor level, and aggregating the measured maintenance performance indicators such as availability, reliability, mean time between failures, *etc.,* from shop floor level to the strategic levels for taking management decisions (Tsang, 2002). Murthy *et al.* (2002) mention that maintenance management needs to be carried out in both strategic and operational contexts and the organizational structure is generally structured into three levels. There is a need to identify and analyse various issues related to maintenance performance and to develop a framework which can address the related issues and challenges of maintenance management, maintenance performance measurement, performance measures and indicators. Maintenance and related processes across strategic, tactical and operational levels of hierarchy for the organization are required to be considered in the PM system. The performance measurement needs to be viewed along three dimensions (Andersen and Fagerhaug, 2007): (1) effectiveness: satisfaction of customer needs, (2) efficiency – economic and optimal use of enterprise resources and (3) changeability – strategic awareness to handle changes. Based on these three dimensions, a number of performance measures are developed. One example of the recent performance measurement system is the ENAPS (European Network for Advanced Performance Studies), a system based on a number of performance measures.

A PM system is defined as the set of metrics used to quantify the efficiency and effectiveness of actions (Neely *et al.* 1995). PM provides a general information basis that can be exploited for decision making purposes, both for management and employees. Performance measurement is examined from three different levels, (1) from the individual performance measures, (2) from the system's performance measurement and (3) relationship between the PM system and its environment. Neely *et al.* (1995) also mentioned three PM concepts which highlight; classifications of performance measures as per their financial and non-financial perspectives, positioning the performance measures from the strategic context, and support of the organizational infrastructure, like resource allocation, work structuring, information system amongst others.

Maintenance Performance Measurement (MPM) is defined as "the multi-disciplinary process of measuring and justifying the value created by maintenance investment, and taking care of the organization's stockholder's requirements viewed strategically from the overall business perspective" (Parida, 2006). The MPM concept adopts the PM system, which is used for strategic and day to day running of the organization, planning, control and implementing improvements including monitoring and changes. PM is a means to measure the implementing strategies and policies of the management of the organization, which is the characteristic of MPM. Key performance indicator (KPI) is to be defined for each element of a strategic plan, which can break down to the PI at the basic shop floor or functional level. MPM linked to performance trends can be utilized to identify business processes, areas, departments and so on, that needs to be improved to achieve the organizational goals. Each organization is required to monitor and evaluate the need for performance improvement of the system. Thus, MPM forms a solid foundation for deciding where improvements are most pertinent at any given time. MPM can be effectively utilized for the improvement and the process evaluation and MPM data can also be used as a marketing tool, by providing information, like; quality and delivery time. MPM is also used as a basis for bench marking, in comparison to other organizations.

MPM is a powerful tool for aligning the strategic intent within the hierarchical levels of the entire organization. Thus, it allows the visibility of the company's goals and objectives from the CEO or strategic level to the middle management at tactical level and throughout the organization. MPM needs to be balanced from both financial and non-financial measures. Thus, MPM framework can be used for different purposes:

- A strategic planning tool;
- A management reporting tool;
- An operational control and monitoring tool; and
- A change management support tool.

A Performance Indicator (PI) is used for the measurement of the performance of any system or process. A PI compares actual conditions with a specific set of reference conditions (requirements) by measuring the distances between the current environmental situation and the desired situation (target), so-called 'distance to target' assessment (EEA, 1999). PIs should highlight opportunities for improvement within companies, when properly utilized (Wireman, 1998). PIs can be classified as leading or lagging indicators. Leading indicators provide an indication or warning of the performance condition in advance and act like a performance drivers. Non-financial indicators are examples of this. The lagging indicators are mostly financial indicators which indicate performance after the activities are completed and hence are also called outcome measures. The outcome measures describe the resources spent or activities performed. Traditionally, management stresses profit measurement, which is mostly outcome measure based. The inputs or the resources put into an operation are mostly performance drivers, which need to be well controlled and managed for performance improvement. A good organizational system will combine the outcome measures with performance drivers as they are interrelated in a chain of ends and means. Within an organization, delivery time for the logistic department is an outcome measure, whereas for a customer it can be a performance driver for customer loyalty enhancement.

2.3 Maintenance Performance

Maintenance productivity aims at minimizing the maintenance cost dealing with the measurement of overall maintenance results/performance and maximizing the overall maintenance performance. Some of the measures of maintenance performances are availability, mean time between failures (MTTF), failure/breakdown frequency, mean time to repair (MTTR) and production rate index. Maintenance productivity indicators measures the usage of resources, like; labor, materials, contractors, tools and equipment. These components also form various cost indicators, such as man power utilization and efficiency, material usage and work order. Control of maintenance productivity (MP) ensures that the budgeted levels of maintenance efforts are being sustained and that required plant output is achieved (Kelly, 1997). Maintenance productivity deals with both maintenance effectiveness and efficiency.

For the process industry, machine downtime in the shop floor is one of the main issues for maintenance productivity. Unlike operational activities, maintenance activities are mostly non-repetitive in nature. Therefore, all maintenance personnel and managers face new problems with each breakdown or downtime of the plant or system, which needs multi-skill levels to solve the conflicting multi-objectives issues. For process or manufacturing industry, the product availability is given in Figure 2.1.

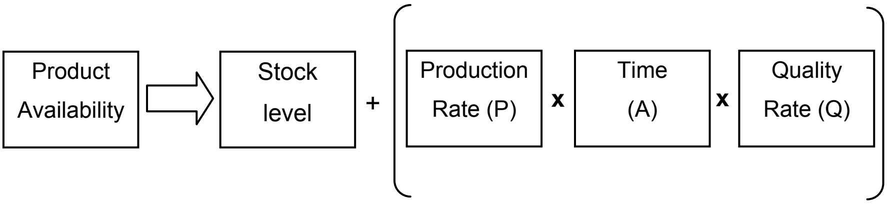

Figure 2.1. Elements of product availability (adapted with permission from Parida 2007)

For process or manufacturing industry, the input raw material issues are important as variation in quality of the raw material prevents the information of the quantity and quality of the products. This leads to reorder or recycle of the process to overcome the shortage of the required products, which also necessitates a safety stock level. As given in Figure 2.1, the product availability is dependant on the production rate, available time for production and quality rate. The production rate is related to the plant or production capacity. If the maintenance effectiveness and efficiency is good, then the production rate will invariably be good. The availability time for production is also dependent on the repair or waiting time, *i.e.,* on the maintenance effectiveness. Quality of the product is also related to the number of stops, where quality loss is there during stop and start of the plant/system, besides the skill level of operators and the quality of the raw material *etc*. Thus, it can be seen that all the four parameters in product availability are dependent on maintenance directly or indirectly. The objective of the management of any process industry is to minimize the stock level, and increase the availability time, production and quality rate. The multiplication of the last three terms – availability, production and quality rate – provides the overall equipment effectiveness (OEE) figure which is one of the most important and effective key performance indicators (KPIs) in the performance measurement.

The machine breakdown or degradation of performance over time and accidents are some of the reason for the plant production interruption affecting the effectiveness of the plant. Normally, the production quantity is worked out by the management as *per* the market demand and situation. For achieving a greater market share, the management must be in a position to predict its plant capacity as well as improve it in a specified time.

The maintenance policy and safety performance of the plant plays a significant role in achieving the operational effectiveness of the plant. The management has to depend on the predicted plant capacity in order to meet the delivery schedules, cost, quality and quantity. An appropriate maintenance and safety strategy are required to be adapted for achieving the optimal production quantities.

Some of the important measures of maintenance productivity are:

- Total cost of maintenance/total production cost;
- A (availability) = (planned time - downtime)/planned time;
- P (production rate) = (standard time/unit)x(unit produced)/operating time; where; operating time = planned time – downtime;
- Q (quality rate) = (total production – defective quantity or number)/total production;
- Mean time to repair (MTTR) = sum of total repair time/number of breakdowns;
- Mean time between failure (MTBF) = number of operating hour/number of breakdowns;
- Maintenance breakdown severity = cost of breakdown repair/number of breakdown;
- Maintenance improvement = total maintenance manhours on preventive maintenance jobs ÷ total manhours available;
- Maintenance cost per hour = total maintenance cost/total maintenance man hours;
- Man power utilization = wrench time/total time;
- Manpower efficiency = time taken/planned time;

- Material usage/work order = total material cost/number of work order; and
- Maintenance cost index = total maintenance cost/total production cost.

All these measures of maintenance productivity need to be organization specific and defined accordingly. This is required to achieve a uniformity and transparency in understanding amongst all the employees and stakeholders of the organization, so that everyone speaks the same language. For example, for manpower utilization, wrench time needs to be specified for meaning and clarification.

2.4 Measurement of Maintenance Productivity

Various factors and issues are required to be considered for measurement of the maintenance productivity performance. Some of the important factors which need to be considered for measuring maintenance productivity are:

1. *The value created by the maintenance:* the most important factor in maintenance productivity measurement system is to measure the value created by maintenance process. As a manager, one must know that what is being done is what is needed by the business process, and if the maintenance output is not contributing/creating any value for the business, it needs to be restructured. This brings to the focus on doing the right things keeping in view the business objectives of the company.
2. *Revising allocations of resources:* the purpose for measuring the maintenance productivity effectiveness is to determine the additional investment requirement and to justify the investment made to the management. Alternatively, such measurement of activities also permits to determine the need for change of what is being done or how to do it more effectively by utilising the allocated resources.
3. *Health Safety and Environmental (HSE) Factors*: it is essential to understand the contribution of maintenance productivity towards HSE issues. An inefficient maintenance performance can lead to incidents and accidents (safety issue) and other health hazards, besides the environmental issues and encouraging an unhealthy work culture.
4. *Knowledge Management*: many companies focus on effective management of knowledge in their companies. Since technology is ever changing and is changing faster in the new millennium, this has brought in new sensors and embedded technology, information and communication technology (ICT) and condition based inspection technology like vibration, spectroscopy, thermography and others, which is replacing preventive maintenance with predictive maintenance. this necessitates a systematic approach for the knowledge growth in the specific field of specialization.
5. *New trends in operation and maintenance strategy:* companies need to adopt new operating and maintenance strategy in quick response to market demand, as well for the reduction of production loss and process waste. This strategy need to be continuously reviewed and modified.

6. Changes in Organizational Structure: organizations are trying to follow a flat and compact organizational structure, a virtual work organization, and empowered, self-managing, knowledge management work teams and work stations. Therefore a need exists to integrate the MPM system within the organization to provide a rewarding return for maintenance services.

2.4.1 Maintenance Performance Indicator (MPI)

Maintenance performance indicators (MPIs) are used for evaluating the effectiveness of maintenance carried out (Wireman, 1998). An indicator is a product of several metrics (measures). A performance indicator is a measure capable of generating a quantified value to indicate the level of performance, taking into account single or multiple aspects. The selection of MPIs depends on the way in which the MPM is developed. MPIs could be used for financial reports, for monitoring the performance of employees, customer satisfaction, the health, safety and environmental (HSE) rating, and overall equipment effectiveness (OEE), as well as many other applications. When developing MPIs, it is important to relate them to both the process inputs and the process outputs. If this is carried out properly, then MPIs can identify resource allocation and control, problem areas, the maintenance contribution, benchmarking, personnel performance, and the contribution to maintenance and overall business objectives (Kumar and Ellingsen, 2000).

2.4.2 MPM Issues

Each successful company measures their maintenance performance in order to remain competitive and cost effective in business. For improving maintenance productivity, it is essential that a structural audit is carried out, in which the following factors are evaluated (Raouf, 1994):

- Labor productivity;
- Organization staffing and policy;
- Management training;
- Planner training;
- Technical training;
- Motivation;
- Management control and budget;
- Work order planning and scheduling;
- Facilities;
- Stores, material and tool control;
- Preventive maintenance and equipment history;
- Engineering and condition monitoring;
- Work measurement and incentives; and
- Information system.

Understanding the need for MPM in the business and its work process, besides the associated issues, is critical for the development and successful implementation of the maintenance productivity performance measurement. Besides maintenance process mapping, the associated issues are discussed.

Maintenance process mapping

It is essential to understand the maintenance process in detail before going on to study the issues involved in MPM system for any organization, so that implementation of the MPM system is possible without difficulty. The maintenance process starts with the maintenance objectives and strategy, which are derived from the corporate vision, goal and objectives based on the stakeholders' needs and expectations. Based on the maintenance objectives, maintenance policy, organization, resources and capabilities, a maintenance program is essentially developed. This program is broken down into different types of maintenance tasks. The execution of the maintenance tasks is undertaken at specified times and locations as *per* the maintenance plan. A maintenance task could be repair, replacement, adjustment, lubrication, modification or inspection. The management needs to understand the importance of maintenance and match the plan to the vision, goal and objectives of the organization. However, in real life there is a mismatch between the expectations of external and internal stakeholders and the capability between the organizational goals and the objectives and the resources allocated for maintenance planning, scheduling and between the execution and the reporting through data recording and analysis. There is a need to map the maintenance process and identify the gap between the maintenance planning and execution.

Logistic support, as *per* requirement is vital for maintenance planning, scheduling and execution. Such support includes the availability of spare parts, consumable materials, tools, instruction manuals, documents, *etc*. Logistic support acts as a performance driver which motivates and enhances the degree of maintenance performance. The non-availability of personnel, spares and consumable materials needs to be looked into, because otherwise it can act as a performance killer. Human factors such as unskilled and unwilling personnel act as a de-motivating factor which prevents the achievement of the desired results. Therefore, one must ensure the human resources and training necessary for the maintenance planning and execution team. The reporting system for MPM/MPIs is a major issue for any maintenance organization. It is necessary to understand the organizational need and then to procure or develop a system. The personnel using the MPM system need to be trained. Analysis of data plays an important role. It is equally important that the management should be involved in the whole process and there should be commitment and support from the top management.

The issues related to MPM are determined by answering the questions like:

- What indicators are relevant to the business and related to maintenance?
- How are the indicators related to one another and how do they take care of the stakeholders' requirements?
- Are the MPIs measurable objectively and how do the MPIs evaluate the efficiency and effectiveness of the organization?
- Are the MPIs challenging and yet attainable?
- Are the MPIs linked to the benchmarks or milestones quantitatively/ qualitatively?

- How does one take decisions on the basis of the indicators?
- What are the corrective and preventive measures? and
- When and how does one update the MPIs?

The MPIs need to be developed based on the answers to the above questions. The relevant data need to be recorded and analyzed on a regular basis and used for monitoring, control of maintenance and related activities, and decision making for preventive and corrective actions. The MPIs could be time- and target-based, giving a positive or negative indication. An MPI could be trend-based in some cases. If it is positive or steady, meaning that everything is working well, and if it shows a negative trend and has crossed the lower limit of the target, then immediate decision to act urgently need to be taken. Various types of graphs and figures like a spider diagram could be used for indicating the health state of the technical system using different color codes for “excellent”, “satisfactory”, “improvement required” and “unsatisfactory performance level”. There could also be other visualization techniques using bar charts or other graphical tools for monitoring MPIs.

The issues related to the development and implementations of MPM are:

1. *Strategy:* how does one assess and respond to both internal and external stakeholders’ needs? How does one translate the corporate goal and strategy into targets and goals at the operational level, *i.e.,* converting a subjective vision into objective goals? How does one integrate the results and outcomes from the operational level to develop MPIs at the corporate level, *i.e.,* converting objective outcomes into strategic MPIs and linking them to strategic goals and targets? How to support innovation and training for the employees to facilitate an MPM-oriented culture?
2. *Organizational issues:* how to align the MPM system with the corporate strategy? Why there is a need to develop a reliable and meaningful MPM system? What should be measured, why it should be measured, how it should be measured, when it should be measured and what should be reported; when, how and to whom? How to establish accountability at various levels? How to improve communication within and outside the organization on issues related to information and decision making?
3. How to measure? how to select the right MPIs for measuring MPM? How to collect relevant data and analyze? How to use MPM reports for preventive and predictive decisions?
4. *Sustainability:* How to apply MPM strategy properly for improvement? How to develop an MPM culture across the organization? How to implement of a right internal and external communication system supporting MPM? How to review and modify the MPM strategy and system at regular intervals? How to develop and build trust in MPIs and MPM system at various levels?
5. *Specifying MPIs:* SMART test is frequently used to specify and determine the quality of the performance metrics (DOE-HDBK-1148- 2002). SMART stands for specific, measurable, attainable, realistic and timely.

The challenges associated with the development and implementation of an MPM system need to be considered for aligning it with the company’s vision and goals. The performance measurement (PM) system needs to be aligned to organizational strategy (Kaplan and Norton, 2004; Eccles, 1991; Murthy *et al.* 2002). The balance scorecard of Kaplan and Norton (1992) focuses on financial aspects, customers, internal processes, and innovation and learning, for the first time, considering both the tangible and intangible aspects of the business. However, it did not consider the total effectiveness considering the external and internal effectiveness in a total, holistic and integrated manner. The total maintenance effectiveness is based on an organizational effectiveness model including both the external and the internal effectiveness. The concept of total maintenance effectiveness envelops the entire organization linking between the internal and external effectiveness. The total effectiveness is a product of the internal effectiveness characterised by issues related to effective and efficient use of resources to facilitate the delivery of the maintenance and related services to be delivered in the most effective way (engineering and business process related to planning and resource utilization) and external effectiveness characterised by customer satisfaction, growth in market share, *etc*. The performance measures for internal effectiveness is concerned with doing things in right way and can be measured in terms of cost effectiveness (maintenance costs per unit produced), productivity (number of work orders completed per unit time), *etc*. and deals with managing resources to produce services as *per* specifications.

The performance measures for external effectiveness deals with measures that have a long term effect on companies profitability and is characterised by doing right things, that is delivering services in a way (quality and timeliness) that meets customer requirements. Here the concept of delivering involves not only the services required by customers but also helping them in their other business process related to their own services. Such an attitude often helps in market growth and capturing or creating new markets. Whenever a balanced maintenance measurement system is developed, all the related criteria and parameters associated with the system are required to be examined. In any organization, first the maintenance process needs to be studied in detail and external effectiveness factors like the stakeholders requirements (front end processes) need to be understood. Then, based on the internal resources and capabilities, supply chain management (back end processes), the maintenance objectives and strategies are formulated, matching and integrating with that of the corporate ones. An important objective of the measurement system should be to bridge the gap and establish the relationship between the internal measures (causes) and the external measures (effects) (Jonsson and Lesshammar, 1999).

2.4.3 MPM System

An MPM system can be divided into three phases: the design of the performance measures, the implementation of the performance measures, and the use of the performance measures to carry out analysis/reviewing (Pun and White, 1996). The feedback from the reviewing to the system design keeps it valid in a dynamic environment.

Both the identification of appropriate measures and explicit consideration of trade-offs between them can be significantly assisted if the relationships between measures are mapped and understood (Santos *et al.* 2002) well in advance. Therefore, the development of the MPM system requires the formation of a PM team which should include stakeholders at various levels and the management, and which should carry out preparatory work for this development work. The PM team should have clear and specified objectives, a time plan and a plan of action as pre-requisites.

2.4.3.1 Integration of Maintenance from Shop Floor to Strategic Level

The maintenance strategy should be derived from and integrated to the corporate strategy. In order to accomplish the top-level objectives of the espoused maintenance strategy, these objectives need to be cascaded into team and individual objectives. The adoption of fair processes is the key to successful alignment of these goals. It helps to harness the energy and creativity of committed managers and employees to drive the desired organizational transformations (Tsang, 1998). For a process industry or production system, the hierarchy is composed of the factory, process unit and component levels. The hierarchy corresponds to the traditional organizational levels of the top, middle and shop floor levels. However, there are some organizations which may require more than three hierarchical levels to suit their complex organizational structure. The MPM system needs to be linked to the functional and hierarchical levels for the meaningful understanding and effective monitoring and control of managerial decisions (Parida *et al.* 2005). Defining the measures and the actual measurements for monitoring and control constitute an extremely complex task for large organizations. The complexity of MPM is further increased for multiple criteria objectives, as shown in Figure 2.2.

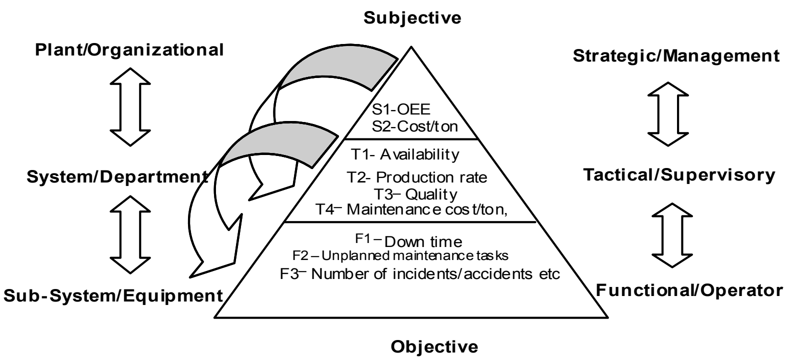

Figure 2.2. Hierarchical levels of an organization

From the hierarchical point of view, the top level considers corporate or strategic issues on the basis of soft or perceptual measures from stakeholders. In a way the strategic level is subjective, as it is linked to the vision and long-term goals (shown as S1 and S2 in Figure 2.3), though the subjectivity decreases down through the levels, with the highest objectivity existing at the functional level. The second level considers tactical issues (shown as T1–T4 in Figure 2.3) such as financial and non-financial aspects both from the effectiveness and the efficiency point of view. This layer is represented by the senior or middle management, depending on the number of levels of the organization in question. If an organization has four hierarchical levels, then the second level represents the senior managerial level and the third level represents the managerial/supervisory level. The bottom level is represented by the operational personnel and includes the shop floor (shown as F1–F3 in Figure 2.2) engineers and operators. The corporate or business objective at the strategic level needs to be communicated down through the levels of the organization in such a way that this objective is translated into the language and meaning appropriate for the tactical or functional level of the hierarchy. The maintenance objectives and strategy, as derived from the stakeholders' requirements and corporate objectives and strategy, considering the total effectiveness, front-end processes and back-end processes, integrating the different hierarchical levels both from top-down and bottom-up manner involve the employees at all levels. At the functional level, the objectives are converted to specific measuring criteria. It is essential that all the employees speak the same language though out the entire organization.

2.4.3.2 Multi-criteria MPM System

The MPM system needs to facilitate and support the management leadership for timely and accurate decision making. The system should provide a solution for performance measurements linking directly with the organizational strategy and by considering both non-financial and financial indicators. At the same time, the system should be flexible, so as to change with time as and when required. The MPM system should be transparent and enable accountability for all the hierarchical levels. From the application and usage point of view, the MPM system should be technology user-friendly and should be facilitated by training the relevant personnel (Figure 2.3).

MPIs can be classified into seven categories (Parida *et al.* 2005) and are linked to each other for providing total maintenance effectiveness:

1. Customer satisfaction related indicators;
2. Cost related indicators;
3. Equipment related indicators;
4. Maintenance task related indicators;
5. Learning and growth related indicators;
6. Health safety and environment (HSE); and
7. Employee satisfaction related indicators.

Before implementation, the MPIs need to be tested for reliability, that is, the ability to provide the correct measures consistently over time, and for validity, which is the ability to measure what they are supposed to measure.

2.4.3.3 Implementation of the MPM System

Implementation of the developed MPM system for an organization is very critical. Neely *et al.* (2000) mention fear, politics and subversion as issues involved in this phase. Ineffective use of information to improve operation without support of appropriate tools and lack of active management commitment and involvement is another critical issue, without which an MPM system cannot be effective or implemented fully (Santos *et al.* 2002). Dumond (1994) mentions lack of communication and dissemination of results as important issues for an MPM system. The alignment of PM with the strategic objectives of the organization at the design and development of MPM system is critical for achieving effectiveness of the implementation phase (Kaplan and Norton, 1992; Lynch and Cross, 1991).

Front-end process
-Timely delivery
-Quality
-HSE issues

External Effectiveness
-Customers/ stakeholders
-Compliance with regulations

Internal Effectiveness
-Reliability
-Productivity
-Efficiency
-Growth & innovation

Back-end process
-Process stability
-Supply chain
-HSE

Hierarchical level / Muli-criteria	Level 1 Strategic /Top management	Level 2 Tactical/Middle management	Level 3 Functional/ Operational
Equipment/ Process related	- Capacity utilization	- Availability - OEE - Production rate - Quality - Number of stops	- Production rate - Number of defects/rework - Number of stops/downtime - Vibration & thermography
Cost/finance related	- Maintenance budget - ROMI	-Mintenance production cost per ton - Maintenance/ production cost	- Mintenance cost per ton
Maintenance task related	- Cost of maintenance tasks	- Quality of maintenance taska - Change over time - Planned maintenance task - Unplanned maintenance task	- Change over time - Planned maintenance task - Unplanned maintenance task
Learning growth & innovation	- Generation of a number of new ideas - Skill improvment training	- Generation of number of new ideas - Skill improvement training	- Generation of number of new ideas - Skill improvement training
Customer satisfaction related	- Quality complaint numbers - Quality return - Customer satisfaction - Customer retaintion	- Quality complaint numbers - Quality return - Customer satisfaction - New customer addition	- Quality complaint numbers - Quality return - Customer satisfaction
Health, safety & Security, environment	- Number of accidents - Number of legal cases - HSSE losses - HSSE complaints	- Number of accidents/incidents - Number of legal cases - Compensation paid - HSSE complaints	- Number of accidents/ incidents - HSSE complaints
Employee satisfaction	- Employee satisfaction - Employee complaints	- Employee turnover rate - Employee complaints	- Employee absentees - Employee complaints

Figure 2.3. Multi-criteria frameworks for maintenance performance measurement (MPM) (Parida, 2006)

Prior to a pilot project studying the MPM system, it is desired that the relevant personnel of the organization should be trained in advance to create an awareness of MPM, the need for MPM and the benefits of MPM. A system of continuous monitoring, control and feedback needs to be institutionalized for the continuous improvement and successful implementation of the MPM system. A holistic view of a multi-criteria MPM framework showing the linkage of different MPIs and criteria leading to achieving long term stakeholders' value is given in Figure 2.4.

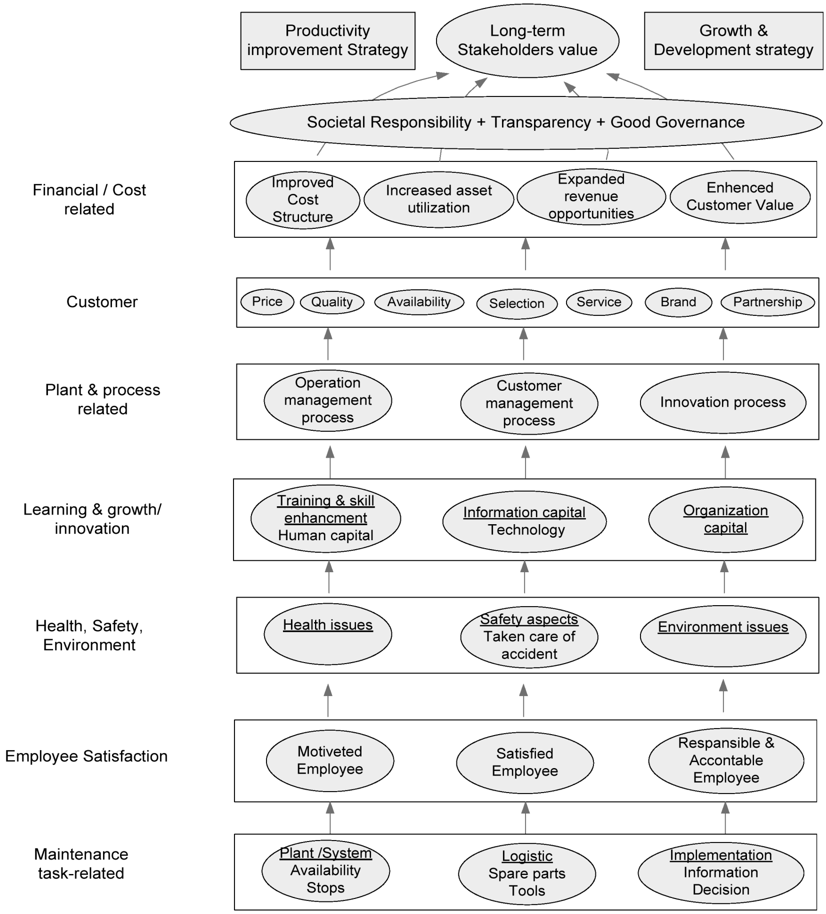

Figure 2.4. Holistic view of a multi-criteria MPM framework showing the linkage of different MPIs and criteria leading to achieving long term stakeholders' value (Parida (2006)

Thus, for implementing the MPM system, management and employee's commitments and involvement, communication and dissemination of results at each hierarchical level and MPIs' alignment with business objectives are some of the important issues need to be considered.

2.5 MPI Standards and MPIs as in Use in Different Industries

The greatest challenge for measuring maintenance performance is the implementation of the MPM system for validation of the MPIs under a real and industrial set up. Implementation first involves executing the plan and deploying the system developed in place of the previously existing or planned system. Second, it means operating with the selected measures and validating the assurance that the defined maintenance measurement system works on a day-to-day basis.

Without any formal measures of performance, it is difficult to plan control and improve the maintenance process. This is motivating senior business managers and asset owners to enhance the effectiveness of maintenance system. Also, with this, the focus is shifting to measure the performance of maintenance. Maintenance performance needs to be measured to evaluate, control and improve the maintenance activities for ensuring achievement of organizational goals and objectives. Different MPM frameworks and indicators to monitor, control and evaluate various performances are in use by different industries. More and more industries are working towards developing a specific MPM framework for their organization and identifying the indicators best suited to their industry. Organizations like International Atomic Energy Agency (IAEA) has already developed and published safety indicators during 2000 for nuclear power plants, and Society for Maintenance and Reliability Professionals (SMRP) and European Federation of National Maintenance Societies (EFNMS) have started organizing working groups and workshops to identify and select MPIs for the industries. They have already defined and standardised some of the MPIs to be followed by their associates and members. Besides, a number of industries have initiated research projects in collaboration with universities to identify suitable MPIs as applicable to their specific industry. MPIs are measures of efficiency, effectiveness, quality, timeliness, safety, and productivity amongst others. Some of the industries where MPM framework has been tried out are in the nuclear, oil and gas (O & G), railway, process industry and energy sectors amongst others. A different approach is used for developing the MPM framework and indicators for different industries, as per the stakeholders' requirements. Each organization under a specified industry is unique and as such the MPIs and the MPM framework is required to be modified or developed specifically to meet its unique organizational and operational needs. Some of the MPM approaches, frameworks and MPIs, as in use or under development by different societies, organizations and industries are discussed as under.

2.5.1 Nuclear Industry

The importance of the nuclear industry for energy generation as an alternate source is growing worldwide. International agencies like the International Atomic Energy Agency (IAEA) has been actively involved and sponsoring the development work in the area of indicators to monitor nuclear power plant (NPP) operational safety performance, from early 1990. The safe operation of nuclear power plants is the accepted goal for the management of the nuclear industry. A high level of safety results from the integration of the good design, operational safety and human performance. In order to be effective, a holistic and integrative approach is required to be adopted for providing a performance measurement framework and identifying the with desired safety attributes for the operation of the nuclear plant. Specific indicator trends over a period of time can provide an early warning to the management for investigating the causes of the observed change and comparing with the set target figure. Each plant needs to determine the indicators best suited to their individual needs, depending on the designed performance and, cost and benefit of operation/maintenance. The NPP performance parameters includes both the safety and economic performance indicators, with overriding safety aspects. To assess the operational safety of NPP, a set of tools like the plant safety aspect (PSA), regulating inspection, quality assurance and self assessment are used. Two categories of indicators of commonly applied are; risk based indicators and safety culture indicators.

Operational Safety Performance Indicators
Indicator development starts attributes usage and the operational safety performance indicators are identified. Under each attribute, overall indicators are established for providing overall evaluation of relevant aspects of safety performance and, under each overall indicator, strategic indicators are identified. The strategic indicators are meant for bridging the gap between the overall and specific indicators. Finally, a set of specific indicators are identified/developed for each strategic indicators to cover all the relevant safety aspects of NPP. Specific indicators are used to measure the performance and identify the declining performance, so that management can take corrective decisions. Some of the indicators used in plants are given in Table 2.1 (IAEA 2000).

2.5.2 Maintenance Indicators by EFNMS

Since, 2004, European Federation of National Maintenance Societies (EFNMS) has conducted a number of workshops by forming a working group from amongst the member National Maintenance Societies of Europe resulting in identifying maintenance indicators for different industries for the national societies and branches. These workshops collected data for the maintenance indicators from industries and also trained the participants in the use of the indicators. The Croatian maintenance society (HDO) hosted the first workshop on maintenance indicators for the food and pharmaceutical business. The workshop was organised to train the maintenance managers in the use of maintenance indicators or Key Performance Indicators (KPIs) and to create an understanding of how to interpret the performance measured by the indicators. The participating maintenance managers were from the food and pharmaceutical industries. A number of workshops are organized in the same sector of industries to compare the results of the industry with the average maintenance performance in the sector. One of the important objectives of these workshops, besides the calculation of the indicators, is to increase the competence of the maintenance manager, who gets an understanding of the mechanism behind the indicators.

Table 2.1. Operational safety performance indicators

	Overall indicators	Strategic indicators	Specific indicators
1.Operates smoothly	1. Operating performance	1. Forced power reductions and outages	1. No. of forced power reductions and outages due to internal causes 2. No. of forced power reductions and outages due to external causes
	2. State of structures, systems and components	1. Corrective work orders issued	1. No. of corrective work orders issued for safety system 2. No. of corrective work orders issued for risk important BOP systems 3. Ratio of corrective work orders executed to work orders programmed 4. No. of pending work orders for more than 3 months
		2. Material condition	1. Chemistry Index (WANO performance indicators) 2. Ageing related indicators (condition indicators)
		3. State of the barriers	1. Fuel reliability (WANO) 2. RCS leakage 3. Containment leakage

These workshops resulted in the methodology for the use of the indicators and defined the draft EN standard 15341. The draft versions of the standard has 71 indicators to measure maintenance performance which are divided into economic indicators, technical indicators and organizational indicators. Among the indicators in the standard are the 13 indicators as defined by the working group of the European Federation of National Maintenance Societies in 2002. After approval, these indicators will be converted to EN standard. These activities resulted in developing a new European standard PrEN 15341 termed “Maintenance key performance indicators”, available at www.efnms.org/efnms/publications/ Firstworkoshopforfoodandpharmeceuticalbusiness.doc.

2.5.3 SMRP Metrics

The SMRP best practices committee has been charted to identify and standardize maintenance and reliability metrics and terminology since 2004. They followed a six step process for the development of the metrics. The SMRP best practice metrics are published by the SMRP under the “Body of knowledge”, available for viewing at www.smrp.org . The numbering system for the metrics is explained on the web-page. Each metric has two files to describe the metric and feedback from the review of the metric. There are 45 metrics under development by different authors as of Feb 2006. A template is developed to provide a consistent method of describing each metric. The basic elements of each metric are:

Title	The name of the metric
Definition	A concise definition of the metric in easily understandable term
Objective	What the metric is designed to measure or report
Formula	A mathematical equation used to calculate the metric
Component definition	Clear definitions of each of the terms that are utilized in the metric formula
Qualifications	Guidance as to when or when not to apply the metric
Sample calculation	A sample calculation utilizing the formula with realistic values

A number of metrics are published at the SMRP web-site, which can be easily accessed. These metrics are explained in a clear and concise manner, which can be used by the personnel at different hierarchical level with out much difficulty. An example of the SMRP best practice metrics is given below:

2.5.4 Oil and Gas Industry

The cost of maintenance and its influence on the total system effectiveness of oil and gas industry is too high to ignore (Kumar and Ellingsen, 2000). The oil and gas industry uses MPIs and MPM framework extensively due to its ever growing and competitive nature of business, besides the productivity, safety and environmental issues. The safe operations of oil and gas production units are the accepted goal for the management of the industry. A high level of safety is essential from the integration of good design, operational safety and human performance. To be effective, an integrative approach is required to be adopted for providing an MPM framework and identifying the MPIs with desired safety attributes for the operation of the oil and gas production unit. Specific indicator trends over a period of time can provide an early warning to management to investigate the causes of the observed change and comparing with the set target figure. Each production unit needs to determine the indicators best suited to their individual needs, depending on the designed performance and cost and benefit of operation/maintenance. Some of the MPIs reported from plant level to result unit level to the result area for the Norwegian oil and gas industry are grouped into different categories as follows (Kumar and Ellingsen, 2000):

- *Production*

  Produced volume oil (Sm3).
  Planned oil-production (Sm3).
  Produced volume gas (Sm3).
  Planned gas-production (Sm3).
  Produced volume condensate (Sm3).
  Planned condensate- production (Sm3).

- *Technical integrity*
  Backlog preventive maintenance (man-hours).
  Backlog corrective maintenance (man-hours).
  Bumber of corrective work orders.
- *Maintenance parameters*
  Maintenance man-hours safety system.
  Maintenance man-hours system.
  Maintenance man-hours other systems.
  Maintenance man-hours total.
- *Deferred production*
  Due to maintenance (Sm3).
  Due to operation (Sm3).
  Due to drilling/well operations (Sm3).
  Weather and other causes (Sm3).

2.5.5 Railway Industry

Railway operation and maintenance is meant for providing a satisfing service to the users, while meeting the regulating authorities' requirements. Today, one of the requirements for the infrastructure managers is to achieve cost effective maintenance activities, a punctual and cost-effective rail road transport system. As a result of a research project for the Swedish rail road transport system, the identified maintenance performance indicators are (Åhren and Kumar, 2004):

- Capacity utilization of infrastructure;
- Capacity restriction of infrastructure;
- Hours of train delays due to infrastructure;
- Number of delayed freight trains due to infrastructure;
- Number of disruptions due to infrastructure;
- Degree of track standard;
- Markdown in current standard;
- Maintenance cost per track-kilometer;
- Traffic volume;
- Number of accidents involving railway vehicles;
- Number of accidents at level crossings;
- Energy consumption per area;
- Use of environmental hazardous material;
- Use of non-renewable materials;
- Total number of functional disruptions; and
- Total number of urgent inspection remarks.

2.5.6 Process Industry

Measuring maintenance performance has drawn considerable interest in the utility, manufacturing and process industry in the last decade. Organizations are keen to know the return on investment made in maintenance spending, while meeting the business objectives and strategy. Under challenges of increasingly technological changes, implementing an appropriate performance measurement system in an organization ensures that actions are aligned to strategies and objectives of the organization. Balanced, holistic and integrated multi-criteria hierarchical maintenance performance measurement (MPM) models developed with seven criteria and specific modification for the industry were tried out for implementation and achieving the total maintenance effectiveness for a pelletization plant and an energy producing service industry of Sweden (Parida *et al.* 2005). The MPIs for the process industry are:

1. Downtime (hours);
2. Change over time;
3. Planned maintenance tasks;
4. Unplanned tasks;
5. Number of new ideas generated;
6. Skill and improvement training;
7. Quality returned;
8. Employee complaints; and
9. Maintenance cost per ton.

In addition, MPIs identified for the multi-criterion hierarchical MPM framework, which are in existence and in use at LKAB (iron ore process company), are OEE, production cost per ton, planned maintenance tasks, quality complaints number, number of accidents, HSE complaints, and impact of quality.

2.5.7 Utility Industry

The MPIs for the utility industry in an energy sector will vary with that of other industries. The MPIs as identified for an energy sector organization of Europe are:

1. Customer satisfaction related: customer satisfaction is one of the main stakeholder group's requirements for the organization. Since, its customer is related to energy supply, duration and interruptions, and the contract, the customer satisfaction related MPIs are taken from the IEEE (1366-2003) and they are as under:

- SAIDI (system average interruption duration index), summation of customer interruption duration to total number of customer served;
- CAIDI (customer average interruption duration index, summation of customer interruption duration to total number of customer interrupted; and
- CSI (customer satisfaction index), obtained through customer survey.

2. Cost related: financial or cost is another main stakeholder group's requirements for any organization. Since, the total maintenance cost has to be controlled and the profit margin has to follow the Government's directive, these two MPIs are suggested to be included in the list of MPI:

- Total maintenance cost; and
- Profit margin.

3. Plant/Process related: the plant or process related MPIs also form important MPIs from internal stakeholder groups. Downtime of power generation and distribution, as well as the overall equipment effectiveness (OEE) rating of generation are the suggested MPIs from this group:

- Down time; and
- OEE rating (overall equipment effectiveness = availability × speed × quality).

4. Maintenance task related: the MPIs related to maintenance tasks are suggested as under:

- Number of unplanned stops (number and time);
- Number of emergency work; and
- Inventory cost.

5. Learning and growth/innovation related: the MPIs related to learning and growths, which are important for knowledge based organization, are:

- Number of new ideas generated; and
- Skill and improvement training.

6. Health, safety and environment (HSE) related: these are society related MPIs and very relevant to any organization today and they are:

- Number of accidents; and
- Number of HSE complaints.

7. Employee satisfaction related: employees are the most important internal stakeholders of the organization and their motivation, empowerment and accountability will be a supportive factor to achieve the organizational goal:

- Employee satisfaction level.

2.5.8 Auto-industry Related MPIs for the CEO

The MPIs used by an auto-industry are given in Table 2.2.

Table 2.2. The MPIs as used by an auto-industry for its CEO (Active strategy, 2006)

Financial	Increase profitability of core products	Core product profitability
	Increase sales of core models	Core model sales in m$
		Core model market share
Customer	Increase customer satisfaction	Customer satisfaction rating
Internal	Improve plant safety	Number of plant accidents
	Improve utilization of CRM system	% of CRM processes adopted
	Improve product launch effectiveness	% of launch plans on schedule
Learning and growth	Improve employee morale	Employee satisfaction survey
		Employee turnover

2.6 Concluding Remarks

Different MPM frameworks and indicators to monitor, control and evaluate maintenance productivity performance are in use by different industries. More and more industries are working towards developing specific MPM frameworks for their organization and identify the indicators best suited to their industry. Organizations like International Atomic Energy Agency (IAEA) have already developed and published safety indicators during 2000 for nuclear power plants, and Society for Maintenance and Reliability Professionals (SMRP) and European Federation of National Maintenance Societies (EFNMS) are organizing working groups and workshops to identify and select MPIs for the industries. In addition, a number of industries have initiated research projects in collaboration with universities to identify suitable MPIs as applicable to their specific industry. MPIs are measures of efficiency, effectiveness, quality, timeliness, safety, and productivity amongst others. Some of the industries where MPM frameworks have been tried out are in the nuclear, oil and gas (O & G), railway, process industry and energy sector amongst others. A different approach is used for developing the MPM framework and indicators for different industries, as per the stakeholders' requirements. However, specific MPIs are required to be identified and developed for an organization, which needs to be integrated with the MPM framework holistically.

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http://www.springer.com/978-1-84882-471-3

Handbook of Maintenance Management and
Engineering
Ben-Daya, M.; Duffuaa, S.O.; Raouf, A.; Knezevic, J.;
Ait-Kadi, D. (Eds.)
2009, XXVII, 741 p., Hardcover
ISBN: 978-1-84882-471-3