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DOCTORAL THESIS

Development of a Multi-criteria Hierarchical Framework for Maintenance Performance Measurement

Concepts, Issues and Challenges

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After 30 years of professional career as an Army maintenance engineer, teacher and trainer, when I arrived in Luleå, in late 2002, I had a unique experience of leading a student's family life, where, I, my wife, my daughter, and my son, all are students. Even today, my self and my son are PhD students at the same time in the University! I started enjoying the student life again, as I never stopped learning in my life.

Coming to the topic of Performance Measurement, as a young workshop officer of the Indian Army Workshops, in early 1970s, I used to keep track of the performance measures like "availability state" and calculate the "Non-Availability Index" etc of the Vehicles and equipments for the Army Units and Formations. There were no computers and till I mastered these calculations, I used to struggle with the figures manually. Up in the ladder of chain of Commands, I had the opportunity to understand of the linkage and impact of these measures with the operational strategy. During post-Army career, while teaching Production, Maintenance and Operation Management, I used to discuss performance measures and performance measurement in the class.

While undergoing the PhD course on "What is this thing called maintenance?" by Professor Uday Kumar, and discussing the various aspects of maintenance, the topic of measuring the maintenance performance again caught my imagination. Later on, I had a detailed and long discussion with Professor Kumar and with his concurrence and continuous encouragement decided to pursue my research in the area of maintenance performance measurement, a relatively new area of research.

First of all, I would like to express my deep gratitude and thanks to my supervisor Professor Uday Kumar and my co-supervisor Dr.Gopi Chattopadhyay, Queensland University of Technology, Australia, for their unlimited support and encouragement at every stage of the research work.

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I also want to thank Professor Raj Rao for his friendly guidance and encouragement. My thanks to all colleagues at the Division of Operation and Maintenance Engineering for helping me to improve the work presented in this thesis. In particular, I would like to express my thanks to Dr Peter Söderholm for his valuable support and critical suggestions, and Javad Barabadi for his help and supporting in handling the thesis manuscript. My thanks and gratitude to Dr Håkan Schunnesson, Arne Nissen, Lina Helgesson for their help and support during the project works leading to case studies of the thesis. I thank Dr Behzad Ghodrtati and Thomas Åhren for their support and willing help. Furthermore, I would like to thank Alireza Ahmedi, Ulla Espling and

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I would like to express my gratitude to all my family members and friends for their total support during my work; particularly, my mother Hemamani and my brothers Girish Parida, and Gadadhar Parida. Besides, my special thanks to Renuji, Kakoli, Col Shakti and Sheelaji, Professor and Mrs D. Acharya, Aruna and Maneesh for their support. Finally, this research work would not have finished without the active support of my wife Minakhi, my daughter Upasana, my son-in-law Munro, and my son Vinit. I would like to express my gratitude for the blessings to my Sadguru, and parents of mine and Minakhi, by dedicating this thesis in their names.

Aditya Parida
Luleå, 2006-09-04

ABSTRACT

Effective management of maintenance process is critical for economic viability and a long term survival of many industries. In fact, an effective and efficient maintenance process is a must for most of industries to assure asset performance often measured in terms of high asset availability, high level of safety and good quality, besides value addition. With this recognition, the measurement of maintenance performance has become an essential element of strategic thinking of asset owners and asset managers. The area of maintenance performance measurement is new and emerging. This is even truer for heavy and capital intensive industries. However, measuring maintenance performance is a complex issue and in practice more difficult than measuring the performance of the business or organisation in terms of total out put due to involvement of many intangibles and difficulty in tracing back the business results to investments and other input to maintenance process.

It is important that factors influencing the performance of maintenance process should be identified; and measured, so that they can be monitored and controlled for improvement.

There are various concepts proposed by researchers for measuring maintenance performance. Some of the concepts used in defining maintenance metrics are unclear of what to measure, how to communicate maintenance performance towards organizational targets, aligning maintenance performance with business goals and strategies. Such ambiguities of maintenance performance are mainly due to not considering complexities involved in breaking down the corporate objectives into measurable targets at the shop floor level; and similarly, aggregation of the measured maintenance performance from shop floor level to the corporate objectives. There is a need to identify factors influencing maintenance performance and analyse various related issues and to develop a framework, which can systematically address these critical issues. Such framework needs to incorporate interrelationship between various factors influencing performance, include desired performance indicators and if possible show their aggregation into key performance indicators (KPIs) at higher level, etc. across strategic, tactical and operational hierarchical levels of the organization.

The scope of this research is to study and analyze different concepts, proposed by researchers in this field and as also followed by the industries. To understand and get a clear picture of performance measurement and especially maintenance performance measurement, an extensive literature study is undertaken. Unfortunately, not much literature is available for maintenance performance measurement. Furthermore, an attempt has been made to define various terms and metrics useful for maintenance performance measurements. Using the theoretical frame of reference the interrelationship between influencing factors are studied at various level in an organisation and a general multi-criteria hierarchical framework for maintenance performance measurement is proposed. The proposed framework considers stakeholders' need, business environment and other relevant factors influential to maintenance effectiveness of the organization. Current practices of two organisations, one in the process industry and the other one in the utility (service) industries are studied in detail and compared against the framework developed in this research. Maintenance performance indicators for nuclear power, oil and gas and railway industries from published literature are also studied and discussed. This research shows that a multi-criterion hierarchical framework for maintenance performance measurement is useful in deciding maintenance policies, procedures and working instructions to monitor and control maintenance effectiveness across various plants and across the industry. Tailor made approaches in developing indicators to address specific stakeholders concern and inform the management of future approaches are recommended. Managing information is key to managing the performance of maintenance effectively. Therefore, application of new and emerging technology such as ICT and implementation of e-Maintenance concept is suggested. The contributions of this study can be summarized are:

- Terms and concepts useful for maintenance performance management, performance measurement, indicators and metrics are discussed and defined.
- An analysis of factors influencing maintenance performance in industrial environment is presented.
- Issues and challenges associated with the maintenance performance measurement are identified, discussed and suggestions are made to deal with them.
- Identified relevant maintenance performance indicators for measuring performance at strategic and operational level.
- A general multi-criteria hierarchical framework for maintenance performance measurement applicable to a wide range of industries is developed.

Keywords: Maintenance performance measurement, maintenance performance indicator, maintenance performance measurement framework, e-Maintenance,

LIST OF APPENDED PAPERS

Paper I: Maintenance Performance Measurement (MPM): Issues and Challenges. Parida, A. and Kumar, U. (2006). *Journal of Quality in Maintenance Engineering*, Volume 12, Number 3, pp. 239-251.

Paper II: Development of Multi-Criteria Hierarchical framework for Maintenance Performance Measurement (MPM). Parida, A. and Chattopadhyay, G. (2006). Submitted and under review.

Paper III: Study and analysis of Maintenance Performance Indicators (MPIs) for LKAB: A Case Study. Parida, A. (2006). Submitted and under review.

Paper IV: Maintenance Performance Measurement system: Application of ICT and e-Maintenance Concepts. Parida, A. (2006). Accepted for publication in the *International Journal of Condition Monitoring and Diagnostic Engineering management* (COMADEM), ISSN 1363-7681.

Paper V: Managing information is key to maintenance effectiveness, Parida, A. and Kumar, U. (2004). Published in the *e-Proceedings of the Intelligent Maintenance System's (IMS)*, 2004, July 15-17, 2004, Arles, France.

LIST OF RELATED PUBLICATIONS (Not appended)

1. Maintenance Performance Measurement: The need of the hour for the mechanized mining industry. Kumar, U. and Parida, A. (2006). Proceedings of the *1st Asian Mining Congress*, 16-18 Jan 2006, Kolkatta, India.

2. Multi-criteria Maintenance Performance Measurement: A conceptual model. Parida, A.; Chattopadhyay, G. and Kumar, U. (2005). Proceedings of the *18th International Congress of COMADEM,* 31st Aug-2nd Sep, Cranfield, UK, pp. 349-356.

3. An integrated approach to design and development of e-maintenance system. Parida, A.; Phanse, K. and Kumar, U. (2004). *VETOMAC-3 and ACSIM-2004*, New-Delhi, Dec 6-9, pp. 1141-1147.

4. Health management of complex technical systems. Söderholm, P. and Parida, A. (2004). Proceedings of the *17th International Congress of COMADEM,* 23-25 Aug, Cambridge, UK, pp. 214-221.

5. E-Maintenance for equipments effectiveness in Mining and Mineral based Industry, Parida, A. and Kumar, U. (2004). Proceedings of *13th International Symposium on Mine Planning and Equipment Selection,* 2004, Sep 01-03, Wroclow, Poland, pp. 475-478.

6. Measurement of environmental management system's effectiveness, Parida, A. and Kumar, U. (2004). Proceedings of *8th SWEMP 2004,* Turkey.

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SOME BASIC DEFINITIONS

Term	Description	Reference
Availability	The ability of an item to be in a state to perform a required function under given conditions at a given instant of time or over a given time interval, assuming that the required external resources are provided	IEV 191-02-05
Framework	A conceptual framework explains, either graphically or in narrative form the main things to be studied-the key factors, constructs or variables- and the presumed relationships among them. Frameworks can be rudimentary or elaborate, theory-driven or commonsensical, descriptive or casual	Miles& Huberman,1994
Indicator	A thing that indicates a state or level	Oxford dictionary
Maintenance	Combination of all the technical and administrative actions, including supervision, intended to retain an item in, or restore it to, a state in which it can perform a required function.	IEV 191-07-01: 1990
Maintenance concept	Interrelationship between the maintenance echelons, the indenture levels and the levels of maintenance to be applied for the maintenance of an item	3.1.10 of IEC 60300-3-14 Ed. 1.0 (2004)
Maintenance improvement	Improvement in maintenance and maintenance support activities is achieved by management support, effective processes, and communication	8.4 of IEC 60300-3-14 Ed. 1.0 (2004)
Maintenance policy	General approach to the provision of maintenance and maintenance support based on the objectives and policies of owners, users and customers	3.1.12 of IEC 60300-3-14 Ed. 1.0 (2004)
Maintenance performance indicators (MPIs)	1. MPIs are a set of measures used for the measurement of maintenance impact on the process performance. MPIs are utilized to evaluate the effectiveness of maintenance carried out 2. MPIs compare the actual conditions with a specific set of reference conditions (requirements/targets)	Wireman, (1998). EEA, (1999).
Maintenance related measurement	The purpose of maintenance-related measurement is to measure the effectiveness of maintenance and maintenance support	8.2.3 of IEC 60300-3-14 Ed. 1.0 (2004)
Measure	Determine the size, amount, or degree of (something) by comparison with a standard unit	Oxford dictionary
Measurement	1. The action of measuring, or a standard unit used in measuring. 2. Measurement is a key management activity, that provides decision makers with information necessary for decision making, monitoring performance and effective allocation of resources 3. Measurements are the yardsticks that tell us how we have done and motivates us to perform	Oxford dictionary Webster and Hung, (1994) Najmi and Kehoe, 2001

Performance	1. The accomplishment or carrying out of something commanded or undertaken; the doing of an action or operation and measurement is the action or an act of measuring or calculating a length, quantity, value, etc. 2. The level to which a goal is attained. 3. Efficiency and effectiveness of purposeful action. 4. Effectiveness (i.e. measuring output to determine if they help accomplish objectives); Efficiency (i.e. measuring resources to determine whether the minimum amount are used in the production of these outputs) 5. A complex inter-relationship between seven performance criteria; effectiveness, efficiency, quality, productivity, quality of work life, innovation, profitability/budgetability	Oxford dictionary Dwight, (1999) Neely *et al*.(2000) Cordero (1989) Rolstadas (1998)
Performance indicator (PI)	Is a measure equipped with baselines and realistic targets to facilitate prognostic and/or diagnostic processes and justify associated decisions and subsequent actions at appropriate levels in the organization to create value in the business process.	Liyanage & Kumar (2003)
Performance management	1. The process by which a company manages its performance. It should be "in line with its corporate and functional strategies and objectives". 2. Performance measurement as the process of quantifying the efficiency and effectiveness of action.	Bititci *et al*.(1997) Neely *et al.(1995)*
Performance measurement (PM)	1. The acquisition and analysis of information about the actual attainment of company objectives and plans and about factors that may influence that attainment. 2. The process of determining how successful organizations or individuals have been in attaining their objectives. 3. Performance measurement serves three basic functions, which are to co-ordinate, to monitor and to diagnose.	Van Drongelen & Cook (1997) Sinclair & Zairi (1996) Atkinson *et. Al* (1997)
Stakeholder	A party having a right, share or claim in a system or in its possession of characteristics that meet that party's needs and expectations	ISO/IEC 15288
System	A combination of interacting elements organized to achieve one or more stated purposes. Note 1- A system may be considered as a product or as the services it provides. Note 2- In practice, the interpretation of its meaning are frequently clarified by the use of an associative noun, e.g. production system. Alternatively the word system may be substituted simply by a context dependent synonym, e.g. production, though this may then obscure a system principles perspective.	ISO/IEC 15288

LIST OF ABBREVIATIONS

AII	Asset Integrity Index
BII	Business Integrity Index
BSC	Balance Scorecard
CAIDI	Customer Average Interruption Duration Index
CEO	Chief Executive Officer
CMMS	Computerised Maintenance Management System
CRM	Customer Relationship Management
CSI	Customer Satisfaction Index
CSF	Critical Success Factor
DOE	Department Of Energy
EEA	European Environment Agency
EFNMS	European Federation of National Maintenance Societies
HSE	Health, Safety and Environment
IAEA	International Atomic Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IEV	International Electrotechnical Vocabulary
ICT	Information and Communication Technology
KPI	Key Performance Indicator
KRA	Key Result Area
LKAB	Lussavara Kirunavara AB (A Swedish Mining Company)
OEE	Overall Equipment Effectiveness
O & G	Oil and Gas
O & M	Operation and Maintenance
MPI	Maintenance Performance Indicator
MPM	Maintenance Performance Measurement
MPMS	Maintenance Performance Measurement System
MTTF	MeanTime To Failure
MTTR	MeanTime To Repair
NPP	Nuclear Power Plant
PI	Performance Indicator
PII	Process Integrity Index
PM	Performance Measurement
PMS	Performance Measurement System
PSA	Plant Safety Aspect
ROMI	Return On Maintenance Investment
SAIDI	System Average Interruption Duration Index
SMART	Specific, Measurable, Attainable, Realistic and Timely
SMRP	Society for Maintenance and Reliability Professionals
SWOT	Strength Weakness opportunity and Threats

1 Introduction

In this chapter, a short description of the research area is outlined; along with the purpose, research questions, the objectives and scope and limitation of the research. The structure of the thesis is also included in this chapter.

1.1 Background

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). Maintenance is a multi-disciplinary process, which provides critical support for heavy and capital-intensive industry by keeping or restoring the machinery and equipment in a safe operating condition. Today it is accepted that maintenance is a key function in sustaining long-term profitability for an organization (Al-Sultan and Duffuaa, 1995).

The measurement of maintenance performance has become an essential element of strategic thinking for asset managers. For many asset-intensive industries, the maintenance costs are a significant portion of the operational cost. For example, the amount spent on maintenance budget for Europe is around 1500 billion euros per year (Altmannshopfer, 2006) and for Sweden 20 billion euros per year (Ahlmann, 2002). In addition, breakdowns and downtime have an impact on the plant capacity, product quality, and cost of production, as well as on health, safety and the environment.

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, the space shuttle Columbia, power outages in New York, UK and Italy, during 2003. Therefore, measuring the impact of maintenance performance on safety related accidents is critical for the any industry. Another safety related example of recent past is that of BP refinery in USA, who paid a fine of US $21m 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 accidents could have enhanced BP's image besides saving billions of dollars. From asset management and changes in legal environment, the asset managers are likely to be charged with "industrial accident deaths" as a result of changes in the legal environment for the future actions or omissions of the maintenance efforts (Mather, 2005). 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 has becoming critical. As a result of the dramatic change due to use of emerging information technology etc, management is relying for monitoring and control of maintenance process, more on software and on professionals from areas other than maintenance. It is unlikely that all these professionals can have a thorough understanding of the maintenance process for correct decision making. Therefore, 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 the societal responsibilities and enhance the effectiveness and efficiency of the asset maintained.

Without any formal measures of performance, it is difficult to plan control and improve the outcome of the maintenance process. Maintenance performance measurement (MPM) has been receiving a great amount of attention from researchers and practitioners in recent years due to a paradigm shift in maintenance. The performance measurement (PM) system needs to be aligned with the organizational strategy (Eccles, 1991; Kaplan and Norton, 2001; Murthy *et al*. 2002).

1.2 Maintenance performance measurement

Measuring maintenance process activity is nothing new. It is there since the beginning and used to be measured by scorecard or indicators like; maintenance cost per unit, maintenance budget, overtime costs and non-availability index due to maintenance etc. However, these maintenance indicators are found to be stand alone indicators localized to the shop floor or operational area only and not linked to the corporate level. With paradigm shift in maintenance, today the senior management wants to know the value created by the maintenance process, while taking care of the safety and environmental issues. Therefore with this shift in management thinking, the MPM has become an important part of the organizational strategy and in corporate governance.

Performance measurement (PM) has caught the imagination and involvement of researchers and managers from the industry alike, in recent years, due to its criticality for measurement of corporate goal and maintenance value addition. According to Ghalayini and Noble (1996), the literature pertaining to PM evolved through two phases. The first phase started in the late 1880s and is known as the cost accounting orientation phase; helped the managers to evaluate the relevant costs of operation. The second phase started after 1980, and attempted to present a balanced and integrated view of PM (Augusto *et al*. 2005 and Gomes *et al*. 2004). During first phase with a financial focus, the approach was criticized for short term measures and failing to measure and integrate all the factors critical to the business success (Banks and Wheelwright, 1979; Hayes and Garvin, 1982, Kaplan, 1983 and 1984, Neely *et al*. 1995).

In the 1980s, the term “productivity” was replaced with “performance”, as the criteria of productivity paradigm was unable to satisfy various stakeholders. A number of studies have pointed out the shortcomings of the prevailing PM systems, especially the ones based on the financial measures only (Johnson and Kaplan, 1987; Kaplan and Norton, 1992; Hall, 1983; Skinner, 1974 and Dixon *et al.* 1990). Traditional financial performance measures provide little indication of future performance and encourage short termism (Hayes and Abernathy, 1980; Kaplan, 1986); they are internal rather than externally focused, with little regard for competitors or customers (Kaplan and Norton, 1992; Neely *et al*. 1995); they lack strategic focus and often inhibit innovation (Skinner, 1974; Richardson and Gordon, 1980). Organization measures what is easy to measure and as a result it is often found that organizations are burdened with data overload (Kennerly and Neely, 2003).

With fast changes taking place in business and industry, the PM concepts of past are outdated today, as they need to be modified according to today's requirements. Some of the concepts used in defining maintenance metrics are unclear of what to measure, how to communicate maintenance performance across the organization, aligning maintenance performance with objectives and strategies (Murthy *et al.* 2002). This has necessitated the development of a framework, facilitating the linkage of maintenance performance to corporate goals. Hence, there is a need to identify and analyse various issues related to maintenance performance and to develop a framework, which can address these issues. Maintenance and related processes across strategic, tactical and operational hierarchical levels of the organization should be incorporated.

Performance measure is used while discussing performance measurement (PM) in general. Performance Indicator (PI) is a more specific measurement gauge or it indicates performance. A PM system is defined as the set of metrics used to quantify the efficiency and effectiveness of actions (Neely *et al.* 1995). Andersen and Fagerhaug (2002) have listed the reasons for measuring performance, for example; to provide management and employees with feedback on the work they are performing. Feedback from employees can generate many potentially positive effects, such as improving motivation or launching improvement initiatives, which can support the organization for achieving continuous improvement. According to Bititci *et al*. (1997), performance management is defined as the process by which a company manages its performance. The MPM concept can adopt 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. Key performance indicator (KPI) is needed to be defined for each element of a strategic plan, which can break down to the PI at the basic shop floor or operational level.

Maintenance performance measurement (MPM) linked to performance trends can be utilized to identify business processes, areas, departments and so on, that need to be improved to achieve the organizational goals. Each organization needs to monitor and evaluate to 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 also MPM data can be used as a marketing tool, by providing information, like; quality and delivery time. MPM is used as a basis for bench marking, in comparison to other organizations. The measurement is entirely relative and there is no fixed reference to indicate how good comparatively, the performance is? So, the measurement trend is one of the most useful aspects to be watched. A reference is to be established, so as to enable target setting for different PM, including MPM based on what others have achieved. If PM is used in the right way, it can help to motivate the whole organization through the feedback system for individuals and departments. PM systems are used differently depending on their application, like the financial reports, costing systems, performance appraisal and reward system, customer satisfaction and competitor ranking and for measuring improvement of the organization (Feurer and Chaharbaghi, 1995).

In the existing literature, the focus is on the measurement of the internal efficiency of the maintenance and no serious efforts have been made to measure the maintenance contribution towards total business goal (often measured in terms of external effectiveness and internal efficiency). Notable exception to study and analyse this concept is Ahlmann (2002). The maintenance performance measurement forms integral part of the process, asset and business integrity, which needs to be cascaded and integrated vertically and horizontally, with other processes of the organization. The real challenge is how to cascade vertically downwards and aggregate the measures upwards, and how to integrate activities amongst various departments within organizations horizontally so that total maintenance effectiveness and desired business objectives are achieved. Also, multiple criteria must be considered when both economic and non-economic factors are involved in decision making (Blanchard and Fabrycky, 1998).

Organizations operating today are facing several kinds of challenges brought in their ways of operation and the characteristics in their business environments. Just to name a few, these new challenges include, highly dynamic business environments, complicated intellectual work at all levels of the company, efficient use of information and communication technologies (ICT), and a fast pace of information and knowledge renewal (Antti, 2004). Today with availability of unique e-maintenance solution by ICT use, industry can have an efficient MPM system from the server-based software applications, latest embedded internet interface devices and state-of-the-art data security. The advent of ICT with e-maintenance application can facilitate ease of real time data collection, analysis and monitoring MPM with different level of data at all hierarchical level for effective decision making.

Earlier, no MPM framework is in use except for the use of PIs for measuring the maintenance performance and use of balance scorecard concept. Most of these PIs used as MPIs by the industry are unable to be applied as the performance drivers. However, the current business scenario demands that the management must have real time plant health condition status to monitor, control, and decision making for measuring maintenance contribution in terms of value addition, safety and accident prevention, and meeting stakeholders requirements. In order to meet these perspectives of the multi-disciplinary facets and criteria, an appropriate MPM framework need to be developed. The MPM framework required to consider the issues of stakeholders' requirements, and total maintenance effectiveness both from internal and external perspectives (Ahlmann, 2002) to identify the relevant MPIs, and then align the MPIs with the corporate objectives. The MPIs are required to be considered from different hierarchical levels of the organization, to achieve efficiency and effectiveness.

1.3 Purpose

The purpose of this research is to develop a multi-criteria hierarchical framework for measuring the performance of maintenance process.

1.4 Research questions

In order to fulfil the above stated purpose, the following research questions need to be answered:

RQ1. What factors do have major influence on performance of maintenance process?
RQ2. What are the issues and challenges associated with the development of an MPM framework?
RQ3. How to develop and implement the MPM framework?

1.5 Objectives

The specific objectives of this research work are to:

1. Study the state-of-the-art of measuring performance of maintenance process.
2. Define and discuss relevant concepts, various issues and challenges useful for developing an MPM system.
3. Develop a multi-criteria hierarchical framework for maintenance performance measurement (MPM).
4. Study and analyse current practices of industrial organisations and compare against the framework developed in this research.

1.6 Scope and limitations

Based on the research questions and objectives, the scope of the research is limited to:

- Studying and identifying the issues and challenges associated with maintenance performance measurement and development of an MPM frame work. This is because; knowing the associated issues and challenges, it is possible to develop a balanced MPM framework. The MPM framework needs to consider the hierarchical levels of the organization and multiple criteria for the maintenance performance indicators.
- The study is limited to the issues related to the measurement of maintenance performance.

1.7 Links between questions, papers and chapters

The chapters and papers that make up the main body of this thesis give answers to the research questions (see figure 1.1). Each chapter and papers included in the thesis, covers some aspects of the research questions and objectives. The RQ1, on what factors do have major influence on performance of maintenance process, is covered in paper 1, 2, 4 and 5, and in chapter 5 of the thesis. The RQ2, on what are the issues and challenges for developing a multi-criteria hierarchical MPM framework, is discussed in paper 1 and chapter 4 of the thesis. Some aspect of issues and challenges are covered in paper 2, 4 and 5. The RQ3, on how to develop and implement the MPM framework, is covered in papers 2, 3, 4 and 5. In chapter 6, two case studies are discussed for the evaluation of the MPM framework.

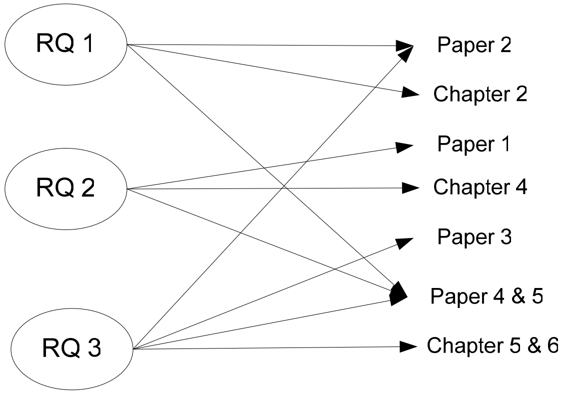

Figure 1.1 Links between research questions and papers

1.8 Thesis structure

The structure of the thesis is divided into different chapters. Each chapter of the thesis illustrates different aspects of the performed research.

Chapter 1 deals with the introduction and background, discusses maintenance performance measurement, the purpose of the research, research questions, objectives of the research; and, scope and limitations. In chapter 2, an overview of the performance measurement frameworks is discussed on the basis of literature survey. In Chapter 3, the research methodology describing the research approach, research strategy, and, quality of the research design are discussed. In chapter 4, various issues and challenges associated with different stages of MPM framework development are presented. Chapter 5 discusses the identified MPIs under different criteria, the concept of multi-criteria and the hierarchical levels of organization, and the development of a multi-criteria hierarchical MPM framework. The concept of total maintenance effectiveness is also discussed. In chapter 6, the case study of identifying MPIs for a mineral processing plant and service utility company are discussed and compared with that of the MPM framework. Chapter 7 contains discussions of the results with reference to research questions and objectives. In addition the research contribution, scope for future research and conclusions are also included in this chapter**.**

2 An Overview of Literature

In this chapter, besides defining all related terms like, maintenance, performance measurement, maintenance performance measurements, indicators, measures are defined and described. An exhaustive study description, analysis of various performance measurement frameworks, MPIs and their strengths and weaknesses are presented. MPIs as in use or identified by different industry and organizations are also presented.

2.1 Introduction

Maintenance is defined as the combination of all the technical and administrative actions, including supervision, intended to retain an item in, or restore it to a state in which it can perform a required function (IEV 191-07-01). Maintenance is an important support function in business with significant investments in physical assets and plays an important role in achieving organizational goals (Tsang, 2002). Maintenance performance measurement (MPM) is required for measuring value created by the maintenance, justifying the investment made and revising resource allocation, taking care of customers, health, safety and environmental issues adapting to new trends in operation and maintenance strategy and organizational structural changes. Therefore, MPM can be defined as "the multi-disciplinary process of measuring and justifying the value created by maintenance investment, and taking care of the organization's stakeholders' requirements viewed strategically from the overall business perspective." While surveying the literature on MPM, the concept of performance measurement (PM) and its frameworks needs to be considered as MPM and PM are to work complementarily in an organizational set-up.

In the past two decades, MPM and its management have received a great amount of attention from researchers and practicenors in industry. In the 1980s, the term "productivity" is replaced with "performance", as the criteria of productivity paradigm are unable to satisfy various stakeholders (Ghalayini and Noble, 1996). Performance measurement (PM) has become one of the most popular subjects for over last two decades for the researchers and managers from the industry. Judging by the 3615 articles published in 1994-1996, one new book per two weeks published in 1996, with 12 million websites existing in 2003 on the subject, and an 1877 % increase in memberships between 1950 and 1991, for the American Institute of Accountants (AIA) and the American Institute of Certified Professional Accountants (AICPA); PM can be named as the most popular subject for both industry and academia, creating a PM revolution (Neely, 1999; De Waal, 2003). Neely (1999) further suggested seven reasons for "the performance measurement revolution: why now" such as; the changing nature of work, increasing competition, specific improvement initiatives, national and international awards, changing organizational roles, changing external demands, and the power of information technology. A large number of PM frameworks or models have been suggested by different authors in the last two decades. Out of them, balanced scorecard (Kaplan and Norton, 1992) is most widely used in the USA and elsewhere and despite all these positive events, studies have indicated that 70 % of PM implementations fail (Bourne and Neely, 2003).

Under the changing business scenario, the previous PM frameworks have not been able to capture all the facets of PM dynamics. Each organization is unique in its structure, function and business position; and cannot be compared exactly with others. As such, the same PM framework that may be suitable for one organization may not be suitable for adoption and implementation by the other. Therefore, there is a need for better understanding of all relevant factors, issues and challenges associated with PM systems.

This Chapter starts with the definitions and current meanings of different terms as used by different authors for PM and maintenance PM, as the subject area is still changing and expanding. The chapter also briefly deals with the overview of literature related to Performance indicator (PI), Maintenance Performance indicator (MPI), Performance measurement (PM), Maintenance performance Measurement (MPM) and various frameworks developed. The attributes and concept of PM in some cases are relevant to MPM, as a holistic approach is adopted for maintenance which is part of the business performance.

2.2 Performance measurement and maintenance performance measurement definitions

According to Amartunga and Baldry (2002), the Procurement Executives' Association, defined "performance management" as, 'the use of PM information to effect positive change in organizational culture, systems and processes, by helping to set agreed-upon performance goals, allocating and prioritising resources, informing managers to either confirm or change current policy or programme directions to meet those goals, and sharing results of performance in pursuing those goals'. Two key components need to be considered to move from performance measurement to performance management: i) the right organizational structure, which facilitates the effective use of PM results; and ii) the ability to use PM results to bring about change in the organization.

Measurement is a method of knowing where an organization is now, to help it plan where it wants to go and to tell when it has arrived there. Measurement provides the basis for an organization to assess how well it is progressing towards its predetermined objectives, helps to identify areas of strengths and weaknesses, and decides on future initiatives, with the goals of improving organizational performance (Amartunga and Baldry, 2002). Metric, measure and performance indicator, are terms often used interchangeably in the developing field of PM. Some authors say 'metric' as the unit of measure, measures means specific observation characterizing performance and performance indicator is a specifically defined variable. A performance measure can be defined as a metric used to quantify the efficiency and/or effectiveness of action (Neely *et al*. 2005).

Vroom (1964) suggested that performance is a function of 'ability and motivation'. Porter and Lawler (1968) presented a model where performance consists of 'efforts, ability and role perception'. The basic concept of performance is function of ability, efforts, and opportunity (Salminen, 2005). Performance is the ability of an organization to implement a chosen strategy. The performance of individuals and groups results in the organizational performance. Performance is not the same thing to all organizations and it also means different things to different stakeholders of the same organization. Performance can be examined from different perspectives, such as customer, financial, process, employee, safety, environment etc. This reveals that performance includes practically everything that describes, or is behind, the success of an organization.

PM is defined as the comparison of results against expectations with the implied objective of learning to do better (Rouse and Putteril, 2003). A PM can be defined as the process of quantifying the efficiency and effectiveness of action (Neely *et al.* 2005). The primary function of any PM system is to control the organizational operations. It provides the language for specifying expectations and performance, so that a basis for each individual's contribution to fulfilling the organizational vision can be established. PM is the process of measuring work accomplishments and output, as well as measuring in-process parameters that affect work output and accomplishments. Performance measurement includes 'hard' financial and non-financial metrics as well as 'soft' metrics like employee attitudes, and covers both processes and results (Salminen, 2005).

2.2.1 Performance measure attributes

Performance measures are used to highlight a soft spot in a company and to analyze it further to find the problem that is causing the indicator to be low. Ultimately, the indicator can then point to a solution to the problem. So, in implementation, there should be multi-level indicators, showing the hierarchical relationship of the PIs. Attributes of performance measures, through which the organization seeks to improve performance relative to its strategic goals, are summarized as; (a) Measures are diverse and complementary, like operational, strategic, financial and non-financial, (b) Measures are objective and accurate, as lower accuracy and objectivity will have an impact on the performance of the organization, (c) Measures are informative, as informative measures can improve evaluation, decision making and value-addition, (d) Benefits outweigh costs of collection, (e) Measures reflect system causality, as a functioning causal PM might also free managers to focus more on strategy and evaluation issues (f) Measures communicate strategy, as the right performance measures align actions and effectively communicate strategy, (g) Measures create incentives for improvement, and, (h) Measures improve decision making (Kaplan and Norton, 2001). A company can consider and choose measures with these attributes and keep only those that display the attributes in practice.

2.2.2 Performance indicators (PIs)

PIs are used for the measurement of 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 are applied in order to find ways to reduce downtime, costs and waste, operate more efficiently, and get more capacity from the operational lines. PIs at the shop floor level or functional level when aggregated to the managerial or higher level are called key performance indicators (KPIs). A KPI can indicate the performance measures of key result area (KRA). It is important for top management to satisfy the needs of all stakeholders/shareholders. These corporate PIs will vary from company to company depending on the current market conditions, business life cycle and the company's financial standing etc. Rather as rule, all PIs must be tied to the long-range corporate business objectives.

PIs could be broadly classified as leading or lagging indicators. A leading indicator is one that warns the user about objectives beforehand. A leading indicator is one of a statistical series that fairly reliably turns up or down before the general economy does (Encyclopaedia Britannica). A leading indicator thus works as a performance driver and supports the concerned head of the specific organisational unit in ascertaining the present status with comparison to the reference one. To know, how the situation is likely to be tomorrow or next year, you need perceptual or intangible measures like stakeholder satisfaction and employee commitment. Perceptual measures are often leading indicators in the sense that they are highly predictive of financial performance. When such measures are tracked today, this will lead to less worry about missing tomorrow's budgets (Case, 1998).

A lagging indicator normally changes direction after economy has. Lagging indicators indicate the condition after the performance has taken place; the value of construction completed for example, is outdated. The maintenance cost per unit or return on investment calculation, could be an example of a lagging indicator. The list of PIs is a long one. But each organization's selection of performance indicators will vary according to their corporate strategy objectives and requirements. Pintelon and Puyvelde (1997) categorize PIs as; global PI, set of PIs, and structured PIs and mentions that introduction of a structured PM system is not an easy job!

2.2.3 Maintenance performance indicators (MPIs)

Maintenance performance indicators (MPIs) are utilized to evaluate the effectiveness of maintenance carried out (Wireman, 1998). MPIs compare the actual conditions with a specific set of reference conditions (requirements/targets) (EEA, 1999). MPIs can also be defined as "the means to measure the efficiency and effectiveness of maintenance and related performance." MPI is a product of several measures (metrics), when used for measurement of maintenance performance in an area or activity; they are called the maintenance performance indicators (Wireman, 1998). Liyanage and Kumar (2003) define a performance indicator of maintenance as "a measure equipped with baselines and realistic targets to facilitate prognostic and/or diagnostic processes and justify associated decisions and subsequent actions at appropriate levels in the organization to create value in the business process". One way of measuring the maintenance performance is to develop maintenance performance indicators (MPIs) and implement them with a total involvement of the entire organisation. MPIs are linked to the reduction of downtime, costs and wastes, and the enhancement of capacity utilization, productivity, quality, health and safety. MPIs also need to be different for different industries and the difference causes a need for other PIs (Arts *et al.* 1998).

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. Maintenance budget, plant or system's availability targets, meantime, between failures and repair (MTBF and MTTR), maintenance reliability and downtime, are some of the examples of MPIs. The establishment of a link between the lagging and the leading indicators helps to monitor and control the performance of the process, and the indicators to be linked are selected in line with the chosen maintenance strategy (Kumar and Ellingsen, 2000).

2.3 Performance Measurement (PM) and PM frameworks

While reviewing the literature, one tends to notice that the terms, frameworks, models and systems are often used interchangeably. A system is an assemblage of entities observed as acting cohesively, based on a holistic concept. There are several concepts and frameworks for measuring the business and maintenance performance. A conceptual framework explains, either graphically or in narrative form the main things to be studied the key factors, constructs or variables and the presumed relationships among them. Frameworks can be rudimentary or elaborate, theory driven or common sensical, descriptive or casual. A framework specifies who and what will and will not be studied, and some relationship as indicated by arrows, which is based on logic (Miles and Huberman, 1994). Rouse and Putterill (2003) explains that frameworks assist in the holistic process by clarifying boundaries, specifying dimensions or views and may also provide initial intuitions about relationships among the dimensions. They should not be treated as models, but they form a good starting point for model building as part of theory development.

To restrict our literature review, we consider the pre-industrial period and there after and broadly divide the PM frameworks into traditional accounting based, and multi-criteria frameworks. The multi-criteria PM frameworks are considered under balanced and multi-criteria, and, cause and effect relationship PM frameworks. These entire PM frameworks are relevant to the MPM framework conceptually as the MPM framework considers the integrated and holistic aspects of the organization, and forms part of the business measurement.

2.3.1 Traditional accounting based PM frameworks

The genesis of the frameworks for financial PM goes back to 1903, when three Du-Pont cousins consolidated their small enterprises with many other small single-unit firms. They completely reorganized the Explosives industry and developed an organizational structure that incorporated the best practice of the period. Du Pont continued and perfected these techniques in such a way that by 1910, they were following all the modern basic methods currently in use. This framework is called the

Du Pont Pyramid of Financial Ratios and Du Pont return on investment (ROI) management accounting model by some authors (Chandler, 1977; Skousen *et. al.* 2001). Following the First World War, companies such as Sears Roebuck and General Motors were starting to use sophisticated budgeting and management accounting techniques (Chandler, 1977). By 1941, 50 % of established US companies were using budgetary control in one form or another (Bourne and Neely, 2003). The Du Pont pyramid's drawbacks were indicated by such studies, as its cost analysis relates to the past and fails to indicate future performance, thus encouraging short-term measures (Bruns, 1998). The post-war phase saw a paradigm shift in organizations from only financial measures to both financial and non-financial measures in their objectives and PM. The basic concept of developing the PM system varies with the approach of the framework; like, Kaplan and Norton (1992) used the process of customer needs for their approach and Dixon *et al*., (1990) used the audit technique. The broader framework of Anthony mentions decision making and information requirements into three broad hierarchical levels: strategic planning, management control and operational control. Anthony's framework focuses mainly on the management control level and deliberately neglects the other two levels of strategic planning and operational control and has strong accounting flavour (Rouse and Putterill, 2003). Johnson and Kaplan (1987) pointed out the deficiencies in the management accounting information used for business management. These indicated the failures of the financial measures to consider changes in the competitive situations and strategies of the changing organizations. As a result of criticism, companies began to rethink and develop their monitoring and measurement systems in the late 1980s. Activity based costing (ABC) of Johnson and Kaplan (1987) is a remarkable reform, where the indirect costs are tracked not in terms of cost pools but by activity. In this, the real costs of operations and products are examined with the aid of cost drivers. Subsequently, concepts like, strategic cost management (SCM), strategic management accounting (SMA) and total management accounting (TMA) have been tried out by the companies. The ABC system and these management accounting concepts solved some drawbacks of traditional cost accounting frameworks, yet the other issues of intangible and integrated performance measurement remain to be solved.

The current management accounting system developed in the USA between 1850 and 1920, as the industrial organizations moved with changes, like; piece-work to wages, single to multiple operations, individual production plants to vertical integrated businesses and individual businesses to multi-divisional firms (Bourne and Neely, 2003). A large number of performance measurement frameworks were evolved by researchers for the companies round the world in different organizational situations. Until the early 1990s, most companies measured their performance only by financial results and criteria. The main focus was to show and reassure all shareholders that the company's performance was successful financially and the earning per share and the progress was in accordance with the business plan.

2.3.2 Limitations of the traditional accounting based PM frameworks

Traditional accounting based PM frameworks have been characterised as being financially based, internally focussed, backward looking and more concerned with local departmental performance than with the overall health or performance of the business (Johnson and Kaplan, (1987); Neely *et al.* (1995); Olve *et al.* (1999). The financial measures are also criticized for being historically focused. For example, the sales turnover simply reports the events of the past month or year, whereas, most of the managers want predictive measures, that will indicate the events of next month or year (Dixon *et al*. 1990). In the traditional accounting system, labour was the major cost driver and other costs are regarded as overhead cost. Today, the average labour cost component rarely exceeds 12 %, while overhead is usually 50-55 % of the manufacturing cost (Ghalayini and Noble, 1996). These changes in the overhead cost due to various intangible perspectives of today's business activities have made this allocation approach of the traditional accounting system as invalid. As discussed by Ghalayini and Noble, (1996), traditional accounting systems are lagging metrics, not incorporated with organizational strategy, inflexible, expensive, and unable to measure customer requirements and quantify the performance.

With the Du Pont pyramid in the background and the performance measurement techniques having been used for such a long period, it is ideal to conclude that a well developed performance measurement system should have been used by the companies by now. But authors and researchers like Kaplan (1984), Geanuracos and Meiklejohn (1993), Neely *et al.* (1995), Ashton (1997), and Neely (1998) have shown that this is not the case. Numerous authors discuss the problems with the performance measures used by organizations today. Traditional financial measures of accounting-based PM frameworks are inappropriate for manufacturing business (Kaplan, 1983, 1984, 1986), and mostly criticised for the following reasons:

(a) Short-term decision making is encouraged, like delayed capital investment (Banks and Wheelwright, 1979; Hayes and Abernathy, 1980).

(b) Not having strategic focus and failure to provide data on quality, flexibility and responsiveness (Skinner 1974, Neely *et al*. 1995)

(c) Managers are encouraged to minimise variance from standard than to improve continuously (Turney and Andersen, 1989).

(d) Failure to provide information on customers' need and competitors' performance (Kaplan and Norton, 1992; Camp, 1989).

(e) Their inappropriateness for managing business of the day and inapplicability to modern manufacturing techniques (Bourne and Neely, 2003).

(f) Encourage local optimization, like, manufacturing inventory to keep the machine and people busy (Goldratt and Cox, 1986; Hall, 1983).

(g) They are rarely integrated with one another or aligned to the business process (Lynch and Cross, 1991).

(h) Performance measures are often poorly defined (Neely, 1999).

The main problem with the financial PM strategy is that all results presented are based on the past performance and data of the company; i.e. the company is managed by looking at the rear view. This approach and strategy are successful to some extent, as the economy was primarily based on tangible assets till the early 1980s. After that there has been a clear shift in strategy for creating value from tangible asset to knowledge-based strategies that create and deploy organizations' intangible assets.

The literature survey by Tsang *et al.* (1999) describes the maintenance performance measures of the 1990s in the following way:

(1) Measures are often selected on the basis of convenience and focused on a biased set of lower level measures encouraging sub-optimization.
(2) Measures selected on the basis of convenience are often unrelated to organizational performance and single measure assessing multidimensional performance.
(3) Outcome measures, which reflect short-term results used for strategic and policy decision that have long-term effects.
(4) Results of a KPMG survey conducted in 1990 of 150 companies found that the information used to monitor performances was rated poor or average by half the respondents in terms of relevance, accuracy, timeliness, completeness, cost effectiveness and presentation. Information available to formulate and review strategy was rated poor.
(5) A postal survey in 1991 of 12,800 organizations in the UK, representing a fifth of the workforce, indicated that less than 20 % were using a PM system, but two thirds had policies for managing employee performance, confirming a patchy and incomplete use of PM in the UK.

2.3.3 Multi-criteria PM framework

In the late 1960s and afterwards, there was a great interest in the development of more balanced PM frameworks considering both financial and non-financial performances, which are included in multi-dimensional PM frameworks. There are three desirable components of performance monitoring systems in the public sector: data components, an analysis component and an action component (Rouse and Putterill, 2003). It was desired that the PM framework needs to consider these three components. A non-financial PM approach is stated by Sink and Tuttle (1989), in their book Planning and Measurement in your Organization of the future. Their theory explained that the performance of an organizational system is a complex interrelationship between seven different criteria, like efficiency, effectiveness, quality, productivity, quality of work life and innovation, profitability or budgetability and excellence survival and growth. Subsequently, development of different PM frameworks, like; performance measures matrix, the SMART (Strategic Measurement and Reporting Technique) pyramid, the results/determinants matrix and the balanced scorecard, have created considerable interest in the industrial and academic world. Various authors have developed and suggested frameworks considering non-financial measurements and intangible assets so as to achieve competitive advantages by the organizations. (Blair, 1995; Weber, 2000; Kaplan and Norton, 2001). Studies have confirmed that companies using integrated balanced PM system perform better than companies not measuring their performance (Kennerly and Neely, 2003; Kaplan and Norton, 1996). Various multi-criteria PM frameworks are discussed below.

2.3.3 (a) Balanced PM frameworks.

Since late 1960s, a number of authors have worked on the balanced PM frameworks with a view to overcoming the shortcomings of the traditional accounting system of PM frameworks. Rouse and Putterill (2003), quote Forrester's industrial dynamics model, which is based around stocks and flows of selected dimensions of firms within an industrial sector. Information on levels of informed decision flows and the effects of policies and delays could be investigated by this model. The model revealed that much of the dynamism of a sector could be explained by the internal structure of firms within the sector. A key focus was on feedback loops in the information flows within firms.

A performance measurement matrix reflecting the need for a balanced measurement is proposed by Keegan *et al*. (1989), who categorise measures as cost or non-cost, and external or internal, thus reflecting a greater balance of measures. This simple framework does not reflect all attributes of the measures, yet could accommodate any measures of performance (Neely *et al*. 1995). This framework allows the organization to plot its measures and identify the need for adjustment with measurement focus. The SMART pyramid developed by Wang Laboratories (Lynch and Cross, 1991) facilitates the need for inclusion of measures that are focussed internally and externally. This follows the concept of cascading down of measures from organization to department and on to work centre level, reflecting the corporate vision as well as internal and external business unit objectives. The four levels of the pyramid embody the corporate vision, accountability of the business units, competitive dimensions for business operating systems and specific operational criteria. A linked structure model proposed by Beischel and Smith (1991) complements the performance pyramid of Lynch and Cross (1991) by an explicit focus on the structural measures linking critical success factors to process levels.

Azzone *et al*. (1991) for the first time presented a multi-dimensional balanced performance measures concept prior to Kaplan and Norton (1992). These performance measures are simple and easy to use. However, the main disadvantage of these performance measures is their sole focus on time and neglecting the other performance measures like; cost, delivery and quality, without controlling which the companies cannot compress time. With a focus on time and measures to assist firms competing on this dimension, organizational learning is evidenced by the importance placed on human resources as a critical success factor for time based competition (Rouse and Putterill, 2003).

The balanced scorecard developed by Kaplan and Norton (1992, 1996), is the most popular and balanced PM framework, used by the most of the industries all over the world. This framework identifies and integrates four perspectives of both financial and non-financial types, like; financial, customer, internal business, and innovation and learning. To ensure financial performance, the other perspectives act as drivers and need to be given equal weighting. According to the authors, it should be possible to arrive at the organization's strategy by reviewing the measures of the framework. Kaplan and Norton (1996), argue that the full potential of the balanced scorecard will only be realised if an organization links its measures clearly identifying the drivers of the performance. According to Kennerly and Neely (2002), the concept of balanced scorecard is similar to Tableau de Bord, developed in France in the early twentieth century, which establishes a hierarchy of interrelated measures and cascading measures to different organizational levels, forcing functions and divisions of an organization to position themselves in the context of the company's overall strategy. This balanced scorecard provides a new framework for describing value-creating strategies that can link both tangible and intangible assets. It measures intangible assets in units and not in currency. It explains how intangible assets get mobilized and combined with tangible assets creates the differentiating customer-value propositions and superior financial outcomes. The balanced scorecard identifies and integrates the four perspectives and, the full potential of the balanced scorecard can be realised, if the organization links its measures clearly identifying the performance drivers (Kaplan and Norton, 1992, 1996).

The balanced scorecard fulfils several managerial requirements, which support the need to complement the traditional accounting based measures. The aim of the balanced scorecard is to clarify and operationalize the vision and strategy of the corporate for the current and future performance. The balanced scorecard encourages the managers to approach the corporate vision and strategy from four perspectives; (a) how do the customers see us? The strategy for creating value and differentiation from the perspective of the customer (Customer perspective), (b) what must we excel at? The strategic priorities for various business processes that create customer and shareholder satisfaction (Internal perspective), (c) can we continue to improve and create value? The priorities to create a climate that supports organizational change, innovation and growth (Innovation and learning perspective), and (d) how do we look to the shareholders? The strategy for the growth, profitability and risk viewed from the shareholder (Financial perspective). These four perspectives provide a balanced view of the performance linking to strategic objectives within each of the perspectives. Balanced scorecard indicates performance from both financial and non-financial points of view.

A "Strategy Map" is a logical and comprehensive architecture for describing strategy (Kaplan and Norton, 1992). A strategy map specifies the critical elements and their linkages for an organization's strategy like; objectives for growth and productivity to enhance shareholders' value, market and account share, acquisition, and retention of targeted customers where profitable growth will occur, value propositions that would lead customers to do higher-margin business with the company, innovation and excellence in products, services, and processes that deliver the value proposition to targeted customer segments, promote operational improvements, and meet community expectations and regulatory requirements, and investments required in people and systems to generate and sustain growth. When these corporate strategies are converted to a logical strategy map structure and that of the balanced scorecard, a basic understandable reference is created amongst all the units, subunits and employees of the organization. In all facets of business strategies today, the focus is more on the areas of maintenance, logistics, and supply chain management. All organizations are paying more attentions to the less optimized areas of maintenance, having a direct effect on both tangible and intangible assets as well as on the corporate objectives and strategies. Although various performance indicators and other means of performance measurements are in vogue, the mapping and measurement of maintenance is becoming increasingly an important issue to be linked and implemented with the corporate objectives and strategies.

Kanji's Comparative business scorecard is a improvement and adaption of Kaplan and Norton's (1992) balanced scorecard and mentions that, to achieve business excellence companies need to: (a) maximize stakeholders' value; (b) achieve process excellence; (c) improve organizational learning; and (d) delight the stakeholder (Kanji and Moura, 2002). Other popular measurement frameworks are the European Foundation for Quality Management's (EFQM) Business Excellence model and its US equivalent the Malcom Baldridge Quality Award, which addresses many of the areas not considered by the balance scorecard, which consist of performance factors, such as enablers and results. The enablers are used by the management as levers to deliver the results and include leadership, policy and strategy, people, partnership and resources, and processes. The results consist of people, customers, key performance and society results.

Otley (1999) proposed a framework with a strong emphasis on management control purposes that clearly encompasses several prominent PM frameworks and is organized around five main set issues: organization objectives and their evaluation, strategies and plan, their implementation and ongoing appraisal, performance targets, incentive arrangements, and information and knowledge management.

Neely and Adam (2000), developed a framework of performance prism to fulfill the growing importance of stockholders' requirements in performance measurement. The five distinct, but linked perspectives of the performance prism identified the following questions for organizations to address when defining a set of performance measures:

- Stakeholders' satisfaction – Who are the key stakeholders and what do they want and what are their need?
- Strategies – What strategies do we have to put in place to satisfy the wants and needs of these key stakeholders?
- Processes – What critical processes do we need to operate and enhance these processes?
- Capabilities – What capabilities do we need to operate and enhance these processes?
- Stakeholder Contribution – What contribution do we require from our stakeholders if we are to maintain and develop these capabilities?

Answering these questions leads to the creation of stakeholders' value. The prism framework explains that an organization's results (stakeholder satisfaction) are a function of determinants, the other prism facets.

***2.3.3 (b) PM frameworks with cause and effect relationship*.**

Based on the PM study in the service sector, Fitzgerald *et al.* (1991) developed a result and determinants framework, which relates to results like; competitiveness, financial performance and focuses on the determinants of those results like; quality, flexibility, resource utilization and innovation. This PM framework explains the concept of cause and effect, indicating the results obtained are a function of the past business performance in relation to specific determinants. In this framework, the results obtained are related to past performance and can be termed as lagging indicators, whereas the determinants can be termed as the leading indicators It is noteworthy to mention that the 'result and determinants framework' reflects similar notions of causality as propounded by Lynch and Cross (1991) and Beischel and Smith (1991), mentioned earlier. The Macro Process Model of the Organization, showing linkages between five stages in a business process and measures of their performance, was developed by Brown (1996) with cause and effect relationship. The five stages are; inputs, processing system, outputs, outcomes and goals respectively. This framework shows the effect of organizational inputs on the processing system's performance and with the top level objectives of the organizational goal. Each stage in this framework acts as the driver of the next performance.

A PM matrix was proposed in 1989, with cost and non-cost, external and internal; as the categories of measures, thus needing a larger balance amongst these measures and need to adjust the measurement focus (Keegan *et al.* 1989). This is a simple framework and, while it does not reflect all of the attributes of measures that are increasingly considered necessary, the matrix needs to accommodate any measures of performance. The matrix is not well balanced and fails to provide linkage amongst various business performance dimensions. These drawbacks were later on considered and incorporated in Kaplan and Norton's balanced scorecard and in the results and determinants framework (Fitzgerald *et al.* 1991).

The PM questionnaire framework is used as an initial audit tool, which also ensures that all the performance dimensions are adequately covered (Dixon *et al.* 1990). Since, this approach consists of several different tools; it is potentially complicated to understand and use. Besides, the questionnaire fails to provide an explicit process for developing the PM system and is inadequate for considering the human resource dimension (Medori, 1998).

The SMART (Strategic Measurement and Reporting Technique) pyramid (also called performance pyramid) is developed by Wang Laboratories (Lynch and Cross, 1991). This pyramid framework includes internally and externally focused measures of performance, providing an explicit link between strategy and operations, while encouraging user-centred design. This pyramid starts from vision of the organization, while considering the market, financial, customer, quality, productivity and delivery related issues. The shortcoming of this framework is that, it fails to specify, in any detail, either the form of the measures or the process for developing them. A comparative list of some PM frameworks is compiled and given in Table 2.1. '

Table 2.1 A list of performance measurement frameworks and performance measures.

Model/framework	Measures/Indicators/Criteria	Reference
Sink and Tuttle (1989)	Efficiency, Effectiveness, Quality, Productivity, Quality of work life and innovation, Profitability/budget ability, Excellence, survival and growth,	Sink and Tuttle (1989)
Du Pont Pyramid	Financial ratios, Return on investment (ROI)	Chandler (1977); Skousen *et al.* (2001)
PM matrix	Cost factors, Non-cost factors, External factors, Internal factors	Keegan *et al.* (1989)
Results and determinants matrix	Financial performance, Competitiveness, Quality, Flexibility, Resource utilization, Innovation	Fitzgerald *et al.* (1991)
PM questionnaire	Strategies, actions and measures are assessed, Extent to which they are supportive? Data analysis as per management position or function, Range of response and level of disagreement	Dixon *et al.* (1990)
Brown's framework	Input measures, Process measures, Output measures, Outcome measures	Brown (1996)
SMART pyramid (Performance pyramid)	Quality, Delivery, Process time, Cost, Customer satisfaction, Flexibility, Productivity, Marketing measures, Financial measures	Developed by Wang Laboratories. Lynch and Cross (1991)
Balanced Scorecard (BSC)	Financial, Customer, Internal processes, Learning & growth	Kaplan & Norton (1992)
Consistent PM system	Derived from strategy, continuous improvement, fast and accurate feedback, explicit purpose, relevance	Flapper *et al.* (1996)
Framework for small business PM	Flexibility, Timeliness, Quality, Finance, Customer satisfaction, Human factors	Laitinen (1996)
Cambridge PM process	Quality, Flexibility, Timeliness, Finance, Customer satisfaction, Human factors	Neely *et al.* (1997)
Integrated dynamic PM System	Timeliness, Finance, Customer satisfaction, Human factors , Quality, Flexibility	Ghalayini *et al.* (1997)
Integrated PM framework	Quality, Flexibility, Timeliness, Finance, Customer satisfaction	Medori and Steeple (2000)
Integrated PM system	Finance, Customer satisfaction, Human factors, Quality, Flexibility, Timeliness	Bititci (1994)
Dynamic PM Systems	External and internal monitoring system, Review system, Internal deployment system, IT platform needs	Bititci *et al.* (2000)
Integrated Measurement model	Customer satisfaction, Human factors, Quality, Flexibility, Timeliness, Finance	Oliver & Palmer (1998)
Comparative Business Scorecard	Stakeholder value, Delight the stakeholder, Organizational learning, Process excellence	Kanji (1998)
Skandia Navigator	Financial focus, Customer focus, Human focus, Process focus, Renewal and development focus	Edvinsson and Malone (1997); Sveiby (1997)
Balanced IT Scorecard (BITS)	Financial perspective, Customer satisfaction, Internal processes, Infrastructure & innovation, People perspective	ESI (1998) as mentioned in Abran and Buglione (2003)
BSC of Advanced Information. Services Inc (AISBSC)	Financial perspective, Customer perspective Processes, People, Infrastructure & innovation	Abran and Buglione (2003)
Intangible Asset-monitor (IAM)	Internal Structure: *Growth, *Renewal, *Efficiency, *Stability, Risk (Concept models, Computers, Administrative systems); External Structure: *Customer, *Supplier, *Brand names, *Trademark & image; Individual Competence: * Skills, *Education*Experience, *Values, *Social skill	Sveiby (1997)
Performance Prism	Stakeholders satisfaction, strategies, processes, capabilities, stakeholders contribution	Neely and Adam (2000)
QUEST	Quality, Economic, Social and Technical factors	Abran & Buglione (2003)
European Foundation for Quality Management (EFQM)	Leadership, Enablers: people management, policy and strategy, resources; Processes, Results: people and customer satisfaction, impact on society; and Business results	http://www.efqm.org/ as mentioned in Wongrassamee *et al.*(2003)

2.3.4 Limitations of multi-criteria and non-financial PM frameworks

Different frameworks have tried to capture the essentials of the existing business environment of that time, but the task today is to match the dynamic and contemporary business and performances' changing requirements. A major cause of companies getting into trouble with manufacturing is the tendency for managements to accept simplistic notions in evaluating the performance of their manufacturing facilities, the general tendency in many companies to evaluate manufacturing primarily on the basis of cost and efficiency. There are many more criteria for judging performance (Skinner, 1971) and especially maintenance performance is has multiple inputs and outputs, and involves multi-disciplinary stakeholders. Many of the companies suffer from adopting a narrow and unfocused traditional performance measurement system, thus leading to the balanced set of performance measures, like Kaplan and Norton, (1992) and others.

The balanced scorecard (Kaplan and Norton, 1992) and EFQM's excellence framework (Wongrassamee *et al*. 2003) tried to overcome some of the shortcomings of the traditional accounting based financial PM frameworks. However, as stakeholders' aspects like safety, societal responsibility and employee involvement are not considered to the fullest extent; with the continuously changing concept and functioning of the business organizations, new frameworks have emerged in the business scenario. Data from Gartner Group, of USA, indicates that 40 % of large companies in the US had adopted the BSC by the end of 2000. Another survey suggests that over 50 % of surveyed firms' world-wide had adopted the BSC by mid 2001, with a further 25 % considering it (Downing, 2001). Hence, the balanced scorecard is a widely adapted framework in US, yet 70 percent of balanced scorecard implementations fail (Neely and Bourne, 2000), making it a conceptual model that is not easy to implement. It is not comprehensive and does not make a system's approach, as it focuses only on customers and does not consider other important stakeholders, like; employees' perspectives, suppliers (outsourcing), society and regulating authorities/ agencies. The balanced scorecard does not identify the role of the community in defining the environment within which the company is performing. It also, focuses primarily on top-down PM and fails to recognise the importance of bottom-up and horizontal integration. Frameworks do not by themselves provide a complete solution and only focus on results. This is because; frameworks do provide different perspectives for categorising performance measures, allowing one to consider the balance between the demands on the business, but, they do not tell a company what to measure (Bourne and Neely, 2003). Also, there is no mechanism for specifying the objectives that should be met. PM needs to be integrated into the management of the business. Kennerly and Neely (2003) have pointed out a number of shortcomings of the balanced scorecard, like; absence of a competitive dimension, failure to recognise the importance of aspects such as human resources, supplier performance, and, no specifications of the dimensions of performance that determine success. Kanji's business scorecard (Kanji and Moura, 2002) though an improvement of the balanced scorecard, still fails to overcome all the shortcomings of the balanced scorecard of Kaplan and Norton (1992).

Ghalayini and Noble (1996) mentioned productivity, cost reduction, and profit orientation by the organizations as the limitations of specific traditional performance measures. Among emerging performance measures, they mentioned; a strategic performance measures and time-based PM system, where, all activities like; new product development, decision making, process and production and customer service are time-based. After discussing the limitations, they suggested that, there is a need for an integrated dynamic PM system with characteristics of; clearly defined improvement areas, performance measures related to company strategy and objectives, the role of time as a strategic performance measure, opportunity for dynamic updating of the improvement areas, PM and PM standards, linking of PM and improvement with shop floor, used as an improvement tool, rather than only a monitor and controlling tool and considering process improvement efforts as basic integrated part of the system.

In the last few decades, a large number of companies have been measuring the non-financial measures like, customer satisfaction, customer loyalty, employee satisfaction etc, which ultimately affect profitability. But, in reality, only a few companies could obtain any benefits from such measurements and studies. This is mostly because, they failed to identify, analyze and act on the right non-financial measures. In a field research conducted in more than 60 manufacturing and service companies and later on supplemented by survey responses from 297 senior executives, it was found that most companies have made little attempts to identify areas of non-financial performance that might advance their chosen strategy (Ittner and Larcker, 2003). The common mistakes companies usually make are summarized as under:

(a) Not linking and aligning PM to strategy. The PM system needs to be aligned with the corporate strategy. Researchers and authors like; Kaplan and Norton, (1996, 2001, 2004); Eccles (1991); and Murthy *et al*, (2002), have discussed the need of the PM to be linked and aligned to the corporate strategy. According to Neely and Adams (2000), measures are to be derived from the organizational strategy. However, to derive measures from strategy is mostly mis-understood for the purpose of measurement and the role of strategy. Performance measures help managers to establish whether they are going to reach the destination, they have set out to reach. However, strategy does not lead to the destination; instead, it shows the route to be chosen to reach the desired destination. Therefore, the starting point is the stakeholders and not strategy.

(b) Not validating the links. Once the strategies are identified and the performance measures are established, it is assumed that everything will be fine. Yet, studies suggest that some 90 % of managers fail to implement and deliver their organization strategies. The main reason is that strategies also contain inherent assumptions about the drivers of improved business performance. So, if the assumptions are false, then the expected benefits will not be achieved (Neely and Adams, 2000). Besides, the organization’s processes are not aligned with its strategy properly and at a later stage, when they want to enforce a fit; it fails to deliver the result. Also, the linkage and alignment of PM to corporate strategy are often not validated in terms of cascading down the performance measures from corporate level to the group and individuals at functional level; and

aggregating the performance measures from individual and group level at operational level to corporate level. This validation is critical for success of the PM system.

(c) Not setting the right performance targets. It is generally observed that organizations have failed to set the right performance targets, or in other words they fail to visualize the gap between the organization's capacity, capability and the target set. This gap leads to the failure of achieving the set targets for the organization. And once this gap starts, leading to non-achievement of performance, it works as a "losing spiral" starting from low moral.

(d) Measuring incorrectly. Measures are used for monitoring and controlling purposes, instead of improvement tools, and do not specify which objective to meet the specific time horizon.

(e) Lack of information for decision making. The measures do not provide timely information to the right people at the right place in the right format for appropriate decision making, thus defeating the very purpose of the PM system.

(f) Focus on past and failure to predict. The PM system fails to look ahead to predict the achievement and improvement of future performance. Rather it is mostly concerned with the past performance and fails to analyze the present performance.

2.4 Maintenance PM frameworks and their limitations

Maintenance is considered as an integral part of business process. Today, the cost of maintenance is too high to be ignored by the business management. Cross (1988), reported that in the UK manufacturing industry, maintenance spending ranges from 12-23 per cent of the total factory operating costs. In refineries, the maintenance and operations departments are very large and each department often consists of up to 30 per cent of the total staffing (Dekker, 1996). The maintenance cost for mining industry moves up to 40-50 % of the total operating cost (Campbell, 1995).

The MPM framework forms a vital and integrated part of the PM framework of the organization. The requirement of an MPM framework and its need for development and implementation is well established now. The nine steps to develop a PM system and its requirements, as suggested by Neely *et al*. (1995) do not start with stakeholders' requirements and as such is found to be unacceptable for following up. The MPM framework need to facilitate and support the management to control and monitor the performance aligned to the organizational objectives and strategy, so as to take timely corrective decisions. The framework needs to provide a solution for performance measurements by linking them directly with the organizational strategy and considering criteria consisting of financial and non-financial indicators (Parida and kumar, 2006). However, there is little literature available that covers the development of a systematic approach to PM in maintenance, one that embraces every aspect of maintenance, namely strategic, tactical and operational (Kutucuoglu *et al*. 2001).

In the past two decades, MPM and its management have received a great amount of attention from researchers and practitioners. The development of MPM system is intimately linked with the PM system and the overall corporate strategy. Therefore it imperative to understand the shortcomings of the prevailing PM systems, while taking the MPM framework into consideration, especially the ones based on the financial measures only, as pointed out by researchers like; Johnson and Kaplan, (1987); Hall, (1983); Skinner, (1971) and Dixon *et al.* (1990). Traditional financial performance measures provide little indication of future performance and encourage short termism (Hayes and Abernathy, 1980; Kaplan, 1986); they are internally rather than externally focused, with little regard for competitors or customers (Kaplan and Norton, 1992; Neely *et al*. 1995); they lack a strategic focus and often inhibit innovation (Skinner, 1974; Richardson and Gordon, 1980). In order to overhaul the shortcomings of the existing traditional measures of the systems, organizations' total competitive circumstances were taken in to consideration (Eccles, 1991; Neely. 1999). Major issues related to this field concern what to measure and how to measure it (Neely, 1999) in a practically feasible and cost-effective way. Organizations need to learn how to cope with a continuously changing business and technological environment in order to remain competitive and be successful (Senge, 1992; Eccles, 1991). Various researchers stress the need for reflective action concerning measures to ensure that they are effective in coping with the continuously changing environment (Dixon *et al.* 1990; Ghalayini and Noble, 1996). Improper implementation and management of a maintenance measurement's system development aiming to use new measures to reflect new priorities often lead to ineffective results. This is due to the failure of the organization to discard measures reflecting old priorities, uncorrelated and inconsistent indicators and inadequate measurement techniques (Meyer and Gupta, 1994). Measurement gives the status of the variable, compares the data with target or standard data and points out what actions should be taken and where they should be taken as corrective and preventive measures.

The characteristics of performance measures include relevance, interpretability, timeliness, reliability and validity (Al-Turki and Duffuaa, 2003). An operational MPM system acts like an early-warning system. In the late 1980s, various researchers were working to develop a balanced performance measurement framework that could take care of both financial and non-financial perspectives. Kaplan and Norton's (1992) balanced scorecard leads in these developments. The balanced scorecard, with its four perspectives, focuses on financial, customers, internal processes, and innovation and learning (Kaplan and Norton, 1992). It looks into both tangible (financial) and intangible aspects of the business process. Subsequently, various researchers have developed frameworks considering non-financial measurements and intangible assets to achieve competitive advantages (Blair, 1995; Weber, 2000; Kaplan and Norton, 2001). It is observed that companies using an integrated balanced performance measurement system perform better than those which do not measure their performance (Kennerly and Neely, 2003; Lingle and Schiemann, 1996). Gomes *et al*. (2004) have described the characteristics of a performance measurement system (PMS) linking non-financial information based on key success factors of business. Further, the traditional performance measurement approach is criticized for encouraging local optimization, for being focused on the past, for not providing adequate information for a productivity measurement and improvement program, for not being externally focused and for failing to measure and integrate all critical factors.

As mentioned by Kutucuoglu *et al*. (2001), performance hierarchies need to be elaborated and link performance to strategy. They recognise three performance needs, namely goals, design and management. Combining performance and strategy into a matrix, they devised a nine performance variables framework. They have also, mentioned about the "The silo phenomenon"; the managers looking at the organization vertically and functionally, turning departments into silos (tall, thick windowless structures), where each function strives to meet its goal. This functional optimization often contributes to the sub-optimization of the organization as a whole, not addressing the cross-functional issues. Therefore, the managers need to look at their organizations as horizontally and vertically functioning systems.

Tsang *et al.* (1999) quotes that a US survey of 200 companies in 1995 concluded that, despite reasonably high level use, non-financial measures and targets, are frequently treated in isolation from strategic objectives. They are not reviewed regularly, nor are they linked to short-term or action plans as they are largely ignored or for interest only. Another study undertaken by Tsang in the late 1990s of six large scales steel, public utility, transportation and process industries in Canada and Hong Kong and their MPM systems' characteristics are:

(a) The maintenance organization exceptionally used a structured process to identify measures for its performance and the management was not aware that a PM system can achieve vertical alignment and horizontal integration of activities across organizational units.

(b) Performance measures were primarily used for operational control only.

(c) The commonly used measures were;

- Financial indicators like; operation and maintenance costs,

- Equipment-based or process-oriented measures like; equipment availability, labor productivity and number of incidents caused by in-service failures.

(d) Benchmarking is gaining acceptance as a methodology to evaluate performance and establish targets by making reference to the achievements of best-in-class organizations.

Involvement of the employees in the development of PM system is highlighted by Sinclair and Zairi (1996). Coetzee (1998) provides a comprehensive list of MPIs and ratios and identifies 21 indices under four categories of; machine/facility maintenance efficiency, task efficiency, organizational efficiency and profit/cost efficiency. Although, the MPIs form a balanced view of the maintenance system, they are limited to other operational and tactical aspects. The MPIs are referred to different hierarchies, but are not specified, which makes it difficult to identify the specific hierarchy. These MPIs do not have clear connections to the corporate strategy. Riis *et al.* (1997) gave a framework showing cross levels and functional integration of maintenance management, which attempts to relate maintenance to manufacturing strategy. However, it fails to take care of other customers and suppliers such as design, finance, top management and issues like, HSE, employee, and corporate strategy.

Total productive maintenance (TPM) presented by Nakajima (1988) provides an MPI, termed as overall equipment effectiveness (OEE), which is defined as a product of availability, production speed and product quality. OEE is a very effective MPI, which offers a starting point for developing quantitative variables linking MPM to corporate strategy. As mentioned by Kutucuoglu *et al*. (2001), Sharp *et al*. (1997) adapted TPM and TQM to improve maintenance performance and identified critical success factors (CSFs) linked to maintenance and defining individual roles. Dwight (1995) explains two other approaches; “the system audit approach” and the “incident evaluation approach”, which defines performance in terms of change in value system. Value is defined here as the probable future earnings of the system.

Tsang (1998) adapted the balanced scorecard (Kaplan and Norton, 1992) to bring a strategic approach to MPM, which could consist of a mix of outcome measures and performance drivers, indicating the outcome of past decisions and predicting the future outcomes. Ahlmann (2002) adapted the balanced scorecard (Kaplan and Norton, 1992) for managing a successful company, by applying the framework on different levels of the firm. Based on the balanced scorecard logic, Ahlmann (2002) recommends developing the internal-external effectiveness model for production and maintenance operations. Further, with the relationship between the four perspectives, it is possible to calculate cost and income as the volume and the price and the final profit margin of the firm. However, as discussed earlier, the balanced scorecard of Kaplan and Norton (1992) is having the limitation of not considering the perspectives like; employee, societal and environmental, for the MPM framework. The concept of total maintenance effectiveness can be explored further and tried out for industrial use.

Kutucuoglu *et al*. (2001) developed a performance measurement system (PMS) for maintenance, using the matrix structure of quality function deployment (QFD), as it is easy to incorporate the deployment criteria. The matrix approach makes it simpler to match the specific goals with suitable PIs and it can hold both objective and subjective data. Though the PMS is a flexible MPM framework, it does not consider societal issues and criteria like; health, safety and environment (HSE) and employee satisfaction. Also, the PMS is not simple to be used by the personnel at shop floor level. Besides, the researchers have not covered the implementation of the system.

Murthy *et al.* (2002) presented an approach called the strategic maintenance management (SMM) approach, which has two key elements: (1) maintenance management is a vital core business activity crucial for business survival and success and as such it must be managed strategically; (2) effective maintenance management needs to be based on quantitative business models that integrate maintenance with other decisions such as production etc. The multi-disciplinary activity of SMM involves; data collection and analysis to assess the performance and state of equipment, building quantitative models to predict maintenance and operation impact on equipment degradation and managing maintenance from a strategic perspective. This approach is strictly not balanced and integrated, as it does not consider all the stakeholders.

Dwight (1999) provided two new approaches; (1) the system audit approach, which concentrates on the degree of alignment between the maintenance systems and the goals of the organization it is serving. Within this framework, the relative performance of individual system activities can be established as a surrogate for performance in terms of value. (2) The event analysis approach focuses on understanding the impact on the value of the organizations of the specific actions undertaken during the period. It also calls for consideration of alternative actions that may provide a higher value, and which become the standards against which the maintenance system, and in particular the actions taken, are judged. Both the approaches focus on a standard of performance related to what could be achieved as opposed to achievement of a budget or framework.

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, 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, a company must ensure that the human resources and training are sufficient for the maintenance planning and execution team. Problems in the reporting system are 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 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 or problem areas as raised by various researchers for MPM are:

(a) Strategy. How does one assess and respond to stakeholders' (internal and external) needs? How does one translate the corporate goal and strategy into targets and goals at the operational level (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 (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?

(b) 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?

(c) 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?

(d) 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 of the organization?

(e) Impact of PM on organizational performance. Bourne *et al.* (2005) have cited a study of 99 papers' findings, in which it was found that PM had a positive impact on organizational performance. Further analysis suggested that the more rigorous the research method used, the less likely PM would be found to have a positive impact. The conclusions of the research findings are contradictory, as only some studies have found that the use of non-financial PM has a positive impact on business performance. The key processes associated with the use of PM have identified seven factors; linking to strategic objectives, method of data capture, data analysis, interpretation and evaluation, provision of information and communication, decision making and taking action.

(f) Measuring performance in changing time and environment. Kennerly *et al*. (2003) mention that many organizations have redesigned their measurement systems to ensure that they reflect their current environment and strategies. But how can the organizations maintain them over changing time in dynamic situations? To answer, the authors have suggested considering critical factors like; culture, process, people, systems and external/internal triggers, for their role as barriers and enablers of measures evolution; for survival.

(g) Impact of maintenance improvement on business profit. MPM when used effectively will lead to maintenance improvement and increase in equipment availability, which has a direct impact on business profit. For example, in the mining sector, the effect of improving availability by 1 % can lead to an increase of 3 % profit. Similarly, one percent increase in productivity can lead to a 3 % on profit, whereas one percent reduction in operating costs and interest rate can have 0.7 – 1.2 and 0.5 – 0.9 % effect on profit (Murthy *et al*. 2002).

2.5 MPI Standards and MPIs as in use at different industries

Without any formal measures of performance, it is difficult to plan control and improve the maintenance process. This motivates senior business managers and asset owners to enhance the effectiveness of the maintenance system. Accordingly, 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 specific MPM frameworks for their organizations and identifying the indicators best suited to their industries. Organizations like; International Atomic Energy Agency (IAEA) has already developed and published safety indicators already in 2000, for the 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 things. Some of the industries where a MPM framework has been tried out are in the nuclear, oil and gas (O & G), railway, process industry and energy sector amongst others. Different approaches are used for developing the MPM frameworks and indicators for different industries, in accordance with the stakeholders' requirements. The MPM approaches, frameworks and MPIs, as in use or under development by different societies, organizations and industries are discussed below.

2.5.1 Nuclear industry

The importance of the nuclear industry for energy generation as an alternate source is gaining popularity world over. The International Atomic Energy Agency (IAEA) has been actively involved and sponsoring the work in the area of indicators to monitor nuclear power plant (NPP) operational safety performance, from the early 1990s. The safe operation of the nuclear power plants is the accepted goal for the management of the nuclear industry. A high level of safety results from the integration of good design, operational safety and human performance. In order to be effective, a holistic and integrative approach needs to be adopted for providing a performance measurement framework and identifying the performance indicators with the 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, the cost and benefit of operation/maintenance.

The NPP performance parameters include 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.

2.5.1 (a) 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 indicator 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. Two of the indicators as used in the plants are given at Table 2.2 as a sample (IAEA, 2000).

Table 2.2 Operational safety performance indicators

Attributes	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

2.5.2 Maintenance indicators by European Federation of National Maintenance Societies

European Federation of National Maintenance Societies (EFNMS) has conducted a number of workshops since, 2004 by forming a working group from amongst the member National Maintenance Societies of Europe resulting on identifying maintenance indicators for different industries for the national societies and branches. These workshops have collected data for the maintenance indicators from industries and also trained the participants in the use of the indicators. HDO, the Croatian maintenance society hosted the first workshop on maintenance indicators for the food and pharmaceutical industry. 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 on how to interpret the performance measured by the indicators. The participating maintenance managers were from the food and pharmaceutical industries. A number of workshops have been 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 managers, who gain an understanding on the mechanism behind the indicators.

The workshop resulted in the methodology for the use of the indicators and defined the draft EN standard 15341. The draft versions of the standard have 71 indicators for measuring maintenance performance and are divided into economic indicators, technical indicators and organizational indicators. Among the indicators in the standard, there are the 13 indicators as defined by the working group in EFNMS 2002. After approval, these indicators will be converted to EN standard. These activities have resulted in developing a new European standard PrEN 15341 termed as “Maintenance key performance indicators” (EFNMS, 2006)

Table2.3. Results from the workshop on maintenance indicators. (EFNMS, 2006)

Maintenance indicators	Result		PrEN 15341	World Class results
I:01 Maintenance costs as a % of Plant replacement value	3,3	%	E1	1,8
I:02 Stores investment as a % of Plant replacement value	1,0	%	E7	0,25
I:03 Contractor costs as a % of Maintenance costs	25,3	%	E10	
I:04 Preventive maintenance costs as a % of Maintenance costs	26,1	%	E16	
I:05 Preventive maintenance man hours as a % of Maintenance man hours	35,4	%	O18	40,0
I:06 Maintenance costs as a % of Turnover	2,2	%		
I:07 Training man hours as a % of Maintenance man hours	4,2	%	O23	
I:08 Immediate corrective maintenance man hours as a % of Maintenance man hours	13,4	%	O17	5,0
I:09 Planned and scheduled man hours as a % of Maintenance man hours	45,8	%	O5	90,0
I:10 Required operating time as a % of Total available time	58,5	%		
I:11 Actual operating time as a % of Required operating time	86,4	%	T1/T2	
I:12 Actual operating time / Number of immediate corrective maintenance events	92,1	Hours	T16	
I:13 Immediate corrective maintenance time / Number of immediate corrective maintenance events	2,7	Hours	T21	
T1 Availability related to maintenance	91,5	%	T1	
T2 Operational availability	90,5	%	T2	95

The results as mentioned at table 2. 3 pertain to the food and pharmaceutical sector and are calculated on the basis of the data contributed by the participating companies in the workshop.

2.5.3 Society for Maintenance and Reliability Professionals (SMRP) metrics

The SMRP best practices committee has been assigned identify and standardize maintenance and reliability metrics and terminology since, 2004. They have 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” (SMRP, 2006). 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 on Feb 2006. A template has been 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
Qualifications: Guidance as to when or when not to apply the metric
Sample calculation: A sample calculation utilizing the formula with realistic values

Till July 2006, five metrics had been published on 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 levels without much difficulty. A sample of SMRP best practice metrics for "Mean time between maintenance (MTBM)" is given below.

SMRP (Sample): Mean Time Between Maintenance (MTBM)

A. Definition:

Mean time between maintenance (MTBM) is the length of time between one maintenance action and another for an asset or component. These actions could be either corrective or preventive maintenance. The metric is applied only for maintenance actions which require or result in function interruption.

B. Objectives:

This metric is used to assess maintenance effectiveness. MTBM measures how many times a maintenance task is being performed on the asset which interrupts the function. It could be a preventive, corrective or an emergency repair task. The objective is to minimize number of function interruptions by designing an appropriate maintenance strategy and applying correct tactics.

C. Formula:

MTBM = Operating time (hours) / Number of Maintenance Actions

D. Component Definitions

Maintenance Action	One or more tasks necessary to retain and item in or restore it to specific condition. A maintenance action includes corrective and certain preventive and predictive maintenance tasks that interrupts the asset function
Operation time	A particular interval of time during which the item or asset is performing its required function

E. Qualification:
1. Indicator type : Leading
2. To be used by : Maintenance personnel and reliability engineers
3. Best when used at an asset or component level

F. Sample Calculation:

If an asset had 10 corrective maintenance, 6 preventive maintenance and 3 predictive maintenance repair tasks, each of which resulted in it's shutdown over 1000 hours of operation, then;

The operating time = 1000 hours
The number of maintenance action = 10 + 6 + 3 = 19
MTBM = Operating time (hours) / Number of Maintenance Actions
MTBM = 1000 hours / 19 maintenance actions = 52.63 hours

2.5.4 Oil and gas industry

The cost of maintenance and its influence on the total system effectiveness of the 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 the ever growing and competitive nature of the 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 for the integration of good design, operational safety and human performance. To be effective, an integrative approach needs 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 the management about investigating 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, the cost and benefit of operation/maintenance. Some of the MPIs reported from plant level to result unit level to result area level for the Norwegian oil and gas industry grouped into different categories are 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)
  - Number of corrective work orders
- Maintenance parameters
  - Maintenance man-hours safety system
  - Maintenance man-hours system 99
  - 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 The Railway industry

Railway operation and maintenance is meant for providing satisfactory 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 disruption due to infrastructure
- Degree of track standard
- Markdown in current standard
- Maintenance cost per track-kilomater
- 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
- Total number of urgent inspection remarks

2.5.6 Auto-industry related MPIs for the CEO

Different auto industries use industry specific MPIs as per organizational needs. The MPIs as used by an auto-industry for its CEO is (Active strategy, 2006) given below as a sample.

1.0 Financial.
    1.1 Increase profitability of core products
        - Core product profitability
    1.2 Increase sales of core models
        - Core model sales in m$
        - Core model market share
2.0 Customer.
    2.1 Increase customer satisfaction
        - Customer satisfaction rating
3.0 Internal
    3.1 Improve plant safety
    - Number of plant accidents
    3.2 Improve utilization of CRM system
    - % of CRM processes adopted
    3.3Improve product launch effectiveness
    - % of launch plans on schedule
4.0 Learning and growth
    4.1 Improve employee morale
    - Employee satisfaction survey
    - Employee turnover

From the study and analysis of the MPIs in different industries, it is observed that each organization is unique in its structure, function and performance and no two organizations are found to be using the same set of MPIs or MPM framework. The list of MPIs in use or under development by different industries is a large one. The list suggested by authors like Wireman (2005), and Andersen and Fagerhaug (2002), and others is equally large. In this chapter, sample MPIs from some of the industries are mentioned, besides the work undertaken by different organizations for standardizing the MPIs.

2.6 Discussions and conclusion

The literature review undertaken and the PM frameworks reported in this chapter have several features and attempts have been made to include all the relevant PM frameworks in this chapter, which are analyzed from MPM context. To-date various PM frameworks and methods of analyzing the appropriateness of the PM systems for different organizations have been proposed (Neely and Adams, 2000, Dixon *et al.* 1990, Kaplan and Norton, 1996). However, little work has been carried out on the process of actually designing the measurement systems. From the research projects, which have sought results in the design of measurement systems, it has become apparent that much of the writing about PM to date has been too superficial, in that it ignores the complexities involved in the actual design of measurement systems (Neely *et al*. 2000). These issues and aspects are applicable for the MPM frameworks also. The implementation of the MPM framework and the measures designed for the organization are the real challenge for the managers.

3 RESEARCH METHODOLOGY

The main objective of this chapter is to explain and describe the research design and process. The analysis design and a discussion of validity and reliability are presented. A brief introduction to the background of the research is also presented.

3.1 Background to the Research

Maintenance performance measurement (MPM) is a relatively new and emerging area of research for academia and industry. Initially, the research work was started as a literature study and theoretical work. After a detailed state-of-the-art study on the subject, related issues and challenges are identified and an MPM framework is developed to be tried out in an industrial setting. The research project is supported by two organisations; one in the process industry and the other one in the utility (service) industry. Both the organizations needed to identify the maintenance performance indicators (MPIs) for their organization, which are studied in detail and compared with the framework developed in this study.

3.2 Research Approach

The purpose of this thesis the research is to develop a framework (Miles and Huberman, 1994) and also indicate a qualitative approach as appropriate. There are some issues to be aware of when approaching a problem and seeking answers. The different approaches available are often closely related to one another and to the formulated purpose of the study. Some examples of questions that should be asked are: whether the study is performed according to induction or deduction; or should it be qualitative or quantitative?

3.2.1 Induction or Deduction

In discussions concerning methodological choices, there is often a differentiation between induction and deduction. Induction means that generalisations are made from the conclusions derived from a specific case. Deduction departs from a general rule in order to explain a specific case. (Molander, 1988; Alvesson and Sköldberg, 1994)

This research is based on a common interest among industry and academia in exploring and describing a phenomenon that is both important in practice and seems to be described in an unsatisfactory manner in the literature. Hence, the research could have a deductive or an inductive approach. However, the project originated from industrial and research interests in the phenomenon. A detailed literature study must have an in depth understanding of the phenomenon. Also, the research is based on both theoretical and empirical irregularities for which an iterative approach between theory and practice is made. Finally, some theoretical contributions based on the combination of both theoretical and empirical findings have been accomplished. It is also believed that the contributions have important practical implications. Therefore an approach similar the deductive approach seems to be appropriate.

3.2.2 Qualitative and Quantitative

Information that is conveyed by words is called “qualitative”, while information that is conveyed by numbers is called “quantitative” (Merriam, 1988). Quantitative research emphasizes the measurement and analysis of variables and relations, and also the identification of causal relations between variables (Denzin and Lincoln, 2000). In qualitative research one is interested in the meaning and understanding of a studied phenomenon (Merriam, 1988). The use of pictures and words is often more useful, and therefore more common than the use of numbers to describe what the researcher has found during the study of a certain phenomenon. Qualitative research may therefore be seen as descriptive and holistic (Taylor and Bogdan, 1984). Marshall and Rossman (1999) states that many qualitative studies are exploratory and descriptive. However, there are also other qualitative studies that are explicitly explanatory, showing relationships between events and the meanings these events have (Marshall and Rossman, 1999). Alvesson and Sköldberg (2000) state that an important distinguishing feature is that a qualitative approach starts from the perspective and actions of the studied subjects, whereas quantitative studies proceed from the researcher’s ideas about the dimensions and categories that should be focused on.

The purpose of this research is not to show relationships between events and the meaning of these events, but to try to explore and describe a phenomenon that is seldom, or incompletely, described in the literature. Furthermore, this research aims not at drawing any statistical generalisations, but at gaining a deeper understanding of how the phenomenon may be characterised. The phenomenon of interest may be seen as a process, of which both the meaning and an understanding are sought for.

The data that has been collected is mainly of a qualitative nature for both the case studies, but for the process industry study quantitative data has also been collected. The research work is based on qualitative approach with quantitative aspects.

3.3 Research Strategies

A research strategy may be thought of as providing the overall direction of the research including the process by which the research is conducted (Remenyi and Williams, 1998). A case study can be considered as an intensive and holistic description and analysis of a restricted phenomenon (Merriam, 1988). The case study strategy may also be used to explain the causal links in real-life interventions that are too complex for survey or experimental strategy (Yin, 2003). In general, a case study methodology is preferred when solving research questions including ‘how’ and ‘why’, when the investigator has little control over events and when the focus is on a contemporary phenomenon within some real-life context. For example, a case study is suitable when studying introduction processes, managerial processes, and organizational changes (Yin, 2003). In this research two complementary strategies have been used to collect and analyse evidence. Empirical evidence has been collected through two case studies, while theoretical evidence has been collected through a literature study.

Case studies are appropriate to obtain the real data and/or collect information through interactive methods to achieve the objectives and answers to the research questions. A case study tries to illuminate a decision or set of decisions: why they were taken, how they are implemented, and with what result (Yin, 2003). Shop floor data and questionnaire guide based interviews are conducted in these two case studies to study and identify the existing MPIs and to compare them with that of the developed MPM framework. Prior to data collections and interviews, a detailed business and maintenance process mapping is undertaken. The core of the thesis work is based on two case studies which formed the basis for paper three and are discussed in chapter 6 of the thesis.

3.4 Data Collection

In these two case studies, six main sources of evidence were applied in order to collect data. These sources of evidence are; documentation, archival records, interviews, observations, and surveys. Each of the six sources has strengths and weaknesses; see for example Yin (2003). Information found in documents is likely to be relevant for nearly every case study topic, especially for confirming and supplementing evidence from other sources. Documents are important in the data collection stage in a case study, due to their overall value. However, care must be taken in the interpretation of documents, since they are often prepared for another purpose and audience than that of the case study (Yin, 2003).

One strength with documentation as a source of evidence is that it is stable and therefore may be reviewed repeatedly. Documentation is also unobtrusive since it has not been created as a result of the case study. Furthermore, documentation contains exact names, references, and details of events and is hence exact. A final strength is that documentation may have a broad coverage over a long time span, with many events, and many settings. However, there are also some weaknesses with documentation as a source of evidence that must be considered. The accessibility may be low, or access may be deliberately blocked. There may also be a bias due to an incomplete collection or reporting by the author. (Yin, 2003)

Interviews are one of the most important sources of case study evidence. The interview is a two-way conversation that gives the interviewer the opportunity to participate actively in the interview (Yin, 2003). The interview can focus more directly on areas that are of interest, at the same time as being insightful and providing perceived causal inference. However, there are also a number of drawbacks that must be considered, such as bias due to the interviewer and/or respondent. According to Holme and Solvang (1991), it is important to interview respondents with the right kind of knowledge in order for the result of the study to be valid and valuable.

Interviews are a source of data that is probably very valuable in the collection of empirical data in this research. Since this research is based on two projects, that is performed in cooperation with the industrial organisation that constitute the cases, it should hopefully be rather easy to identify roles and specific persons that are valuable to interview. Research considerations, such as what roles may be interesting for interview and how to prepare the interviews was mainly prepared and discussed within the author's division at the University. Practical considerations, regarding what specific persons to interview and how to gain access to these persons, can be facilitated by the participation of members of the project group that work at the studied organisation.

The author thinks that a combination of document studies and interviews is valuable in order to collect data that are useful in order to gain knowledge of the studied phenomenon. By the collection of data through these two sources it is also possible to both compare and combine data from different sources, which is believed to be valuable. This is because the strengths of each source may be maximised at the same time as their weaknesses, to some degree, may be compensated for.

In the case of case study I, data was collected of the maintenance system, production process and stop recording, which included; running and stop time, production speed, quality, and failure data of the conveyor belts of the balling area of the Pelletization plant. Besides, questionnaire guide based interviews were also conducted in both the case studies to explore data for further conversion to information for analysis of the research study. Opinion survey is carried out to further secure the data collected for the maintenance process and the MPM as well in both the cases. Observations were made in the case study-I for the pelletization plant on the shop floor to observe various maintenance activities including during two half yearly maintenance stops of the plant.

3.5 Data Analysis

According to Miles and Huberman (1994), the analysis of qualitative data consists of three activities: data reduction, data display, and conclusion drawing. There are three general strategies for the analysis of collected case study data. The first, and preferable one, is to rely on theoretical propositions Yin (2003). The second analysis strategy tries to develop and test rival explanations. The third analytical strategy is to develop a descriptive framework for organizing the case study. Theoretical propositions direct attention to something that should be examined within the scope of the study. Some studies may have legitimate reasons for not having any propositions. These are studies in which a topic is the subject of "exploration". However, every exploration should still have some purpose as well as criteria by which the exploration will be judged successful.

The typical mode of data display in qualitative research is narrative text, although narrative text alone is sometimes considered a weak and cumbersome form of display (Miles and Huberman, 1994). However, Czarniawska (1999) states that narrative knowledge is an attractive approach in order to bridge the gap between theory and practice.

The general strategy that is to be applied in the case study analysis is the developed MPM framework. This framework is based on the theories presented in Chapter 2 (Kaplan and Norton, 1992; Neely, 2002; Dwight, 1999; Kutucuoglu *et al*. 2001).

Furthermore, the framework should reflect some of the theoretical propositions of the research. However, the third analysis strategy, i.e. to develop and test rival explanations, is unlikely to be applied in totality.

There are two major theoretical propositions that are made in this research. The first proposition is that the MPM framework has to be multi-criteria and the second proposition that it has to be hierarchical. However, existing theories about MPM frameworks very seldom cover the whole, but only parts.

In order to arrange the findings of the case study initially, and reduce the number of them, some of the Seven Management Tools have been used. These tools are compiled to aid in the analysis of qualitative data, with the exception of Matrix Data Analysis, which is equivalent to Principal Component Analysis (Mizuno, 1988). One of these management tools is the Process Map, which supports the methodology of Process Mapping (Mizuno, 1988). The methodology of Process Mapping has been used to map the maintenance process of the pelletization process. Thereafter, the Process Map has been used to display the relationships between identified stakeholders.

3.6 Research Design Quality

There are basically two different ways of judging the quality of research design, i.e. validity and reliability (Yin, 2003).

3.6.1 Validity

Validity is a general term denoting correctness of measure, i.e., that it does in fact measure what it purports to measure (Yaremko *et al*. 1986). There are different tactics available for increasing the validity (Yin, 2003):

- The use of multiple sources of evidence (during data collection).
- Establishing a chain of evidence (during data collection).
- Having the draft case study report studied by key informants (during composition).

In the case studies document studies, interviews, surveys, and observations have been applied as sources of evidence, in order to affect the validity positively. This application of multiple sources of data is called data triangulation, and by using multiple perspectives on the same data set a theory triangulation can also be achieved (Yin, 2003). The chain of evidence is achieved through a clear description of the research, from stated research questions to case study conclusions, which would also contribute positively to the research's reliability. By having drafts of the case study report studied by key informants the validity is also strengthened. Colleagues at the university have also studied drafts of both research plans and compiled material throughout the research, which should contribute to the validity positively.

3.6.2 Reliability

Reliability is a general term denoting consistency of measurements derived from repeated observations of the same subject under the same circumstances (Yaremko *et* *al*. 1986). Yin (2003) states that reliability demonstrates the operations of a study, such as the data collection procedures, may be repeated with the same results. The author thinks that it may be valuable to compare reliability with precision. Precision in measurement is defined as having small measurement errors, as indexed by the standard deviation (Yaremko *et al.* 1986). The more precise a measuring instrument is, the smaller standard deviation of the values obtained from repeated measurements of an object (Yaremko *et al*. 1986).

In order to affect the reliability positively Yin (2003) recommends that a case study protocol and a case study database are constructed. A case study database can be constructed with the aid of a software program, ordinary folders with indexes, or a combination of both. However, due to some data being classified as confidential, due to organisational interest, the reliability of the study is affected negatively. This is because those outside the studied organisation may have difficulties in getting access to some of the documents. In order to reduce the negative influence on the reliability, it may be valuable to use sources of evidence that are not classified, but that have corresponding information as the sources that are classified. In order to affect the reliability positively a case study protocol is valuable. To further strengthen the reliability the thesis is written to achieve transparency and inter-subjectivity.

4 Issues and Challenges associated with development of MPM framework

In this chapter various issues and challenges associated with development of the MPM framework is presented. These issues and challenges are discussed and presented for the pre-design stage, development stage, implementation, and analysis and feedback stages.

4.1 Issues and Challenges

There are various concepts proposed by researchers for measuring maintenance performance. There is a need to identify and analyse the issues related to maintenance performance and to develop a framework, which can systematically address the related issues and challenges of maintenance management, performance measures, indicators and maintenance performance measurement. It includes key performance indicators (KPIs), metrics and measurement techniques. For the whole process, it needs to cover across strategic, tactical and operational, hierarchical levels of the organization.

Therefore, it is essential that, various issues and challenges associated with failure of measurement initiatives need to be studied and examined, prior to development and implementation of the MPM system. Understanding the need for MPM in the business and its work process is critical for the development and successful implementation of the maintenance performance measurement.

The feedback from the reviewing to the system design keeps it valid in a dynamic environment. Anderssen and Fagerhaug (2002) have presented an exhaustive discussion on development of an eight-step PM system design process, which can be used for the MPM framework also. The basic questions involved in the design, development and implementation of an MPM system are presented in Figure 4.1.

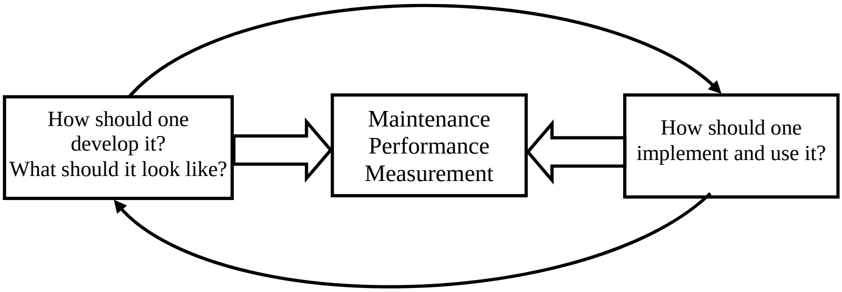

Figure 4.1 Questions involved in the development and implementation of MPM (Parida & Kumar, 2006)

Development of MPM needs to consider various issues at the following stages:

1. Predesign stage,
2. Design and development stage, and
3. Implementation stage
4. Analysis and feedback for continuous improvement

4.2 Predesign stage

This stage consists of understanding and mapping the business structures and processes, and maintenance process, including its need for MPM framework for the business organization and its work process, developing business performance priorities, besides the readiness level of the organization. The answer to the questions, why measure, and if the organization is ready to undertake MPM and at what level, are required at this stage. The following activities are needed during this stage (for details see paper 1 and 2).

- Understanding organizational strategy and stakeholders' analysis
- Justifying investment.
- Health safety and environmental (HSE) issues
- Focus on knowledge management.
- Organizational issue
- Business and maintenance process mapping

4.3 Design and development stage

The design and development stage with the related MPIs is a complex activity, as all the requirements of multiple stakeholders of the MPM system are to be met. The steps involved at this stage are; developing relevant MPIs, deciding how to collect the required data and designing reporting and performance data presentation formats. During this stage, it is very essential that, measures are clearly defined, and validated by all associated people, which offers an excellent scope for achieving organizational goals aligning with the organizational strategy. As mentioned by Neely *et al.*, (2005), Maskell's seven principles given below for PM system design are considered during the design and development stage;

(1) the measures should be directly related to the firm's manufacturing strategy;
(2) non-financial measures should be adopted;
(3) it should be recognized that measures vary between locations- one measure is not suitable for all departments or sites;
(4) it should be acknowledged that measures change as circumstances do;
(5) the measures should be simple and easy to use;
(6) the measures should provide fast feedback; and
(7) the measures should be designed so that they stimulate continuous improvement rather than simple monitor

Both the identification of appropriate measures and explicit consideration of trade-offs between them can be significantly assisted if the relationships among 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 the team 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.

The related issues of this stage are mentioned below. For details see paper 1 and 2.

- Strategy
- Designing MPIs
- How to measure?

4.4 Implementation stage

Implementations of the developed MPM framework is very important, and answer to question like; how to measure, take care of the associated activities in this stage. Employing a combined top-down and bottom-up approach, the organization is informed of the likely MPM system implementation from the very beginning and various people from the organization would be involved in the project. Correct and timely flow of information, aggregating from the data from functional level to the management level through the managerial one, for evaluation, analysis, and appropriate decision making, are the requirements at this stage. The relevant data needs to be recorded and analyzed on a regular basis and used for monitoring, control of maintenance and related activities. The following issues have made pressing demands for effective management of maintenance performance even more challenging:

(a) Measuring value created by the maintenance. The most important reason for implementing a maintenance performance system is to measure the value created by the 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 the focus on doing the right things keeping in view the business goal of the company.

(b) Revising resource allocations. The basic purpose for measures of effectiveness is to determine if additional investment is required and to justify the investment if, management needs more of what you are doing. Alternatively, such measurement of activities also permit you to determine whether you need to change what you are doing or how you are doing it more effectively by using the resources allocated.

(c) Other challenging issues. The other challenges to be taken care of during implementation stage:

- The performance measures need to be linked to the business goal.
- All the users need to be involved in the development and implementation of and training in the measurement system.
- The need to reduce excessive focus on the data collection, collecting only the required data and improving the data analysis for decision support.
- The need to provide feedback on the data collection or analysis and to inform concerned managers?
- The need to link the individual/team/department to business unit goals.
- The need to be pro-active using predictive aspects of MPM rather than isolated values.
- The need to limit the measurement to manageable MPIs and data.

(d) Sustainability.

Sustainability development is the development that lasts while also contributing to a better quality of life for everyone involved (stakeholders). This concept integrates and balances the social, economic, and environmental factors. The following sustainability issues need to be considered during the implementation stage:

(a) How to apply MPM strategy properly for sustainability improvement?
(b) How to develop an MPM culture across the organization?
(c) How to implement a right internal and external communication system supporting MPM?
(d) How to review and modify the MPM strategy and system at regular intervals?
(e) How to develop and build trust in MPIs and MPM systems at various levels?

(e) Performance drivers and killers of MPM implementations. The performance drivers for a successful MPM system are; top management commitment, and the perceived benefits arising from implementing and using the performance measures. The performance killers are; difficulty of implementing MPM system due to the non-availability of required IT support, time and resource required, resistance to MPM system, and some other new and important initiative implementation by the company.

4.5 Analysis and feedback for continuous improvement

Analysis of the data from the implementation of the MPM framework and continuous feedback of the information to the appropriate level at the right time will result in continuous improvement of the MPM system and the organizational performance. Performance monitoring and control are the most common usage of the MPM system. The analysis and feedback of the MPM framework will focus on:

(a) Continuous monitoring of the MPM at different levels and improvement of the organizational performance.
(b) Providing decision support at different levels on a daily basis.
(c) Performing self-audit and diagnosis of the organization.
(d) Carrying out a bench marking of the organization’s performance with respect to the best in the industry.
(e) Facilitating improvement of the organization and process.

To ensure continuous feedback and updating, forming a system review board is recommended to be formed, to avoid making incoherent and partial improvements of the system all the time. The review board is responsible for getting feedback and carrying out periodic assessment of the system.

4.6 Challenges associated with MPM systems

Implementation of the developed MPM system for an organization is very critical. Finding appropriate solutions to the issues of the MPM system are the challenges for the system that have to be taken care of. Ineffective use of information to improve operation without support of appropriate tools and lack of active management commitment and involvement is another critical issue, which can cause an MPM system not to be effective or implemented fully (Santos *et al*., 2002). Dumond (1994), mentions lack of communication and dissemination of results as important issues.

Prior to a pilot project studying the MPM system, it is desirable 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. Some of the challenges which need to be taken care of; are as follows (Parida and Kumar, 2006).

- MPM framework not integrating the three levels of measures and measurement system; the individual performance measures, the MPM system as an entity, and the relationship between MPM system and the environment within which it operates. This shows the performance measures integration both across the organization's functions and through its hierarchy.
- MPM framework not aligned with the strategic objectives of the organization.
- Organizations introduce new measures, but they seldom get rid of the obsolete ones. This leads to loss of time and resources making the MPM system complex and the MPM system need to be refreshed regularly.
- How to overcome disconnected MPM systems with in organization? The requirement is to design and develop a balanced and integrated MPM system for the organization and matching the internal and external environment requirements with the PM system.
- According to Neely (2004), in design, the challenge lies in choosing the right measures. In the late 1980s and early 1990, many organizations used to measure the wrong things that are easy to measure and many of which were financial and historical in orientation. With a desire to quantify absolutely everything, now the problem is excessive measurement. So, the challenge in an MPM system is to identify what you need to measure, which is absolutely vital.
- Use of improper data by the management, encouraging defensive behaviour (measurement is all about understanding what is happening inside the organization and working out, and how to introduce improvement)
- How can the evolution of MPM systems be managed over the long term?
- A challenge arising from the human dimensions, as performance management is not only science based, but also people based.
- Information access. The need for the right information at the right time, to the right people and place, in the right quantity and format. Also, ineffective use of information to improve operation without support of appropriate tools (Santos *et al*., 2002) needs to be taken care of.
- Fear, politics and subversion (Neely *et al.*, 2000), people's fear of measurement and the games they play to try to manipulate target setting so as to ensure the

setting of targets that are achievable, so that no blame can be attributed. To combat this, people need to be educated and trained to create an awareness to understand the purpose and use of the MPM system.

- Lack of communication and dissemination of results is another challenge, which is crucial for the management.
- How to manage the excess of data called the data overload and how to bridge the gap with in the organization to have relevant and correct information.
- An MPM system needs to take care of outsourcing, predictive and e-maintenance requirements for the organizations, stakeholders, and, as well as for the maintenance department to meet the future challenges of the organization and business.
- Lack of active management commitment and involvement (Santos *et al.*, 2002), which are also most vital requirements for the MPM framework's development and implementation.

4.6.1 Integration of the maintenance from shop floor to strategic level

The maintenance strategy should be derived from and linked 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 goals. 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. Murthy et al. (2002) claim that maintenance management needs to be carried out in both strategic and operational contexts and the organizational structure is generally structured into three 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. Defining the measures and the actual measurements for monitoring and control constitutes an extremely complex task for large organizations. The complexity of MPM is further increased for multiple criteria objectives.

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, though the subjectivity decreases down through the levels, with the highest objectivity existing at the functional level. The second level considers tactical issues 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 functional personnel and includes the shop floor 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, integrate the different hierarchical levels in a both from top-down and bottom-up manner involving the employees at all levels. At the functional level, the objectives are converted to specific measuring criteria. Similarly, the PIs of the functional level aggregate to KPIs or MPIs at the tactical and strategic level. It is essential that all the employees are totally involved and speak the same language throughout the entire organization for a successful MPM system.

5 Development of a conceptual multi-criteria hierarchical MPM framework

In this chapter concept of multi-criteria approach and multi-hierarchical levels are discussed. The steps required for the development of the MPM framework is given and an MPM framework is developed and presented.

5.1 MPM framework

Measurement of maintenance performance is important for identifying the operational problem areas of an organization and resolving priorities so that the management can take appropriate and timely decision. Maintenance criteria are perceived differently, as different researchers have indicated different criteria for measuring maintenance performance, like; maintenance process, and maintenance task related etc (Ghalayini and Noble, 1996; Atkinson *et al*. 1997; Kutucuoglu *et al.* 2001; Gomes *et al.* 2004). According to Campbell and Jardine, (2001), MPM can be subdivided into five main components of productivity, organization, work efficiency, cost and quality. Maintenance performance measurement in organizations is changing fast with technology from record keeping in the past to forward looking, predicting and controlling performance.

The MPM framework should form a vital and integrated part of the PM framework of the organization. The requirement of an MPM framework and its need for development and implementation are well established now. The MPM framework has to facilitate and support the management to control and monitor the performance aligned to the organizational objectives and strategy, so as to take timely corrective decisions. The framework needs to provide a solution for performance measurements by linking it directly with the organizational strategy and considering criteria consisting of financial and non-financial indicators. At the same time, the framework should be flexible, so as to change with time, according to the situation, as and when required. The MPM framework needs to have transparency and enable accountability for all the hierarchical levels. From the application and usage point of view, the MPM framework should be technology and user friendly and should be easily facilitated by training the relevant personnel. The development of the MPM framework under discussion in this chapter is based on a multi-criteria and different hierarchical level of the organization, as discussed in chapter 2 and 3 and paper 1.

In any planning and development activity, there are several alternatives available, and one has to choose the alternative that is best suited. Normally, the objectives of the decision maker can be expressed in terms of criteria. If there are a number of criteria, multi-criteria choice problems arise, which is solved by having the information on the relative importance of criteria (Noghin, 2005). The selection of factors or variables constituting various performance criteria, such as productivity, effectiveness, efficiency etc, are an important step in developing a performance measurement system in an organization, conceived essentially as multi-criteria decision making (Ray and Sahu, 1990). Since all these measures of the criteria will normally stimulate behavior in a direction encouraged by the organization, this will contribute to an alignment towards the same goals, objectives and strategy of the management. MPM data can be used to monitor development over time i.e. the performance trend. Storing historical data can be an even more powerful source for analytical approaches.

5.2 Multi-criteria approach

The MPM framework, being part of the business performance is a multi-faceted concept. To meet these multi-faceted demands within competitive environment of 21st century, multi-criteria approach or goal functions need to be considered from different stakeholders' requirements, so as to satisfy their needs. These criteria can be broken down to different maintenance indicators like; meantime between failure (MTBF), downtime, number of minor stops, and maintenance cost, planned maintenance tasks and unplanned maintenance tasks, etc. These maintenance indicators need to be integrated from the functional level to the strategic level. The development and implementation process for indicators has been discussed by Andersen and Fagerhaug (2002) and Engelkemeyer and Voss (2000). The development and identification of MPIs for an organization is cascaded down from the vision, objectives and strategy points of view and on the requirements of both the external and the internal stakeholders' as given in Figure 5.1.

Figure 5.1 Developing and identifying MPIs from the vision, objectives and strategy points of view.

In the development process of MPM framework, besides the maintenance criteria, the basic four perspectives of Kaplan and Norton's balanced scorecard, (1992) are considered. In addition, health, safety and environment, and employee satisfaction, are considered to make this MPM framework a balanced and holistic from the sustainability and organizational point of view. The MPM framework developed is made balanced and integrated into the organization both from the stakeholders' point of view and from a top-down and bottom-up approach considering the organizational and the environmental issues and challenges. Criteria like; equipment related and maintenance task related issues are included to justify the relevance of the MPM framework and make it holistic in its approach. Therefore, the MPIs in the MPM framework are classified into seven criteria (Parida *et al*. 2005) and are linked to each other for providing total maintenance effectiveness (Ahlmann, (2002). The criteria are:

(a) Customer satisfaction related indicators
(b) Cost related indicators
(c) Equipment related indicators
(d) Maintenance task related indicators
(e) Learning and growth related indicators
(f) Health safety and environment (HSE)
(g) Employee satisfaction related indicators

After development and prior to implementation, the MPIs need to be tested for; reliability and validity. Reliability is the ability of the MPI to provide the correct measures consistently over time, and validity is the ability of the MPI to measure what it is supposed to measure. The developed multi-criteria hierarchical MPM framework needs to be applied under industrial set-ups, besides comparing the framework concept and MPIs with other industries.

5.3 Multi-hierarchical levels

The MPIs need to be considered from the perspective of the multi-hierarchical levels of the organization. Organizations need a framework to align their PM system with the corporate strategic goals of a company by setting objectives and defining key performance at each level (Kutucuoglu *et al*. 2001). Depending on the organizational structure, the hierarchical levels could be different and can consist of three or more than three levels. For our MPM framework, we have considered three hierarchical levels. The first hierarchical level could correspond to the strategic or top management level, the second to the tactical or middle management level, and the third to the functional/operational level. Three hierarchical levels are given in Figure 5.2, which has been adopted for our MPM framework. It is a challenge to cascade down the MPIs derived from the corporate objectives and strategy, from the strategic or top management level to the functional level through the tactical or middle management level, which is a top-down approach. Similarly, under a bottom-up approach, the challenge lies in collecting MPM data and information and to integrate the MPIs from the functional level to strategic or top management level through the tactical or middle management level. This will ensure evaluation of the MPIs with that of the corporate objectives and necessitates transparency of information flow across the organization. Another important challenge exists for the involvement of all employees in this MPIs development process, so that everyone speaks the same language.

The MPIs of the MPM framework at the functional level are integrated and linked to the tactical or middle level to help the management with analysis and decision making at the strategic or tactical level. The MPIs at the strategic or top management level may appear to be subjective, when seen from the functional level, but after cascading down the levels, the MPIs need to be objective and specific at the functional level. The role of managers at the tactical or middle management level is equally critical as they have to translate the corporate objectives and MPIs to the functional level and vice-versa.

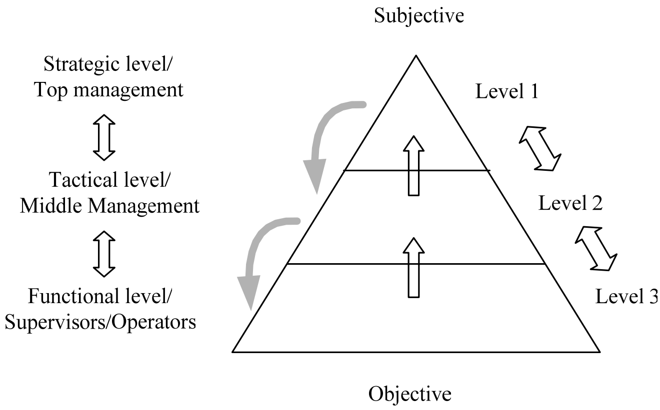

Figure 5.2 Hierarchy levels of MPM framework

5.4 Development of MPIs for the multi-criterion hierarchical MPM framework

While defining the MPIs, the following questions need to be answered (Neely *et al.* 2002).

- What is the reason for this MPI?
- Why do we want to measure it?
- Who is going to act on the measure once the data become available?
- What do they then do with the benefit of this knowledge?
- Where are we going to get the data from?
- Who is going to collect the data?
- How often are they going to collect the data?
- How often will the data be reviewed?

After answering to these questions, the 'target' of the MPI needs to considered, as without an appropriate target, it is not known if the desired level of maintenance performance can be achieved or not. To overcome this issue, for each MPI, a 'MPI definition format' needs to be completed as given at Table 5.1.

Table 5.1 MPI definition format.

MPI	
Aim/goal	
Related to	
Metric/formula	
Target level	
Frequency of measurement	
Source of data	
Who measures	
Owner of the data	
How data is used	
Notes	

The format needs to be considered for each MPI, its goal or aim, related to the key result area, what is the method of calculating the value of the metric and formula, what is the target level of the MPI (if it is achievable?), frequency of measurement, what is the source of the data, and who is going to measure it (accountability), who is the owner of the data (responsibility), how the data is going to be analysed and used (what information for decision making) and any other information required further as notes. The MPIs are classified according to seven criteria are explained and given in paper 2.

5.5 Total maintenance effectiveness and maintenance measuring criteria

Figure 5.3, describes the linkage between the external and internal effectiveness and considers the concept of total maintenance effectiveness (Ahlmann, 2002). The external effectiveness is highlighted by stakeholders need like return on investment and customer satisfaction. The internal effectiveness is high lighted through the desired organizational performance reflected by optimized resources like workforce excellence including knowledge up gradation and innovations. From external stakeholders, the quantity of annual production level is decided, while considering the customers' requirements, return on investment and internal plant capacity and plant availability etc. From internal effectiveness, the organization considers department's integration, employee requirements, as also organizational climate and skill enhancement. After formulation of the MPM system, the multi-criteria MPIs are placed under the multi hierarchical levels of the organization.

In Figure 5.3 the seven criteria considered for the multi-criteria MPM framework (see Parida *et al.* 2005) are given in the small rectangular boxes with the MPIs written with each criterion. This linkage of the Strategy with total maintenance effectiveness and maintenance measuring criteria is likely to provide a balanced and holistic MPM framework.

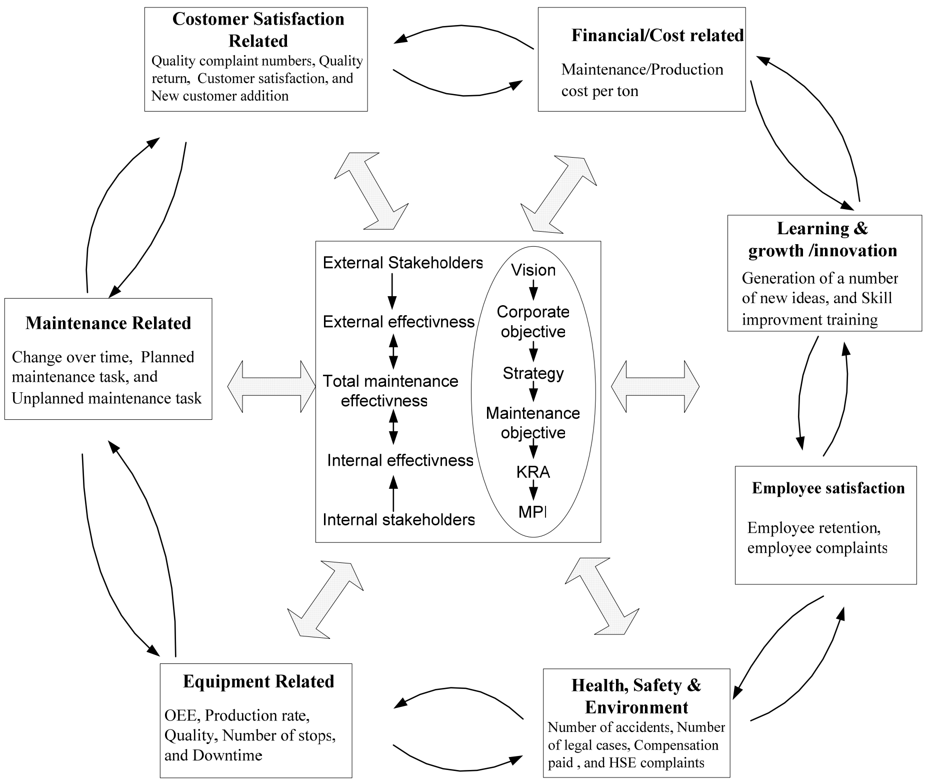

Figure 5.3. Linking strategy, total maintenance effectiveness and maintenance measuring criteria. KRA=Key Result Area, MPI= maintenance performance indicator, OEE= overall equipment effectiveness, HSE= health, safety and environment

5.6 Process, asset and business integrity index link and effect model

The total maintenance strategy is developed from the internal efficiency supporting the external effectiveness. Maintenance, is not only an internal efficiency factor, but also is an intermediate factors for increased asset value, asset utilization, quality and cost efficiency, when combined leads to external effectiveness factors like; stakeholders, quality and sustainability. This concept is given in Figure 5.4; starting with Plant/system integrity index, which is an internal effectiveness with factors of; OEE, availability, reliability and capacity, and employee involvement and motivation. The intermediate level is asset integrity index, with factors of, asset utilization, quality and cost effectiveness. The external and overall business integrity index (BII) is related to the stakeholders of the company, sustainability and transparency. The organizations or companies strive for attaining a high level of BII in order to survive in the competitive business scenario.

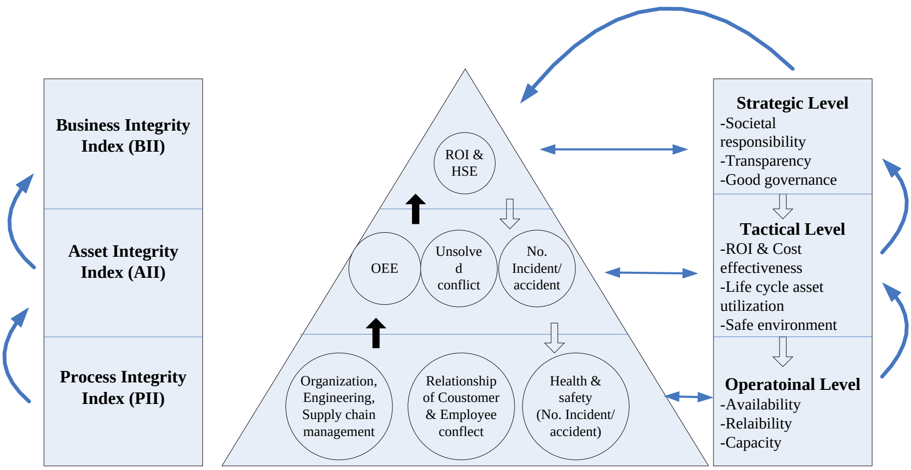

Figure 5.4. Process, asset and business integrity Index link and effect model

⬆ Objectively measure data from operational to strategical level

⇩ MPIs derived from strategical to operational level

Organizations operating today face several kinds of challenges brought in their ways of operation and the characteristics in their business environments. Just to name a few, these new challenges include, highly dynamic business environments, complicated intellectual work at all levels of the company, efficient use of information and communication technologies (ICT), and a fast pace of information and knowledge renewal (Antti, 2004). In order to meet the various perspectives of the multi-disciplinary facets of MPM, different criteria consisting of a number of maintenance performance indicators (MPIs) need to be considered. The MPM framework needs to consider the issues like the stakeholders' requirements, and total maintenance effectiveness both from internal and external perspectives to identify the relevant MPIs, and then align the MPIs with the strategy. The MPIs are required to be considered from different hierarchical levels of the organization, so that they can be cascaded from strategic to functional level or aggregated from functional to strategic level to achieve efficiency and effectiveness (Parida and Kumar, 2006).

Thus, the efficiency and effectiveness of the MPM frame work is very essential for achieving the organizational objectives and the desired plant, asset and business integrity index. Therefore, all the relevant and associated issues and challenges of the MPM frame work are required to be considered for its development, implementation and evaluation.

5.7 Multi-criteria hierarchical MPM framework linking MPIs

The effectiveness of any performance measurement system is meant to meet the needs of the operations and maintenance processes. The critical strategic areas vary from company to company, but generally include areas such as financial or cost-related issues, health safety and environment related issues, processes-related issues, maintenance task related issues, and learning growth and innovation related issues, while at the same time comprising the internal and external aspects of the company. It is important to link and integrate the overall objectives and strategy of the company. The linkage between visions, objectives and strategy and measures of performance such as return on maintenance investments (ROMI) and health, safety and environment (HSE) indicators are considered in our multi-criteria hierarchical MPM framework. The multi-criteria hierarchical MPM framework linking to multiple PIs as proposed is given in Table 5.2.

A logical cause-and-effect structure has been created, while identifying and deciding the different performance indicators for each critical strategic area to measure the maintenance performance. The proposed MPM framework is designed to be balanced and integrated as a link-and-effect structure to achieve the total maintenance effectiveness both from external effectiveness (to do right things) and internal effectiveness (to do things right), which contribute to the overall objective of the organization and its business units. As shown in figure, the internal and external aspects, which act as parts of a back-end or front-end process, are analyzed before deciding the relevant criteria at various levels for the maintenance performance measurement. The front-end process is derived from the needs of the external stakeholders, e.g. the shareholders or owners, financers, customers, suppliers, outsourced agencies and regulating authorities. Therefore, the front-end process needs could include higher productivity, HSE ratings, timely delivery and quality. The back-end process, which is derived from internal aspects like the capacity and capability of the organization, may comprise the integration of departments, employee requirements, the organizational climate and skill enhancement. The back-end processes are; cost reduction, employee retention and innovation. After developing the front and back-end processes, the multi-criteria MPIs are placed, in a balanced and integrated framework, which leads to long-term stakeholders' value as shown in Table 5.2.

Table 5.2 Multi-criteria framework for Maintenance Performance Measurement

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 / Multi-criteria	Level 1 Strategic /Top management	Level 2 Tactical/Middle management	Level 3 Functional/ Operator
Equipment/ Process related	- OEE - Downtime	- Availability - Production rate - Quality - Number of stops	- Production rate - Quality - Number of stops - Downtime
Cost/finance related	- Maintenance/ Production cost per ton	- Mintenance/ Production cost per ton	- Mintenance cost per ton
Maintenance task related	- Costly maintenance task	- 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 - New customer addition	- Quality complaint numbers - Quality return - Customer satisfaction - New customer addition	- Quality complaint numbers - Quality return - Customer satisfaction
Health, safety & environment	- Number of accidents - Number of legal cases - Compensation paid - HSE complaints	- Number of accidents - Number of legal cases - Compensation paid - HSE complaints	- Number of accidents - HSE complaints
Employee satisfaction	- Employee retention - Employee complaints	- Employee retention - Employee complaints	- Employee complaints

When the multi-criteria MPM framework is seen in terms of the different criteria, like; financial/cost related, customer, plant and process related, learning, growth and innovation, HSE related, employee satisfaction and maintenance task-related; as shown at Figure 5.5, its different and associated factors need to be considered for integration. These factors across the entire organization need to be integrated to achieve the societal responsibilities, transparency and good governance. In Combination they lead to long-term stakeholders' value and organizational objectives. The MPIs are to be identified considering the criteria and the associated factors holistically.

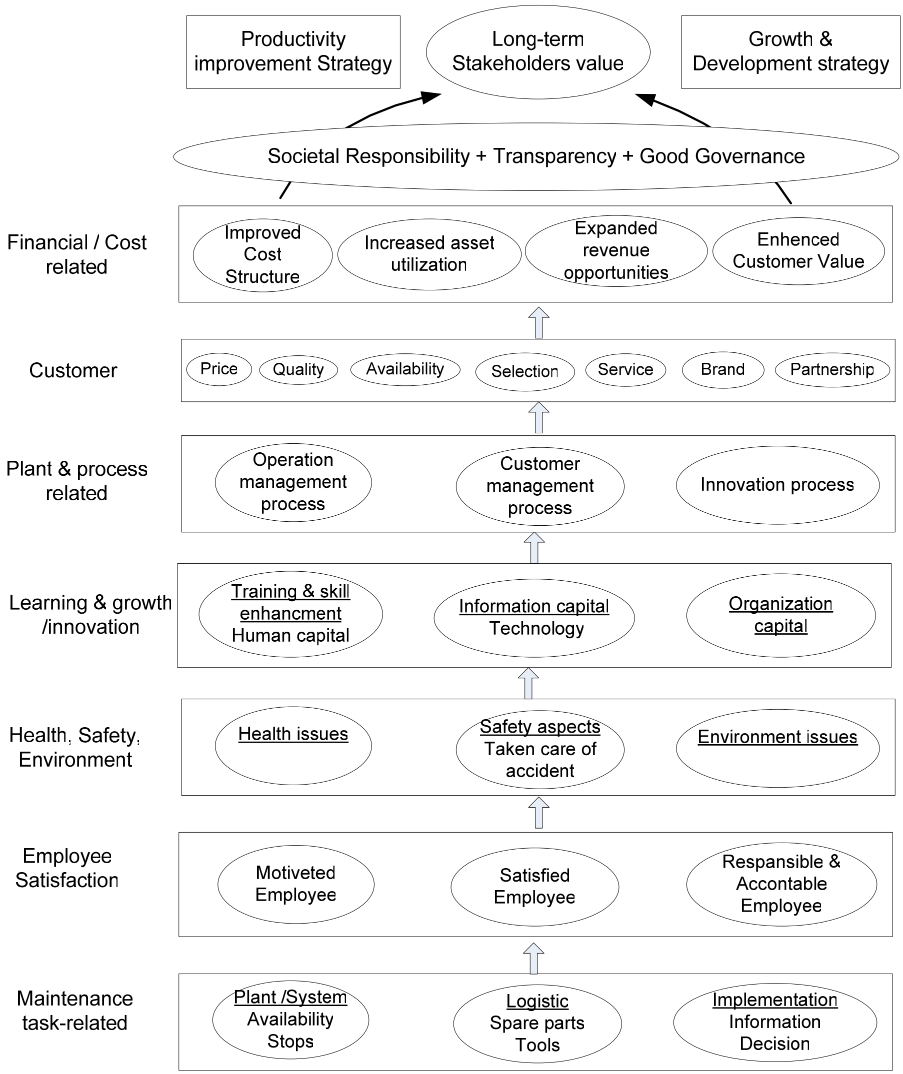

Figure 5.5 Holistic view of a multi-criteria MPM framework showing the linkage of different MPIs and criteria leading to achieving long term stakeholders' value.

6 Case studies

In chapter 6, two case studies under industrial settings are discussed and presented. Case study I is undertaken with a mineral processing industry of LKAB and the other case study is carried out with an energy utility (service) industry of Vattenfall AB. The MPIs identified for these two industries are compared with the MPIs identified and developed for the MPM framework.

6.1 Introduction

The greatest challenge for measuring the 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. Secondly, it means operating with the selected measures and to validating the assurance that the defined maintenance measurement system works on a day-to-day basis. The MPIs developed for the multi-criteria hierarchical MPM framework were tried out under industrial set-ups for two distinct industry sectors; one for LKAB (Lussavara Kirunavara AB) a leading Swedish automated mining processing company, and another with Vattenfall Services AB, a leading Swedish energy generating and distributing company of the Europe.

6.2 Case study I at LKAB

The MPIs developed for the multi-criteria hierarchical MPM framework were tried out in LKAB, a leading Swedish automated mining processing company, for its mineral processing plant for implementation and evaluation. During autumn of 1999, LKAB restructured its organization as part of its improvement plan, to be a more process oriented organization. The purpose of this improvement plan is to take advantage of the synergies that are available at that time and the company is ready to apply the experience and knowledge they have acquired for changing over to a more effective operational organization. The production and service are transferred to the production division, which is to act as the strategic driving force for quality and cost effectiveness in the LKAB group. The goal of this improvement plan is to re-engineer the process by 20 % more production before 2006.

A preliminary study of these issues was performed during 2005 at one of the pelletization plants of LKAB. Personnel from process, production, automation and maintenance departments are interviewed and interacted with, besides visiting the plant for maintenance process mapping. During detailed discussions and study of the problem areas for the year 2004, it was noticed that a large number of shorter and unplanned stops occurred in the balling area of the pelletization plant. A majority of these stops were due to faulty speed control and other issues of the conveyer belt. It was also felt that the failure cause and effect analysis of the shorter stops needed to be made to study the failure pattern, cost, risk and capacity utilization. The analysis further suggested for undertaking appropriate maintenance approaches depending on the failure pattern and consequences, prioritizing the faults and maintenance works. It is also noticed that conveyer belts within each balling drum area had not been defined as the prioritized or critical ones, and therefore full and complete inspection of these conveyer belt was not carried out. The conveyer belts in the balling were chosen as the first prioritized area for inspection by the operators and the maintenance staff (level I and II of inspection). The purpose of this case study is to identify and develop maintenance performance indicators (MPIs) for LKAB, while studying and analyzing the short plant stops and planned maintenance stops. In this case study, the existing MPIs are analysed and a set of MPIs like; return on investment reflected through higher availability, production rate (speed), product yield (quality) and maintenance cost per ton, are considered to measure the performance of balling area of the pelletization plant, where the effect of shorter stops in the process are studied, analysed and measured, and linked to the management's objectives. The utility of the MPIs are tested and validated within the framework of a multi-criteria and hierarchical MPM framework developed.

6.2.1 Methodology/Approach

This study is limited to the conveyor belts of balling area and is undertaken in two phases, namely; Understanding the organizational structure and the process, and analysis of data and MPIs.

Phase I: Understanding the organizational structure and the process:

(a) To study and understand the organizational structure and its goal and strategy, and the maintenance organization, its policy and strategy
(b) Interviews are conducted of the key personnel at the shop floor, planning and managerial level with the help of interview guide to understand the operation and maintenance process in detail; and to carryout a process mapping; integrating the process, production, maintenance and automation activities.
(c) The study of the work processes consisted of; maintenance, inspection, maintenance planning and work order system, maintenance task implementation and reporting, analysis of maintenance task and feedback
(d) To understand, if the employees' aware of the PM system and why they are measuring maintenance

Phase II: Analysis of data and MPIs

(a) Collection, classification and analysis of stop data of balling area and related maintenance task undertaken
(b) The total maintenance effectiveness of the process is studied both from internal and external stakeholders' point of view to understand the requirement and identify the MPIs.
(c) The plant stop data of the balling area are analysed for MPIs like the availability, production rate, maintenance cost per ton and quality amongst others, as well as for maintenance decision making.

6.2.2 Performance of the study

The study is performed in two phases, discussed as follows.

Phase I: Understanding the organizational structure and maintenance process:

The organizational structure and maintenance process were studied in detail while going through various briefing, documents, explanation and discussions. The maintenance department is functioning in a planned and structured manner in accordance with production and maintenance stop schedules. In order to understand the maintenance process, a process mapping of the production system of the pelletization plant with special reference to balling area was undertaken. For details see paper 3 of the appended paper to this thesis..

The pelletization plant is consists of mainly three systems as shown in Figure 6.1:

- Dewatering
- Balling area
- Grating/hot area

For our study purpose, we are confined to the balling area.

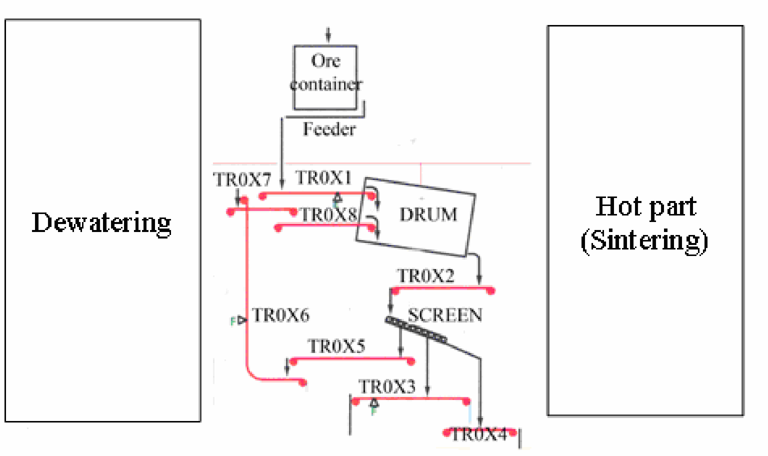

Figure 6.1 Process diagram of a balling area

(b) Combined responsibilities of maintenance. The production division is primarily responsible for the operation of the plant and for performing operator's routine cleaning and maintenance. The production department takes an active role in performing the daily checking and initiating failure reports as failure occurs or likely to occur. To maintain a high availability of the balling circuit for production, the maintenance department is responsible for planning and execution of the maintenance activities. This is primarily done during planned stops. Simultaneously, the process engineer and the automation engineer also share the responsibility for maintaining the working condition of the system in order to achieve the desired production level. Besides, there are some external actors are involved in condition monitoring; and in maintaining the conveyor belts, and the rollers for the conveyor belts.

(c) Maintenance process. Attempts are made to link the existing maintenance strategy with the organizational vision, strategy and objectives, based on what the production targets are set and on how the maintenance schedule and planning are formulated. The maintenance schedule followed is as shown below:

- Planned stops: Long stops like yearly/half yearly, and weekly stops
- Deferred maintenance (UU)
- Emergency maintenance (AU)
- Maintenance system recording (data collection)
- Active involvement of operators in level one inspection (TK1)

The maintenance work process is given in Figure 6.2. For detail s see paper 3 of the appended paper.

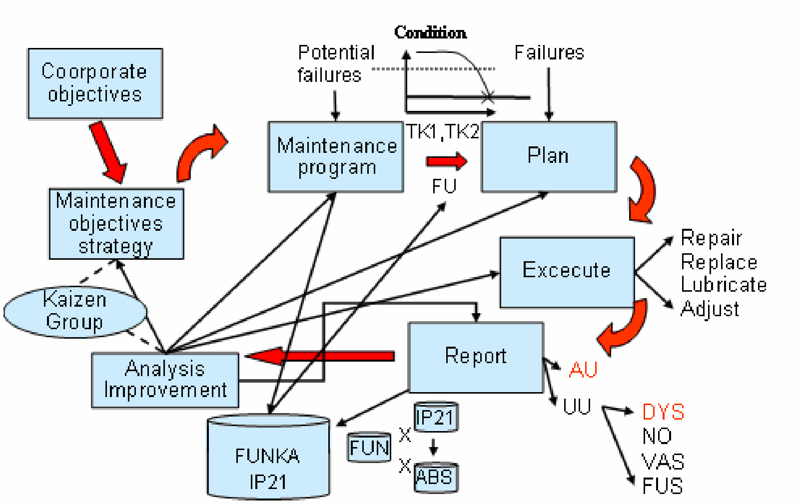

Figure 6.2. A schematic figure of the Maintenance work process. AU: Emergency maintenance; UU: Deferred maintenance; FU: Predetermined maintenance; TK: Preventive maintenance, DYS: one day stop, NO: Normal, VAS: weekly stop, FUNKA/ IP21/FUN/ABS: different computerised systems in use

The linkage between the maintenance priority and types are as given in the Table 6.1. Due to large number of priorities, personnel at shop floor level find it difficult to follow. After having these inputs, the maintenance work can be planned to be done immediately or may be deferred to be done during next daily/weekly stop or main maintenance stop depending on the urgency/priority of the maintenance tasks. Accordingly, the work orders are prepared and maintenance planning is worked out for provisioning of required manpower, material, tools and external assistance, if any. The maintenance plan is then implemented as scheduled, after which the inspection/checks are carried out to ascertain the correctness of functional efficiency of the components or the sub-system. All these activities are documented in to the operational

/maintenance software system. The data so collected are analyzed and validated for any further operational improvements and to achieve the production targets.

Table 6.1. Type and priority

Types	Priority
Emergency	AU/BR
Immediate	AU/AK
Normal	NO/UU(FUs/Vas/DYs)
Deffered	FU/TK

(d) Maintenance reporting. Reporting plays an important role in the maintenance process. In reporting the activities are:

- When the work order is initiated (time)
- When the work order is finished (time)
- Which system is maintaining the information (data)
- What is cost of maintenance (cost)
- Spare parts (cost)

In LKAB, there exist two different computerised systems; maintenance system and failure reporting system (operation system), that up-keep information about maintenance activities. Unfortunately, these two systems have no link and lack compatibility, causing loss of appropriate information and time to retrieve information. For example; while maintenance system provides information of work order initiation, the finished time is indicated by the other system. This problem has been reported to the management and a more versatile and single computerised maintenance management system is under consideration for change.

(e) Analyzing. Analyzing is an important aspect of data/information system, as without data analysis, the information is useless as it cannot be used for the decision making. Though a proper data analysis system does not exist to analyze for decision making, there is a system:

(i) Weekly meeting, amongst, production, maintenance, process and automation are held to discuss the operational bottlenecks and problems, so as to take corrective action.

(ii) Improvement group's meeting; amongst, production, maintenance, process and automation to discuss various maintenance/operational issues and take on spot decision/recommendation to management as required for improvement of the system/plant

Phase II. Data collection, classification and analysis of the shorter stops for MPIs

Maintenance related data is collected through the maintenance reporting system at the plant. In reporting, the important activities are; when the work order is initiated (time), when the work order is finished (time), which system is maintaining the information (data), what is cost of maintenance, and spare parts cost. Two different information systems are in use for recording data of maintenance activities.

1. Maintenance system
2. Failure report system (operation system)

The relevant data are collected from both these systems, and, combined or segregated to analyse the data to check the number of failures, stop times, reasons for failures, availability, speed and quality and to validate these MPIs with the organizational goal and strategy. For details of these analyses see paper 3 appended.

(i) Number of failures and stop time for conveyor belts. The data for the number of stops and stop time are collected and analyzed. It is obvious that the number of stops and stop time will be higher than these values during 2005. Although there has been improvements made of the conveyer belts, they do not seem to affect the statistics to any higher extent. It must also be said that the stop time is waiting time and not actual repair time. Number of stops and stop time are indications of good monitoring and control measures at the operational and tactical level of the MPM framework. The stop time in hours for each conveyor belt of the balling circuits, provided a clear picture of the faulty conveyor belts, which need immediate management attention. After taking corrective measures like; replacing gear boxes, conveyor belts and rollers, during planned maintenance stops of April and October, the number of failures reduced almost to the desired level.

(ii) Availability. Maintenance department has the responsibility for achieving the stated availability of 90 % for the system and this can be followed in failure report system. Measuring the availability in a system where at least four units should work is not easy. The availability state of the balling circuits provides the desired information to the managers at tactical level for achieving the targeted production figure. If the availability figure is down the desired level, the manager at the tactical level has to look in to the problems and the issues; and find a quick solution.

(iii) Performance speed. The output from the balling area is very much dependant on the screen. A new routine is established in April 2005 for checking the screen at every 2 000 h and it is proved that the production speed has increased since the planned maintenance stop in April. The adjustment was initiated by the process engineers and is seen as an improvement activity. It is important to upkeep the maintenance standard and maintenance department is responsible for keeping the screen in such a good condition that this is possible. In this work, more ore paste is put into the process (increase of speed) and fewer oversized pellets are rejected (quality is increased). During the last quarter 2005, it is seen that the production speed has decreased and it is a sign that the standard is not kept.

(iv) Quality. In LKAB quality is checked as properties of the product and is nearly equal to the acceptable selling standard of the customer. These qualities are quantified in the parameters like; iron content, silica content, pellet size and strength of pellets formed. All these parameters are regularly and strictly measured, tested and generally found to be under control. The number of short stops affects the quality, due to:

- More number of start and stops of the balling drums affects the conveyor belt and drum speed resulting in in-consistent pellets quality.
- The number of stops also affects the uniformity of speed of pellets' production, leading to overheating of pellets especially when the flow rate of pellets is low.
- Also, more number of start and stops of the balling drums affects the starting of motors and gear box and other related sub-systems due to more torques during starting and damaging other systems, thus affecting on their life lengths, and more stops and more quality problems.

6.2.3 Linking MPM system with organizations objectives and strategies

MPM system needs to be aligned to organizational strategy. The total effectiveness based on organizational effectiveness concept includes both the external and internal effectiveness of the organization. The external effectiveness is highlighted by stakeholders' need, like return on investment and customer satisfaction, which is the front end process. The internal effectiveness is high lighted through the desired organizational performance reflected by availability, performance speed and quality of product or services rendered and the back processes like the availability of spare parts, supply chain management, and optimized resources like workforce excellence including knowledge upgrading and innovations. The internal effectiveness process is also called as back end process of the organization.

Different figures or targets set by top management are permeated down the levels of the organization up to the shop floor. For example, to achieve a set target of production, if the requirement is to achieve an OEE level of 75 % at strategic level, the requirements at tactical or middle level are; availability of 90 %, production of speed of 500 ton/hour and a quality level of 99 %. When these are translated to the shop floor level, the maintenance indicators are to keep the number of maintenance stop at 0.8 per belt per month or the stop time to remain below 1.2 hour per belt per month. The shop floor engineers and managers at middle level have to intervene and take preventive decision, once these limits are crossed. Similarly, when these indicators are aggregated upwards, it will lead to the aggregated target set by the top management. The maintenance indicators are specific and objective at the shop floor level and their objectivity converts to subjectivity as the aggregation level reaches upward at the top management level.

6.2.4 MPIs identified and linkage with strategy and stakeholders value

The existing MPIs identified are; availability and performance speed in percentage, number of stops, accidents, environmental complaints and quality complaint. However, these MPIs are not analyzed frequently as they should be and do not reflect the effective utilization of work force and organizational performance, to an extent.

The new set of MPIs suggested under the seven criteria of the MPM framework is analyzed and checked qualitatively and quantitatively for the balling area of the pelletization plant under study at LKAB. The MPIs are:

(i) Downtime (hours)

(ii) Change over time
(iii) Planned maintenance tasks
(iv) Unplanned tasks
(v) Number of new ideas generated
(vi) Skill and improvement training
(vii) Quality returned
(viii) Employee complaints
(ix) Maintenance cost per ton

In addition, MPIs identified for the multi-criteria hierarchical MPM framework, which are in existence and in use at LKAB, are; OEE, production cost per ton, planned maintenance tasks, quality complaints number, and number of incidents/accidents, HSE complaints, and impact of quality. The MPIs target set, for availability of the pelletization plant is 91 %, production speed of 592.4 ton per hour and quality of 90 %, number of failure of one failure per belt per month, downtime of one hour per month per belt and 12 hours training per quarter. The key result area (KRA) identified are; conveyor belt failure, operator's maintenance task, skill improvement, and failure analysis. The relevant MPIs in use and as identified for use map and confirm the MPIs developed for the multi-criteria hierarchical MPM framework of this thesis work.

6.3 Case study II at Vattenfall Services AB

The second case study is undertaken at Vattenfall Services AB, one of the largest Swedish power generating and distributing company of Europe, during 2005. In this case study, it is intended to suggest an MPM framework through aggregating the relevant MPIs for the strategic or top management level of Vattenfall Service AB that are likely to reflect and measure the effectiveness and efficiency of the distribution channel for supply, repair and maintenance services. Such MPIs intend to reflect Vattenfall Service AB's maintenance performance management as required by stakeholders' with relation to strategic resources, operational capabilities and desired financial outcomes. The MPIs are intended to confirm with the maintenance strategy, the types of maintenance performance necessary to achieve the strategy and financial outcomes. Thus, the MPIs are likely to reflect the performance measurement as required by Vattenfall Services AB for its different stakeholders including the customers and the distribution companies.

The corporate structure of the Vattenfall Service AB, which is wholly owned by the Swedish state, is studied in detail. It is a well spread and complex organization with a 100 years long history of power generation and distribution, having customers in Sweden, Finland, Germany, Poland and Denmark. The net sales of Vattenfall for 2004 are EUR 12,586 million and SEK 129,158 million in 2005 with a full-time work force over 32,000 persons. In Sweden, Vattenfall has about 100 hydropower plants, providing 33 Terawatt-hour (TWh) a year in Sweden and Finland. Vattenfall is active at all stages of the electricity value chain- generation, transmission, distribution, and sales. Vattenfall is also active in electricity trading and generates, distributes and sells heat.

6.3.1 Case study objective

The objective of this case study is to analyze and identify the present status of MPIs and to suggest the MPIs for the strategic level of the organization and finally to evaluate them for the multi-criteria hierarchical MPM framework

6.3.2 Approach and Methodology

Interactive approach is adopted for this case study. The study is limited to the strategic level (top level) of the organization only. The methodology of the case study is as under:

(i) Vattenfalls' annual report for 2004 and 2005, corporate social responsibility report 2004 and other published web materials are studied. Besides, other study report, contract documents for stakeholders like the industrial customers and distribution company, and maintenance business initiatives (MBI) proposals of Vattenfall AB, are studied and discussed.

(ii) The status and requirements of maintenance strategy, process and practices with in the organization are studied and evaluated to understand and identify the MPIs and MPM requirements, besides the internal competence, capability, and capacity with respect to the stakeholders' requirements.

(iii) The maintenance needs from holistic approach under different hierarchical levels and multi criteria matching with the internal and external needs for PM operation/distribution and maintenance work process are studied.

(iv) Interviews and in-depth discussions on the relevant issues of this study are carried out with selected and concerned personnel from the two companies namely; Vattenfall Services South (VSS) and Vattenfall Services North (VSN**).**

6.3.3 Corporate and Stakeholders requirements of Vattenfall Service AB

The vision, mission statement, stakeholders, stakeholders' expectation and Vattenfall's five strategic ambitions, and three strong driving forces as mentioned in the management's annual and social responsibility report are:

> *Vision.* To be a leading European Energy Company.
>
> *Mission statement*. We create caring solutions for our customers and the environment.

Critical importance (Critical success factor). Customer satisfaction, responsible handling of environmental issues and contributing to economic development, besides, market share and sustainable solutions.

Three strong driving forces. First is, environmental impact**-** principally the green house effect, the second is the primary energy supply, and the third is technological development. These three driving forces, with open markets and effective market mechanism are providing effective solutions for sustainable development.

Vattenfall's main stakeholder groups

(a) *Society.* Neighbours, citizens, potential employees, media, politicians, authorities and non-governmental organization
(b) *Customers.* Prospective and existing business and private customers
(c) *Internal.* Employees, employee representatives and managers
(d) *Financial.* The Swedish state (owner) and other capital provider

Stakeholders' expectation. The stakeholders' expectations have been divided into three main areas: *Environmental performance, Social performance, and economical performance*. It is accepted that the demarcations among the three areas are somewhat ambiguous.

Vattenfall's five strategic ambitions:

(a) To continue the profitable growth.
(b) To become the benchmark for the industry
(c) To become number one for the customer
(d) To become number one for the environment
(e) To be the employer of the choice

The vision statement, objectives and strategies of Vattenfall AB are based on sound logic and business perspectives. However, while discussing with different personnel from both the business units belonging to Vattenfall Services AB, it is found that, each company and their departments are having their own vision, strategy, objectives and MPIs, which are not integrated with that of Vattenfall Services AB. The communication and information flow are found to be non-transparent. Subsequently, it is found that, Vattenfall Service AB is aware of the non-integration of the MPIs and non-transparent communication across various business units, departments and stakeholders of the organization, for which they have initiated the maintenance business initiatives (MBI) study and the study undertaken by Luleå University of Technology (LTU).

6.3.4 Linking strategy with MPIs and the MPM framework

An organization's strategy describes how it intends to create value for its shareholders, customers and citizens (Kaplan and Norton, 2004). According to Neely *et al*. (2002), an organization's strategy is described in accordance with its stakeholders' requirements. A step by step evolution of MPM and MPIs from the mission, values, vision and strategy is shown in Figure 6.3. The example for organizational mission from maintenance point of view is caring solutions to customer and environment. The vision is, the maintenance personnel are not visible, as the assets are functioning without any problem. The maintenance strategy is based on preventive and opportunity based maintenance and the multi-criteria hierarchical MPM framework is based on seven criteria as shown in the Figure 6.3. The expected strategic outcomes are high reliability and availability, High capacity utilization, stakeholders' satisfaction, excellent HSE record

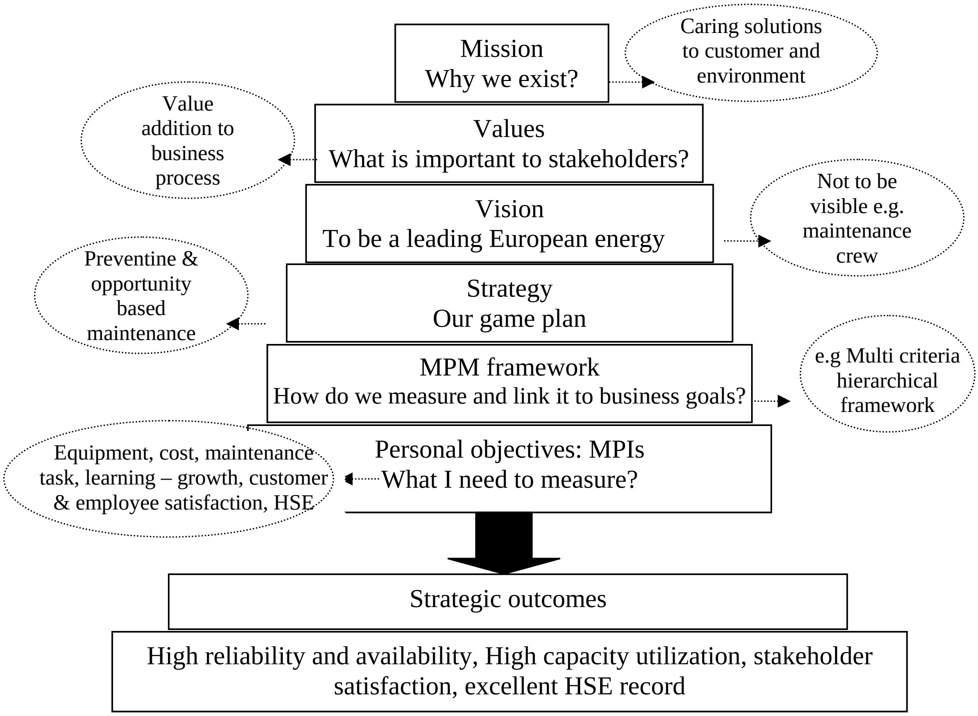

Figure 6.3 Step by step creation of MPM and MPIs from strategy, adapted from Kaplan and Norton (2004).

According to Vattenfall AB's policy, they plan to create long-term stakeholder values through the different stakeholders' group, like; Society, Customers, Internal stakeholders and financial. This is shown in Figure 6.4.

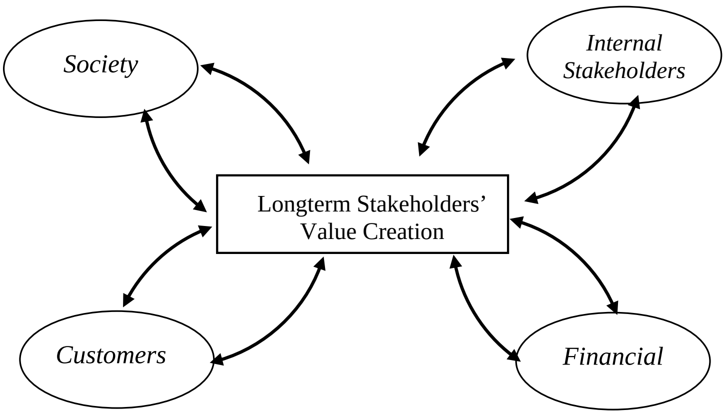

Figure 6.4 Stakeholders value creation, as per Vattenfall's policy

6.3.6 Conduct of interview and analysis of summary of interview

As part of interactive approach, it is planned to interview and have discussions with the selected key and responsible personnel of VSS and VSN with a view to gaining an in-depth understanding of the organization's stakeholders' needs, maintenance process and the existing MPM system. An interview guide was prepared and validated with the key personnel. The personnel interviewed and discussed are, the two managing directors of the companies, one business development director, and a head of each departments of the two companies of Vattenfall Services AB. There after, interviews and discussions are conducted at the strategic/corporate and tactical/managerial level of both the companies with the help of the "Interview guide", which is given at appendix "A". The summary of the interviews is given at appendix "B". The findings from discussions and interviews are as under:

(a) Vision. Each business unit/departments has its own goal, which they mixed up with the vision and it is not linked to that of the Vattenfall Services AB. The vision statement is stated differently by different senior personnel and it shows that the vision statement has not cascaded down the organization of Vattenfall Services AB. This link needs to be established as a first step, so that all personnel are aware of the vision and mission.

(b) Strategy. It seems, each business unit/departments have their own strategy, which they mix up with that of Vattenfall Services AB. The strategy is stated differently by different senior personnel and it has not cascaded down the organization. In fact, all senior personnel of any organization need to be aware of the Strategy of their organization.

(c) Objectives. The answers received on the objectives are neither specified nor clear. They should be specified and linked to all subunits. The objectives are stated differently by different senior personnel and the objectives of the business unit/department are perceived as that of the organization. The objectives and the strategy based on the stakeholders' requirements are critical issues to be linked with MPIs and MPM system and employees of an organization need to be aware of these.

(d) Currently used MPIs. Some lists of MPIs were stated during interviews. They are neither consistent nor standardized for Vattenfall Service AB and may belong to individual business unit/departments. For example, the Process department of Vattenfall services south are using most of the MPIs as identified in this thesis's MPM framework successfully, while other departments have stated differently. The lists of MPIs have to be segregated for different hierarchical levels and some new ones are to be added according to Vattenfall Services AB's requirements (Like; safety, training on skill, training and environment).

(e) Additional MPIs. The list provided and as suggested, gives the indications that additional MPIs need to be included. However, most of the suggested MPIs by the interviewees are neither relevant nor consistent with the organizational objectives and strategy.

(f) Stakeholders. The list of stakeholders is clearly specified in the web-site and reports of the organization. However, this has failed to reach most of the employee. This indicates the need for training and communication system to enhance the awareness of organizational information to the employees.

(g) Considering stakeholders' requirements. The interviewees feel that stakeholders' requirements need not to be considered. The answers are based on individual perception and Vattenfall Service AB's MPIs are not clear to them. Hence, a linking of MPIs with stake holder's requirement is essential, and then only a transparency of purpose will be known to all employees.

(h) North and South MPIs difference. General statements are satisfactory (no one admits of any major differences and the difference that exists depends on the different customer categories). But, MPIs have to permeate down the organization and differ according to functional requirements.

(i) Maintenance performance measurement. Not very clear (except for what is regulated in the agreement with Vattenfall AB), though some of the participants like VSS-Process have very specific and implementable MPIs. Similar MPIs are required for other business units/departments to complement that of Vattenfall Service AB.

(j) Integration of MPIs. From the answers and the discussion, it is visualised that MPIs are not integrated across the whole organization, which are a must for the organization.

(k) Monitoring failure report. Monitoring of the failure report at lower level is reasonably satisfactory, but there is no upward compilation of report for the organization and there is thus lack of a desirable data base for future use.

(l) Type and level of inspection. It appears that there are too many inspections at functional level, which needs to be rationalised and only the minimum essential number of inspections be retained in the system. The operation control centres are working 24 hours all over Sweden.

(m) External agency. Outsourcing of tasks to outside agencies is made mainly for digging work only, other works are done with in the organization.

(n) Computerised Maintenance Management system (*CMMS) in use.* A standardized CMMS needs to be implemented for the effective and efficient monitoring, control and reporting system. (SAP is there, but not in use). It is evident from the interview and discussion that no centralised CMMS system for the entire organization is not in place and this is very essential considering the present and future need.

(o) Data analysis and evaluation. This seems to be a grey area, as it is linked with the CMMS and control and monitoring of the MPIs and the MPM system of the organization besides the decision making.

(p) Feedback and improvement system. It is there, but not very effective. The feedback of performance measurement is important as a first step for improvement. This system needs to be organized.

(q) Quality improvement and suggestions. Some award system is there, but has failed to catch the imagination of the employees. A transparent, structured and organization oriented quality improvement and suggestions system is essential for supporting genuine innovativeness and motivating the employees for the system

(r) Using PIs (MPIs) at different levels. The interviewees are not very sure of using the MPIs at different hierarchical levels of the organization. Considering the multi-criteria hierarchical MPM framework, it is essential that MPIs be specified for different hierarchical levels of the organization.

(s) Aggregating PIs. All respondents felt that PIs are needed to be aggregated from the functional level upwards, so that they become the desires KPIs/MPIs at the higher level and are linked with the organizational objectives and strategy.

(t) Criteria for performance measurement. Some suggestions are received from the respondents. However, training needs to be imparted in this area for creating awareness amongst all level of employees.

6.3.7 Suggested MPIs

After analyzing the summary of the interviews, organizational requirements from the stakeholders' point of view and comparing the MPIs from the multi-criteria hierarchical MPM framework, some of the MPIs are recommended. These, recommended MPIs are again discussed with the key personnel of the organization for its validity and acceptability. As mentioned earlier, most of the MPIs suggested in the multi-criteria hierarchical MPM framework are in use by the Process department of the VSS and this fact is accepted by the key personnel during the study presentation. The suggested MPIs for the strategic or top level (level I) of Vattenfall are as under:

a) Customer satisfaction related. Customer satisfaction is one of the main stakeholder group's requirements for Vattenfall Service AB. Since, Vattenfall's customers are related to energy supply duration and interruptions, and the contract, the customer satisfaction related MPIs are taken from the IEEE standards 1366-2003 and they are as under:

1. SAIDI (System average interruption duration index). SAIDI is summation of customer interruption duration to total number of customer served
2. CAIDI (Customer average interruption duration index), CAIDI is summation of customer interruption duration to total number of customer interrupted
3. NKI (customer satisfaction index)

b) Cost related. Financial or cost is another main stakeholder group's requirements for Vattenfall Service AB. Since, the total maintenance cost has to be controlled and the profit margin has to follow the Swedish Government's directive, these two MPIs are suggested to be included to the list of MPIs.

4. Total maintenance cost
5. Profit margin

c) Plant/ process related. The plant or process related MPIs also forms important MPIs from internal stakeholder group. Downtime of power generation and distribution, as well as the OEE rating of generation are the suggested MPIs from this group.

6. Downtime
7. OEE rating (overall equipment effectiveness=Availability x speed x quality)

d) *Maintenance task related.* The MPIs related to maintenance tasks are suggested as under.

8. Number of unplanned stop (number and time)
9. Number of emergency work
10. Inventory cost

e) Learning and growth/Innovation related. The MPIs related to learning and growths, which are important for knowledge based organization, are:

11. Number of new ideas generated
12. Skill and improvement training

f) Health, safety and environment related. These are society related MPIs and very relevant to Vattenfall Service AB.

13. Number of accidents
14. Number of HSE complaints

g) 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.

15. Employee satisfaction level

6.3.8 Conclusion

Due to organizational time constraints, this case study identified the MPIs for the corporate/strategic level, and most of the identified MPIs are accepted by the management of the Vattenfall Service AB. The multi-criteria hierarchical framework suggested by this thesis work with the identified MPIs is acceptable to the organization for implementation. Further, it is interesting to note that most of the MPIs identified for the general MPM framework in this thesis are in use at the Process Department of the Vattenfall Services South. Both these case studies of LKAB and Vattenfall Services AB confirm the identified MPIs of the developed multi-criteria hierarchical MPM framework under two distinct industrial sectors.

7 Discussions, Contributions, Limitations and Suggestions for future research

In this concluding chapter, discussions on MPIs and MPM framework, research objectives, questions, contribution of this research work; limitation and suggestions for future research are presented.

7.1 Discussions on the MPIs and MPM framework

The scope of this research and thesis outline is discussed in Chapter 1. Chapter 2 incorporates a literature study, intended to establish a theoretical frame of reference of the research in the area of MPM and its related topics. Since, a clear definition and specific explanation of the terminology like; measures, performance metrics, PI, PM, performance management, MPI and MPM, are not found; these terms concepts and their definitions and standards are discussed in this chapter. The need and evolution of various factors and aspects of PM and PM frameworks starting from early 20th century till now are discussed and are analyzed for their strengths and weaknesses. Most of the PM frameworks with their PIs and references are tabulated in this chapter. Similarly, various issues, needs and aspects of MPIs and MPM, including the ICT and e-maintenance concept, are discussed in this chapter in a comprehensive manner. The MPIs used by nuclear, oil and gas, and railway industries, and, MPI standards as developed by EFNMS and SMRP are studied and discussed.

In chapter 3, the research approach and methodology is discussed, in which the methodological choices are included. The method of data collection, analysis, validity and reliability are discussed briefly. In chapter 4, various issues and challenges associated with the pre-development, development, and implementation and feedback stages of an MPM system are examined and discussed. This chapter also looks into organizational related issues and challenges associated with the MPM system, including the integration of MPIs from shop floor or functional level to the strategic level i.e. the aggregation of objective MPIs from functional level. Similarly, the cascading down of strategic objectives and MPIs from strategic level to functional level through the tactical or managerial level, i.e. converting the subjective vision into objective goals; is also considered and discussed, besides forming a PM team for the organization from the pre-development stage. Some of the major challenges while developing and implementing MPIs are, namely involvement of employees who are going to collect data, analyze them and use right from the beginning and agreeing among all in the company about the meaning of downtime and failures. Without these there is only a remote chance that any measurement system will succeed in its goal.

Before formulation of the MPM framework in chapter 5, the related concept and approaches like the multi-criteria approach, Linkage of MPIs with corporate objectives and strategy, and multi-hierarchical levels of the organization are discussed for consideration. The MPIs under multi-criteria hierarchical MPM framework from total maintenance effectiveness are identified for implementation and presented in this chapter. The multi-criteria hierarchical MPM framework as developed is also explained and presented in this chapter.

Chapter 6 deals with two case studies where the MPIs and the multi-criteria hierarchical MPM framework are mapped with LKAB, a mineral processing company and Vattenfall AB, a multi-national energy utility company. In LKAB case study, mapping of MPIs at the shop floor or functional and at the tactical or managerial level are carried out through data collection, analysis and verification. In Vattenfall Services AB case study, the MPIs are identified and mapped with the multi-criteria hierarchical MPM framework for the strategic or top management level. These comparisons and further discussions with the managers of these two organizations indicates that a multi-criteria hierarchical framework for maintenance performance measurement is useful in deciding maintenance policies, procedures and working instructions, which can monitor and control maintenance effectiveness across various plants and across the industry.

Information is key to maintenance effectiveness, as it will ensure smooth management of the maintenance performance. With emerging technologies like, ICT and e-Maintenance, it is possible to monitor and control the maintenance activities on real time through the MPIs. Paper 4 and 5 refers.

The MPM framework suggested considers and incorporates all the factors influencing the maintenance process and its linkage to corporate business goal. The MPM framework suggested is balanced as it considers both financial and non-financial perspectives and it facilitates integration of outcome from shop floor to corporate business goal. MPM framework is found to facilitate correct decision making in maintenance using identified MPIs. The developed MPM framework makes the gap between corporate objectives with the achieved results more visible.

The MPIs at LKAB are examined using the framework to see their utility in their operation with positive outcome. While studying the various MPIs in use in Companies, it is found that there is no consensus about the meaning of downtime within the same organization. Many employees at the shop floor level are not aware about the usefulness and purpose of indicators in use. MPM framework visualizes and facilitates understanding of total business goals in relation to their work and indicators generated by them.

7.2 Research Objectives

The first objective of this research is to “study the state-of-the-art of measuring performance of maintenance process”. In chapter two, a detailed literature survey on the past and existing MPM practices and concepts are examined and analyzed in detail. The literature review of the same with critical analysis is undertaken at paper 1.

The second objective of this research is to “define relevant concepts and discuss various issues and challenges useful for developing an MPM system”. The issues and challenges associated with MPIs and multi-criteria hierarchical MPM framework under pre-development, development, and implementation and feedback stages are discussed at chapter three of the thesis and in paper one.

The third objective is to "develop a multi-criteria hierarchical framework for maintenance performance measurement", and this is discussed and explained in chapter four, as well as paper two. For developing a multi-criteria hierarchical MPM framework, various steps required are discussed in this chapter, besides, the concept like multi-criteria, multi hierarchical level, linkage of MPIs with corporate objectives and strategy and with the MPM framework.

The fourth objective "to study and analyse current practice of industrial organizations and compare against the framework developed in this research"is examined at chapter six. In this chapter, two case studies are discussed, where the MPIs and the multi-criteria hierarchical MPM framework is compared with LKAB, a Swedish mineral processing company and Vattenfall AB, a multi-national energy utility company. In the LKAB case study, MPIs are studied and verified at the shop floor/functional level. In Vattenfall AB case study, the MPIs are identified and presented after discussion for the strategic/top management level.

7.3 Research Questions

The "RQ1. What factors do have major influence on performance of maintenance process? is discussed in at chapter four. In the appended paper 1 and two, besides related issues and challenges, a background and overview of MPM is also examined. Issues like involvement of all employees and meaning of downtime, mapping of maintenance processes and MPI's need and characteristics are taken up for discussion in paper 1, besides the concept of total maintenance effectiveness.

The RQ2 of "What are the issues and challenges associated with the development of an MPM framework?" is discussed in detail at chapter four and paper 1. In this paper related issues and challenges are discussed under pre-development, development, implementation and feedback stages. The characteristics of MPIs are also given in chapter four of the thesis and in paper 1. All the aspects of stake holders requirements are considered for identifying the MPIs.

The RQ3 of "How to develop and implement the MPM framework?" are discussed at chapter five and six. In chapter five, the development of the MPM framework is discussed and explained. In chapter six, two case studies are discussed and the detailed implementation part is given in paper 3. Besides evaluation, requirements of monitoring, control and decision making at different hierarchical levels are also discussed. Application of ICT and implementation of e-Maintenance concept is suggested for effective and efficient implementation of MPM system (paper 4 and 5)

7.4 Contributions

This research has discussed and defined the various terms and concepts useful for maintenance performance measurements, indicators and metrics, and developed a multi-criteria hierarchical framework for maintenance performance measurement (MPM). The framework has considered stakeholders' need, business environment and relevant factors influencing the maintenance effectiveness of the organization. The current practices of two Swedish companies, one in the process industry and the other one in the utility (service) industry, have been studied in detail and compared against the framework developed in this research. Maintenance performance indicators for nuclear power, oil and gas, automotive industry, and railway industries from published literature have also been studied and included in the thesis. This framework can be used to monitor and control maintenance effectiveness across various plants and industries. Application of ICT and implementation of e-Maintenance concept is suggested for effective and efficient maintenance performance measurement.

The main contributions of this research are:

- Various factors influencing maintenance performance are analyzed and discussed (Chapter 2, chapter 4, paper 1, paper 2, and paper 4).
- Defined various terms useful for maintenance performance management (Chapter 2, paper 1, and paper 4).
- Identified issues and challenges associated with the maintenance performance measurement (Chapter 4, and paper 1, and paper 4).
- Identified Maintenance Performance Indicators (MPIs) considering seven important criteria (Chapter 5, chapter 6, and paper 3).
- Development of a multi-criteria hierarchical framework for maintenance performance measurement (MPM) applicable to a wide range of industries after specific modifications (Chapter 5, and paper 2).
- Concepts of total maintenance effectiveness, business-asset and process integrity index are discussed and explained (Chapter 5, and paper 1).
- Application of ICT and implementation of e-Maintenance is suggested to facilitate effective maintenance performance (Paper 4, and paper5).

7.5 Limitations

Multi-disciplinay, issues like; human resource, organizational and cultural, and logistics are not included in this research work. Due to organizational constraints, such as accidents and quality failure data suppression or non-documentation, maintenance activity given a low priority, the data or information obtained from the organization is likely to be incomplete and inconsistent. In case of LKAB, the case study is limited to the shop floor level, while, in case of Vattenfall Services AB, it is limited to strategic level only. Hence together these case studies cover all the three levels of an organization.

7.6 Suggestions for future research

This thesis is limited to a few studies and each of them is delimited in some respect. Therefore, several relevant research topics, which can be the scope for future research as visualised after this thesis work are:

- The MPM framework needs to satisfy the specific industry's need for 'adopting appropriate MPM framework specific to that industry'.
- The related MPIs of the multi-criteria hierarchical MPM model needed to be developed to answer 'What are determinants of specific business performance'?
- Develop complex MPM models linking organizational culture, human factors, motivation and MPM related financial decision making needs.
- Need to explore if, and how, the relationship between different dimensions of business performance can be mapped and to solve the taxing issue of how predictive performance measures or leading indicators can be developed.
- How MPM systems could be developed and managed in a sustainable way.
- Effectiveness of MPM based on various country and cultural settings.

References

Abran, A. and Buglione, L. (2003). A multidimensional performance model for consolidating Balanced Scorecards, *Advances in Engineering Software*, Vol. 34, pp. 339-349.

Active strategy (2006). Downloaded from *Scorecard business review*, www.activestrategy.com dated 2006-07-31.

Ahlmann, H. (2002). From traditional practice to the new understanding: The significance of life cycle profit concept in the management of industrial enterprises, Proceedings of the *International Foundation for Research in Maintenance, Maintenance Management & Modelling*, 6-7 May, Växjö, Sweden.

Al-Sultan, K. S. and Duffuaa, S.O. (1995). Maintenance control via mathematical programming, *Journal of Quality in Maintenance Engineering*, Vol. 1, No. 3, pp. 36-46.

Altmannshoffer, R. (2006). Industrielles FM, *Der Facility Manager* (In German), April Issue, pp. 12-13.

Al-Turki, U. and Duffuaa, S. O. (2003). Performance measures for academic departments, *International Journal of Educational Management*, Vol. 17, No. 7, pp. 330-338.

Alvesson, M. and Sköldberg, K. (1994). *Interpretation and reflection: philosophy of science and qualitative method* (In Swedish), Lund, Studentlitteratur.

Amaratunga, D. and Baldry, D. (2002). Moving from performance measurement to performance management, *Facilities*, Vol. 20, No. 5/6, pp. 217-223.

Andersen, B. and Fagerhaug, T. (2002). *Performance Measurement Explained*, ASQ Quality Press, Milwaukee, Wisconsin.

Antti, L. (2004). *Business Performance Measurement for Knowledge-Intensive Organizations*, http://www.pmteam.tut.fi/julkaisut/HK.pdf, visited on 2004 Aug 22.

Arts, R.H.P.M., Knapp, G.M. and Mann Jr, L. (1998). Some aspects of measuring maintenance performance in the process industry, *Journal of Quality in Maintenance Engineering*, Vol. 4, No. 1, pp. 6-11.

Ashton, C. (1997). *Strategic Performance Measurement: Transforming Corporate Performance by Measuring and Managing the Drivers of Business Success*, Business Intelligence Ltd, Wimbledon.

Atkinson, A. A., Waterhouse, J. H. and Wells, R. B. (1997). A stakeholders approach to strategic performance measurement, *Sloan Management Review*, Vol. 38 No. 3, pp. 25-37.

Augusto, M., Figueira, J. and Lisboa, J. (2005). An application of a multi-criteria approach to assessing the performance of Portugal's economic sectors, *European Business Review*, Vol. 17. No. 2, pp. 113-132.

Azzone, G., Masella, C. and Bertele, U. (1991), Design of performance measures for time-based companies, *International Journal of Operation & Production Management,* Vol.11, No. 3, pp. 77-85.

Åhren, T. and Kumar, U. (2004). Use of maintenance performance indicators: a case study at Banverket. *Conference proceeding of the 5th Asia-Pacific Industrial Engineering and Management Systems Conference* (APIEMS2004), Gold Coast, Australia.

Banks, R.L. and Wheelwright, S.C. (1979). Operations versus strategy- reading tomorrow for today, *Harvard Business Review,* pp. 112-120.

Beischel, M.E. and Smith, R. (1991). Linking the shop floor to the top floor, *Management Accounting,* Vol. 83, pp. 25-29.

Bititci, U. (1994). Measuring your way to profit, *Management Decision,* Vol. 32, No. 6.

Bititci, U.S., Carrie, A.S. and McDevitt, L. (1997). Integrated performance measurement systems: a development guide, *International Journal of Operation & Production Management,* Vol. 17, No. 5, pp. 522-34.

Bititci, U.S., Turner, T. and Begemann, C. (2000). Dynamics of performance measurement systems, *International Journal of Operations and Production Management*, Vol. 20, pp. 692-704.

Blair, M. B. (1995). *Ownership and Control: Rethinking Corporate Governance for the Twenty-first Century,* Washington, D.C., Brookings Institute.

Blanchard, B. S. and Fabrycky, W. J. (1998). *Systems Engineering and Analysis,* 3rd Edition, Prentice Hall, New Jersey, USA.

Bream, R. (2006), Lawsuit poses further risk to BP's image, *Financial Times,* Friday, June 30

Brown, M. (1996). *Keeping score: using the right metrics to drive world class performance*, Quality Resources, New York, NY.

Bruns, W. (1998). Profit as a Performance Measure: Powerful Concept, Insufficient Measure, Performance Measurement – Theory and Practice: *the first International Conference on Performance Measurement,* Cambridge, 14-17 July.

Bourne, M. and Neely, A. (2003). Performance measurement system interventions: the impact of parent company initiatives on success and failure, ICFAI *Journal of Operation and Management,* www.som.cranfield.ac.uk.

Bourne, M., Keenerly, M. and Franco-Santos, M. (2005). Managing through measures: a study of impact on performance, *Journal of Manufacturing Technology Management*, Vol. 16, No. 4, pp. 373-395.

Camp, R.C. (1989). *Benchmarking-the Search for Industry Best Practices that Lead to Superior Performance,* ASQS Quality Press, Milwaukee, WI.

Campbell, J.D. (1995). *Uptime: Strategies for Excellence in Maintenance Management*, Productivity Press, Portland, US.

Campbell, J. D. and Jardine, A. K. S. (2001). Maintenance Excellence: Optimizing Equipment Life-Cycle Decisions. Mercer Dekker, New York.

Case, J. (1998). Using Measurement to Boost Your Unit's Performance. *Harvard Management Update*, Vol. 3, pp. 1-4.

Chandler, A.D. (1977). The Visible Hand–Managerial Revolution in American Business, Harvard University Press, Boston, MA, pp. 417.

Coetzee, J.L. (1998). *Maintenance*, Maintenance Publishers, Republic of South Africa.

Cordero, R. (1989). The measurement of innovation performance in the firm: an overview, Reasearch Policy, Vol. 19, pp. 185-192.

Cross, M. (1988). Raising the value of maintenance in the corporate environment, *Management Research News*, Vol. 11, No. 3, pp. 8-11.

Czarniawska, B. (1999). *Writing Management: Organization Theory as a Literary Genre*. Oxford University Press, Oxford.

Dekker, R. (1996). Applications of maintenance optimization models: a review and analysis, *Reliability Engineering and System Safety*, Vol. 51, pp. 229-40.

Denzin, N. K. and Lincoln, Y. S. (2000). *Handbook of Qualitative Research*, Second Edition, Sage Publications, Thousand Oaks, California.

De Waal, A. A. (2003). The future of the Balanced Scorecard: an interview with Professor Dr Robert S. Kaplan, *Measuring Business Excellence*, Vol. 7, No. 1, pp.30-35.

Dixon, J.R., Nanni, A. J and Vollmann, T. E. (1990). The *new performance challenge-Measuring Operations for World-class Competition*, Dow Jones-Irwin, Homewood, IL.

DOE-HDBK-1148-2002. (2002). *Work Smart Standard (WSS) Users' Handbook*, Department of Energy, USA, www.eh.doe.govt/tecgstds/standard/hdbk1148/hdbk11482002.pdf

Downing, L. (2001). The Global BSC community: a special report on implementation experience from scorecard users worldwide, *European Summit on Balanced Scorecard*, Nice, May, 2001.

Dumond, E. J. (1994). Making best use of performance measures and information, *International Journal of Operation and Production Management*, Vol. 14, No. 9, pp. 16-31.

Dwight, R.A. (1995). *Concepts of measuring maintenance performance, New Developments in Maintenance*, More Ernst & Young Management Consultants, Netherlands, pp. 109-25.

Dwight, R.A. (1999). Searching for real maintenance performance measures, *Journal of Quality in Maintenance Engineering*, Vol. 5, No. 3, pp. 258-275.

Eccles, R.G. (1991). The performance measurement manifesto, *Harvard Business Review*, January-February, pp. 131-137.

Edvinsson, L. and Malone, M.S. (1997). *Intellectual Capital: Realizing your Company's True Value by Finding Its Hidden Brainpower*, Harper Business, New York.

EEA (European Environment Agency). (1999). Enviromental indicators: Typology and overview. *Technical Report No 25*, Copenhagen.

EFNMS. (2006). European Federation of National Maintenance Societies. www.efnms.org/efnms/publications/Firstworkoshopforfoodandpharmeceuticalbusiness.doc

Encyclopaedia Britannica. *Economic Indicator*. http://search.eb.com/ Dated 2004-05-20.

Engelkemeyer, S. and Voss, R. (2000). Bearing the gift of royal performance indicators, *Quality Progress*, Vol. 33, No. 2, pp. 35-39.

Feurer, R. and Chaharbaghi, K. (1995). Strategy formulation: a learning methodology, Benchmarking for Quality, *Management and Technology*, Vol. 2, No. 1, pp. 38-55.

Fitzgerald, L., Johnson, R., Brignall, S., Silvestro, R. and Voss, C. (1991). *Performance Measurement in Service Businesses*, CIMA, London.

Flapper, S., Fortuin, L. and Stoop, P. (1996). Towards consistent performance management systems, *International Journal of Operation & Production Management*, Vol. 16, No. 7, pp. 27-37.

Geanuracos, J. and Meiklejohn, I. (1993), *Performance measurement: the new agenda*, Business Intelligence, London.

Ghalayini, A. M. and Noble, J. S. (1996). The Changing basis of performance measurement, *International Journal of Operation & Production Management*, Vol. 16, No. 8, pp. 63-80.

Ghalayini, A., Noble, J. and Crowe, T. (1997). An integrated dynamic performance measurement system for improving manufacturing competitiveness, *International Journal of Production Economics*, Vol. 48, pp. 207-225.

Gomes, C. F., Yasin, M. M. And Lisboa, J. V. (2004). A literature review of manufacturing performance measures in an organizational context: a framework and direction for future research, *Journal of manufacturing Technology Management*, Vol. 15, No. 6, pp. 511-530.

Goldratt, E. M and Cox, J. (1986). *The Goal: Beating the Competition*, Creative Output Books, Hounslow, UK.

Hall, R. W. (1983). *Zero Inventories*, Dow-Jones Irwin, Homewood, IL.

Hayes, R. H and Abernathy, W. J. (1980). Managing our way to economic decline, *Harvard Business Review*, pp. 67-77.

Hayes, R. H. and Garvin, D. A. (1982). Managing as if tomorrow mattered, *Harvard Business Review*, pp. 70-79.

Holme, M. and Slovang, B. K. (1991). *Forskningmetodik: om kvalitativa och kvantitativa metoder*. Studentlitteratur, Lund.

IAEA. (2001). A Framework for the establishment of plant specific operational safety performance indicators, (report), *International Atomic Energy Agency*, Viena, Austria.

IEC 60300-3-14 *Dependability Management – Part 3: Application Guide – Section 14 Risk Analysis of Technological Systems*. Commission Electrtechnique Internationale, Geneva

IEV. 191-07-01 (International Electrotechnical Vocabulary). on line (2006-01-07). http://std.iec.ch/iev/iev.nsf

Ittner, C. D. and Larcker, D. F. (2003). Coming Up Short on Nonfinancial Performance Measurement, *Harvard Business Review*, Vol. 81, Issue. 11.

Johnson, H. T. and Kaplan, R. S. (1987). *Relevance Lost–The Rise and Fall of Management Accounting*, Harvard Business School Press, Boston, MA.

Kanji, G. K. (1998). Measurement of business excellence, *Total Quality Management*, Vol. 9, pp. 633-643.

Kanji, K. K. and Maura, E S. A, Patricia. (2002). Kanji's Business Scorecard, *Total Quality Management*, Vol. 13, No. 1, pp. 13-27.

Kaplan, R. S. (1983). Measuring manufacturing performance: a new challenge for managerial accounting research, Accounting *Review*, Vol.58. No. 4. pp. 686-703.

Kaplan, R. S (1984). Yesterday's accounting undermines production, *Harvard Business Review*, Vol. 62, pp. 95-101.

Kaplan, R. S. (1986). Accounting lag – the obsolescence of cost accounting systems, *California Management Review*, Vol. 28, No. 2, pp. 174-99.

Kaplan, R. S. and Norton, D. P. (1992). The balanced scorecard – measures that drive performance, *Harvard Business Review*, Vol. 70, pp. 71-79.

Kaplan, R. S and Norton, D. P (1996). *The Balanced Scorecard: Translating Strategy into Action*, Harvard Business School Press.

Kaplan, R. S. and Norton, D. P (2001). Transforming the balanced scorecard from performance measurement to strategic management Part I, "*Accounting Horizons*", Vol.15, Issue 1.

Kaplan, R. S. and Norton, D. P. (2004). *Strategy Map: Converting intangible asset into tangible outcomes*, Harvard Business School Press, USA.

Keegan, D. P., Eiler, R. G., and Jones, C. R. (1989). Are your performance obsolete? *Management Accounting* (US), Vol. 70, No. 12, pp. 45-50.

Kennerly, M. and Neely, A. (2002). Performance Measurement Frameworks: A Review. *Business Performance Measurement*. Cambridge University Press, Cambridge, pp. 145-156.

Kennerly, M. and Neely, A. (2003). Measuring performance in a changing business environment. *International Journal of Operation & Production Management*, Vol. 23 No. 2, pp. 213-229.

Kennerly, M., Neely, A., and Adams, C. (2003). Survival of the fittest: measuring performance in a changing business environment, *Measuring Business Excellence*, Vol. 7, No. 4, pp. 37-43.

Kumar, U. and Ellingsen, H. P. (2000). Development and implementation of maintenance performance indicators for the Norwegian oil and gas industry. *Proceedings of the 14th International Maintenance Congress (Euro maintenance 2000)*, 7-10 March, Gothenburg, Sweden, pp. 221-228.

Kutucuoglu, K. Y., Hamali, J., Irani, J. and Sharp, J. M. (2001). A framework for managing maintenance using performance measurement systems, *International Journal of Operation and Production Management*, Vol. 21, No. ½, pp. 173-194.

Laitinen, E. (1996). *Framework for small business performance measurement*, Vasa, Vaasan yliopisto (University of Vaasa).

Lingle, J. H. and Schiemann, W. A. (1996). From Balanced Scorecard to Strategy gauge: Is measurement worth it? *Management Review*, March Issue, pp. 56-62.

Liyanage, J. P. and Kumar, U. (2003). Towards a value-based view on operations and maintenance performance management, *Journal of Quality in Maintenance Engineering*, Vol. 9, pp. 333-350.

Lynch, R. L. and Cross, K. F. (1991). *Measure up! The Essential Guide to Measuring Business Performance*, Mandarin: London.

Marshall, C. and Rossman, G.B. (1999). *Designing Qualitative Research*. Sage Publications, Thousand Oaks, California.

Maskell, B. (1998). Performance measures for world class manufacturing, *Management Accounting*, May Issue, pp. 32-33.

Mather, D. (2005). An introduction to maintenance scorecard, *The plant maintenance News letter* edition 52, dated 13 April 2005.

Medori, D. (1998). *Integrated Performance measure framework*, Coventry University, Coventry.

Medori, D. and Steeple, D. (2000). A framework for auditing and enhancing performance measurement systems, *International Journal of Operation & Production Management*, Vol. 20, No. 5, pp. 520-533.

Merriam, S. B. (1988), *Case study research in education: a Qualitative Approach*. Jossey-Bass Publishers, San Francisco.

Meyer, M. W. and Gupta, V. (1994). The performance paradox, in Straw, B. M and Cummings, L. L (Eds), *Research in Organizational Behavior*, Vol. 16, JAI Press, Greenwich, CT, pp. 309-69.

Miles, M. B. and Huberman, A. M. (1994). *Qualitative Data Analysis*, Sage Publication, California, USA.

Mizuno, S. (1988). *Management for Quality Improvement: The Seven New QC Tools*, Productivity Press, Cambridge.

Molander, B. (1988). *Vetenskapsfilosofi: en bok om vetenskapen och den vetenskapande människan.* Second Edition. Thales, Stockholm. (In Swedish)

Murthy, D. N. P., Atrens, A. and Eccleston, J. A. (2002). Strategic maintenance management, *Journal of Quality in Maintenance Engineering*, Vol. 8, No. 4, pp. 287-305.

Najmi, M. and Kehoe, D. F. (2001). The role of performance measurement systems in promoting quality development beyond ISO 9000, *International Journal of Operation & Production Management,* Vol. 21, No ½, pp. 159-172.

Nakajima, S. (1988). *Introduction to TPM, Total Productive Maintenance*, Cambridge, MA: Productivity Press.

Neely, A. D., Gregory, M. and Platts, K. (1995). Performance Measurement System Design–A Literature Review and Research Agenda, *International Journal of Operations and Production Management*, Vol. 15, No. 4, pp. 80-116.

Neely, A. D., Richards, A. H., Mills, J. F., Platts, K. W. and Bourne, M. C. S. (1997). Designing performance measures: a structured approach, *International Journal of Operation & Production Management*, Vol. 17, N. 11, pp. 1131-53.

Neely, A. D. (1998). *Measuring Business Performance: Why, Why and How*, Economist Books, London.

Neely, A. D. (1999). The Performance Measurement Revolution: Why Now and What Next? *International Journal of Operations and Production Management*, 19, 2, pp. 205-228.

Neely, A. and Adams, C. (2000). Perspective on performance: the performance prism, downloaded from: *www.som.cranfield.ac.uk/som/cbp/prismarticle.pdf*, 2004-06-01.

Neely, A. (2002). *Business Performance Measurement, Theory and Practice*, Cambridge University Press, UK.

Neely, A. and Bourne, M. (2000). Why measurement initiative fail, *Measuring Business Excellence*, Vol.4.4, pp. 3-6.

Neely, A., Mills, J., Platts. K., Richards, H., Gregory, M., Bourne, M., and Kennerley, M. (2000). Performance measurement system design: developing and testing a process-based approach, *International Journal of Operations & Production Management*, Vol. 20, No. 10, pp- 1119-1145.

Neely, A., Adams, C. and Kennerely, M. (2002). *The Performance Prism, The scorecard for measuring and managing business success*, Prentice Hall, Financial Times, London.

Neely, A. (2004). The challenges of performance measurement (in conversation with Sarah Powell), *Management Decision*, Vol. 42, No. 8, pp. 1017-1023.

Neely, A. (2005). Update the evolution of performance measurement research, development in the last decade and a research agenda for the next, International *Journal of Operation & Production Management*, Vol.25, No. 12, pp. 1264-1277.

Neely, A., Gregory, M. and Platts, K. (2005). Performance Measurement System Design: A Literature Review and Research Agenda, *International Journal of Operations and Production Management*, Vol. 25, No.12, pp. 1228-1263.

Noghin, V. D. (2005). *Decision Making in Multicriteria Environment: a Quantitative Approach*, ISBN 5-9221-0517-5, www.apmath.spbu.ru/en/staff/noghin dated 2006-02-16.

Oliver, L. and Palmer, E. (1998). Integrated model for infrastructural implementation of performance measurement, *Performance Measurement – Theory and Practice (Conference Proceedings)*, Vol. 2, Cambridge, Cambridge University, pp. 695-702.

Olve, N., Roy, J and Wetter, M. (1999). *Performance Drivers: a Practical guide to Using the Balanced Scorecard*, John Wiley and Sons, UK.

Otley, D. (1999). Performance management: a framework for management control systems research, *Management Accounting Research*, Vol.10, No. 4, pp. 363-382.

Parida, A., Chattopadhyay, G. and Kumar, U. (2005). Multi criteria maintenance performance measurement: a conceptual model, *Proceedings of the 18th International Congress COMADEM*, 31st Aug-2nd Sep 2005, Cranfield, UK, pp. 349-356.

Parida, A. and Kumar, U. (2006). Maintenance performance measurement (MPM): Issues and challenges, *Journal of Quality in Maintenance Engineering,* Vol.12, No.3, pp. 239-251.

Pintelon, L. and Puyvelde, F. V. (1997). Maintenance performance reporting systems: Some experiences, *Journal of Quality in Maintenance Engineering*, Vol. 3, No. 1, pp. 4-15.

PI-TEC-T5/REV0, (Task 5 Development of indicators). (2000). *Development and implementation of operation and maintenance performance indicators*, dated 2000 April 18 of SDV, Norway.

Porter, L. W. and Lawler, E. E. (1968). *Managerial Attitudes and Performance*. Dorsey, Homewood, Illinois, USA.

Pun, K. F. and White, A. S. (1996). A performance measurement paradigm for integrating strategy formulation: a review of systems and frameworks, *International Journal of Management Reviews*, Vol. 7, Issue 1, pp. 49-71.

Ray, P. K, and Sahu, S. (1990). Productivity measurement through multi-criteria decision making, *Engineering Costs and Production Economics*, Vol. 20, Issue 2, pp. 151-163.

Richardson, P. R. and Gordon, J. R. M. (1980). Measuring total manufacturing performance, *Sloan Management Review*, Winter issue, pp. 47-58.

Riis, J. O., Luxhoj, J. T. *and* Thorsteinsson, U. (1997). A situational maintenance model, *International Journal of Quality & Reliability Management*, Vol. 14 No. 4, pp. 349-366.

Lynch, R. L, and Cross, K. F. (1995). Measure Up! Yardsticks for Continuous Improvement. 2nd ed. Cambridge, Blackwell Publishers Inc., pp. 250.

Rolstadas, A. (1998). Enterprise performance measurement, *International Journal of Operations & Production Management*, Vol. 18, No. 9/10, pp. 989-99.

Rouse, P. and Putterill, L. (2003). An integral framework for performance measurement, *Management decision*, Vol. 41, No. 8, pp. 791-805.

Salmein, J. (2005). *Measuring performance and determining success factor of construction sites,* Doctoral dissertation, Helsinki University of Technology, ISBN. 951-22-7493-0.

Santos, S. P., Belton, V. and Howick, S. (2002). Adding value to performance measurement by using system dynamics and multi-criteria analysis, *International Journal of Operation & Production Management*, Vol. 22, No. 11, pp. 1246-1272.

Senge, P. N. (1992*). The Fifth Discipline: the Art and Practice of the Learning Organization*, Century Business Press, London.

Sharp, J. M., Irani, Z., Wyant, T. and Firth, N. (1997). TQM in Maintenance to improve manufacturing performance, *Proceedings of PICMET Conference*, Portland, Ohio, US.

Sinclair, D. and Zairi, M. (1996). Effective process management through performance measurement: part 3 – in integrated model of total quality – based performance measurement, *Business Process Re-engineering and Management Journal*, Vol. 1, No. 3, pp. 50-65.

Sink, D. and Tuttle, T. C. (1989). *Planning and measurement in your organization of the future,* Industrial Engineering and Management Press, Norcross, Georgia.

Skinner, W. (1971). The anachronistic factory, *Harvard Business Review*, Jan-Feb, pp. 61-70.

Skinner, W. (1974). The decline, fall and renewal of manufacturing, *Industrial Engineering*, pp. 32-38.

Skousen, K., Albrecht, J., Stice, E and Swain, M. (2001). *Management Accounting*. 2 Cincinnati, OH: South-Western.

SMRP. (2006). Society for Maintenance and Reliability Professionals. www.smrp.org

Sveiby, K.E. (1997).The *New Organizational Wealth: Managing and Measuring Knowledge Based Assets*, Berett Koehler, San Francisco, CA.

Taylor, S. J. and Bogdan, R. (1984). Introduction to Qualitative Research Methods: The search for Meanings, John Wiley, New York.

Tsang, A. H. C. (1998). A strategic approach to managing maintenance performance, *Journal of Quality in Maintenance Engineering*, Vol.4, No. 2, pp.87-94.

Tsang, A. H. C., Jardine, A. K. S., and Kolodny, H. (1999). Measuring Maintenance Performance: a holistic approach, *International Journal of Operation & Production Management,* Vol. 19 No. 7, pp. 691-715.

Tsang A. H. C. (2002). Strategic dimensions of maintenance management, *Journal of Quality in Maintenance Engineering*, Vol. 8, No. 1, pp. 7-39.

Turney, P. B. B and Anderson, B. (1989). Accounting for continuous improvement, *Sloan Management Review*, Vol. 30, Issue. 2, pp. 37-48.

Van Drongelen, C. K. and Cook, A. (1997). Design principles for the development of measurement systems for research and development processes, *R & D Management,* Vol. 27, No. 4, pp. 345-57.

Vroom, V. H. (1964). *Work and Motivation*, John Wiley & Sons, New York.

Weber, A. M. (2000). New math for a new economy, *"Fast Company*", Jan-Feb.

Webster, C. and Hung, L. (1994). Measuring service quality and promoting decentring, *The TQM Magazine*, Vol. 6 No. 5, pp. 50-55.

Wireman, T. (1998). *Developing Performance Indicators for Managing Maintenance*, Industrial Press, Inc, New York.

Wireman, T. (2005). *Developing Performance Indicators for Managing Maintenance*, Second edition, Industrial Press, Inc, New York.

Wongrassamee, S., Gardiner, P. D. and Simmons, J. E. L. (2003). Performance measurement tools: the balanced scorecard and the EFQM Excellence Model, *Measuring Business Performance*, Vol. 7, pp. 14-29.

Yaremko, R. M., Harari, H. Harrison, R. C. and Lynn, E. (1986). Handbook of Research and Quantitative Methods in Psychology: For Students and Professional. Lawrence Erlbaum Associates, Hillsdale, New Jersey.

Yin, R. K. (2003). *Case study Research: Design and Methods*. Third Edition, Sage Publication, Thousands Oak, California, USA.

Appendix A: Interview Guide

VATTENFALL – LTU STUDY PROJECT

Objective of the project: To study and analyze the maintenance process and function in order to identify possible Maintenance Performance Indicators appropriate to the operations/services of Vattenfall Service AB.

Questionnaire:

1. Can you explain the vision of Vattenfall service AB?
   (Vision is the expected future aspiration of an organization. Example: "To be the leading energy provider of the World")
2. What are the objectives of Vattenfall?
   (Objectives are the specific and quantifiable statements of organizational goals. Example, "To produce 5 million. tons by 2006".)
3. What are the strategies of the Vattenfall Service AB?
   (Strategy is the long term direction to achieve the organizational objectives. Example: "Continuing emphasis consistent quality of customer service and delivery to the market place with value for money".)
4. Can you list out the currently used Key Performance Indicators (KPIs) of Vattenfall Service AB to measure the business performance?
5. In your opinion, which KPIs are additionally required to be included and which of the existing KPIs needed to be deleted?

6 (a). Who are the stakeholders?
(b). What are their expectations?

7. Which of those stakeholders' expectations have been considered for the KPIs?
8. How do the KPIs differ from North to South?

9 (a). How the maintenance performances are measured?
(b). What are the Maintenance Performance Indicators (MPIs)?

10. Do you think they are taking care of corporate requirements?
11. How these MPIs are integrated in to the entire organization?
12. How the failure in energy distribution or energy production is detected and report initiated?

13 (a). What are the types /level of inspection?
(b). What are the inspection tasks?
(c). Who are responsible for carrying out these inspections?

14. Who are the external agencies involved (if any outsourcing?) and what are their specific roles?
15. What is the Computerized Maintenance Management System (CMMS: Software used) Vattenfall Service AB is using and what is its effectiveness?

16 (a). How the data analysis and evaluation is carried out?
(b). Who does it and how carried out and when?

17. How does the communication/feedback system from functional level to corporate management level works? (Bottom-up)
18. What is the quality improvement/suggestion system and how does it works?
19. How the KPIs at different hierarchical levels are aggregated to strategic level?
20. In your opinion what are the various criteria of performance measurements?
21. How do you measure customer satisfaction?
22. What is the percentage of your customer retention (old customers' continuity)?
23. How many customers complain do you receive each year (Quality complaints?)?
24. How many new customers are added each year?

Appendix B: Interview summary of Vattenfall

1. Can you explain the vision of Vattenfall service AB?

- To be the leading energy provider of the world
- To be a leading entrepreneur in power
- Deliver 3 % margin of the investment
- To provide very good maintenance to Vattenfalls power plants and distribution system
- Be the best service company in Norrland
- Continuously develop the service

2. What are the strategies of the Vattenfall Service AB?

- Becoming a better supplier of maintenance and service by maintaining a number external customer
- Be very good at maintenance
- Focus on larger maintenance contracts
- Gap between vision and strategy and dictated by regional requirements
- All the companies have to be competitive and bid for open tender to provide service at optimal level

3. What are the objectives of Vattenfall?

- A margin of 3 %
- Have 35% of the work outside of Vattenfall (today it is 28%)
- Annual increase in turn-over of 5%
- Make VSN a strong and well known market brand
- Growth in industry and infrastructure
- Partnering together with main customers
- Reduction of corrective maintenance
- Number of work orders

4. Can you list out the currently used key performance indicators? (KPIs) of Vattenfall Service AB to measure the business performance?

- The measurement of performance has started from this year, though not much historical data are not available

Economy:

- Profit margin
- Project margin
- Administration
- Indirect project cost
- Unsold time
- Reduction of on-call cost and time for EKA and Uppsala
- Maintenance cost and acute maintenance cost per station and year
  Personnel:
- Conducted “medarbetarsamtal”
- Sick leave
- Employee satisfaction

Maintenance process
- Maintenance planning
- Component criticality and uncritically
- Competence development own and customer
- Predictive maintenance-vibration & thermography
- 5 – S (House keeping)
- Set of KRAs and KPIs

For Service:
- Time for emergence response
- Maintenance hours
- Number of emergency works (number)
- Water losses
- Acute work cost (emergency)
- Failure to start of turbines per station and year
- Lead time
- AMS (automated maintenance service) 70 % - 30 % to 20 % - 80 %
- Planned work vrs unplanned work
- TAK (OEE) level
- Reduction in inventory

For Distribution:
- SAIDI
- CAIDI
- NQI
- SAIFI
- PM for Grid and service station for acute work
- Number of emergencies
- Total number of disturbances

5. In your opinion, which KPIs are additionally required to be included and which of the existing KPIs needed to be deleted?
- More and better KPI is required
- It is also important to have an agreement with the customers regarding the KPI
- Customer satisfaction
- Station voltage level/causing distribution
- Disturbances
- PIs not worked out in details till now, be developed for different hierarchical level
- KPIs for external stakeholders are ok, but the KPIs for internal stakeholders needs to be studied, identified and developed
- Business scorecard (economy, market, employees and development) is used by VSS Process
- KPIs are required additionally at lower levels

6. Who are the stakeholders and what are their requirements? What are the matching maintenance strategy, objectives and KPIs/PIs?
- Government
- Employee including unions
- Customers
- Other control authorities
- Distribution companies

- Hydro power production
- Board of Directors
- Bohus and Uppasala

7. Have these requirements been taken in to considerations for KPIs?

- Not all?

8. How do the KPIs differ from North to South?

- It is different today mostly dependent on difference in customer and customer categories. In the future it must be the same KPIs
- For VSS only economical KPIs are used, as they are influenced by the distribution companies and VSN is influenced by hydropower and the distribution part is integrated to it
- VS AB has agreed to reduce the cost by 10 %
- VSN: 700 employees, 50 % hydro power and 20 % industry, maintenance
  VSS: 1300 employees, 70 % netdistribution, investment
- We don't know
- No measurement for maintenance for VSS and VSN

9. How the maintenance performances are measured? What are the MPIs? Do you think they are taking care of corporate requirements?

- Doubtful
- Asset performance-output
- Disturbances
- Failure to start turbine
- Response time (45 minutes to one hour as per agreement
- Maintenance cost per year/month/week per station
- Cost for generation/control system per station

10. How these KPIs are integrated in to the entire organization?

- Many of them are regularly presented at their home page
- Annually travels round and visit the entire organisation by seniors
- Education/training
- Meetings and discussions
- Newsletter (weekly and quarterly)
- Integrated at lower levels, to some extent in other level

11. How the failure is monitored, detected and report initiated?

- This can be better. Some actions are regulated in the general agreement with Vattenfall. A lot of the systematic approach disappeared during the period when of personnel reduction but today they go back to a more systematic reporting
- Every report is reported with varying quality, training for clarity required
- Not focussed for distribution

12. What are the types /level of inspection, inspection tasks and responsibilities?

- Too much inspections, and would like to se less inspections and instead more analysis
- Drift control (DC) all over Sweden, 24 hours service centre to receive failure report and solving problem
- Preventive (periodic) and Predictive (CBM)

13. Who are the external agencies involved (if any outsourcing?) and what are their specific roles?

- Not much. Cleaning, some construction works, diving
- More than 1000 suppliers for north and 2000 f*or south*
- Standardization required
- For digging work of large areas

14. What is the CMMS Vattenfall Service AB is using and what is its effectiveness?

- SAP is used/not in use. A risk for too much data and too little analysis
- For HR and Economy
- MAXIMA
- CONWIDE – Failure handling system for hydro power

15. How the data analysis and evaluation is carried out? Who does it and how carried out and when?

- Not su*re/grey area*
- The goal is to predict market requirements, set targets for asset performance and set target for maintenance
- Collecting lots of data but not converted nor analyzed for decision making

16. How does the feedback/improvement system works?

- In VSN "it is an open climate" with regular meeting at all levels. No formal system thought. VSN have 1 person working with education and 5 working with human resources
- Middle level is a problem and some important information is not transferred up or down from this level
- It is there, but not effective
- Nothing in structured way, under progress

17. What is the quality improvement/suggestion system and how does it works?

- See question 16
- All kind of strange suggestions are awarded

18. How the PIs can be used at different hierarchical level (functional/tactical)?

- Not su*re*
- Higher level is ok, needs to be organized
- Lower level is ok, higher level not ok

19. Can these PIs be aggregated to KPIs at strategic level?

- Not su*re*
- Needs to be organized

20. Can you tell us the various criteria of performance measurements?

- Not su*re*
- Financial (economy)
- Maintenance (customer/asset based)
- Employee satisfaction, long term
- Asset quality
- Consistent performance
- No long term maintenance exists in Vattenfall

APPENDED PAPERS

PAPER I

Maintenance Performance Measurement (MPM): Issues and Challenges

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APPLICATIONS AND CASE STUDIES

Maintenance performance measurement (MPM): issues and challenges

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Abstract

Purpose – The purpose of this study is to identify various issues and challenges associated with development and implementation of a maintenance performance measurement (MPM) system.

Design/methodology/approach – An analytical approach is adopted to identify the issues and challenges associated with MPM.

Findings – The study finds that for successful implementation of MPM all employees should be involved and all relevant issues need to be considered. Furthermore, the traditional overall equipment effectiveness (OEE) used by the companies is inadequate, as it only measures the internal effectiveness. For measuring the total maintenance effectiveness both internal and external effectiveness should be considered.

Practical implications – What cannot be measured cannot be managed effectively. To manage maintenance process operating managers and asset owners need to measure the contribution of maintenance towards their business goals. This paper discusses issues and challenges associated with MPM system, there by helping the managers to take care of the pitfalls of the MPM system and advocates that managers should focus on measuring the total effectiveness of maintenance process.

Originality/value – The paper presents a concept of total maintenance effectiveness with focus on both internal and external effectiveness, and integration of the hierarchical levels and multi-criteria maintenance performance indicators of MPM system.

Keywords Maintenance, Performance measures, Employee involvement

Paper type Research paper

Introduction and background

Maintenance is defined as the combination of all the technical and administrative actions, including supervision, intended to retain an item, or restore it to a state in which it can perform a required function (International Electrotechnical Commission, 2006). Maintenance provides critical support for heavy and capital-intensive industry by keeping machinery and equipment in a safe operating condition. Today it is accepted that maintenance is a key function in sustaining long-term profitability for an organization (Al-Sultan and Duffuaa, 1995).

Maintenance performance measurement (MPM) has received a great amount of attention from researchers and practitioners in recent years due to a paradigm shift in maintenance, as explained in Figure 1. Prior to the early 1900s, maintenance was considered as a necessary evil. Technology was not in a state of advanced development, there was no alternative for avoiding failure, and the general attitude to maintenance was, "It costs what it costs." With the advent of technological changes

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and after the Second World War, maintenance came to be considered as an important support function for production and manufacturing. During 1950-1980, with the advent of techniques like preventive maintenance and condition monitoring, the maintenance cost perception changed to: "It can be planned and controlled." Today maintenance is considered as an integral part of the business process and it is perceived as: "It creates additional value" (Liyanage and Kumar, 2003). The measurement of maintenance performance has also become an essential requirement for the industry of today.

The efficiency and effectiveness of the maintenance system play a pivotal role in the organization's success and survivability. Therefore, the system's performance needs to be measured using a performance measurement (PM) technique. According to Bititci *et al.* (1997), performance management is defined as the process by which a company manages its performance. It should be "in line with its corporate and functional strategies and objectives". Neely *et al.* (1995) defined PM as the process of quantifying the efficiency and effectiveness of action.

A PM system is defined as the set of metrics used to quantify the efficiency and effectiveness of actions. For many asset-intensive industries, the maintenance costs are a significant portion of the operational cost. In addition, breakdowns and downtime have an impact on the plant capacity, product quality, and cost of production, as well as health, safety and the environment.

This paper analyses the issues and challenges associated with the different facets of MPM and outlines the scope of a multi-criteria hierarchical approach to maintenance performance measurements.

The following is an outline of this paper. The first section provides the background and a brief introduction to maintenance performance measurements. The next section provides an overview of MPM techniques and maintenance performance indicators (MPIs). The following section outlines the issues involved in MPM for any complex organization. Challenges associated with the development of MPIs and practical applications in the real world are discussed in the penultimate section. The final section provides a summary of the paper and discusses the scope of future work.

An overview of maintenance performance system (MPM)

In the past two decades, PM has received a great amount of attention from researchers and practitioners. Major issues related to this field concern what to measure and how to measure it (Neely, 1999) in a practically feasible and cost-effective way. Improper implementation and management of measurement system development aiming to use new measures to reflect new priorities often lead to ineffective results. This is due to the failure of the organization to discard measures reflecting old priorities, uncorrelated and inconsistent indicators and inadequate measurement techniques (Meyer and Gupta, 1994). Measurement gives the status of the variable, compares the data with

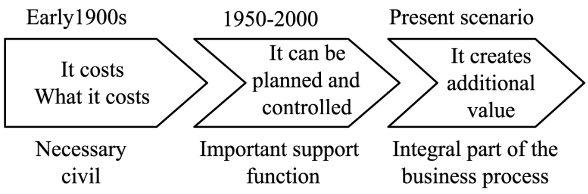

Figure 1.
Paradigm shift in maintenance

target or standard data and points out what actions should be taken and where they should be taken as corrective and preventive measures. This is extremely difficult without adequate data to develop models for supporting the decision-making process (Wealleans, 2000). The characteristics of performance measures include relevance, interpretability, timeliness, reliability and validity (Al-Turki and Duffuaa, 2003). An operational PM system acts like an early-warning system.

Several frameworks have been developed for measuring performance over the years. Till 1980, the PM was based on mostly on financial measures. The balanced scorecard, with its four perspectives, focuses on financial aspects, customers, internal processes, and innovation and learning (Kaplan and Norton, 1992). It looks into both tangible (financial) and intangible aspects of the business process. Subsequently, various researchers have developed frameworks considering non-financial measurements and intangible assets to achieve competitive advantages (Kaplan and Norton, 2001). It is observed that companies using an integrated balanced PM system perform better than those that do not measure their performance (Kennerly and Neely, 2003; Lingle and Schiemann, 1996). The issues and challenges associated with MPM system concern relevance, interpretability, timeliness, reliability, validity, cost and time effectiveness, and ease of implementation, updating and maintenance for regular use by stakeholders at various levels.

MPM

Maintenance works as an important support function in business with significant investment in physical assets and plays an important role in achieving organizational goals (Tsang, 2002). Cross (1988) reported that, in the UK manufacturing industry, maintenance spending ranges from 12-23 percent of the total factory operating costs. In refineries, the maintenance and operations departments are very large and each department often consists of up to 30 percent of the total staffing (Dekker, 1996). A study by the Swedish mining industry shows that the cost of maintenance in a highly mechanized mine can be 40-60 percent of the operating cost (Danielson, 1987). Some of the important factors behind demands on maintenance performance measures are:

- *Measuring value created by the maintenance.* The most important reason for implementing maintenance performance 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 the focus on doing right things keeping in view the business goal of the company.
- *Justifying investment.* The second basic reason for measuring maintenance effectiveness is to justify the organization's investment made in maintenance organization; not so much as to whether you are doing the right thing, but whether the investment they are making is producing a return on the resources that are being consumed.
- *Revising resource allocations.* The third basic purpose for measures of effectiveness is to determine if additional investment is required and to justify the investment if, management needs more of what you are doing. Alternatively, such measurement of activities also permit you to determine whether you need to

change what you are doing or how you are doing it more effectively by using the resources allocated.

- *Health safety and environmental (HSE) issues.* The fourth reason can be to understand the contribution of maintenance towards HSE issues. A bad maintenance performance can lead to accidents (safety issue) and pollutions (health hazards and environmental issues), besides encouraging an unhealthy work culture and environment.
- *Focus on knowledge management.* Many companies especially those involved in delivery of maintenance and product support services are focused on effective management of knowledge in their companies. Furthermore, 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 such as vibration, spectroscopy, thermography and others, which is replacing preventive maintenance with predictive maintenance. This necessitates a systematic approach for the knowledge growth in the field of specialization.
- *Adapting to new trends in operation and maintenance strategy.* New operating and maintenance strategy is adopted and followed by industries in quick response to market demand, for the reduction of production loss and process waste. MPM measures the value created by the maintenance.
- *Organizational structural changes.* Today organizations are trying to adopt a flat and compact organizational structure, a virtual work organization, and empowered, self-managing, knowledge management work teams and workstations. All these innovations need to integrate the MPM system to provide a rewarding return for maintenance services.

MPI

MPIs are utilized to evaluate 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 HSE rating, and overall equipment effectiveness (OEE), as well as many other applications. When designing 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 provide or 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).

Issues and challenges involved in MPM for any organization

Maintenance is an important issue for any organization today. The PM system needs to be aligned to organizational strategy (Kaplan and Norton, 2001; Eccles, 1991; Murthy *et al.*, 2002). Each successful company measures its maintenance performance in order to remain competitive and cost effective in business. Understanding the need for MPM in the business and its work process is critical for the development and successful implementation of the MPM. 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).

Maintenance process mapping

It is essential to understand the maintenance process in detail, before going to study the issues involved in MPM system for any complex 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' expectations. Based on the maintenance objectives, maintenance policy, organization, resources and capabilities, a maintenance program needs to be 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. Examples of maintenance tasks are repair, replacement, adjustment, lubrication, modification and 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 of and resources allocated for maintenance planning, 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.

Appropriate logistic support is vital for both maintenance planning and maintenance execution. Such support includes the availability of spare parts, consumable materials, tools, instruction manuals, documents, etc. Logistic support acts as a performance driver that 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 that prevents the achievement of the desired results. Therefore, one must ensure the human resources and training necessary for the maintenance planning and execution team. Problems in the reporting system are 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 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 such as: "What indicators are relevant to the business and related to maintenance?"; "How the indicators are related to one another and 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?"; and "What are the corrective and preventive measures and when and how does one update the MPIs?".

Some of the basic questions require deliberation and critical examination while designing such MPM system. The questions that form the basic challenges associated with the development and implementation of MPM system are given in Figure 2.

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, then the action is "do nothing". If it shows a negative trend and has crossed the lower limit of the target, then the decision is to act immediately. The value of the MPI, when falls within the limits (as set by the decision maker), then the decision is "wait and see". Different types of graphs and figures 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 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:

- *Strategy*. How does one assess and respond to stakeholders' (internal and external) needs? How does one translate the corporate goal and strategy into targets and goals at the operational level (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 (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?
- *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?
- *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?
- *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

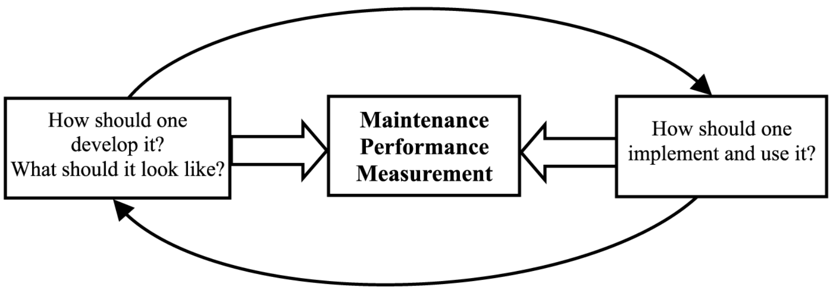

Figure 2.
Questions involved in the development and implementation of MPM

and modify the MPM strategy and system at regular intervals? How to develop and build trust in MPIs and MPM system at various levels.

The SMART test is frequently used to provide a quick reference to determine the quality of the performance metrics (Department of Energy, 2002). SMART stands for:

- *S*. Specific – clear and focused to avoid misinterpretation. Should include measure assumptions and definitions and be easily interpreted, e.g. maintenance cost/ton.
- *M*. Measurable – can be quantified and compared to other data. It should allow meaningful statistical analysis. Avoid "yes/no" measures except in limited cases, such as start-up or systems-in-place situations.
- *A*. Attainable – achievable, reasonable, and credible under the conditions expected.
- *R*. Realistic – fits into the organization's constraints and is cost-effective.
- *T*. Timely – obtainable within the time frame given.

The MPM system for the total maintenance effectiveness

Often an MPM system implemented in companies' deals with internal effectiveness of the maintenance system that is all these measures are focused on measuring the productivity in terms of maintenance cost per unit or maintenance productivity in terms of work order executed per unit of time. The development and implementation of an MPM system should normally be focused on measuring total maintenance effectiveness, reflecting the contribution of maintenance process to the companies' business goal. It is difficult to develop an MPM that incorporates metrics for measuring the external effectiveness. Currently, the most challenging issue for the maintenance managers is to develop and implement a system that measures both the external and internal effectiveness of maintenance process.

The total maintenance effectiveness based on an organizational effectiveness model considering both the external effectiveness and the internal effectiveness is given in Figure 3. The concept of total maintenance effectiveness envelops the entire organization. The total effectiveness is a product of the internal effectiveness measured through internal efficiency, which is characterized by issues related to effective and efficient use of resources. These facilitate the delivery of the maintenance and related

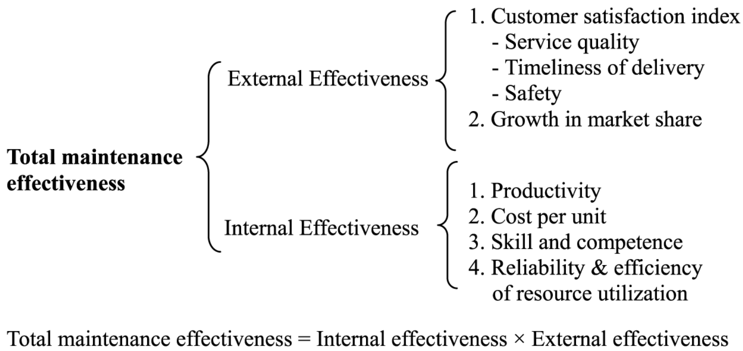

Figure 3.
Total effectiveness based on an organizational effectiveness model

services in the most effective way characterized by the engineering and business processes related to the planning and resource utilization; and external effectiveness characterized by customer satisfaction, growth in market share, etc. (Bruzelius and Skärvad, 2004; Ahlmann, 2002). 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 long term effect on companies profitability and is characterized by delivering right type of maintenance services the customer wants. From customers' perspective quality and timeliness of service delivery is often of utmost importance. Here the concept of delivering is 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, innovative service and service delivery; and capturing or creating new markets.

For measuring the total maintenance effectiveness, a balanced, multi-criteria and hierarchical MPM system is considered to be effective, which considers both the external effectiveness and internal efficiency (Parida *et al.*, 2005). There is a need to workout an overall total maintenance effectiveness considering all the factors and criteria. In general measures for total maintenance effectiveness must be combined with process owners' capability to change maintenance and service processes and adapts to new technology and work practices without any major involvement of resources and at right time.

Empirical example of total maintenance effectiveness

Traditionally, the concept of OEE, used by manufacturing company to measure the effectiveness of their organization is inadequate as it only measures the internal effectiveness of maintenance or organization. For example, if the OEE level of an organization is high, then, the product of availability, performance speed, resource utilization and quality will be high, reflecting a higher internal efficiency. But, if the external effectiveness, which is characterized by a customer satisfaction index, such as service quality (of repair/modification and promptness of response), timeliness of delivery and safety, is low; then, the total maintenance effectiveness will be low. Internal effectiveness is expressed in terms of internal efficiency, which is reflected in terms of manufacturing of products in right way, in right quality and quantity (Ahlmann, 2002). Internal effectiveness for manufacturing company is generally expressed in terms of OEE, which is a product of availability, performance speed and product quality. For service industry, the internal effectiveness is measured differently as given in the empirical example. External effectiveness is a measure of business performance reflecting the client's judgement of satisfaction, service quality, future purchase intentions and willingness to recommend the service firm to others (Paulin *et al.*, 1999).

To give an empirical example, for a multi-national utility company in the service sector, the internal effectiveness of maintenance process measured through internal efficiency such as average interruption period per year, number of all unsuccessful starting up of plant, unwanted water spillage, and number of work order scheduled to number of work order received is calculated to be 90 percent. External effectiveness (delivering the right product/service to customers on demand in right time) is 58.7 percent, which is measured through customer satisfaction index considering all customer-related factors, such as customer retention, customer satisfaction and growth (SKI, 2005). The total maintenance effectiveness of the company is given in Table I. We assume that this index also in someway reflects the external maintenance effectiveness.

For an internationally reputed mineral processing plant producing world-class iron ore pellets, the internal efficiency, measured through availability, performance speed and production quality (overall equipment effectiveness) is 72 percent. The external effectiveness of this plant; measured through customer satisfaction, which considers; timely product and service delivery, quantity and quality of the product delivered, besides customer retention and growth. Issues like; how many times ship has to wait at the harbor due to plant production breakdown and what is the customer retention, and market growth; are considered for measuring external effectiveness. In the past three years, there are no customer complaints with regard to timely delivery and product quality. With an external effectiveness of 99 percent, the total maintenance effectiveness of the plant is given in Table II.

These two empirical examples indicate that for high total maintenance effectiveness, both the internal and external effectiveness should be high.

Integration of the maintenance from shop floor to strategic level

The maintenance strategy should be derived from and linked 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 goals. 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. 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. However, there are some organizations that 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

Internal efficiency	External effectiveness	Total maintenance effectiveness
0.90	0.58	0.52

Table I.

Internal efficiency	External effectiveness	Total maintenance effectiveness
0.72	0.99	0.71

Table II.

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.

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, though the subjectivity decreases down through the levels, with the highest objectivity existing at the functional level. The second level considers tactical issues 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 functional personnel and includes the shop floor 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 involving 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 throughout the entire organization.

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 among 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.

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 have transparency and enable accountability for all the hierarchical levels. From the application and usage point of view, the MPM system should be technology and user-friendly and should be easily facilitated by training the relevant personnel. 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.

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 can not be effective or implemented fully (Santos *et al.*, 2002). Dumond (1994), mentions lack of communication and dissemination of results as important issues. 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).

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.

Conclusion

In this paper, the need for maintenance PM is analyzed and a brief review of existing maintenance performance measures is provided. Measurement of maintenance is a complex issue, and when it comes measuring the external effectiveness, it becomes more difficult in linking the objective outcome at operational level to corporate strategic level. The issues and challenges involved in developing and implementing an effective MPM system is discussed. MPM model can facilitate the correct estimation of the contribution of maintenance to the business goal. There is enough scope for future work in this research area. The authors are currently working on development of a multi-criteria hierarchical model for maintenance PM with two industries and the results will be published in the future.

References

Ahlmann, H. (2002), "From traditional practice to the new understanding: the significance of life cycle profit concept in the management of industrial enterprises", paper presented at the IFRIM Conference, Vaxjo, May 6-7.

Al-Sultan, K.S. and Duffuaa, S.O. (1995), "Maintenance control via mathematical programming", *Journal of Quality in Maintenance Engineering*, Vol. 1 No. 3, pp. 36-46.

Al-Turki, U. and Duffuaa, S. (2003), "Performance measures for academic departments", *International Journal of Educational Management*, Vol. 17 No. 7, pp. 330-8.

Bititci, U.S., Carrie, A.S. and McDevitt, L. (1997), "Integrated performance measurement systems: a development guide", *International Journal of Operation & Production Management*, Vol. 17 No. 5, pp. 522-34.

Bruzelius, L.H. and Skärvad, P.H. (2004), *Integreraded Organisationlära*, Studentlitteratur, Lund (in Swedish).

Cross, M. (1988), "Raising the value of maintenance in the corporate environment", *Management Research News*, Vol. 11 No. 3, pp. 8-11.

Danielson, B. (1987), *A Study of Maintenance Problems in Swedish Mines, Study Report*, Idhammar Konsult AB (in Swedish).

Dekker, R. (1996), "Applications of maintenance optimization models: a review and analysis", *Reliability Engineering and System Safety*, Vol. 51 No. 3, pp. 229-40.

Department of Energy (2002), *Work Smart Standard (WSS) Users' Handbook*, DOE-HDBK-1148-2002, Department of Energy, Washington, DC, www.eh.doe.govt/tecgstds/standard/hdbk1148/hdbk11482002.pdf

Dumond, E.J. (1994), "Making best use of performance measures and information", *International Journal of Operation and Production Management*, Vol. 14 No. 9, pp. 16-31.

Eccles, R.G. (1991), "The performance measurement manifesto", *Harvard Business Review*, January-February, pp. 131-7.

Jonsson, P. and Lesshammar, M. (1999), "Evaluation and improvement of manufacturing performance measurement systems: the role of OEE", *International Journal of Operations & Production Management*, Vol. 19 No. 1, pp. 55-78.

International Electrotechnical Commission (2006), "International electrotechnical vocabulary", IEV 191-07-01, available at: http://std.iec.ch/iev/iev.nsf (accessed July 1).

Kaplan, R.S. and Norton, D.P. (1992), "The balanced scorecard: measures that drive performance", *Harvard Business Review*, January-February, pp. 71-9.

Kaplan, R.S. and Norton, D.P. (2001), "Transforming the balanced scorecard from performance measurement to strategic management, part I", *Accounting Horizons*, Vol. 15 No. 1.

Kennerly, M. and Neely, A. (2003), "Measuring performance in a changing business environment", *International Journal of Operation & Production Management*, Vol. 23 No. 2, pp. 213-29.

Kumar, U. and Ellingsen, H.P. (2000), "Development and implementation of maintenance performance indicators for the Norwegian oil and gas industry", *Conference Proceedings of 15th European Maintenance Conference (Euro Maintenance 2000), Gothenburg*.

Lingle, J.H. and Schiemann, W.A. (1996), "From balanced scorecard to strategy gauge: is measurement worth it?", *Management Review*, March, pp. 56-62.

Liyanage, J.P. and Kumar, U. (2003), "Towards a value-based view on operations and maintenance performance management", *Journal of Quality in Maintenance Engineering*, Vol. 9 No. 4, pp. 333-50.

Lynch, R.L. and Cross, K.F. (1991), *Measure up!: The Essential Guide to Measuring Business Performance*, Mandarin, London.

Meyer, M.W. and Gupta, V. (1994), "The performance paradox", in Straw, B.M. and Cummings, L.L. (Eds), *Research in Organizational Behavior*, Vol. 16, JAI Press, Greenwich, CT, pp. 309-69.

Murthy, D.N.P., Atrens, A. and Eccleston, J.A. (2002), "Strategic maintenance management", *Journal of Quality in Maintenance Engineering*, Vol. 8 No. 4, pp. 287-305.

Neely, A., Gregory, M. and Platts, K. (1995), "Performance measurement system design: a literature review and research agenda", *International Journal of Operation & Production Management*, Vol. 15 No. 4, pp. 80-116.

Neely, A., Mills, J., Gregory, M., Platts, K., Richards, H., Gregory, M., Bourne, M. and Kennerly, M. (2000), "Performance measurement system design: developing and testing a process-based approach", *International Journal of Operation & Production Management*, Vol. 20 No. 10, pp. 1119-45.

Neely, A.D. (1999), "The performance measurement revolution: why now and where next", *International Journal of Operation & Production Management*, Vol. 19 No. 2, pp. 205-28.

Parida, A., Chattopadhyay, G. and Kumar, U. (2005), "Multi criteria maintenance performance measurement: a conceptual model", *Proceedings of the 18th International Congress of COMADEM, 31 August-2 September, Cranfield*, pp. 349-56.

Paulin, M., Ferguson, R.J. and Salazar, A.M.A. (1999), "External effectiveness of service management: a study of business-to-business relationship in Mexico, Canada and the USA", *International Journal of Service Industry Management*, Vol. 10 No. 5, pp. 40-2.

Pun, K.F. and White, A.S. (1996), "A performance measurement paradigm for integrating strategy formulation: a review of systems and frameworks", *International Journal of Management Reviews*, Vol. 7 No. 1, pp. 49-71.

Santos, S.P., Belton, V. and Howick, S. (2002), "Adding value to performance measurement by using system dynamics and multicriteria analysis", *International Journal of Operation & Production Management*, Vol. 22 No. 11, pp. 1246-72.

Swedish Quality Index (SKI) (2005), "2005 report", available at: www.kvalitetsindex.se (accessed March 29).

Tsang, A.H.C. (1998), "A strategic approach to managing maintenance performance", *Journal of Quality in Maintenance Engineering*, Vol. 4 No. 2, pp. 87-94.

Tsang, A.H.C. (2002), "Strategic dimensions of maintenance management", *Journal of Quality in Maintenance Engineering*, Vol. 8 No. 1, pp. 7-39.

Wealleans, D. (2000), *Organizational Measurement Manual*, Ashgate Publishing, Abingdon.

Wireman, T. (1998), *Developing Performance Indicators for Managing Maintenance*, Industrial Press, New York, NY.

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PAPER II

Development of a Multi-criteria Hierarchical framework for Maintenance Performance Measurement (MPM)

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Development of a Multi-criteria Hierarchical Framework for Maintenance Performance Measurement (MPM)

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Abstract: *Performance measurement is a complex issue for any industry even in its simplest form. Measuring performance of maintenance process is more difficult as it involves multiple inputs, outputs and criteria. All the relevant and influential factors need to be considered in the development of the maintenance performance measurement (MPM) framework. Besides, the stakeholders' needs from different hierarchical levels of operational, tactical and strategic, multi-criteria aspects are required to be considered. In this paper, the authors have considered seven criteria consisting of twenty six maintenance indicators from three hierarchical levels and presented an integrated, holistic and balanced MPM framework, which is proposed for the application by the companies.*

Purpose – The purpose of this study is to develop a multi-criteria hierarchical maintenance performance measurement framework, which is balanced, holistic and integrated with the organization.
Design/methodology/approach – Analytical and conceptual approaches are adopted to study and identify the multi-criteria and hierarchical MPIs for the proposed balanced, holistic and integrated MPM framework.
Findings – A balanced, holistic and integrated multi-criteria hierarchical framework for maintenance performance measurement is proposed for developing and implementing a relevant, timely, reliable, cost and time-effective, and easy to implement maintenance system for regular use by stakeholders at various levels. The indicators at the subsystem/component level, plant level and corporate level are linked with the MPIs for the organizational objectives and strategy. The proposed model needs to be suitably modified to the needs of the specific organization before implementation.
Originality/value – The paper presents a proposed MPM framework, which is balanced, holistic and integrated, and focuses on both internal and external effectiveness, considering the maintenance performance indicators from multi-criteria hierarchical levels of the organization
Key words: *Maintenance Performance Measurement (MPM), Maintenance Performance Indicators (MPIs,) Multi-criteria hierarchical framework*
Paper type Research paper

***Practical implications*-**Management of maintenance performance is critical for long term economic viability of business organizations and industry. Development of an integrated, balanced and holistic MPM system needs to consider various issues to measure the contribution of maintenance towards total business goal. In this paper, a general multi-criterion hierarchical MPM framework has been developed and suggested for implementation, which can be used by the operating managers for their organizations after suitable modifications. This integrated, holistic and balanced MPM framework has been tried out for a process and utility company for verification. The results are encouraging, which are going to be published in near future.

Introduction

Maintenance works as an important support function in a business with significant investment in physical assets and plays an important role in achieving organizational goals (Tsang, 2002). Cross (1988), reported that in the UK manufacturing industry, maintenance spending ranges from 12-23 per cent of the total factory operating costs. In refineries, the maintenance and operations departments are very large and each department often consists of up to 30 per cent of the total staffing (Dekker, 1996). The maintenance cost for mining industry moves up to 40-50 % of the total operating cost (Campbell, 1995). Maintenance performance indicators (MPIs) are linked to the reduction of down-time, costs and wastes, and the enhancement of capacity utilization, productivity, quality, health and safety (Parida *et al.*, 2005). MPIs compare the actual conditions with a specific set of reference conditions (requirements/targets) (EEA, 1999).

Performance measurement has been arousing great interest in the manufacturing and process industry in the past two decades, mainly because of increasing technological changes and dynamic business environments. Implementing an appropriate performance measurement system ensures that actions are aligned to the strategies and objectives of the organization (Lynch and Cross, 1991). Measurement of performance is essential, so that it can be managed properly using corrective and preventative measures.

Many companies have developed their own framework or have adapted the existing framework to measure the performance of their organization. Du Pont used the Pyramid of Financial Ratios and the Return on investment (ROI) management accounting model as early as in 1903 (Chandler, 1977; Skousen *et al.* 2001). Performance indicators (PIs) are used for measuring the performance and indicating the effectiveness of a process. Multiple criteria for the performance of organizational hierarchical levels are considered in this paper for developing an integrated, holistic and balanced MPM model applicable to the complex structure of production/process engineering and maintenance. The model integrates different hierarchical levels, such as the subsystem/component, plant and corporate levels, linking various functions across the various organizational levels for decision making. Management needs to look into MPM from operational, tactical and strategic points of view. They need to consider performance monitoring and decision making for corrective and preventive measures to achieve or surpass performance targets set at various levels of the organization.

The following is an outline of the present paper. Section 1 provides the background and a brief introduction to maintenance performance measurements. Section 2 provides an overview of maintenance performance measurement frameworks and maintenance performance indicators. Section 3 outlines the various criteria that need to be considered for an effective MPM framework applicable to a complex organization. A hierarchical MPM framework linking maintenance performance indicators for practical application in the real world is proposed in Section 4. In the final section, a summary of the paper is presented and the scope of future work is discussed.

An overview of performance measurement frameworks and indicators

In the past two decades, performance measurement (PM) and management have received a great amount of attention from researchers and practitioners. According to Ghalayini and Noble (1997), the literature pertaining to PM evolved through two phases. The first phase was started in late 1880s and known as cost accounting orientation phase; helped the managers to evaluate the relevant costs of operation, and the second phase started after 1980, which attempted to present a balanced and integrated view of PM (Augusto *et al.*, 2005 and Gomes *et al*., 2004). During first phase with a financial focus, the approach was criticized for short term measures and failing to measure and integrate all the factors critical to the business success (Banks and Wheelwright, 1979; Hayes and Garvin, 1982; Kaplan, 1983, 1984).

In the 1980s, the term “productivity” was replaced with “performance”, as the criteria of productivity paradigm was unable to satisfy various stakeholders. A number of studies have pointed out the shortcomings of the prevailing PM systems, especially the ones based on the financial measures only (Johnson and Kaplan, 1987; Hall, 1983; Skinner, 1971 and Dixon et all, 1990). Traditional financial performance measures provide little indication of future performance and encourage short termism (Hayes and Abernathy, 1980; Kaplan, 1986); are internal rather than externally focused, with little regards for competitors or customers (Kaplan and Norton, 1992; Neely et al., 1995); lack strategic focus and often inhibit innovation (Skinner, 1974; Richardson and Gordon, 1980). In order to overhaul the short comings in the existing traditional measures of the systems, organizations total competitive circumstances were taken in to consideration (Eccles, 1991; Neely, 1999). Major issues related to this field concern what to measure and how to measure it (Neely, 1999) in a practically feasible and cost-effective way. Organizations need to learn how to cope with a continuously changing business and technological environment in order to remain competitive and be successful (Senge, 1992; Eccles, 1991). Various researchers stress the need for reflective action concerning measures to ensure that they are effective in coping with the continuously changing environment (Dixon *et al.,* 1990; Ghalayini and Noble, 1996). Improper implementation and management of measurement system development aiming to use new measures to reflect new priorities often lead to ineffective results. This is due to the failure of the organization to discard measures reflecting old priorities, uncorrelated and inconsistent indicators and inadequate measurement techniques (Meyer and Gupta, 1994). Measurement gives the status of the variable, compares the data with target or standard data and points out what actions should be taken and where they should be taken as corrective and preventive measures.

The characteristics of performance measures include relevance, interpretability, timeliness, reliability and validity (Al-Turki and Duffuaa, 2003). An operational performance measurement system acts like an early-warning system. In late 1980s, various researchers were working to develop a balanced performance measurement framework, which can take care of both financial and non-financial perspectives. Kaplan and Norton's balanced scorecard leads in these developments. The balanced scorecard, with its four perspectives, focuses on financial aspects, customers, internal processes, and innovation and learning (Kaplan and Norton, 1992). It looks into both tangible (financial) and intangible aspects of the business process. Subsequently, various researchers have developed frameworks considering non-financial measurements and intangible assets to achieve competitive advantages (Blair, 1995; Weber, 2000; Kaplan and Norton, 2001). It is observed that companies using an integrated balanced performance measurement system perform better than those which do not measure their performance (Kennerly and Neely, 2003; Lingle and Schiemann, 1996). Gomes *et al*. (2004) have described the characteristics of a performance measurement system (PMS) linking non-financial information based on key success factors of business. Further, the traditional performance measurement approach is criticized for encouraging local optimization, for being focused on the past, for not providing adequate information for a productivity measurement and improvement program, for not being externally focused and for failing to measure and integrate all critical factors. Therefore, a PM system needs to have features such as; integrated, which can link all the perspectives in a balanced manner, besides having a holistic approach for the entire organization to achieve the stakeholders' goals at various levels. The authors have examined different frameworks and performance measures and some of the PM frameworks along with measures and indicators developed by various authors and researchers are presented in Table 1.

Multi-criteria and hierarchy of the MPM framework

Measurement of maintenance performance is important for continuous improvement and in identifying and resolving priorities. MPM is subdivided into five main components: productivity, organization, work efficiency, cost and quality, together with some overall measurements (Campbell and Jardine, 2001). Different researchers have indicated different criteria for measuring maintenance performance, like; maintenance process, and maintenance task related etc (Atkinson *et al*., 1997; Ghalayini and Noble, 1996; Gomes *et al.* 2004; Kutucuoglu *et al.* 2001). Performance measurement in organizations is changing from record keeping to looking forward and predicting.

Maintenance performance indicators (MPIs) are a set of measures used for the measurement of maintenance impact on the process performance (Wireman, 1998).

Allander (1997) defines performance indicators as measures that can be extended to a working environment. Liyanage and Kumar (2002) define a performance indicator as "a measure equipped with baselines and realistic targets to facilitate prognostic and/or diagnostic processes and justify associated decisions and subsequent actions at appropriate levels in the organization to create value in the business process". 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. PIs are broadly classified as leading or lagging indicators. A leading indicator is one which warns the user in advance about the non-achievement of objectives. A leading indicator is of the non-financial and statistical type that fairly and reliably predicts in advance. A leading indicator thus works as a performance driver and ascertains the present status in comparison with the reference one. Lagging indicators is an outcome measures and provides basis for studying the deviations after the completion of the activities

Table 1 *A list of performance measurement frameworks and performance measures developed*

Model/framework	Measures/Indicators/Criteria	Reference
Sink and Tuttle (1989)	Efficiency, Effectiveness, Quality, Productivity, Quality of work life and innovation, Profitability/budget ability, Excellence, survival and growth,	Sink and Tuttle (1989)
Du Pont Pyramid	Financial ratios, ROI	Chandler (1977); Skousen et al. (2001)
PM matrix	Cost factors, Non-cost factors, External factors, Internal factors	Keegan et al. (1989)
Results and determinants matrix	Financial performance, Competitiveness, Quality, Flexibility, Resource utilization, Innovation	Fitzgerald et al. (1991)
PM questionnaire	Strategies, actions and measures are assessed, Extent to which they are supportive? Data analysis as per management position or function, Range of response and level of disagreement	Dixon et al. (1990)
Brown's framework	Input measures, Process measures, Output measures, Outcome measures	Brown (1996)
SMART pyramid (Performance pyramid)	Quality, Delivery, Process time, Cost, Customer satisfaction, Flexibility, Productivity, Marketing measures, Financial measures	Developed by Wang Laboratories. Lynch and Cross (1991)
Balanced Scorecard (BSC)	Financial, Customer, Internal processes, Learning & growth	Kaplan & Norton (1992)
Consistent PM system	Derived from strategy, continuous improvement, fast and accurate feedback, explicit purpose, relevance	Flapper et al. (1996)
Framework for small business PM	Flexibility, Timeliness, Quality, Finance, Customer satisfaction, Human factors	Laitinen (1996)
Cambridge PM process	Quality, Flexibility, Timeliness, Finance, Customer satisfaction, Human factors	Neely et al. (1997)
Integrated dynamic	Timeliness, Finance, Customer satisfaction, Human	Ghalayini et al.

PM System	factors , Quality, Flexibility	(1997)
Integrated PM framework	Quality, Flexibility, Timeliness, Finance, Customer satisfaction	Medori and Steeple (2000)
Integrated PM system	Finance, Customer satisfaction, Human factors, Quality, Flexibility, Timeliness	Bititci (1994)
Dynamic PM Systems	External and internal monitoring system, Review system, Internal deployment system, IT platform needs	Bititci et al. (2000)
Integrated Measurement model	Customer satisfaction, Human factors, Quality, Flexibility, Timeliness, Finance	Oliver & Palmer (1998)
Comparative Business Scorecard	Stakeholder value, Delight the stakeholder, Organizational learning, Process excellence	Kanji (1998)
Skandia Navigator	Financial focus, Customer focus, Human focus, Process focus, Renewal and development focus	Edvinsson and Malone (1997); Sveiby (1997)
Balanced IT Scorecard (BITS)	Financial perspective, Customer satisfaction, Internal processes, Infrastructure & innovation, People perspective	ESI (1998) as mentioned in Abran and Buglione (2003)
BSC of Advanced Information. Services Inc (AISBSC)	Financial perspective, Customer perspective Processes, People, Infrastructure & innovation	Abran and Buglione (2003)
Intangible Asset-monitor (IAM)	Internal Structure: *Growth, *Renewal, *Efficiency, *Stability, Risk (Concept models, Computers, Administrative systems); External Structure: *Customer, *Supplier, *Brand names, *Trademark & image; Individual Competence: * Skills, *Education*Experience, *Values, *Social skill	Sveiby (1997)
QUEST	Quality, Economic, Social and Technical factors	Abran & Buglione (2003)
European Foundation for Quality Management (EFQM)	Leadership, Enablers: people management, policy and strategy, resources; Processes, Results: people and customer satisfaction, impact on society; and Business results	http://www.efqm.org/ as mentioned in Wongrassamee et al.(2003)

The maintenance cost per unit or return on investment calculations are examples of lagging indicators. The establishment of a link between the lagging and the leading indicators helps to monitor and control the performance of the process, and the indicators to be linked are selected in line with the chosen maintenance strategy (Kumar and Ellingsen, 2000).

Multi-Criteria approach: In any planning and development activity, there are several alternatives available, and one has to choose the alternative that fits in the best. Normally, the objectives of the decision maker are expressed in terms of various criteria. If there are a number of criteria, multi-criteria choice problems arise, which is solved by having the information on the relative importance of criteria (Noghin, 2005). The selection of factors or variables constituting various performance criteria, such as productivity, effectiveness, efficiency etc, are important step in developing a performance measurement system in an organization, conceived essentially as multi-criteria decision making (Ray and Sahu, 1990).

In an MPM system, there are a number of criteria or goal functions which needs to be considered from different stake holders' view. These criteria can be broken down to different maintenance indicators like; mean time between failure, downtime, and maintenance cost, planned maintenance tasks and unplanned maintenance tasks, etc. These maintenance indicators need to be integrated from operational level to the strategic level.

The development and implementation process for indicators has been studied by Andersen and Fagerhaug (2002) and Engelkemeyer and Voss (2000). The development and identification of maintenance performance indicators (MPIs) for an organization is undertaken from the vision, objectives and strategy points of view and on the basis of the requirements of both the external and the internal stakeholders a given in Figure 1.

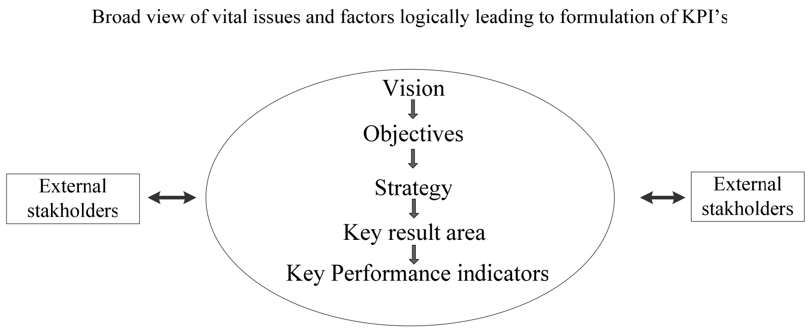


Figure 1 Developing and identifying MPIs from the vision, objectives and strategy points of view

In our development process of maintenance performance measurement model, the basic four perspectives of Kaplan and Norton's balanced scorecard are considered, besides the maintenance criteria. In addition, health, safety and environment and employee satisfaction, are considered to make this MPM system a balanced and holistic from the organizational point of view (Parida *et al.,* 2005).

The MPIs are required to be considered from the perspective of the multi-hierarchical levels of the organization. The first hierarchical level could correspond to the corporate or strategic level, second to the tactical or managerial level, and the third to the functional/operational level. Depending on the organizational structure, the hierarchical levels could be more than three.. The maintenance indicators of the functional level are integrated and linked to tactical or middle level to help the management for analysis and decision making at strategic or tactical level. It is a challenge to inetgrate MPIs from top-down and bottom-up flow of informations. Another important challenge exists for the involvement of all employees in this MPIs development process, so that everyone speaks the same language. The strategic goals need to be broken down into objective targets for operating maintenance managers which may act as performance driver for the maintenance group. While linking back the objective outcome from the operating level in terms of Key performance indicator (KPI) to strategic goals the subjectivity increases as we integrate the objective outcomes to get KPI at higher level or to stratetegic level (see Figure 2). Three hierarchical levels are given in Figure 2, which has been adopted for our MPM framework.

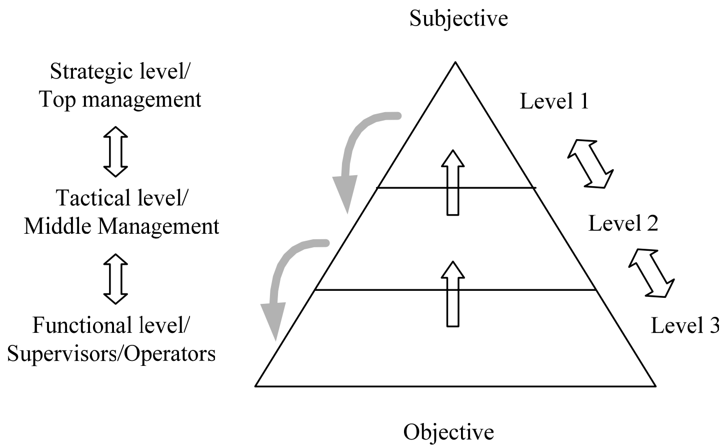


Figure 2 Hierarchy levels of MPM model

After considering the external stakeholders' requirements and the internal capability and capacity of the organization, and the different hierarchy, the MPIs are grouped in to seven criteria. A list of some important MPIs identified based on our literature survey and interviews conducted in process and utility industries during our studies are grouped under seven criteria of the proposed MPM framework. These are discussed in the following.

Equipment-related indicators

a) Availability: The availability is expressed as the percentage of the plant availability used for manufacturing/production. This is calculated as the ratio of the mean time to failure (MTTF) to the total time, i.e. MTTF plus the mean time to repair (MTTR). It is subjective at the management level and objective at the functional/operational level.

b) Impact of performance rate: This rate indicates the speed of production and is expressed as a percentage of the production/performance speed. The impact of maintenance standard affects the performance speed.

c) Impact of quality: This indicator refers to the quality rate. This is the percentage of good parts produced out of the total number of parts produced and is also called the "yield". (The overall equipment effectiveness (OEE) is one of the main benchmarks or indicators for the total process of a company. The OEE compares the equipment availability, performance rate and impact of quality.)

d) Number of small and big stoppages: This indicator is the number of stoppages, either big or small. Stoppages can also be quantified in time (hours and minutes).

e) Down-time for the number of small and big stoppages: This is expressed in hours and minutes for the total number of stoppages or for each small or big stoppage.

f) Rework: The waste due to rejected quality of output is expressed in time (hours and minutes), the number of pieces on which rework has been carried out and the cost of the rework undertaken.

Maintenance task related indicators

a) Change over time: This is the time in hours/minutes for the change-over from a stoppage to a running condition.

b) Planned maintenance task (preventive maintenance): The planned maintenance tasks are quantified either as the number of tasks undertaken or in terms of the time/cost needed for carrying out the planned maintenance tasks.

c) Unplanned maintenance tasks (corrective maintenance) (number/time): The unplanned maintenance tasks are quantified either as the number of tasks undertaken or in terms of the time/cost needed for carrying out the unplanned maintenance tasks.

d) Response time for maintenance: The response time indicates the time taken in minutes/hours for undertaking the maintenance tasks after the same have been reported by the production/operation personnel.

Cost-related indicators

a) Maintenance cost/unit: This indicator is a common measure of the maintenance performance. It divides the maintenance costs by the volume of production and is expressed in dollars per ton. The production volumes vary for reasons not under the control of the maintenance department. Therefore, this PI is good for broad analysis over time, but cannot be used as a sole PI.

b) Production cost per unit: This indicator can be used for ascertaining the relative impact of high or low maintenance efforts. The unit of expression is dollars per ton of production.

c) Return on maintenance investment (ROMI): This indicator compares the return earned due to an increased maintenance investment with a past record/benchmark. The actual calculation or use of this PI seems a little complex. However, once obtained, this PI can pinpoint the shortcomings in the overall maintenance performance. This indicator is expressed as a percentage.

Impact on customer satisfaction

a) Number of quality complaints: Customers are the most important stakeholders for any company. A direct measure of customer satisfaction can be obtained by calculating the number of complaints about the products. A comparison with the past values can also indicate the improvement achieved. This Pi is subjective and cannot be measured directly.

b) Low quality returns (number/quantity): This PI indicates the number or quantity of products returned to the manufacturer or the plant due to poor quality. This is an objective PI, as it specifies the number/quantity of low quality returns of the finished product.

c) Customer satisfaction (value-for-money feedback etc.): An indirect way of measuring the satisfaction level is by carrying out a customer survey in the form of questionnaire. Customer satisfaction is a subjective PI, but a very important PI for the management, as no organization can survive in its present business environment without customer satisfaction.

d) Customer retention: In the present market scenario, the percentage or number of customers retained over a past period is an important PI and an objective indication of customer satisfaction. Managements are more interested in having this objective information than in having subjective information on customer satisfaction.

e) Number of new customers added: This PI gives the number or percentage of new customers as compared to past figures. This PI also constitutes an objective figure which is essential for the management to understand their marketing achievement.

Learning and growth

a) Number of new ideas generated: In an organization based on knowledge management, it is essential to measure the use of knowledge for the continuous improvement of the organization. Hence, the number of new ideas generated and implemented can function as a measure of innovation and development, as well as the employees' participation in and motivation for the organization. This is an objective PI that is very essential for the management.

b) Skills and competency development/training: Skills and competency development and training also play an important role in a learning organization. The amount of money spent on training, the number of training programs conducted per training year and how the skill is used to upgrade the competency level are also good indicators of performance that consider the human resources. These are subjective indicators, as accurate measurement of skill and competency development/training is difficult.

Health, safety and the environment (HSE)

a) Number of accidents: A sure indication of the safety factors is provided by the number of accidents or casualties in any company. Please check whether or not "company" is better here.] in a given period of time. This is an objective indicator from the management point of view.

b) Number of legal cases: The number of legal cases is an objective indicator that can be used to measure the performance of the safety factors in an industrial set-up.

c) Number of compensation cases/amount of compensation paid: This indicator provides an objective indication of negligence on the part of the management.

d) Number of HSE complaints: The number of HSE complaints indicates the compliance with the HSE guidelines on the part of the management of the organization.

Employee satisfaction

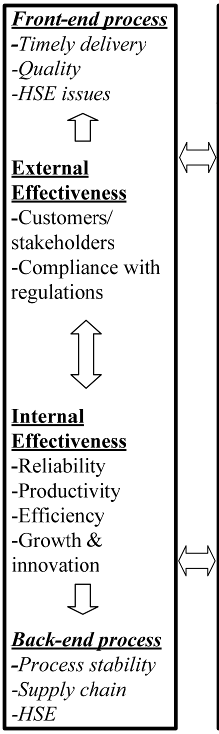
a) Employee complaints: The number of employee complaints can be a direct measure of the effectiveness of the human resource management. This is an objective indicator.

b) Employee retention in percentage: The employee retention percentage objectively indicates the employee satisfaction level and the effectiveness of the organizational work culture.

Multi-criteria and hierarchical MPM framework linking MPIs

The effectiveness of any performance measurement system is meant to meet the needs of the operations and maintenance processes. The critical strategic areas vary from company to company, but generally include areas such as financial or cost-related issues, health safety and environment related issues, processes-related issues, maintenance task related issues, and learning growth and innovation related issues, while at the same time comprising the internal and external aspects of the company. It is important to link and integrate the overall objectives and strategy of the company. The linkage between visions, objectives and strategy and measures of performance such as return on investments (ROI) and health, safety and environment (HSE) indicators are considered in our proposed MPM framework.

A logical cause-and-effect structure has been created, while identifying and deciding the different performance indicators for each critical strategic area to measure the maintenance performance. The proposed MPM framework is designed to be balanced considering different criteria, holistic from the entire organizational point of view and integrated as a link-and-effect structure to achieve the total maintenance effectiveness both from external and internal effectiveness, which would contribute to the overall objective of the organization and its business units. The multi-criteria hierarchical MPM framework linking to multiple PIs as proposed in this paper is given in Figure 3. As shown in the figure 3, the internal and external aspects, which act as parts of a back-end or front-end process, need to be analyzed before deciding the relevant criteria at various levels for the maintenance performance measurement. The front-end process is derived from the needs of the external stakeholders, e.g. the shareholders or owners, financers, customers, suppliers and regulating authorities. Therefore, the front-end process needs could include higher productivity, HSE ratings, timely delivery and quality. The back-end process, which is derived from internal aspects like the capacity and capability of the organization, comprise of the departments, employee requirements, the organizational climate and skill enhancement. The back-end processes are; cost reduction, employee retention and innovation. The MPIs at functional and tactical levels gets aggregated at strategic level. For example, MPIs like: the availability (downtime), production rate and quality at level 3 and 2, under the criteria of "equipment/process related", aggregated to overall equipment effectiveness (OEE) at the strategic /top management level.



Hierarchical level / Muli-criteria	Level 1 Strategic /Top management	Level 2 Tactical/Middle management	Level 3 Functional/ Operator
Equipment/ Process related	- OEE - Downtime	- Availability - Production rate - Quality - Number of stops	- Production rate - Quality - Number of stops - Downtime
Cost/finance related	- Maintenance/ Production cost per ton	- Mintenance/ Production cost per ton	- Mintenance cost per ton
Maintenance task related	- Costly maintenance task	- 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 - New customer addition	- Quality complaint numbers - Quality return - Customer satisfaction - New customer addition	- Quality complaint numbers - Quality return - Customer satisfaction
Health, safety & environment	- Number of accidents - Number of legal cases - Compensation paid - HSE complaints	- Number of accidents - Number of legal cases - Compensation paid - HSE complaints	- Number of accidents - HSE complaints
Employee satisfaction	- Employee retention - Employee complaints	- Employee retention - Employee complaints	- Employee complaints

Figure 3 A multi-criteria hierarchical maintenance performance measurement (MPM) frameworks.

Concluding remarks

In this paper, various maintenance performance measurement frameworks are analyzed and a brief review of existing performance measures is provided. A balanced, holistic and integrated multi-criteria hierarchical framework for maintenance performance measurement is proposed for developing and implementing a relevant, timely, reliable, cost and time-effective, and easy to implement, maintain system for regular use by stakeholders at various levels. The indicators at the subsystem/component level, plant level and corporate level are linked with the MPIs for the organizational objectives and strategy. There is enough scope for future work, including the research areas such as:

- Development of multi-criteria hierarchical frameworks for maintenance performance measurement for specific industries like; mining, process and utility industries.

- Collection and analysis of industry data for tailoring the model to specific industries, estimation of parameters and validation of framework s.
- Development of a management system where the data is easy to collect, which can interface with relevant information systems, and which provides managerial reports for stakeholders at various levels for corrective and preventive measures to achieve or surpass performance targets set at various levels of the organization.

The authors are currently working on some of these areas and the results will be published in the future.

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References

Abran, A. and Buglione, L. (2003). A multidimensional performance model for consolidating Balanced Scorecards, *Advances in Engineering Software*, 34, pp. 339-349.

Allander H. (1997). Objectives matrix provides information balance, *Water Engineering & Management*, 144, 9, pp. 30-31.

Al-Turki, U. and Duffuaa, S. (2003). Performance measures for academic departments, *International Journal of Educational Management*, Vol. 17, No. 7, pp. 330-338

Andersen, B. and Fagerhaug, T. (2002). Eight steps to a new performance measurement system, *Quality Progress*, 35, 2, pp. 1125.

Atkinson, A. A., Waterhouse, J. H. and Wells R. B. (1997). A stakeholder approach to strategic performance measurement, *Sloan Management Review*, Spring issue, pp. 25-7.

Augusto, M; Figueira, J. and Lisboa, J (2005). An application of a multi-criteria approach to assessing the performance of Portugal’s economic sectors, European Business Review, Vol. 17. No. 2, pp. 113-132.

Banks, R. L and Wheelwright, S. C (1979). Operations versus strategy – Trading tomorrow for today, Harvard Business Review, pp. 112-120.

Bititci, U. (1994). Measuring your way to profit, *Management Decision*, Vol. 32, No. 6.

Bititci, U. S., Turner, T. and Begemann, C. (2000). Dynamics of performance measurement systems, *International Journal of Operations and Production Management*, Vol. 20, pp. 692-704.

Blair, M. (1995). Ownership and Control: Rethinking Corporate Governance for the Twenty-first Century, Washington, D. C., Brookings Institute.

Brown, M (1996). Keeping score: using the right metrics to drive world class performance, Quality Resources, New York, NY.

Campbell, J. D and Jardine, A. K. S (2001). Maintenance Excellence Optimizing Equipment Life-Cycle Decisions, Mercel Dekker, New York.

Campbell, J. D (1995). Uptime: Strategies for Excellence in Maintenance Management Portland, OR: Productivity Press.

Chandler, A. D. (1977). The Visible Hand: the Managerial Revolution in American Business, Boston, MA, Harvard University Press, pp. 417.

Cross, M. (1988). Raising the value of maintenance in the corporate environment, *Management Research News*, Vol. 11, No. 3, pp. 8-11.

Dekker, R. (1996). Applications of maintenance optimization models: a review and analysis, *Reliability Engineering and System Safety,* Vol. 51, pp. 229-40.

Dixon, J. R., Nanni, A. J. and Vollmann, T. E. (1990). The Performance Challenge: Measuring Operations for World-Class Competition, Homewood, IL, Dow Jones-Irwin.

Eccles, R. G. (1991). The performance measurement manifesto, *Harvard Business Review*, January-February, pp. 131-137.

Edvinsson, L. and Malone, T. (1997), Intellectual Capital: Realising Your Company's Time Value by Finding its Hidden Brainpower, New York, Harper Collins

EEA (European Environment Agency) (1999). Enviromental Indicators: Typology and Overview. Technical Report No 25, Copenhagen.

Engelkemeyer, S. and Voss, R. (2000). Bearing the gift of royal performance indicators, *Quality Progress*, 33, 2, pp. 35-39.

Fitzgerald, L., Johnson, R., Brignall, S., Silvestro, R. and Voss, C. (1991). Performance Measurement in Service Businesses, London, CIMA.

Flapper, S., Fortuin, L. and Stoop, P. (1996). Towards consistent performance management systems, *International Journal of Operation & Production Management*, Vol. 16, No. 7, pp. 27-37.

Ghalayini, A. M. and Noble, J. S. (1997). The changing basis of performance measurement, *International Journal of Operations and Production Management*, Vol.16, No. 8, pp. 63-80.

Ghalayini, A., Noble, J. and Crowe, T. (1997). An integrated dynamic performance measurement system for improving manufacturing competitiveness, *International Journal of Production Economics*, Vol. 48, pp. 207-225.

Gomes, C. F., Yasin, M. M. and Lisboa, J. V. (2004). A literature review of manufacturing performance measures and measurement in an organizational context: a framework and direction for future research, *Journal of Manufacturing Technology and Management*, Vol. 15, No. 6, pp. 511-530.

Hall, R.W (1983). Zero Inventories, Dow-Jones Irwin, Homewood, IL.

Hayes, R. H and Abernathy, W. J (1980). Managing our way to economic decline, Harvard Business Review, pp. 67-77.

Hayes, R. H. and Garvin, D. A. (1982). Managing as if tomorrow mattered, Harvard Business Review, pp. 70-79.

Johnson, H. T and Kaplan, R. S (1987). Relevance Lost – The Rise and Fall of Management Accounting, Harvard Business School Press, Boston, MA..

Kanji, G. K. (1998). Measurement of business excellence, *Total Quality Management,* Vol. 9, pp. 633-643.

Kaplan, R. S. (1983). Measuring manufacturing performance: a new challenge for managerial accounting research, Accounting Review, Vol.58. No. 4. pp. 686-703.

Kaplan, R. S (1984). Yesterday's accounting undermines production, Harvard Business Review, 62, pp. 95-101.

Kaplan, R. S (1986). Accounting lag – the obsolescence of cost accounting systems, California Management Review, Vol. 28, No. 2, pp. 174-99.

Kaplan, R. S. and Norton, D. P. (1992). The balanced scorecard: measures that drive performance, *Harvard Business Review*, pp. 71-79.

Kaplan, R. S. and Norton, D. P. (2001). Transforming the balanced scorecard from performance measurement to strategic management, Part I, *Accounting Horizons*, Vol. 15, Issue 1.

Keegan, D., Eiler, R. and Jones, C. (1989). Are your performance measures obsolete? *Management Accounting,* June, pp. 45-50.

Kennerly, M. and Neely, A. (2003). Measuring performance in a changing business environment, *International Journal of Operation and Production Management,* Vol. 23, Number 2, pp. 213-229.

Kumar, U. & Ellingsen, H.P. (2000). Development and implementation of maintenance performance indicators for the Norwegian oil and gas industry, in Proceedings of the 14th International Maintenance Congress (Euro-Maintenance, 2000), 7-10 March 2000, Gothenburg, Sweden, pp. 221-228.

Kutucuoglu, K. Y., Hamali, J., Irani, Z. and Sharp, J. M. (2001). A framework for managing maintenance using performance measurement systems, *International Journal of Operation and Production Management*, Vol. 21, Issue 1.

Laitinen, E. (1996). Framework for small business performance measurement, Vasa, Vaasan yliopisto (University of Vaasa).

Lingle, J. H. and Schiemann, W. A. (1996). From balanced scorecard to strategy gauge: is measurement worth it? *Management Review*, March, pp. 56-62.

Liyanage, J.P. and Kumar, U. (2002). Adjusting maintenance policy to business conditions: value-based maintenance performance measurement, in Proceedings of the International Foundation for Research in Maintenance, Maintenance Management and Modelling Conference, (IFRIM-2002), paper no. 20, Växjö, Sweden, May 2002.

Lynch, R. L. and Cross, K. F. (1991). Measure up!: the Essential Guide to Measuring Business Performance, London, Mandarin.

Medori, D. and Steeple, D. (2000). A framework for auditing and enhancing performance measurement systems, *International Journal of Operation & Production Management*, Vol. 20, No. 5, pp. 520-533.

Meyer, M. W. and Gupta, V. (1994). The performance paradox, in Straw, B. M. and Cummings, L.L. (Eds), *Research in Organizational Behavior*, Vol. 16, Greenwich, CT, Press, pp. 309-69.

Neely, A. D. (1999). The performance measurement revolution: why now and where next, *International Journal of Operation and Production Management*, Vol. 19, No. 2, pp. 205-228.

Neely, A., Gregory, M. and Platts, K. (1995). Performance measurement system design: a literature review and research agenda, *International Journal of Operation and Production Management*, Vol. 15, No. 4, pp. 80-116.

Neely, A., Richards, H., Mills, J., Platts, K. and Bourne, M. (1997). Designing performance measures: a structured approach, *International Journal of Operation & Production Management*, Vol. 17, No. 11, pp. 1131-52.

Noghin, V. D, (2005). Decision Making in Multicriteria Environment: a Quantitative Approach, ISBN 5-9221-0517-5, www.apmath.spbu.ru/en/staff/noghin dated 2006-02-16

Oliver, L. and Palmer, E. (1998). An integrated model for infrastructural implementation of performance measurement, in *Performance Measurement – Theory and Practice (Conference Proceedings)*, Vol. 2, Cambridge, Cambridge University, pp. 695-702.

Parida, A., Chattopadhyay, G. and Kumar, U. (2005). Multi criteria maintenance performance measurement: a conceptual model, in Proceedings of the 18th International Congress of COMADEM, 31st Aug - 2nd Sep 2005, Cranfield, UK, pp. 349-356.

Ray, P.K, and Sahu, S, (1990). Productivity measurement through multi-criteria decision decision making, Engineering Costs and Production Economics, Vol. 20, Issue 2, pp. 151-163.

Richardson, P. R and Gordon, J. R. M (1980). Measuring total manufacturing performance, Sloan Management Review, Winter, pp. 47-58.

Senge, P. N. (1992). The Fifth Discipline: the Art and Practice of the Learning Organization, London, Century Business Press.

Sink, S. and Tuttle, T. (1989). Planning and Measurement in your Organization of the Future, Norcross, GA, Industrial Engineering & Management Press.

Skinner, W (1971). The anachronistic factory, Harvard Business Review, Jan-Feb, pp. 61-70.

Skinner, W (1974). The decline, fall and renewal of manufacturing, Industrial Eng neering, pp. 32-38.

Skousen, K., Albrecht, J., Stice, E. and Swain, M. (2001). Management Accounting. 2, Cincinnati, OH, South-Western.

Smith, R. (2001). Key Performance Indicators: leading or lagging and when to use them, from www.reliabilityweb.com , dated 2003 March 12.

Sveiby, K. E. (1997). The New Organizational Wealth: Managing and Measuring Knowledge-based Assets, San Francisco, Berrett-Koelher.

Tsang, A. H. C. (2002). Strategic dimensions of maintenance management, *Journal of Quality in Maintenance Engineering*, Vol. 8, No. 1, pp. 7-39.

Wealleans, D. (2000). Organizational Measurement Manual, Abingdon, Oxon, GBR, Ashgate Publishing Limited.

Weber, A. M. (2000). New myth for a new economy, *Fast Company*, Jan-Feb.

Wireman, T. (1998). Developing Performance Indicators for Managing Maintenance, New York, Industrial Press, Inc.

Wongrassamee, S., Gardiner, P. D. and Simmons, J. E. L. (2003). Performance measurement tools: the balanced scorecard and the EFQM Excellence Model, *Measuring Business Performance*, Vol. 7, pp. 14-29.

PAPER III

Study and analysis of Maintenance Performance Indicators (MPIs) for LKAB: A Case Study

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Study and analysis of Maintenance Performance Indicators (MPIs) for LKAB: A case study

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Abstract

Purpose – The purpose of this case study is to identify and develop maintenance performance indicators (MPIs) for a mineral processing plant producing high quality iron ore pellets, as well studying and analyzing the short plant stops and planned maintenance stops. In this paper, the existing MPIs are analysed and a set of MPIs are developed to measure the performance of balling area of the pelletization plant, where the effect of shorter stops in the process have been studied, analysed and measured, and linked to the management's objectives. The utility of the MPIs are tested and validated within the framework of a multi-criterion and hierarchical Maintenance Performance Measurement (MPM) model.

Methodology/Approach - Action research approach was adopted for this study, with interactive process of interviews. The plant stop data of the plant were collected and analysed for MPIs like the availability, production rate, maintenance cost per ton and quality amongst others, and for maintenance decision making. Some other criteria though not directly related to maintenance performance were also considered from holistic, integrated and balanced view point in the model.

Findings – This study resulted in identifying a set of MPIs for the operational level of the pelletization plant of LKAB, after analyzing the short plant stops and planned maintenance stops data, and the stakeholders' requirements. This study has identified 12 MPIs at operational level or shop floor level that describe the status of plant and at the same time facilitates linking of plant performance with corporate strategy.

Originality and Value – This paper presents an approach to identify MPIs relevant to the plant status and facilitate measuring maintenance performance at corporate level in a structured way.

Practical implications –The approach used in the paper to study, analyse and develop MPIs, can be useful for plant managers and asset owners to select and develop MPIs that can describe the health status of their plant and asset and also can be linked to the corporate strategy. The framework used to verify the multi-criteria hierarchical model can also be used by similar asset managers and infrastructure owners. This study has also lifted the impact of short duration stoppages thus highlighting the total influence in terms of reduced life length, quality and productivity. This approach can be used by plant engineers, asset managers and infrastructure owners to assess the performance of maintenance process.

Key words- Maintenance performance measurements, maintenance performance indicators, capacity utilization, productivity, quality, short plant stops

Paper type Case study

1. Introduction

Performance measurement is extensively used by the business units and industries to assess the progress against the set goals and objectives in a quantifiable way for its effectiveness and efficiency. Performance measurement provides the required information to the management for effective decision making. Performance can not be managed with out measurement, as measurement can only indicate the present status of performance. Research results demonstrate that companies using integrated balanced performance systems perform better than those who do not manage measurements (Kennerly and Neely, 2003; Lingle and Schiemann, 1996).

Each organization spends considerable resources and time for measuring the performance and to assess the success of the organization. Performance measurement literatures emphasises the importance of maintaining relevant measures that continue to reflect the issues of importance to the business (Lynch and Cross, 1991). However, most of the organizations pay little or no attention to integrate the performance measurement system with their organizational hierarchical levels and the different measurement criteria linked to the external and internal stakeholders as well as the operational process. Besides, enough importance is not given to the external and internal effectiveness, to achieve the total maintenance effectiveness for the organization.

Considering all these aspects, for measuring the maintenance performance, the concept used in the balanced, holistic and integrated multi-criteria hierarchical MPM model (Parida *et al*, 2005, Parida and Chattopadhyay, 2006), was applied in this case study. This paper looks in to the complexities of maintenance performance measurement and indicators, while studying the large number of unplanned and shorter stops of the balling area of a pelletization plant in LKAB. The performance indicators were identified at equipment level and system/subsystem level linking the improvement in performance speed and quality besides availability. The outline of this paper is as follows. Section 1 provides introduction of this paper, section 2 provides an overview of various performance indicators and measurement techniques, and section 3 provides the research approach, data collection and data analysis of the case study. In section 4, the results and analysis of the MPIs are discussed, followed by the conclusions at section 5.

2. MPI and MPM frame work

MPIs are used for measurement of maintenance impact on the process performance (Wireman, 1998, Parida *et al.,* 2003). MPIs need to be linked to down time, costs and wastes, capacity utilization, productivity, quality, health and safety (Parida and Kumar, 2004) to compare actual performance with a specific set of reference conditions (requirements) (EEA, 1999). Under challenges of increasingly technological changes, implementing an appropriate performance measurement system in an organization ensure that actions are aligned to strategies and objectives (Lynch and Cross, 1991). In fact, performance cannot be managed, if it cannot be measured.

The development and implementation process for indicators has been studied by Andersen and Fagerhaug (2002) and Engelkemeyer and Voss (2000). The development and identification of MPIs for an organization is undertaken from the vision, objectives and strategy points of view and on the basis of the requirements of both the external and the internal stakeholders (see Kumar and Ellingsen, 2000, Liyanage 2003). The MPIs are required to be considered from the perspective of the multi-hierarchical levels of the organization. The first hierarchical level could correspond to the corporate or strategic level, second to the tactical or managerial level, and the third to the functional/operational level. Depending on the organizational structure, the hierarchical levels could be more than three. However, only three hierarchical levels are adopted for our MPM model. The maintenance indicators of the functional level are integrated and linked to tactical or middle level to help the management for analysis and decision making at strategic or tactical level. It is a challenge to integrate MPIs from top-down and bottom-up flow of information. Another important challenge exists for the involvement of all employees in this MPIs development process, so that everyone speaks the same language. The Subjectivity increases as we integrate the objective outcomes from the shop floor to get key performance indicators at higher level.

The effectiveness of any performance measurement system is meant to meet the needs of the operations and maintenance processes. The critical strategic areas vary from company to company, but generally include areas such as financial or cost-related issues, health safety and environment related issues, processes-related issues, maintenance task related issues, and learning growth and innovation related issues, while at the same time comprising the internal and external aspects of the company. It is important to link and integrate the overall objectives and strategy of the company. The linkage between visions, objectives and strategy and measures of performance such as return on investments (ROI) and health, safety and environment (HSE) indicators are considered in the proposed MPM model, as discussed and given in this case study. A logical cause-and-effect structure has been created, while identifying and deciding the different performance indicators for each critical strategic area to measure the maintenance performance. The proposed MPM model is designed to be balanced considering different criteria, holistic from the entire organizational point of view and integrated as a link-and-effect structure to achieve the total maintenance effectiveness both from external and internal effectiveness, which would contribute to the overall objective of the organization and its business units.

3. Case study and methodology

In this case study, the MPIs were studied for one of the pelletization plant of LKAB, Sweden, to link with the improvement in performance rate, availability and quality as maintenance performance indicators, amongst others. This study was limited to the conveyor belts of balling area of the pelletization plant. Action research approach was adopted for this study, including interactive process of interview and detailed discussion. The methodologies adopted were as under:

(i) The plant was visited and interviews were conducted with help of interview guide to understand the operation and maintenance process in detail; and to carryout a process mapping; integrating the process, production, maintenance and automation activities.

(ii) The total maintenance effectiveness of the process was studied both from internal and external stakeholders' point of view to understand the requirement and identify the MPIs.

(iii) The MPIs were studied both from multi-criteria and hierarchical levels based on the multi criteria and hierarchical maintenance performance measurement (MPM) model (Parida *et al.* 2005).

(iv) The plant stop data of the balling area were collected and analysed for MPIs like the availability, production rate, maintenance cost per ton and quality amongst others, as well as for maintenance decision making.

(v) Some other criteria though not directly related to maintenance performance were also considered from holistic, integrated and balanced view point in the model.

3.1 Maintenance process mapping

Process mapping is a critical and important initial step to understand the existing flow of various work processes constituting operation and maintenance process and existing work practices in the plant. The process mapping was conducted under two phases, like the; process study and interviews.

3.1.1 Process study - The production area of the process industry under study was studied in detail for understanding the production process and to undertake a process mapping. The conveyor belts were studied in detail to understand their layouts, design, capacity and drawbacks. The bottlenecks and the critical spots were studied for any likely drawback to the production process. The maintenance department is responsible for planning and execution of the maintenance activities. This is primarily done during planned maintenance stops. The production department takes an active role in performing the daily cleaning and maintenance checks, and initiating failure reports, as failure occurs or likely to occur. Simultaneously, the process engineer and the automation engineer also share their responsibilities to maintain the working condition of the system for achieving the desired production level. Besides, there are some external players, who are involved in condition monitoring; in maintaining the conveyor belts and rollers for the conveyor belts.

The existing maintenance strategy does follow the organization's vision and business objectives, based on which the production targets are set and the maintenance strategy has been formulated considering the business strategy. The maintenance strategy adopted at the plant can be characterized by the following types of maintenance:

- Planned stops- like yearly/half yearly/weekly stops
- Deferred maintenance
- Corrective maintenance
- Maintenance system recording (data collection)

- Operators maintenance (cleaning and inspection)

In the maintenance work process, the operator/production supervisor reports the maintenance requirements through:

(i) Failure stops – When ever there is a stop due to failure of the sub-system/components
(ii) Likely failure – Which is noticed due to partial/less operational failure of the components/sub-system

(iii) Operators inspection /observation – During these inspection/observations noticed for some failure or likely failure of components/sub-system. This is undertaken by the operators during the scheduled stops and corrective actions taken. These maintenance requirements are communicated to the maintenance planning mostly by the production chiefs.

Additional maintenance requirements are also obtained from:

(i) Inspections by the maintenance staff. These inspections are carried out during planned stops, so as to carryout detained inspection and checks.
(ii) Monitoring/data analysis; from the condition monitoring of components and sub-system. If this is non-continuous type, then the inspection also carried out during planned stop.
(iii) Input from improvement group after analyzing the maintenance/inspection data of the sub-system/system.

The maintenance activity could consist of; replacing, repairing, adjustments, inspection, pre-determined maintenance like lubrication, modification, no failure found (checking) and routine cleaning. The maintenance planning is made for undertaking the maintenance tasks immediately or may defer it to be undertaken during next daily/weekly stop or major maintenance stop depending on the urgency/priority of the maintenance tasks. Accordingly, the work orders are prepared and maintenance planning is worked out for provisioning of required manpower, material, tools and external assistance, if any. The maintenance plan is then implemented as scheduled, after which the inspection/checks are carried out to ascertain the correctness of functional efficiency of the components or the sub-system. All these activities are documented in to the operational/maintenance software system. The data so collected are analyzed and validated for any further operational improvements and to achieve the production targets.

3.1.2 Interviews - In order to understand the existing maintenance process, 38 personnel were selected depending on their positions and work assignments from production, maintenance, automation, account and finance, and process departments at shop floor and managerial level of LKAB. Interviews were conducted with the help of an interview guide to;

- Understand the production process, maintenance and automation, and describing process of balling area

- Types and classification of maintenance and analysis of maintenance tasks (process)
- Maintenance working process, work order, job card, maintenance planning, inspection system, maintenance task reporting, describing failure system of maintenance process
- How the maintenance task is carried out (implementation), maintenance data analysis
- Study the process design for, conveyor belts, gear boxes, motor, screen, and drum, ascertain the critical conveyor belts/components creating bottlenecks
- Can these maintenance tasks/modifications be planned to be undertaken during maintenance stop?
- To study the process design, OEM specification (where ever required), check/discuss with operators, technician, process and automation for any other insight/suggestions.
- Study and check the productivity figures, maintenance costs, targets and capacity to establish a possible linkage, how to improve the availability, speed and quality?

4. Data collection and analysis of the shorter stops for MPIs

Maintenance related data is collected through the maintenance reporting system at the plant. In reporting, the important activities are; when the work order is initiated (time), when the work order is finished (time), which system is maintaining the information (data), what is cost of maintenance, and spare parts cost. Two different information systems are in use for recording data of maintenance activities.

- Maintenance system
- Failure report system (operation system)

However, compatibility needs to be improved between these two systems. For example; while the maintenance system provides information of work order initiation, the finished time is indicated by failure reporting system only. A system of; weekly meeting and improvement groups meeting are in practice to discuss various maintenance/operational issues and take on spot decision.

4.1 Number of failures and stop time for conveyor belts.

The data for the number of stops and stop time are collected for analysis and is given in Figure 1. It is obvious that the number of stops and stop time will be higher than these values during 2005. Although there has been improvements made on the conveyer belts, they do not seem to affect the statistics in any higher extent. It must also be said that the stop time is waiting time and not actual repair time.

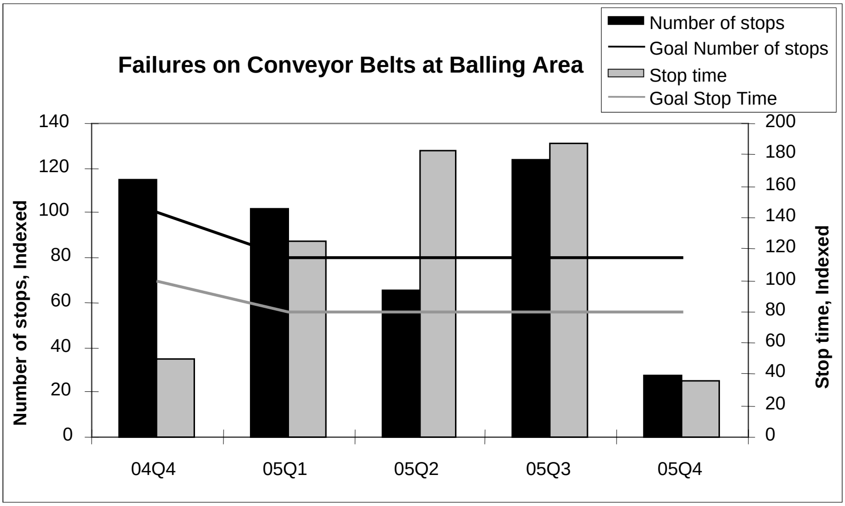

Figure 1 *Number of failures and stop time for conveyer belts at Balling area. Lines represent the goal value set for a quarter.*

Number of stops and stop time are indications of good monitoring and control measures at the operational and tactical level of the MPM framework. The stop time in hours for each conveyor belts of the balling circuits (BA 1 to BA 5, given at Table 1), provides a clear picture of the faulty conveyor belts, which need immediate management attention. The number of failure stops of the conveyor belts month wise is given at Figure 2, which also indicates the belts requiring critical attention. As can be seen in the Figure 2; belt A has maximum number of stops during February-March and June to September 2005. After taking corrective measures during the planned maintenance stops of April and October, the number of failures reduced almost to the desired level.

Table 1. *Stop time for all balling areas and mixer showing each conveyer belt 2005 (>6 h/month marked grey)*

2005

Belt	BA 1	BA 2	BA 3	BA 4	BA 5	Total
Belt A	36	5	1	18	16	**75**
Belt B	1	7	26	8	8	**50**
Belt C	3	1	5	3	1	**14**
Belt D	0	8	1	1	0	**10**
Belt E	5	69	0	0	0	**75**
Belt F	78	10	81	6	0	**175**
Belt G	11	2	1	42	8	**64**
Belt H	23	3	0	40	0	**67**
	157	**105**	**115**	**119**	**34**	**530**

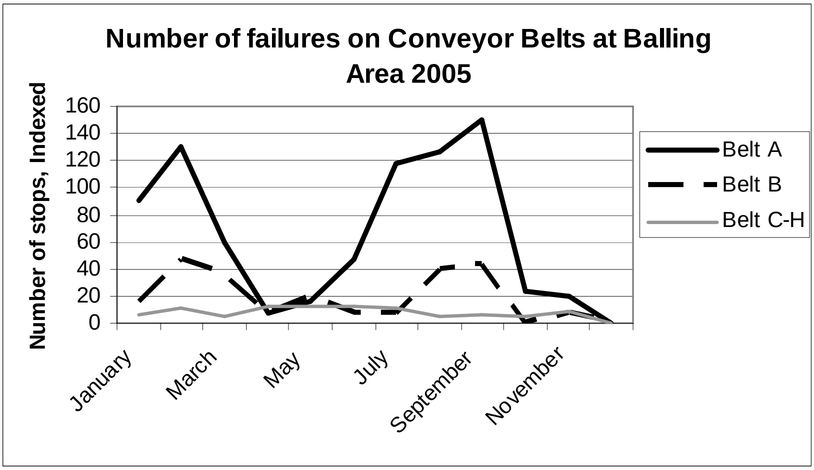

Figure 2 *Number of failures for conveyer belts at Balling area. Belt A and B vary over time but the others not very much.*

4.2. Availability

Maintenance department has the responsibility for achieving the stated availability of the system and this can be followed in failure report system. Measuring the availability in a system where at least four units should work is not easy. Figure 3 shows the availability level of the balling area when combinations of five or four balling circuits are working. The availability state of the balling circuits provides the desired information to the managers at tactical level for achieving the targeted production figure. If the availability figure is down the desired level, the manager at the tactical level has to look in to the problems and the issues; and find a quick solution**.**

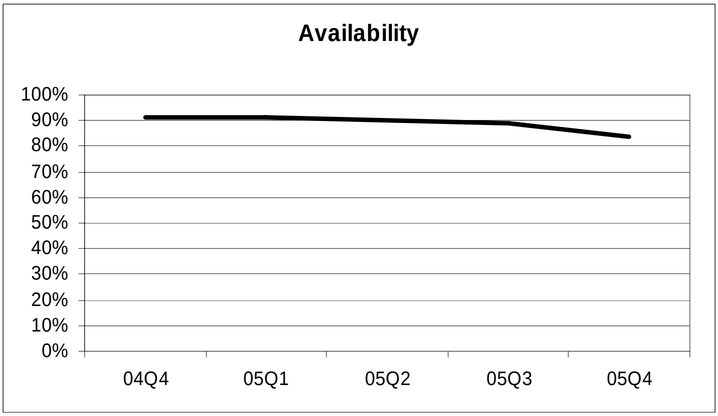

Figure 3 Availability state with number of drums working

4.3 Performance speed
The output from the balling area is very much dependant on the screen. A new routine was established in April that the screen should be checked every 2 000 h and it has been proved that the production speed has increased since the planned maintenance stop in April. The adjustment was initiated by the process engineers and is seen as an improvement activity.

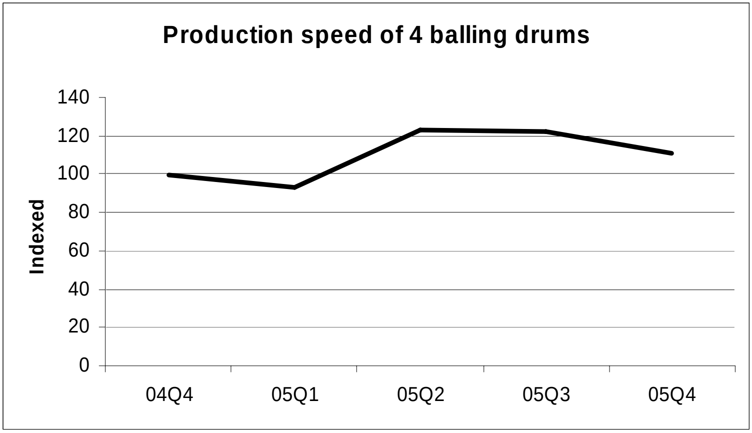

Figure 4 *Performance speed*

It is important to upkeep the maintenance standard and maintenance department is responsible to keep the screen in such a good condition that this is possible. In this work, more ore paste is put into the process (increase of speed) and less oversized pellets are rejected (quality is increased). During the last quarter 2005, it is seen that the production speed has decreased and it is a sign that the standard is not kept**.**

4.4 Quality
In LKAB quality is defined as properties of the product and is nearly equal to the acceptable standard to sell to the customer. These qualities are quantified in the parameters like;

- Iron content
- Silica content
- Pellet size
- Strength

All these parameters are regularly and strictly measured, tested and ensured in the plant. There are no major quality problems existing in LKAB as of today. In the literature of maintenance and especially in the Total Productive Maintenance (TPM) literature, quality is used for products that need rework. The cost will increase in case the product needs rework. In case of pellets production, the size wise rejected pellets are re-circulated in to the balling circuits.

4.5 Identifying existing MPIs and linking with organizations objectives and strategies

Performance measurement (PM) system needs to be aligned to organizational strategy (Kaplan, 1983; Eccles, 1991, Murthy *et.al,* 2002). The total effectiveness based on organizational effectiveness concept includes both the external and internal effectiveness of the organization. The external effectiveness is high lighted by stakeholders need like return on investment and customer satisfaction, which is the front end process. The internal effectiveness is high lighted through the desired organizational performance reflected by availability, performance speed and quality of product or services rendered and the back processes like the spare parts availability, supply chain management, and optimized resources like workforce excellence including knowledge up gradation and innovations. The internal effectiveness process is also called as back end process of the organization.

Different figures or targets set by top management are permeated down the levels of the organization up to the shop floor. For example, to achieve a set target of production, if the requirement is to achieve an OEE level of 75 % at strategic level, the requirements at tactical or middle level are; availability of 90 %, production of speed of 500 ton/hour and a quality level of 99 %. When these are translated to the shop floor level, the maintenance indicators are to keep the number of maintenance stop at 0.8 per belt per month or the stop time to remain below 1.2 hour per belt per month. The shop floor engineers and managers at middle level have to intervene and take preventive decision, once these limits are crossed. Similarly, when these indicators are aggregated upwards, it will lead to the aggregated target set by the top management. The maintenance indicators are specific and objective at the shop floor level and their objectivity converts to subjectivity as the aggregation level reaches upward at the top management level.

The existing MPIs identified are; availability, performance speed, number of stops, Number of accidents, environmental complaints and quality complaint numbers. However, these MPIs are not analyzed frequently as it should have. As a result, these are not reflected the effective utilization of work force and organizational performance, to an extent.

5. Development of MPIs and multi-criterion hierarchical MPM model

The internal and external aspects, which act as parts of a back-end or front-end processes, need to be analyzed before deciding the relevant criteria at various levels for the maintenance performance measurement. The front-end process is derived from the needs of the external stakeholders, e.g. the shareholders or owners, financers, customers, suppliers and regulating authorities. Therefore, the front-end process needs could include higher productivity, HSE ratings, timely delivery and quality. The back-end process, which is derived from internal aspects like the capacity and capability of the organization, comprise of the departments, employee requirements, the organizational climate and skill enhancement. The back-end processes are; cost reduction, employee retention and innovation. The MPIs at functional and tactical levels gets aggregated at strategic level. A balanced, holistic and integrated multi-criteria hierarchical model linking MPIs is proposed in this model and given at Figure 5. The three hierarchical levels are; Strategic/Senior Manager/Plant, Tactical/Middle manager and Functional/Operators level. The multi-criteria, which are considered and included in this MPM model, are;

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

The new set of MPIs developed under these seven criteria was critically checked both qualitatively and quantitatively for the balling area of KK3 Plant of LKAB. The MPIs 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
9. Maintenance cost per ton

The existing and new set of MPIs under seven criteria of the Multi-criteria Maintenance Performance Measurement (MPM) Framework for balling area of KK3 Plant of LKAB is given at Figure 5.

External Effectiveness
-Regulating Bodies/ Government/ Local/Envir-onmental etc
-Shareholder
-Financier
-Suppliers
-Customers etc

Front-end process
-Higher-Productivity
-Timely delivery

Back-end process
-Cost reduction
-Employee retention
-Innovation

Internal Effectiveness
-Departments Integration
-Employee Unions etc
-Org. climate
-Skill enhancement

Hierarchical LEVEL OF MPIs / MULTI-CRITERIA OF MPIs	Level I	Level II	Level III
	Strategic/Senior Manager/ Plant	*Tactical/Middle manager/ system/ subsystem*	*Functional/ Operators/ Equipment/ item*
Equipment/ Process related	1. OEE (Total production)	1.Availability 2.Downtime(hours) 3.Performance speed 4.Impact of quality	1.No of stop 2.Downtime(hours)
Cost-related/ Financial	2.Maintenance cost per ton 3.Production cost per ton	5.Maintenance cost 6.Production cost/ton	
Maintenance Task-related		7.Change over time 8.Planned maintenance tasks 9.Unplanned tasks	3.Change over time 4.Planned maintenance tasks 5.Unplanned tasks
Learning & Growth/ Innovation	4.Number of new ideas generated 5.Skill improvement & training	10.Number of new ideas generated 11.Skill improvement & training	6.Number of new ideas generated 7.Skill improvement & training
Customer Satisfaction related	6.Quality complaint numbers 7.Quality return	12.Quality complaint numbers 13.Quality return	8.Quality complaint numbers 9.Quality return
Health, safety & environment (HSE)	8.No of accidents 9.HSE complaints	14.No of accidents or incidents 15.HSE complaints	10.No of accidents or incidents 11.Environmental standards/ complaints
Employee/ Satisfaction	10. Employee complaints	16.Employee complaints	12.Employee complaints

Figure 5 *Suggested Multi-criteria Maintenance Performance Measurement (MPM) Framework* for *balling area of KK3 Plant of LKAB* (Adapted from Parida *et al*., 2005)

6. Conclusion

An attempt has been made in this case study to study the existing system, identify the relevant maintenance indicators and adapt a balanced, holistic and integrated MPM model for the balling area of KK3 plant of LKAB and to align the plant performance with the corporate strategy. The short plant stops and planned maintenance stops data have been analysed and relevant maintenance indicators were identified for effective monitoring and control of maintenance, during the conduct of this study.

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References

Andersen, B. and Fagerhaug, T. (2002). Eight steps to a new performance measurement system, *Quality Progress*, 35, 2, pp. 1125.

Eccles, R. G. (1991). The performance measurement manifesto, *Harvard Business Review*, January-February, pp. 131-137.

EEA (European Environment Agency), Environmental indicators: Typology and overview. “Technical Report No 25”, 1999, Copenhagen.

Engelkemeyer, S. and Voss, R. (2000). Bearing the gift of royal performance indicators, *Quality Progress*, 33, 2, pp. 35-39.

Kaplan, R. S. (1983). Measuring manufacturing performance: a new challenge for managerial accounting research, Accounting Review, Vol.58. No. 4. pp. 686-703.

Kennerly, M. and Neely, A. (2003). Measuring performance in a changing business environment, *International Journal of Operation and Production Management*, Vol. 23, Number 2, pp. 213-229.

Kumar, U. & Ellingsen, H.P. (2000). Development and implementation of maintenance performance indicators for the Norwegian oil and gas industry. *Proceedings of the 14th International Maintenance Congress (Euro maintenance 2000)*, 7-10 March 2000, Gothenburg, Sweden, pp. 221-228.

Lingle, J.H. and Schiemann, W.A. (1996). “From balanced scorecard to strategy gauge: Is measurement worth it?” Management Review, March, pp. 56-62.

Lynch, R. L. and Cross, K. F. (1991). Measure Up- The essential Guide to Measuring Business Performance, Mandarin, London.

Murthy, D. N. P, Atrens, A. and Eccleston, J. A. (2002). Strategic maintenance management, *Journal of Quality in Maintenance Engineering*, Vol. 8, No. 4, pp. 287-305.

Parida, A., Ahren, T. and Kumar, U. (2003). Integrating Maintenance Performance with Corporate Balanced Scorecard, “COMADEM 2003”, Proceedings of the 16th International Congress, 27-29 August 2003, Växjö, Sweden, pp. 53-59.

Parida, A. and Kumar, U. (2004). Application of Overall Equipment Effectiveness (OEE) as a Process Performance Indicator: A case study from Kiruna Mines, "ENTMS 2004", 11-12 May, Bhubaneswar, India, pp. 32-35.

Parida, A., Chattopadhyay, G and Kumar, U (2005). Multi Criteria Maintenance Performance Measurement: A Conceptual Model, Proceedings of the 18th International Congress of COMADEM, 31st Aug-2nd Sep 2005, Cranfield, UK, pp 349-356.

Wireman, T, (1998). "Developing Performance Indicators for Managing Maintenance", Industrial Press, Inc, New York.

PAPER 4

Maintenance performance measurement system: Application of ICT and e-Maintenance Concepts

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Maintenance performance measurement system: Application of ICT and e-Maintenance Concepts

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Abstract

With emergence of intelligent sensors to measure and monitor the health state of the components and implementation of information and communication technologies (ICT), conceptualization and implementation of e-Maintenance is becoming a reality. e-Maintenance facilitates decision making in real time by monitoring plant and systems health and its behaviour in real time, benchmarking the status against the specified standards and by evaluating the associated business risks with various alternatives at hand by using embedded intelligent sensors internet and technology. To benchmark the health state and the performance characteristics invariably different types of performance trend charts and indicators are envisioned to be generated and implemented for use by the experts while making decisions in maintenance. Though, e-Maintenance shows a lot of promise, seamless integration of ICT into the industrial environment and setting, remains a challenge. In this paper, the author argues that understanding the requirements and constraints from maintenance performance and ICT perspective is essential for effective implementation of such concepts. The related issues are needed to be addressed for successful use of ICT and e-Maintenance for measuring maintenance performance. The paper discusses the concepts of e-Maintenance and is based on experiences gained through an ongoing project in this area and examines its applicability for generating on-line indicators suitable for various hierarchies in management.

Keywords: information and communication technology (ICT), e-Maintenance, embedded intelligent sensors, performance measurement, performance indicator

1. Introduction

The production and process industries are passing though a phase of continuous transformation and improvement due to dynamic global changing business scenario coupled with advancement of information and communication technology (ICT). The business scenario is focussing more on e-business intelligence to perform transactions with a focus on stakeholders' need for enhanced value and improvement in asset management. Prognostic business need of this type, demands to reduce the operational downtime by reducing machine degradation and maintenance times through effective maintenance performance measurement (MPM). Such organizational requirements need the development of a proactive maintenance strategy, which can deliver continuously improved performance with decreased numbers of failure and breakdown.

Without any formal measures of performance, it is difficult to plan control and improve the outcome of the maintenance process. Maintenance performance measurement (MPM) is receiving a great amount of attention from researchers and practitioners in the recent years due to a paradigm shift in maintenance. The performance measurement (PM) system needs to be aligned with the organizational strategy (Eccles, 1991; Kaplan and Norton, 2001; Murthy *et al*., 2002). Corporate or business performance management controls, monitors and align these individual business and operational units together to ensure that they are working for the same corporate strategy.

The main problem for decision-making in operation and maintenance process is the non-availability of relevant data and information. The recent application of information and communication technology (ICT) and other emerging technologies facilitate easy and effective collection of data and information. To support the right decision making in operation and maintenance processes, the information logistic needs to be streamlined, and the information logistics are; the right information, at the right time, to the right person, in the right form and format (Parida and Kumar, 2004). With the growing application of plant health condition monitoring and internet in the management of maintenance process, the information logistic is required to be streamlined. The e-condition monitoring, using intelligent health monitoring techniques like; the embedded intelligent sensors through wireless communication system, is integrated with the maintenance process, to monitor and control the health status of plant and machineries. This is achieved by analyzing the data after it has been collected through effective decision making. The most important application of the measurement is the identification of opportunities to improve existing equipment and plant state, before new investment or to promote improved supplier performance. Thus, application of the ICT and e-Maintenance can facilitate the on-line and off-line health status condition monitoring and taking right decision for management of the maintenance process.

As a result of serious accidents and statutory violations by the corporate world, like; BP’s 300 violations in USA (Bream, 2006); and changes in legal environment, the asset managers are likely to be charged with “accident and deaths” due to changes in the legal environment for the future actions or omissions of the maintenance efforts (Mather, 2005). Due to outsourcing, asset owners and asset managers are separated, making it a complex accountability for the asset management. Therefore, measurement of asset maintenance performance and its continuous control and evaluation is becoming critical for the long term value creation and economic viability for many industries. The performance of the maintenance process is monitored and measured, for taking appropriate and corrective actions to reduce and mitigate risks in the area of safety, enhance the effectiveness and efficiency of the asset maintained and meet the societal responsibilities.

2. Concept of e-Maintenance

e-Maintenance is a management concept whereby operations involving the plants and machineries are monitored and managed over wireless and on real-time communication through use of intelligent sensors. e-Maintenance provides the organization with intelligent tools to monitor and manage assets like; machines, plants, proactively through ICT. It facilitate to ascertain the state in which the process or asset is working and detects likely failure of the asset to avoid incidents, accidents and the loss caused thereby. Use of ICT focuses on the health degradation monitoring and prognostic, instead of fault detection and diagnostics. Today, with availability of unique e-Maintenance solution, industry can benefit from the server-based software applications, latest embedded internet interface devices and state-of-the-art data security. With access to the e-Maintenance solution, the following systems can be accessed by the concerned industry.

- Instant virtual supervisory control and data acquisition (SCADA) and computerised maintenance system facilities to manage plants and equipments
- Real time monitoring and control including alerts through condition monitoring
- Maintenance systems availability for 24 hours a day and 7 days a week
- Web-based technical support and solution
- Virtual instrument panels on desktop computer
- Data availability, confidentiality and integration for e-Maintenance solution

As it can be seen, e-Maintenance creates a virtual knowledge centre with users, technicians/experts and the manufacturers, specializing in operation and maintenance of manufacturing, process and service industry. e-Maintenance provides solution in its entirety for the process industry with objectives to reduce the overall costs, bring in a change and savings in resources through maintenance performance indicators (MPIs) like; overall equipment effectiveness (OEE) and return on maintenance investment (ROMI) etc. Condition monitoring techniques generally include one or several alarms that are triggered, if a tolerance limit is exceeded or if a trend deviates from the expected values in time. References of the working points of signals are provided by knowledge-based systems and by comparison with a model of the system. These signals are acquired by sensor system (Lodewijks, 2004). An e-Maintenance solution consists of virtual connectivity of:

- Plant/equipment fitted with intelligent and wireless sensors
- On-line (wireless) connectivity to outsourced contractors/stakeholders
- Operation/control platform of online and wireless warning system
- Virtual maintenance team or expert support

The real time connectivity amongst all concerned stakeholders is mentioned which facilitates collection of system health and performance information. US companies have a substantial lead in the interoperable maintenance-oriented tools area with MIMOSA (Machinery Information Management Open System Alliance), which has elaborated a set of standards (Kahn and Klemme-Wolf, 2004). In the Europe, organizations like ITEA (Information Technology for European Advancement), established in 1999, conducting PROTEUS project (ITEA 01011) to provide a fully integrated platform to support any broad e-maintenance strategy (Thomas *et al.* 2004). Other e-maintenance platforms, which are trying to standardise are; CASIP (Baptise, 2004) and GEM@WORK (Wang *et al*. 2004).

2.1 e-maintenance framework. Some of the existing e-Maintenance solutions provide the server based software, equipment embedded internet interface devices (health management card) through condition monitoring. These e-Maintenance solutions provide 24 x 7 (24 hours a day and 7 days a week) real-time monitoring, control and alerts, at the operating centre. This system converts data into information, available to all concerned stakeholders for decision-making and predicting the performance condition of the plant and machineries on a real time basis. This enables the system to match with the e-business and supply chain requirements. For example, once the supervisor knows the plant degradation condition, its related effects on material, and inventory, then the delivery status can be planned and coordinated with a greater speed to satisfy the customer.

A broad e-maintenance framework indicating different stakeholders and their role is given at Figure 1. A stakeholder is a party having a right, share or claim in a system or in its possession of characteristics that meet that party's needs and expectations (ISO/IEC 15288). In this framework, the stakeholders are; internal, like; the management, employees, different groups or departments, and external, like; the customers, suppliers, outsourced agencies and partners, regulating authorise, virtual consultants/experts etc.

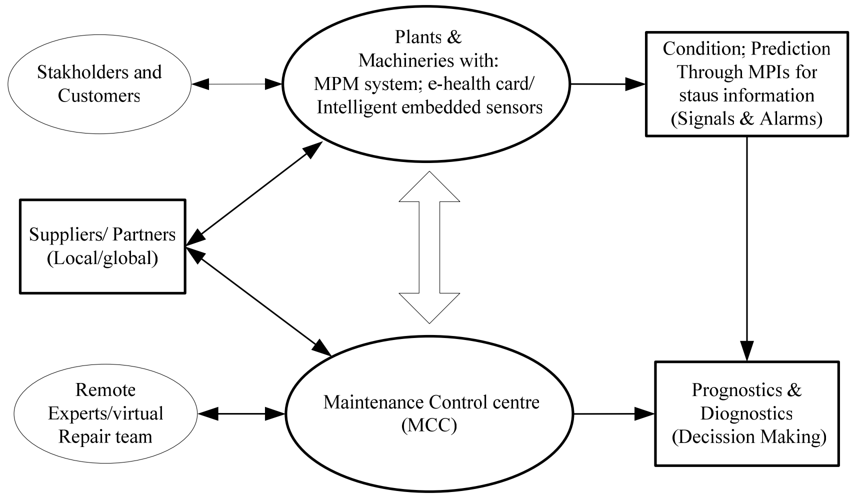

Figure 1 e-maintenance framework, Legend used: MPM: Maintenance performance measurement, MPIs: Maintenance performance indicators

The plant/machinery health state condition data is collected through the e-health card/intelligent embedded sensors and compared with the pre-specified MPI limits. Accordingly, once the warning or alarm level is reached all affected parties get a signal to have a look and take appropriate preventive/predictive action. The maintenance control centre (MCC) controls, monitor and coordinate all maintenance activities in-house or through help of the experts on-line and virtual repair teams. The suppliers or the outsourced partners are also part of this e-Maintenance network and provides real time support as and when required. Since, the customers and other stakeholders are getting real time information and support as well; the e-Maintenance framework can take care of all stakeholders. As it can be seen, e-Maintenance creates a virtual knowledge centre with users, technicians/experts and the manufacturers, specializing in operation and maintenance. E-Maintenance can provide solution in its entirety for the process industry with objectives to reduce the overall costs, bring in a change and savings in resources through MPIs like; OEE and ROMI etc.

Plant/equipment health management system (PHMS) can be defined as an approach used for corrective, preventive and predictive maintenance besides other supportive activities. With a need to achieve zero down time, zero defect, instantaneous response and decision making, and world class OEE (overall equipment effectiveness) performance; prognostics and diagnostics are used through embedded sensors and device to business tool (D2B). PHMS thus, consisting of condition monitoring (CM) diagnostics and prognostics, and condition based operation and support, can improve the dependability and safety of the technical systems, besides decreasing life cycle cost of varying and complex demands of operation and support (Mobley, 1990, Compbell and Jardine, 2001), (Soderholm and Akersten, 2002). This system delivers data and information, which indicates the health condition of the system. The stakeholders of the system are the receivers of the data and information (Lyytinnen and Hirschheim, 1987, ISO/IEC 1528.2002), Soderholm, 2003). The problem today in a health management system is the existing information islands, i.e. the different specialized systems, with in an organization speaking a different data and information language.

Some of the existing e-Maintenance solution provide the server based software, equipment embedded internet interface devices (health management card). These e-maintenance solutions provide a real-time monitoring, control and alerts, at the operating centre. This system converts data in to information, available to all concerned for decision-making and predicting the performance condition of the plant and machineries on a real time basis. This enables the system to match with the e-business and supply chain requirements. For example, once the supervisor knows the plant degradation condition, its related effects on material, and inventory, then the delivery status can be planned and coordinated with a greater speed to satisfy the customer.

3. An integrated e-Maintenance approach for measuring maintenance performance

The three primary components of an e-maintenance system are; (1) the maintenance environment, i.e. the plant, equipment and organization as well as the operating environment; (2) the embedded (sensor based) computing technology; and (3) the communication technology (platforms, architecture, protocols and adapters). To facilitate successful e-Maintenance system, these three components must be considered in an integrated manner; the design and development of (2) and (3) should address the constraints and requirements defined by the maintenance environment (1). For measuring maintenance performance, an integrated e-Maintenance system is needed. The MPM system supported by e-Maintenance and ICT collects the maintenance activity related information through the MPIs, when linked into the operational information; facilitate to evaluate performance and decision making to achieve enhanced maintenance effectiveness.

While evaluating the MPIs, the evaluation are carried for the plant and machineries, for a specified period along with their history and the results are analysed for preparing report for decision making. These MPIs could be analogue or digital indicators for the decision makers. Managing these aspects of the information needs effective information management, involving all stakeholders. With application of intelligent e-Maintenance system into the manufacturing, process and service industries, the management of maintenance information system converts the shop floor data into useful information so that appropriate decisions can be made through on-line or through wireless means.

From maintenance point of view, avoiding data overload and information island are the important requirements. Data overload in the maintenance system can create problem for taking appropriate decision making due to non-availability of right information creating tremendous work overload. Information island, similarly prevents the integration of information within the organization. Besides these two, the following constraints and challenges in the design, development and deployment of an e-Maintenance system from an ICT perspective as follows are visualized (Parida et al. 2004).

- The system is inherently heterogeneous – the types of plants and equipment being monitored, the types of computing devices involved (from traditional desktop computers and handheld personal digital assistants to miniature, resource-limited sensors), the physical media of communication (wire line and wireless) and the nature of access (stationary and mobile). Hence, the one size fits all paradigms are inapplicable.
- Given the challenging, hostile environment in which computation and communication will be carried out, network survivability and fault tolerance are of primary importance.

- In such environments, we anticipate intermittent connectivity as being the rule rather than the exception. Hence, opportunistic communication architecture is necessary.
- There is a need to explore if the new generation of cognitive, smart radios (FCC, 2003) can be integrated onto miniature sensors for facilitating robust, energy-efficient sensor networking.
- The existence of ambient intelligence (sensors) in the environment could be used for enabling the location of equipment and personnel, situational (normal/ emergency, etc) computing.
- Given that the data being monitored and transmitted could be of varying levels of importance (from mission critical to casual), there is a need to provide differentiated, prioritized service while collecting and transferring such data.

4. Discussion

Maintenance has come a long way from the mechatronics to the infotronics stage. Adopting the emerging condition-based component degradation and monitoring system, integrated with appropriate e-Maintenance model, organizations can achieve effective maintenance monitoring and control through measuring maintenance performance. Managing varieties of condition monitoring information demands effective information management involving and integrating all stakeholders, so as to achieve the desired maintenance performance. With development and emergence of intelligent e-Maintenance in the manufacturing and process industries, the objectives of managing maintenance information system is to convert the field data into useful information, so that decisions to achieve desired maintenance performance can be made on-line and/or remotely through wireless means.

However, various constraints and challenges, as appropriate to the organizations' are to be resolved, prior to the e-Maintenance system's adoption and implementation. The e-Maintenance real time measuring system can act as a performance driver and help the organizations to know the plant/equipment health state and take prognostic action well in advance. This integrated approach of the e-Maintenance system using ICT for measuring maintenance performance can support and facilitate the organization to have transparency and good corporate governance, while taking care of the health, safety (accident prevention), economic, and environmental issues.

e-Maintenance will facilitate to provide real time information to the different hierarchical levels of the organization, so as to provide the right information in the right quantity to right people, at right time and place, in right format. This will facilitate ease of taking right decision across the organization. This flow of information will create transparency and inter-subjectivity at all levels.

5. Conclusion

Managing effective information with condition based component degradation and monitoring system coupled with e-Maintenance model can lead to an effective and integrated MPM system for the organization. The consideration of cost reduction, reducing downtime and improving availability, with the use of maintenance performance indicators forms integral part of this MPM system. This paper has discussed various conceptual issues for the role of ICT and e-Maintenance in measuring maintenance performance.

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References

Baptise, J. (2004). A case study of remote diagnosis and e-maintenance information system, e-proceedings of Intelligent Maintenance System, 15-17 July, Arles, France.

Bream, R (2006). Lawsuit poses further risk to BP's image, Financial Times, Friday, June 30.

Campbell, J.D. and Jardine, A. K. S. (2001). *Maintenance excellence: optimizing equipment life-cycle decisions*. Marcel Dekker, New York.

Eccles, R. G. (1991). The performance measurement manifesto, *Harvard Business Review*, January-February, pp. 131-137.

FCC (2003). Cognitive Radio Technologies Proceedings, Federal Communications Commission (FCC), May 2003.

ISO/IEC 15288, (2002). Systems Engineering: System Life Cycle Processes. International Organization for Standardization, Geneva Commission Electrotechnique Internationale, *Geneva.*

Kahn, J and Klemme-Wolf, H (2004). *Overview of MIMOSA and the Open System Architecture for Enterprise Application Integration*, Proceedings of the 17th European Congress, pp. 333-341, May 2004.

Kaplan, R. S. and Norton, D.P (2001). Transforming the balanced scorecard from performance measurement to strategic management Part I, "*Accounting Horizons*", Vol.15, Issue 1.

Lee, J. (1999). *Machine Performance Assessment Methodology*, Reports on Frontiers in Engineering, pp. 75-83, National Academy of Engineers

Lodewijks, G. (2004). Strategies for Automated Maintenance of Belt Conveyer Systems, *Bulk solids handlings*, Volume 24, No. 1. January/February, pp.16-22.

Lyytinnen, K. and Hirschheim, R. (1987). *Information system failures: a survey and classification of the empirical literature. Oxford surveys in information technology.* Oxford University Press, Oxford, 4, p. 257-309.

Mather, D (2005). An introduction to maintenance scorecard, *The plant maintenance News letter* edition 52, dated 13 April 2005.

Mobley, R. K.. (1990). *An introduction to predictive maintenance.* Van Nostrand Reinhold, New York.

Murthy, D. N. P, Atrens, A. and Eccleston, J. A. (2002). Strategic maintenance management, *Journal of Quality in Maintenance Engineering*, Vol. 8, No. 4, pp. 287-305.

Parida, A; Phanse, K and Kumar, U. (2004). An integrated approach to design and development of e-maintenance system. *Proceedings of VETOMAC-3 and ACSIM-2004*, New-Delhi, Dec 6-9, pp. 1141-1147

Parida, A and Kumar, U. (2004). Managing Information is key to Maintenance Effectiveness, in the *e-Proceedings of the Intelligent Maintenance System (IMS)' 2004*, July 15-17, 2004, Arles, France.

Söderholm, P. (2003). *Continuous Improvement of Complex Technical System: Aspects of Stakeholder Requirements and System Functions*. Licentiate Thesis, Division of Quality and Environmental Management, Lulea University of Technology, Sweden.

Söderholm, P. and Akersten, P. A. (2002). Aerospace Diagnostics and Prognostics in a TQM- Perspective. *Proceedings of the 15th Intenational Congress of COMADEM*, 2-4 September, Birmingham, UK, 80-89.

Thomas, B; Denis, R; Jacek, S.; Jean-Pierre, T and Noureddine, Z. (2004). PROTEUS – An Integration Platform for Distributed Maintenance Systems. *Proceedings of the 17th European Congress*, pp. 333-341, May 2004.

Wang, X, Liu, C and Lee, J. (2004). Intelligent Maintenance Based on Multi-sensor Data Fusion to Web-enabled Automation Systems, Proceedings of the 17th European Congress, pp. 333-341, May 2004.

PAPER V

Managing information is key to maintenance effectiveness

Parida, A. and Kumar, U. (2004) Managing information is key to maintenance effectiveness, The e-Proceedings of the Intelligent Maintenance System's (IMS), July 15-17, Arles, France

Managing Information is key to Maintenance Effectiveness

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Abstract

Under present business scenario, maintenance is emerging as an important part of the strategic thinking of assets owners and infrastructure managers. To manage maintenance activities effectively, measurement of the maintenance performance is desired to be undertaken. Implementation of a successful maintenance performance management system essentially necessitates an effective management of all relevant maintenance related information. Managing information is important to enhance the effectiveness of maintenance process. Right information in right time facilitate easy and correct decision making. With the advent of ICT (information and communication technology), asset owners and managers are finding it easier to use information in an innovative manner to enhance maintenance effectiveness and thereby reduce the business risks related to production volume, quality and safety targets. A step taken towards implementation e-Maintenance concepts is one of such example, where the goal is to facilitate seamless flow of maintenance and production related information to meet the business goals. In this paper, we discuss the importance of information logistics with a special reference to management of maintenance process. While discussing various aspects of maintenance information system, a conceptual framework for e-Maintenance and performance measurement for maintenance effectiveness is discussed in this paper.

Keywords: *Maintenance information, e-Maintenance, Information and communication technology (ICT), Performance indicator*

1. Introduction

Improvement in maintenance performance and effectiveness is a topic of great interest to industry managers and researchers, for its significant impact on safety, dependability and financial activities [1,2]. To enhance the effectiveness of maintenance, its performance must be monitored; measured and corrective actions should be taken. Performance measurement of the maintenance process provides a basis for improvement, since without measurement the improvement cannot be judged. Performance measurement is a powerful methodology, which allows engineers/managers to plan, monitor and control their operation/business. However, measuring the performance of maintenance process is a complex task, since multiple inputs and outputs; both desirable and undesirable are involved in the maintenance process. . The performance management is dependent on the quality of information being collected and processed for the purpose. Such information are characterised by various indicators developed by processing raw data and other related information. Such indicators which describe the performance of maintenance process are called maintenance performance indicators (MPIs). A maintenance indicator is a product of several metrics (measures), when used for measurement of maintenance performance in an area or activity; is called the maintenance performance indicators [2, 3, 4]. Different performance measurement and analysis systems like the balanced scorecard [5], performance pyramid system [6] and the performance prism [7] are well known. Performance indicators are applied in order to find ways to reduce down time, costs and waste, operate more efficiently, and get more capacity from the operational lines.

To develop, control indicator or to launch maintenance improvement programme, we need to understand the various sub processes constituting maintenance process (see Figure 1) and types of information needed to make these processes effective and streamline the information logistic: "*right information in the right formats and form to the right person in the right time*".

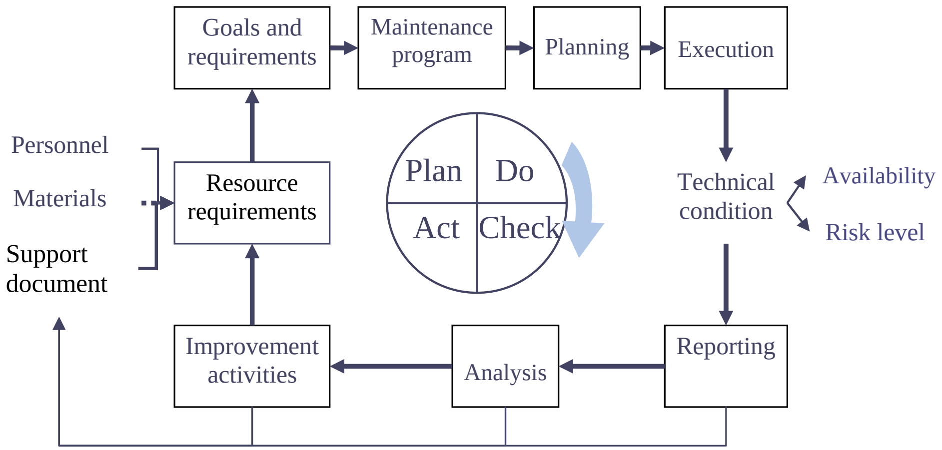

Figure 1. Maintenance management process
Adapted from [22]

The maintenance goals and requirements are derived from the organizational goals and objectives. Based on the maintenance objectives, the maintenance program of the process and sub-processes are decided and required maintenance planning is made based on the technical conditions and resources requirements. Operational requirements, resource availability and schedule have to be considered for the planned maintenance activities. The implementation of undertaken maintenance plan enhances the availability of the equipment and reduces the associated risks.

The information collected about the technical condition of the equipment are analyzed for evaluating both performance and improvement activities within sub-processes.As visualized in figure.1, each maintenance sub-process needs information for implementation, monitoring and control of the activities within that sub-process and to produce in put to the next sub-process. Information is common to all the sub processes of the maintenance process. The summation of the information flow from all the sub-processes also enhances the maintenance effectiveness through efficient monitoring and control.

A modern day condition monitoring uses various intelligent health monitoring techniques to monitor and control the health status of plant and machineries. Flow of information through online and off-line condition monitoring and measurement of degradation of plant and machineries is an essential requirement for the management to facilitate right decision making. The application of information and communication technologies (ICT) facilitates the on-line and off-line condition monitoring and measurement.

In this paper, an information model for maintenance effectiveness is developed and discussed. In this model, the information is managed on-line and/or remotely through wireless means.

2. Managing Information

Data are consisting of raw numbers and facts, while information is a processed data or flow of messages. Knowledge is actionable information that is possessed in the mind [9, 10].

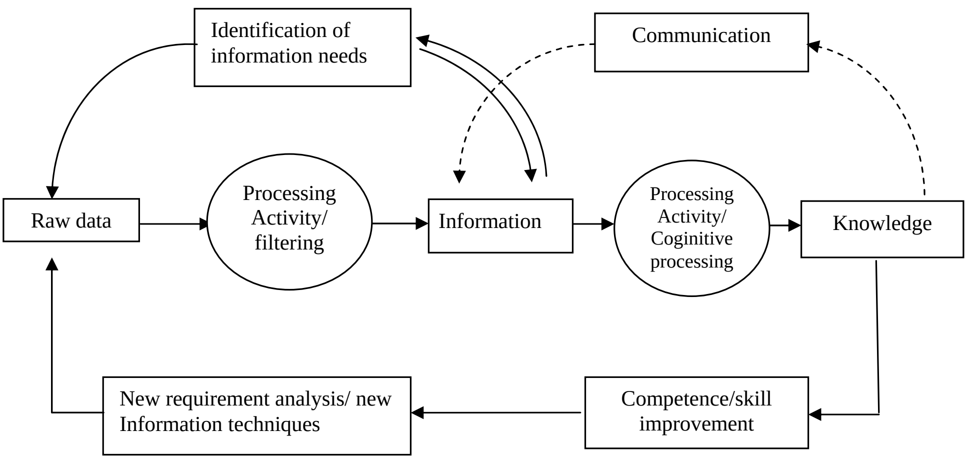

Figure 2. Basic information model

Alavi and Leidner [11] argued that information becomes knowledge, when it is processed in the mind of an individual and knowledge becomes information, when it is articulated or communicated to others in the form of text, computer output, speech or written words, etc. So, information is obtained by processing the raw data for some meaningful conclusion from the quantitative or qualitative data. Effective information processing needs means to communicate the inferences to convert it into knowledge. The basic concept is given at figure 2.

The flow of information for maintenance objective as considered by organizational management is given in figure 3. Information management forms part of organizational management of the processes and systems that collect, create, organize, shares, distributes and uses information. In a production organization, the information is required to establish the production requirement, which is obtained from the stakeholder's requirement and decided after assessing the capacity requirement, as well as the equipment's availability requirement. This leads to establish the production and maintenance objectives of the organization. All these activities need data and information to establish the maintenance objectives. Information is also required for maintenance planning and resources scheduling.

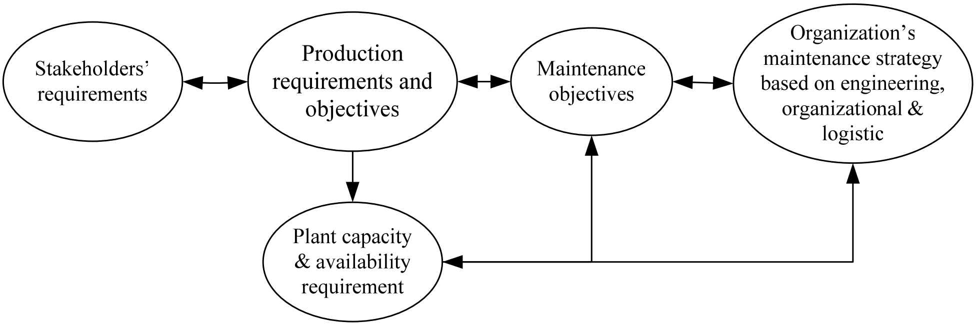

Figure 3. Maintenance objective and information flow

Data management has been called one of the biggest weaknesses of maintenance operations in the world [12]. This weakness compels the maintenance staff to adopt a reactive approach, resulting in a low reliability, availability and high cost. For maintenance operation, the interaction and information flow between the operators to the maintenance personnel is vital.

Effective information flow is the backbone of maintenance management. From the old system of person to person (verbal/written) system, computerised system with the help of ICT is the need of the hour for all operational units as shown in Figure 4.

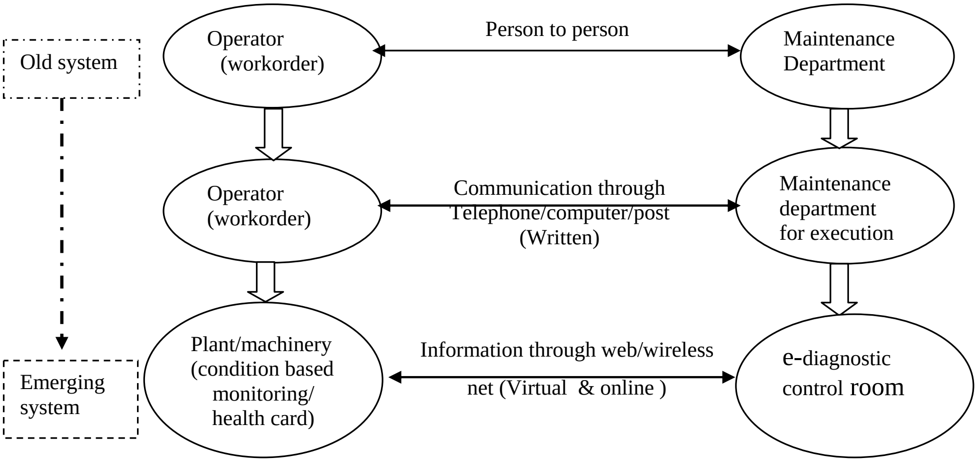

Figure 4. Information system between operators to maintenance personnel

3. Plant Health Management System (PHMS)

PHMS can be an approach for corrective, preventive and predictive maintenance besides other support activities.With a need to achieve zero down time, zero defect, instantaneous response and decision-making and world-class OEE performance; prognostics and diagnostics are used through embedded sensors and information flow. To meet the challenges in information flow, PHMS needs to be implemented to ensure right information to right person.All these needs can have lead to development of e-health card for measuring the equipment's degradation assessment, which forms part of e-maintenance. PHMS thus, could consist of condition monitoring (CM) diagnostics and prognostics, and condition based operation and through MPM support, to improve the dependability and safety of the technical systems, besides decreasing life cycle cost of operation and support [13], [14], [15]. This system delivers data and information, which indicates the health condition of the system. The stakeholders of the system are the receivers of the data and information [16], [17], [18], aggregated through the MPIs. The problem today in a health management system is the existing information islands, i.e. the different specialized systems, with in an organization speaking a different data and information language.

Figure 5, shows the schematic for an integrated Maintenance Information System (MIS), which begins with the basic information collection from different sources with in the organization. The defined maintenance performance indicators (MPIs) with their specified criteria, when linked into the operational information, provide supports to evaluate performance and decision making to achieve maintenance optimization. While evaluating the MPIs, the evaluation is carried for the equipment and machineries, for a specified period along with their history and the results are analysed for preparing report for decision making. These indicators could be analogue or digital indicators for the information of the decision makers. Managing all these aspects and varieties of information, demands effective information management involving and integrating all stakeholders, so as to achieve the desired maintenance optimization. With development and emergence of intelligent e-maintenance in the manufacturing and process industry, the objectives of managing maintenance information system is to convert the field data into useful information, in form of either trend or performance indicator, so that decisions to achieve maintenance optimization can be made on-line and/or remotely through wireless means [19].

A performance indicator (PI) is a variable that expresses quantitatively the effectiveness or efficiency or both, of a part of or a whole process, or system, against a given norm or target [20].

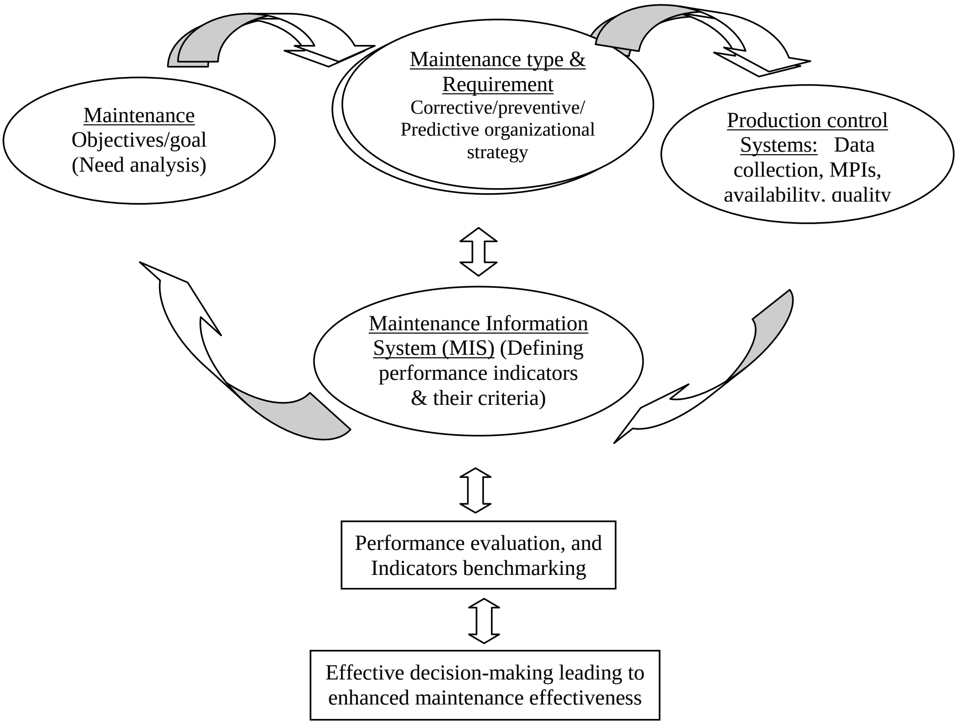

Figure 5. Integrated maintenance information system

Maintenance performance indicator developed for maintenance evaluation is used for assessment of the effectiveness of a plant. Maintenance indicators are based on the types of operational data and type of maintenance amongst others. Based on the performance area, maintenance performance indicators are divided in two types [21]:

- Basic and direct indicators: Linked directly with the operational data like maintenance task carried out, duration of maintenance, cost, unavailability duration etc. They are the measure regulators own activities and tend to use the data generated.
- Indirect indicators: derived from the direct and other indicators. They are the performance indicators of other stakeholders to find the performance of the regulating body. For example, Maintenance intensity, reliability and availability etc

Maintenance performance indicators (MPI) are of three classes as per their level of operations:

- MPI for the plant at the global or business level (maintenance policy, safety policy by International agencies etc)
- MPI for the asset/system's performance rating, monitoring etc
- MPI for process components including maintenance characteristics of the components etc.

Some of the existing e-maintenance solution provide the server based software, equipment embedded internet interface devices (health management card). These e-maintenance solutions provide 24 x 7 (24 hours 7days a week) real-time monitoring, control and alerts, at the operating centre. This system converts data in to information, available to all concerned for decision-making and predicting the performance condition of the plant and machineries on a real time basis. This enables the system to match with the e-business and supply chain requirements. For example, once the supervisor knows the plant degradation condition, its related effects on material, and inventory, then the delivery status can be planned and coordinated with a greater speed to satisfy the customer.

4. Process, asset and business integrity index link and effect model

For achieving maintenance effectiveness, it is desired that the total maintenance strategy is developed from the internal efficiency supporting the external effectiveness. Maintenance, is not only an internal/process efficiency factor, but also is an asset factors for increased asset value, asset utilization, quality and cost efficiency, when combined leads to external effectiveness factors like; stakeholders, quality and sustainability, leading to business integrity. This concept is given in Figure 6; starting with process/system integrity index, which is an internal effectiveness factors like; OEE, availability, reliability and capacity, and employee involvement and motivation. The intermediate level is asset integrity index, with factors of, asset utilization, quality and cost effectiveness. The external and overall business integrity index is related to the stakeholders of the company, sustainability and transparency resulting in desired return on investment (ROI) and health, safety and environmental (HSE) requirements. The information flows from strategic to operational level converting the subjective corporate goals in to objective indicators at the operational level. Similarly, in the bottom-up information flow, the objective performance information, of the operational level, is aggregated to provide information about achieving corporate objectives.

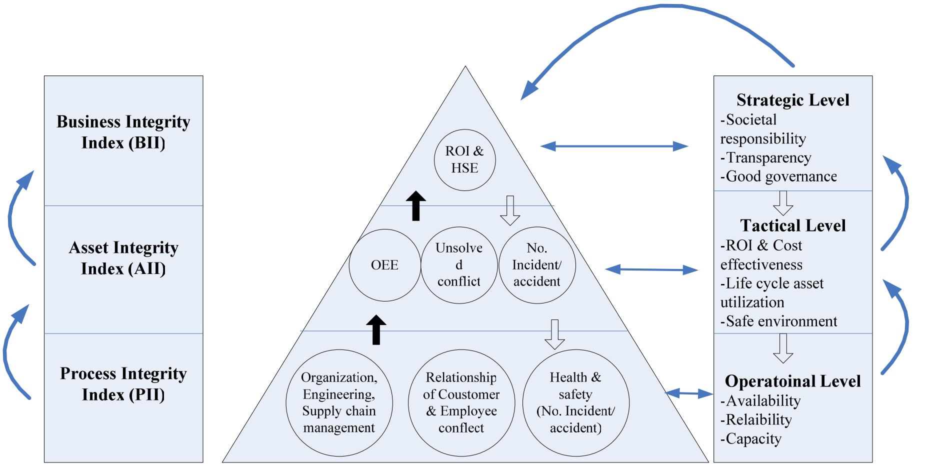

Figure 6. Process, asset and business integrity Index link and effect model

Objectively measure data from operational to strategical level

MPIs derived from strategical to operational level

Organizations operating today face several kinds of challenges brought in their ways of operation and the characteristics in their business environments. Just to name a few, these new challenges include, highly dynamic business environments, complicated intellectual work at all levels of the company, efficient use of information and communication technologies (ICT), and a fast pace of information and knowledge renewal (Antti, 2004). In order to meet the various perspectives of the multi-disciplinary facets of MPM, different criteria consisting of a number of maintenance performance indicators (MPIs) need to be considered. The MPM frame work need to consider the issues like the stakeholders' requirements, and total maintenance effectiveness both from internal and external perspectives to identify the relevant MPIs, and then align the MPIs with the strategy. The MPIs are required to be considered from different hierarchical levels of the organization, so that they can be cascaded from strategic to functional level or aggregated from functional to strategic level to achieve efficiency and effectiveness. The e-Maintenance and ICT use with enterprise resource planning (ERP) is tried out by different companies to achieve the desired maintenance effectiveness.Thus, the efficiency and effectiveness of the MPM frame work is very essential for achieving the organizational and maintenance objectives and the desired plant, asset and business integrity index.

5. Maintenance effectiveness

Different maintenance strategies within an optimization scheme are to be evaluated for the objectives of interest, typically profit and availability for the maintenance effectiveness [1]. Majority of the literature assume that the system's degradation level can only be known through periodic inspection. Condition based monitoring complimented by e-maintenance model can found to be an effective solution. Maintenance effectiveness can be enhanced by methods like reduction of total cost and equipment downtime by assessing the total business risks. A trade-off between costs, risk and benefit has to be arrived for achieving optimal maintenance effectiveness. MPI like, return on maintenance investment (ROMI) can be a very useful tool for arriving at an optimal level.

The identification of effective and efficient maintenance strategies for the plant and machineries is of a major importance from global competition, safety and financial point of view. Today, most of the organizations are trying to follow the condition based preventive maintenance, based on component degradation state. But in reality, the relevant parameters behind the degradation process are very complex, and needs to be undertaken analytically. Another aspect of enhanced maintenance effectiveness is to integrate the strategy and objectives of the organization within the maintenance process.

5. Concluding remarks

Managing effective information with condition based component degradation and monitoring system coupled with e-maintenance model can lead to effective maintenance optimization using MPM system. The consideration of cost reduction, reducing downtime and maximizing availability, with the use of maintenance performance indicators forms integral part such MPM system. An attempt has been made in this paper to cover the related aspects to develop the conceptual model for achieving maintenance effectiveness.

6. References

[1] M. Marseguerra, E. Zio. and L. Podofillini. (2002). Condition based maintenance optimization by means of genetic algorithms and Monte Carlo simulation. Reliability Engineering & System Safety, vol. 77, issue 2, August 2002, pp. 151-165.

[2] A. Parida, T. Ahren, and U. Kumar. (2003). *Integrating Maintenance Performance with Corporate Balanced Scorecard*, COMADEM 2003, Proceedings of the 16th International Congress, 27-29 August 2003, Växjö, Sweden, pp. 53-59.

[3] T.Wireman, (1998). *Developing Performance Indicators for Managing Maintenance*, Industrial Press, Inc, 1998, New York.

[4] R. Smith. (2003). Key performance Indicators-leading or Lagging and when to use them, "*www.reliabilityweb.com*", 2003, Dated Mar. 12.

[5] Kaplan, R. S and Norton, D.P. (1992). *The Balanced Scorecard: Translating Strategy into Action*, Harvard Business School Press, 1996, pp.322.
[6] R.L Lynch, and K. F. Cross. (1995). *Measure Up! Yardsticks for Continuous Improvement. 2nd ed. Cambridge*, Blackwell Publishers Inc., 1995, pp.250.
[7] A. Neely, and C. Adams. (2002). Perspective on Performance: The Performance Prism. Crane field University. http://www.cranefield.ac.uk/som/cbp/prism.htm (8.4. 2002)
[8] G. Lodewijks. (2004). Strategies for Automated Maintenance of Belt Conveyer Systems, Bulk solids handlings, Volume 24, No. 1. January/February, 2004, pp.16-22
[9] J. Maglita. (1995). Martren Up!, Computerworld, Volume 29, 1995, pp. 84-86.
[10] I. Nonaka. (19949. A dynamic theory of knowledge creation, Organization Science, Volume 5, No. 1, 1994, pp. 14-37.
[11] M. Alavi, and D. Leidner. (1999). Knowledge management system: Emerging views and practice from the field, Proceedings of the 32nd Hawaii International Conference system science, 1999.
[12] Denco Planning Services Inc. (2004). Industrial Maintenance Management E-Maintenance, www.dencoplans.com, 2004 Mar19.
[13] R. K. Mobley (1990). *An introduction to predictive maintenance.* Van Nostrand Reinhold, New York, 1990.
[14] J.D. Campbell, and A. K. S. Jardine. (2001). *Maintenance excellence: optimizing equipment life-cycle decisions. Marcel Dekker, New York, 2001.*
[15] P. Söderholm and P. A. Akersten. (2002). Aerospace Diagnostics and Prognostics in a TQM Perspective. Proceedings of the 15th International Congress of COMADEM 2002, 2-4 September, Birmingham, UK, pp. 80-89.
[16] K. Lyytinnen and R. Hirschheim. (1987). *Information system failures: a survey and classification of the empirical literature, Oxford surveys in information technology.* Oxford University Press, Oxford, 1987, pp. 257-309.
[17] ISO/IEC 15288, Systems Engineering: System Life Cycle Processes, International Organization for Standardization, Geneva Commission Electrotechnique Internationale, Geneva, 2002.
[18] P. Söderholm. (2003). *Continuous Improvement of Complex Technical System: Aspects of Stakeholder Requirements and System Functions*, Licentiate Thesis, Division of Quality and Environmental Management, Lulea University of Technology, Lulea, 2003.
[19] J. Lee. (1999). *Machine Performance Assessment Methodology,* Reports on Frontiers in Engineering, National Academy of Engineers, March 1999, p. 75-83.
[20] L Clemens, F. Leonard, and W. Marc. (2004). Designing a Performance measurement system: A case study, European Journal of Operational Research 156, 2004, pp.267-286.
[21] Nuclear Energy Agency Committee on the Safety of Nuclear Installations, NEA/CSNI/R(2001)11, p 6.
[22] NPD (1998), maintenance baseline study: A method for self-assessment of maintenance management system, Norwegian Petroleum Directorate.