Abstract number 015-0936

Integrated Maintenance: Feasibility and Effectiveness of Interoperability between Condition Monitoring and Integrated Management System

Robson de Paula Alves – rpalves@metrosp.com.br;

Tamio Shimizu – tmshimiz@usp.br;

University of São Paulo – USP -, Production Engineering Dept.

Av. Prof. Almeida Prado, 128, travessa 2 – 2 andar, sala 216, São Paulo – Brazil

Caixa Postal 61.548 – CEP 05508-900

POMS 21st Annual Conference

Vancouver, Canada

May 7 to May 10, 2010

Abstract

The subject of study is the model called INTEGRATED MAINTENANCE MANAGEMENT, i.e., the architecture composed by Information Systems applied to the maintenance function, but in an integrated manner. More specifically were examined the systems dedicated to support technical Condition Based Maintenance activities, better known as Condition Monitoring Systems and its possible interface with CMMS – Computerized Maintenance Management Systems. The methodology adopted was the case study, in a plant maintenance function. The research universe was the preventive maintenance environment, with a sample, not probabilistic, chosen intentionally. The main objectives of the study were: 1.test and evaluate a model of Integrated Maintenance Management; 2. apply and test this model; 3. put together, in an organized way and with scientific basis, updated "state-of-the-art" information about the subject.

INTRODUCTION

In the past, especially in the period before World War II, the maintenance function had its focus on repair or restore physical equipment just after the break. With the development of Reliability Engineering, from the 1950s, the concepts of preventive maintenance began to be implemented, trying to avoid breakage. In the 1970s came the theory of Condition Based Maintenance, where preventive maintenance was performed based on failure symptoms recognized and analyzed using techniques of monitoring or diagnosis, which increased the accuracy of the timing of the intervention. Since then, there have been new developments of these strategies - for example, Reliability Centered Maintenance, Risk Bases Maintenance, Inspection Based Maintenance, etc. Thus, by 1990, according to the scenario in which the corporation (and therefore its assets) was entered, the importance about the best possible selection of appropriate maintenance strategy to be implemented, has grown exponentially (MOUBRAY, 1997; KARDEC, NASCIF, 2001; TAKATA et al., 2004).

In parallel to the development of maintenance, and providing essential support to this development, the application of Information Technology (IT) in this environment has evolved too and came very definitely to take part of the group of major strategic resources of Maintenance function. From the original role of simple information systems for just historical record of events off-line, to the evolution, nowadays, when it provides sophisticated functionality to information systems in highly specialized maintenance, this kind of resource became a must (WIREMAN, 1994; CAMPBELLl & REYES-PICKNELL, 2006).

It can be argued that the practice development of Maintenance, from an activity essentially "reactive" to an activity focused on "predictability" was possible largely thanks to this IT development and its application in this environment. However, despite the developments in IT have been in a historical moment very close to the development of own area of maintenance, the application of IT in the maintenance environment did not occur in a standardized and comprehensive way. Reviewing some literature about IT on Maintenance (WIREMAN, 1994; MOUBRAY, 1997; ALVES, 2005; MULLER et al., 2008) it was possible to identify two parallel, but distinct ways that the application of IT in this environment, walked in recent decades:

1) First, focusing on strategic and tactical levels, the application of IT in Maintenance evolved as a support tool for Maintenance Management. Its application had more highlight in the early 1970s, from simple information systems, with basic function as a repository of records of maintenance actions, toward the scene of today, when there are available complex and sophisticated tools for managing maintenance, often coupled to Integrated Management Systems (like ERP´s), and,

2) On the other hand, focused on operational level, technological progress has enabled to embed sophisticated functionality on own assets, in order to support assets maintenance, such as: i) sensors, auto diagnostic, alarm devices, ii) facilitating resources - dedicated outputs - for use in techniques for monitoring the asset performance condition.

Such IT applications enable collection and analysis of data from the use of techniques in Condition Based Maintenance in expert systems, aimed to support techniques such as Thermography, Ultrasound, Vibration Analysis, among others. They are here called just Condition Monitoring Systems.

These two parallel and distinct paths created progressively an undesirable gap between the IT tools applied to this scenario, which imposes difficulties on the existence of a natural flow of information between these two universes. According to authors such as Campbell & Reyes-Picknell (2006), Mathew et al. (2006), once these two universes are completely integrated, the information obtained from condition monitoring techniques can support more accurate decisions at the strategic level, through Integrated Management Systems. It can provide information about the most appropriate time to maintain, refurbish or change an operating asset, not only from a technical but also economic point of view. This model of Integrated Maintenance Management is also recognized by some authors as "e-maintenance" (MULLER et al., 2008).

Thus, the issue raised in this paper centers on studies about the nature and scope of this mentioned gap and current reflections on what the real benefits have been obtained from the IT applied in a setting of Integrated Maintenance Management. This issue raises questions such as:

1) What would be the "state of the art" of this integration?
2) It would now be feasible, in practice, a full "dialogue" between the two types of systems - those that cover the operational level with those covering the tactical and strategic levels - in order to explore as much as possible the potential of IT applied to the Maintenance environment?

The importance of developing studies in this area (in order to analyze the current situation and the stage of practical development of this model of Integrated Maintenance Management) is particular

based on authors such as Campbell & Reyes-Picknell (2006) and Haider & Koronios (2006), whereby state that data from the systems at the operational levels, especially those from Condition Monitoring Systems, once properly integrated with systems at the strategic level, have a high potential for dynamic economic decision support, financial and strategic not only limited to the operational environment, but at the corporate level, ie, that full integration can bring "real economic value" to the production processes and thus become an important form of competitive differentiation. But apart from this theoretical statement, there was no evidence of actual cases reported in the academic literature studied, thus suggesting the existence of a gap in scientific and empirical research to be completed.

Another factor that strengthens and brings evidence about the relevance of the theme is the recent emergence of a number of international non-profit, multidisciplinary, joint action academia-industry organizations, with the mission to develop and encourage the adoption of open standards interface that allow interoperability between operating and maintenance systems and equipments. Examples include the U.S. "Machinery Information Management Open Systems Alliance - MIMOSA," to "The Open Initiative & M - Operation and Maintenance" and European "PROTEUS" (SZYMANSKI et al. 2003; JOHNSTON, PYATT, 2005; MATHEW et al. 2006; MULLER et al., 2008).

OBJECTIVES

The conducted research, with a qualitative approach, aimed at primary:

- Demonstrate that the practical implementation of the Integrated Maintenance model (e-Maintenance) provides real improvements in analysis and / or prevention of failures in maintenance environment - analysis of efficacy - as suggested in the literature (CAMPBELL and REYES, 2006; MULLER et al., 2008).

As a secondary objective:

- Investigate, understand and record how and what was the reason why the organization analyzed (the case study) developed an applied a pilot model of integration between systems "Condition Monitoring" and its CMMS (Computerized Maintenance Management System) ;

The desired contributions from the work are:

1. Helping to fill the gap theoretical / scientific identified and decrease the apparent lack of empirical scientific work about integration of maintenance systems;

2. Check and record possible real benefits to the analyzed organization, the result of system integration, seeking theoretical and scientific justification to support eventual continued investments in any other similar projects inside the organization.

THEORETICAL FOUNDATIONS

The new face of Maintenance

Although the concepts and methodologies of traditional maintenance have advanced significantly, particularly over the past 25 years, the Maintenance function still has a negative image in many fields of study, perhaps because of stigma, in the common sense, to be considered merely "a measure against problems." The maintenance departments in corporations are still often seen as more than a "cost center", which usually has no commitment to generating profits for the company (TAKATA et al., 2004; MULLER et al. 2008).

However, if we look at the Maintenance function from the business perspective, as a function whose responsibility has become, little by little, from a mere "equipment restorer" to "managing the

lifecycle of the assets of the corporation", we see a completely different bias (Association Française de Normalization, 1982; MOUBRAY, 1997; CAMPBELL, REYES-PICKNELL, 2006).

The importance of Maintenance has increased, primarily due to the expansion of its original role of maintaining the physical assets with focus on the preservation of assets, and improve availability and security as well as help ensure the quality of produced goods and too, more recently, without harming the environment (MOUBRAY, 1997; PALMER, 1999; TAKATA et al., 2004; MULLER et al., 2008). The current scenario of industrial production increasingly demand a very high level of reliability of its plant and equipment involved in their production processes and, consequently, this demand has radically altered the way the Maintenance traditionally has operated.

The Information and Communication Technology (ICT) are rapidly supplanting some conventional techniques of human inspections (sound and visual) and eliminating the dependencies of these practices in management and acquisition of information paper based. The importance of maintenance is now dictated by the fact that any change in the conditions of a key asset in a production process, has a direct impact on critical aspects of the business, not just on the production line, but also in resource planning, sales and distribution (STENGL, EMANTINGER, 2001; HAIDER, KORONIOS, 2006).

In today's competitive market-oriented consumers, corporations have to provide resources and services more efficiently. As an illustration one can say that just one minute of downtime of a production line of an automobile, can cost about US $ 20 mil (DJURDJANOVIC et al., 2003). Allied to this, especially in modern industries, the maintenance costs of its assets constitute a significant proportion of operating expenses, leading managers invariably to consider them in their planning goals and profitability. It can be seen in the industry an increasing migration from traditional Time-Based Maintenance to Condition Based Maintenance (term usually known as

CBM), aimed at reducing the downtime of equipment and therefore the cost reduction (VANIER, 2001; KOÇ et al., 2005, MA, 2007).

In parallel, companies started to invest, especially since the 1990s, in Integrated Management Systems (like ERP´s), covering several business areas as accounting, financial, commercial, human resources, logistic, maintenance, among others (LAURINDO, MESQUITA, 2000).

Evolution of the Computerized Maintenance Support

Based on Campbell and Reyes-Picknell (2006), we can characterize the evolution of support systems for Maintenance in 5 phases:

1. In the 1970s, the earlier maintenance information systems were characterized as just repositories of data about routines actions and work orders that were concluded, with enormous difficulties in information retrieval and time response about days;

2. Arise in the early '80s, Computerized Maintenance Management Systems (widespread for its initials in English-CMMS), with some forms of automation, but still confined to the processes of maintenance;

3. With the evolution of the maintenance concept with a focus on restoring function, arise around 1990´s, the Enterprise Asset Management (EAM). In fact, an extension of the functionalities of CMMS's, covering at that time, the processes of materials management / logistics and incorporating automated workflows;

4. At the turn of the millennium, the systems suppliers have put further features to EAMs, including planning resources and possibilities of integration with the Integrated Management Systems (ERP´s);

5. In the past seven years we have seen a revolution in the systems market share, with several mergers and acquisitions of suppliers of such products by global IT giants companies like IBM,

INFOR and ORACLE. There was also the consolidation of these systems as native modules of Integrated Management Systems (including ERPs).

By the end of this decade (2010) we saw signs of a new wave of promising features in both: the Maintenance Management Systems, which are increasingly incorporating features on the basis of cost, as in the systems with operational focus, for example, the Monitoring Condition Systems. Concomitantly, it is noted that the market has become aware that even small reductions in the area of Maintenance can bring significant increases in corporate profits, since the Maintenance costs can represent up to 12% of average income of enterprises, including the investiment in finding a model that allows interoperability between such systems (TAVARES, SILVA FILHO, 2001; ABRAMAN, 2007).

The Integrated Maintenance Management

An Integrated Maintenance Management System includes the full integration of data and information from a number of cases in a more operational level (eavesdropping assets, prognosis, diagnosis, etc.) with a series of cases focusing strategic and tactical (especially related to cost control, political, corporate management, etc.).

In an industrial plant, for example, these processes are operating to maintain the mission to better monitor the degradation and performance of assets and operating systems involved in the manufacture and can be supported by dedicated systems, such as support for Condition-Based Maintenance. In turn, cases with strategic focus and tactical, have the mission to better lead the productive capacity of the organization as a whole and can be supported by generic management systems such as ERP (BLAKE et al., 2003; MULLER et al., 2008).

Authors such as Zhang et al. (2006) is opposed to this idea and propose the adoption of systems called System for Assessment of Assets Condition. To lead Condition Based Maintenance in an

effective way, these systems combine analysis of condition monitoring, reliability analysis, and consider restrictions like making predictions about the best economic period for maintenance services. Such systems have various sources of information and present results varied according to the level of users (operational, tactical or strategic). This proposal goes against some authors idea as Vanier (2001), Campbell & Reyes-Picknell (2006) and Muller et al. (2008), who advocate a single, integrated system of management with such functions.

Concepts standardization

There are a wide variety of terms found in the literature analyzed to explain the same concepts within the object of study proposed here, both used by organizations like in the academy. Some of them were found in a interchangeably way. So, in order to minimize misinterpretation, it follows a simple pattern of some key concepts used in this paper:

It is understood here as "asset", a component of a manufacturing, production or service, that has value, enables or participates in the provision of services and has an economic life greater than twelve months. Similarly, "Asset Management" here is understood as a set of disciplines, methods, procedures and tools necessary to optimize the life cycle of the assets of a corporation, in terms of their impact on production cost, performance and risks, in combination with its availability, efficiency, quality, longevity and in accordance with the laws / regulations pertaining to safety, health and environment (HAIDER; KORONIOS, 2006).

Maintenance Management is a multidisciplinary field that deals directly or indirectly, various branches of Engineering and Production Management, such as Logistics, Asset Management, Total Productive Maintenance (TPM), Reliability Centered Maintenance (RCM), Condition Based Maintenance (CBM), among others, in order to ensure that any assets or their components, to achieve its pre-determined life cycle (VANIER, 2001; SODERHOLM et al., 2007).

The model of Integrated Maintenance Management, also known as "e-maintenance" by authors such as Muller et al. (2008), includes full integration of a series of processes in a maintenance area, at the Operational (asset eavesdropping, prognostic, diagnostic, etc), with a series of cases in Strategic and Tactical level (especially maintenance costs, policies, human resource management, etc.). This model allows to combine data and information about the "health" of the asset, but restricted to the operating environment, with economic data and information assets (cost of failure, repair costs, replacement costs, costs of the consequences of failure, etc.) in order to better decide about maintenance plans and the best time (technical and economical) to replace/refurbish the asset.

"Life Cycle" of assets represents the actual time period during which the asset (or its components) performs its functions without any unexpected cost of unavailability due to maintenance and repairs. It can be technical or economic. Useful life takes into account exclusively for your functional requirements, and economic life cycle takes into account also the maintenance cost versus replacement cost (VANIER, 2001).

Delineation of the object of study

The object of study is the model called "Integrated Maintenance Management" ie, the architecture consists of information systems applied to the maintenance function, but in an integrated manner. More specifically had been analyzed the systems dedicated to technical support for Condition Based Maintenance, the so-called condition monitoring systems, and its possible interface with Integrated Management Systems (or its specific function, conducted by CMMS´s).

Preliminary Literature analysis (“horizontal” research)

A preliminary literature was investigated, which identified the theoretical gap mentioned, and that formed the basis of presented research. It was a combination of classical references about Maintenance Management, associated with current and relevant books and papers published in

journals and conference proceedings about the subject. During this phase it was possible to identify references with mentions about IT application in the area of Maintenance and Asset Management, but without explicit references about empirical applications of Maintenance systems in an integrated manner.

METHODS AND TECHNIQUES

For the purpose of description and rationale for the research, the initial method used was the bibliographic research in order to establish a more detailed map of the references for the study (horizontal and vertical literature search). The aim was to identify gaps in the literature, the major issues and aspects related to the object of study (visions of various authors, and issues already raised, benefits provided / obtained and recorded, questions, comments, statements, any empirical studies, etc.).

Then, in order to verify the implementation and practical results of the study object, we conducted a empirical research using the Case Study (unique) method. In this way it was intended to allow a comparison between the theory of the benefits and problems raised in the literature and practical application of integrated systems in a real company, identifying the similarities and differences between theory and practice, to relate the benefits and difficulties encountered and demonstrate eventual feasibility and effectiveness of this integration.

The main reasons for choosing this approach were: the researcher acted as a passive observer, with no control over events, the context is current and relevant and the data collected and analyzed had qualitative nature.

The instruments of data collection used were semi-structured interviews with professionals and managers in the organization selected, as well as maintenance experts. The researchers also

provided data collection by recording direct observations and from document analysis (reports, procedures, spreadsheets and other documents indicators of the unit of analysis). These data were intended to, after proper analysis, create a chain of evidence to provide support to the conclusions.

The research universe was the maintenance environment for mission-critical, which presents evidence in the literature (SZYMANSKI et al. 2003; JOHNSTON, PYATT, 2005; MATHEW et al. 2006; MULLER et al., 2008) a higher probability of find practical applications of the model.

The organization that was object of study, a mass public transport company, was selected intentionally, but with objective criteria, in order to provide robust results and mitigate the natural limitations of generalizing from a single case study:

- It was an internationally recognized company, renowned in the maintenance of critical mission systems, holder of ISO 9001, OHSAS 14000 international certifications in all its maintenance processes, with more than 7000 employees (more than 2000 only in maintenance department);

- The company takes part of an international benchmarking, led by Imperial College London, which brings together the 12 largest companies in its segment of the world. It indicates willingness to participate in academic studies and benchmarking, which can bring too benefits and improvements to its processes;

-The researcher had good autorised access to data, sites and other employees for interviews and field observations;

-The company had probably one of the few real registered cases of application of maintenance systems integration;

The case-study involved observations, interviews and data collection on a pilot model applied by the analysed company, mentioned by Pereira et al. (2007), where was encountered a technical integration of databases maintenance systems with different purposes:

- On the one hand, data from a traditional CMMS –Computerized Maintenance Management System, with information about maintenance routines of equipments (labor, materials, locations of faults, dates of failure, corrective and preventive actions, what was the defect, what was the repairs done , etc.);

- On the other hand, data from one Condition Based Maintenance System, specifically a analysis thermographic system (temperature data collected from equipment during predictive inspections in electrical and electromechanical assets)

Since these data were present on the same basis, in a pilot model, it was possible to observe how the company performed crosses between these data and whether it was possible to obtain some tangible benefit of this integration, comparing with the theoretical foundations on the subject.

CONCLUSIONS AND COMENTS

Through analysis of data collected in the research and also by means of triangulation of these data, we could obtain the following observations and conclusions:

1. the first pilot model in the case analyzed was conducted across information about predictive thermographic inspections with instances of equipment failures, seeking a correlation between the data. The main reason that led the company to look for and initiate the adoption of a model of Integrated Maintenance Management was basically the need to cross information systems in different focus (strategic / tactical and operational), avoiding rework, various accesses to different

database and use of special tools for data extraction. This purpose was achieved successfully and today the company can already look interrelationships between these two systems using this pilot model.

2. although it appears in its future plans, the company has not yet received measurable benefits related to the *economic* evaluation of the life cycle of assets and strategic information for decision at the most appropriate exchange or refurbishment of assets, taken from the model of Integrated Maintenance Management;

3. the main tangible benefits, with evidence of results thanks to the implementation of pilot model, were significant improvements, but still has no possibility of quantitative measurement, about the velocity of failures data analysis and the possibility of establishing links between facts in advance and preventive (eg: observation of new parameters of temperature equipment, its trends, gradients and thresholds, comparisons of the number of failures versus temperature, etc.);

Thus, it can be said that, within the context of the analysis, the Integrated Maintenance Management model shows up as a viable tool and with potential to bring benefits for the management of maintenance, as it is suggested in the literature review.

It should be noted that, once the study was carried out under the natural limitations of a single case, any extrapolation of this conclusion need to be further advance in the circumstances detailed in the analysed model.

Other colleted observations:

-The current scenario or "state of the art" of integrating these systems, despite the growing number of publications and theoretical studies about the subject, has not advanced far beyond the academic studies, but were restricted to few cases of empirical application of this model;

-The impediments to the desired system integration, besides the question of technology, seems to focus on difficulty in awakening the interest of manufacturers of these systems to seek interoperability, since it is difficult to see direct gains for this group (manufacturers);

-Confirmed the relevance and importance of the issue among professionals and maintenance experts (through interviews) but were not found quantitative evidences about companies that have already been able to deploy such integration. However, in the case of the company analyzed, there are already signs of development of financial indicators (KPI´s) that could reflect more informed decision-making. Besides there were not evidences about real cases related to replacement / renewal of assets in the most appropriate economic times, based in this model analyzed, we believe that it could stimulate the development of such model and encourage investment in its use, thus confirming the model as a potential competitive advantage.

FUTURE WORK PROPOSAL

According to Vanier (2001) and Campbell & Reyes-Picknell (2006), managers of corporations, especially industrial plants, face in their day-to-day many difficulties related to decision-making about "when" and "how to" inspect, maintain, repair and refurbish the assets of their companies, in a way that the effective cost of these actions, is really, accurately and quickly, taken into consideration. These managers usually have few tools, including accessible library resources and intelligent information systems, to assist them in decision-making. This way, solutions are

frequently fragmented and isolated, requiring enormous effort and time to gather information from various sources in different formats and standards.

As one can see, the problem is wider than expected and this paper does not intend to give the latest and definitive answers and conclusions about the subject.Thus, aligned to the objectives proposed in this paper, some concrete products pointed here can be extended in a deeper and more complete study, like:

1. the update of a record documented, in an organized and scientific basis, of current information about the "state of the art" of object's research and the prospects, achievements, paths taken and best practices to achieve the desired system integration, to support scholars and organizations in implementing this kind of integration for decision making;

2. documented record of results, evidence and analysis of viability of the empirical application of other real models of Integrated Maintenance Management;

3. record of the comparison of results obtained before and after implantations, with other evidences of effectiveness of the models analyzed.

Another claim is that the results of this study may stimulate further reflection and empirical studies on the subject in corporates and industries. Thus, in the same way such concerns have stimulated the development of new fields of study in North America and Europe, which together - academia and industry- resulted in international projects such as PROTEUS and MIMOSA (already discussed in this paper), this kind of discussion can stimulate similar projects in Latin America, with a view to practical application of this management model.

REFERENCES

ABRAMAN. Associação Brasileira de Manutenção. **Documento Nacional 2007**: a situação da manutenção no Brasil. 2007. Available in: <http://www.abraman. org.br/documento_nacional /ResultadosDN2007(site).pdf>. Access: ago. 2008.

ALVES, R.P. **Sistemas de informação e inteligência organizacional aplicados à gestão da manutenção**: proposta de um modelo conceitual. 2005. 123 f. Dissertação (Mestrado em Ciência da Informação) – Programa de Mestrado em Ciência da Informação, Pontifícia Universidade Católica de Campinas, Campinas, 2005.

ASSOCIATION FRANÇAISE DE NORMALISATION. **NFX60-010**: Maintenance: concepts et définitions des activités de maintenance. Paris: AFN, 1982. 28 p.

BLAKE, S.; SIDEBOTTOM, B.; JOHNSTON, A. Mobile solution for the warfighter. *In*: MEETING THE READINESS CHALLENGE, Tampa, 2003. **Proceedings**... Available in: <http://www.mimosa.org/downloads/10/index.aspx >. Access: jul. 2008.

CAMPBELL, J. D.; REYES-PICKNELL, J. V. **Uptime**: strategies for excellence in maintenance management. New York: Productivity Press, 2006. 392 p.

DJURDJANOVIC, D.; LEE, J.; NI, J. Watchdog agent: an infotronics-based prognostics approach for product performance degradation assessment and prediction. **Advanced Engineering Informatics**, [s.l.], v. 17, p. 109-125, 2003.

HAIDER, A.; KORONIOS, A. E-prognostics: a step towards e-maintenance of engineering assets. **Journal of Theoretical and Applied Electronic Commerce Research***,* [S.l.], v. 1, n. 1, apr. 2006.

JOHNSTON, A.T.; PYATT, M. From CMMS to EAM and beyond: bridging the vision gap with standars-based interoperability. *In*: INTERNATIONAL MAINTENANCE CONFERENCE - MIMOSA SEMINAR, Tampa/Florida, 2005. **Proceedings**... Tampa: MIMOSA Technical, 2005.

KARDEC, A.; NASCIF, J. **Manutenção função estratégica**. Rio de Janeiro: Qualitymark, 2001.

KELLY, A.; HARRIS, M.J. **Administração da manutenção industrial**. Rio de Janeiro: Instituto Brasileiro do Petróleo (IBP), 1980.

KOÇ, M. *et al*. Introduction to e-manufacturing. *In*: ZURAWSKI, R. **The industrial information technology handbook**. Michigan: CRC Press, 2005. p. 97-1–97-9.

LAURINDO, F.J.B.; MESQUITA, M.A. Material requirement planning: 25 anos de história: uma revisão do passado e prospecção do futuro. **Gestão & Produção**, São Carlos, v.7, n.3, p. 320-337, dec. 2000.

LEVITT, J. **The Handbook of maintenance management**. New York: Industrial Press Inc., 1997.

MA, L. Condition monitoring in engineering asset management. *In*: ASIA-PACIFIC VIBRATION CONFERENCE, 12., Hokkaido, 2007. **Proceedings**... Hokkaido: Hokkaido University, 2007.

MATHEW, A.D.; ZHANG, D.; MA, L. A review of the MIMOSA OSA-EAI database for condition monitoring systems. *In*: WORLD CONGRESS ON ENGINEERING ASSET

MANAGEMENT, Gold Coast, 2006. **Proceedings**... Gold Coast: The Queensland Government's Department of State Development, 2006.

MONCHY, F. **A função manutenção**: formação para a gerência da manutenção industrial. São Paulo: Durban, 1989. 367 p.

MOUBRAY, J. **RCM II - Reliability-centred maintenance**. Oxford: Butterworth-Heinemann, 1997.

MULLER, A.; CRESPO MARQUEZ, A.; IUNG, B. On the concept of e-maintenance: review and current research. **Reliability Engineering and System Safety**, [s.l.], v. 93, p. 1165-1187, 2008.

PALMER, D. **Maintenance planning and scheduling handbook**. New York: McGraw-Hill, 1999.

PEREIRA, L.N.; SOUZA, C.A.; WATANABE, J.C.K.; Termografia na Cia. Do Metrô de São Paulo – Desenvolvimento de aplicativos para estudos de temperaturas dos equipamentos. *In*: XII SEMINÁRIO BRASILEIRO DE MANUTENÇÃO PREDITIVA E INSPEÇÃO DE EQUIPAMENTOS, São Paulo, 2007. **Proceedings**...São Paulo: Excelencia, 2007. p.18-30

SÖDERHOLM, P.; HOLMGREN, M.; KLEFSJÖ, B. A process view of maintenance and its stakeholders. **Journal of Quality in Maintenance Engineering**, Dahran, v. 13, n. 1, p. 19-32, 2007.

STENGL, B.; EMANTINGER R. **SAP R/3 Plant Maintenance**: making it work for your business. London: Person Education Limited, 2001. 348 p.

SZYMANSKI, J. *et al*. PROTEUS: a European initiative for e-maintenance platform development. *In:* EMERGING TECHNOLOGIES AND FACTORY AUTOMATION - ETFA '03, 9., Lisbon, 2003. **Proceedings**... Lisbon: IEEE Conference, 2003. v. 2, p. 415-420.

TAKATA, S. *et al*. Maintenance: changing role in life cycle management. **CIRP ANNUALS – Journal of Manufacturing Technology**, Paris, v. 53, n. 2, p. 643-655, 2004.

TAVARES, L.A.; SILVA FILHO, A.A. Sistemas de gestão integrada de manutenção. *In*: SEMINÁRIO PLANEJAMENTO E CONTROLE DA MANUTENÇÃO, Belo Horizonte, 2001. **Proceedings** ... Belo Horizonte: TECEM, 2001. p. 33-42.

VANIER, D. J. Asset Management: from "A" to "Z". *In*: ASSET MANAGEMENT SUPER-SISIZED SESSION - APWA INTERNATIONAL PUBLIC WORKS CONGRESS, Philadelphia, 2001. **Proceedings**... Available in: <http://www.nrc.ca/irc/uir/apwa>. Access: jul. 2008.

WIREMAN, T. **Computerized maintenance management systems**. 2. ed. New York: Industrial Press, 1994. 179 p.

ZHANG, L. *et al*. Implementation of Asset Health Assessment System with Pattern-Oriented Design and Practice. *In*: INTERNATIONAL IEEE CONFERENCE INTELLIGENT SYSTEMS, 3., Varna, 2006. **Proceedings**... Varna: IEEE-University of Westminster, 2006. p. 666-671.