COMADEM 2011
Proceedings of the 24th INTERNATIONAL CONGRESS on
Condition Monitoring and Diagnostics Engineering Management
Clarion Hotel Stavanger, Stavanger, Norway, 30th May – 1st June, 2011
(Editors) Maneesh Singh, Raj B. K. N. Rao and J. P. Liyanage,
COMADEM International, U.K., ISBN: 0-9541307-2-3

eMaintenance Decision Support System: Case Studies for Securing Production Process & Following up Maintenance Contribution in Company Business

Basim Al-Najjar

Techniques for Maintenance and Production Management,

School for Engineering, Linnaeus University, Sweden

basim.al-najjar@lnu.se

ABSTRACT

In general, all the elements involved in a production process, such as tools, machinery, methods, competence and working environment are exposed to dynamic changes. Thus, in order to maintain and improve company profitability and competitiveness especially during financial crises and lower profit-margin, it is necessary to reduce losses through maintaining and improving the quality of the elements involved in the production process. Therefore, the maintenance strategy applied should be dynamic to follow all these changes cost-effectively. The accuracy of maintenance decisions is essential for reducing economic losses generated due to unnecessary stoppages especially when stoppage time is very expensive. Therefore, it is necessary for maintenance and production managers to have a system providing the data required to achieve dynamic and cost-effective maintenance decisions. In this paper, the role of & importance of dynamic and cost effective maintenance in company business is discussed. Also, a scenario for applying a new eMaintenance Decision Support System (eMDSS) for achieving dynamic and cost-effective maintenance decisions is introduced, tested and discussed. eMDSS introduces four different strategies for continuously improving the cost-effectiveness of maintenance and production processes. It consists of three toolsets and five software modules for performing six services to;

1. enhance accuracy of maintenance decisions
2. select the most cost-effective maintenance solutions
3. identify and prioritise problem areas, and assess losses in production time
4. map, follow up and assess maintenance cost-effectiveness (maintenance savings and profit) for achieving continuous & cost effective improvement.

The major result of this tsudy is a new innovative eMDSS. The system has been tested at Fiat (car manufacturer)/CRF in Italy and GORATU (CNC-machine manufacturer). The main conclusion is; applying eMDSS it is possible to map production an maintenance processes, identify and prioritise investments results.

Keywords : *Dynamic eMaintenance, Cost-effective and Accurate Decisions, Maintenance Savings, Profit & Risk Capital Investment, Return on Investment in Maintenance, Prediction of Vibration Level, Assessment of Probability of Failure, Assessment of Residual Time, Startegies for Cost-Effectiveness.*

1. INTRODUCTION

Maintenance has mainly handled by using special models for different cases where these models are more or less static, i.e. it should be used does not matter the application circumstances, see for example Cox (1967), Barlow and Proschan (1967), Jardin (1973), Jardin et al. (2006). Djurdjanovic et al. (2004) claims that significant savings (up to 20%) can be approached in a company through reducing losses in the production process. According to the Garg and Deshmukh (2006), the Maintenance costs represent the next largest after energy costs. Many authors see for example Fu et al. (2002), Cerrada et al. (2007) and Nadakatti et al. (2008), emphasis on that many software modules and tools are available and utilised for developing knowledge bases which can be used for fault diagnosis. With growing attention on zero-downtime and cost-effective decision support systems, conventional oil and gas practices have largely been challenged in major oil and gas companies in the North Sea region, Liyanage (2007). Pintelon (1997) points out the importance of a well functioning maintenance reporting system, and also the fact that most systems in this area are limited only to budget reporting. Sloan et al. (2000) claims that combined production and maintenance models lead to significantly greater reward (about 25 % more) compared to a traditional method.

Maintenance is generally treated as a necessary cost that gives nothing in return, while it can instead be treated as a profit-generating centre since it is closely related to company's internal efficiency (Al-Najjar 2007). Using an efficient maintenance policy, such as Vibration-Based Maintenance (VBM) policy for rotating machines, leads to fewer planned stoppages and failures, lower level of spare part inventory and a smother production process. It will also lead to a higher quality and more profitable production process especially in process, chemical, energy and recently in manufacturing engineering industry Bloch and Geitner (1994). Therefore, it becomes essential to use relevant data to be able to control maintenance cost-effectiveness. To be able to monitor, map, analysis, assess, predict and improve the outcome of different maintenance actions properly it is necessary to gather and use the data covering relevant disciplines, i.e. technical, financial and managerial data. Data gathering and analysis processes can even be more trouble-free and cost-effective if it is computerised in a form such as Decision Support System (DSS). This allows following up production and maintenance performance measures more frequently. It will also be easier to trace the causes behind deviations and allow for quicker reactions at an early stage for avoiding economic losses. Thereby, planning and executing maintenance actions cost-effectively, and answering where, how much and why an investment in maintenance may have the best financial payoff can easily be achieved, Al-Najjar (2009).

2. PROBLEM ANALYSIS AND IDENTIFICATION OF RELEVANT DATA

Using Condition monitoring (CM) aims to map, describe and analyse the status of a component/equipment in order to avoid failures and disturbances. Applying CM, such as using shock pulse measurements, vibration, sound, acoustic emission, etc. provides measurements/data that are required for describing the behaviour of the CM value when there is damage, i.e. damage development. Diagnosis of the information provided by these measurements can be used to describe what was happened, what is ongoing, what mechanisms and parameters were involved, etc. In other words, we may have an idea about what has happened, why and where has happened, but we have big difficulties in assessing with high accuracy the severity of the damage that is necessary for properly planning maintenance actions, see for example Collacott (1977) and Bloch and Geitner (1994). Maintenance cost-effective decisions cannot be achieved effectively without relevant data of high quality describing properly production and maintenance processes, Al-Najjar (2007). Also, identification of and gathering relevant data demand properly conducted technical analysis of the production and maintenance processes' problems for identifying relevant CM parameters providing the information required for decision making. Thus, a systematic analysis can ease and increase the faith in the identification and application of relevant CM systems as it described by the eight-step procedures, FIGURE 1. These eight steps are classified in two major categories: 1) mapping, classifying and prioritising, 2) technical & economic analysis, results, identification & work improvement. The steps introduced in FIGURE 1 assist effective detection of deviations in component condition & make cost-effective decisions by using relevant data. It is approached through mapping the situation, identification, classification, analysis, prioritising problems, identification of relevant data and treating problems using relevant data. The description of the problems usually eases selection of the most relevant (informative) CM systems.

3. ROLE OF DYNAMIC AND COST-EFFECTIVE MAINTENANCE IN COMPANY BUSINESS

An estimation of maintenance contribution in company profit, i.e. savings generated due to maintenance, is interesting because it highlight the role of maintenance in reducing production cost. Also, it describes maintenance role in the company's business, profitability and competitiveness (Al-Najjar 2007). In this paper, we consider a cost-effective decision is that which increases savings due to less unplanned and planned stoppages, shorter stoppages, better product quality, etc. In the economic terms, it is the decision which contributes in more profit for the company. Dynamic and cost-effective maintenance decisions should offer a flexible maintenance system that enables the user following the changes in the production process and surroundings dynamically and cost-effectively. But, it demands relevant data and clear description of the links describing the conversion of all investments in maintenance to income (money – to- money) in a plant, i.e.

Capital investments in maintenance - to **- Maintenance technical output -** to **- Production technical output -** to **– Income (Capital)**

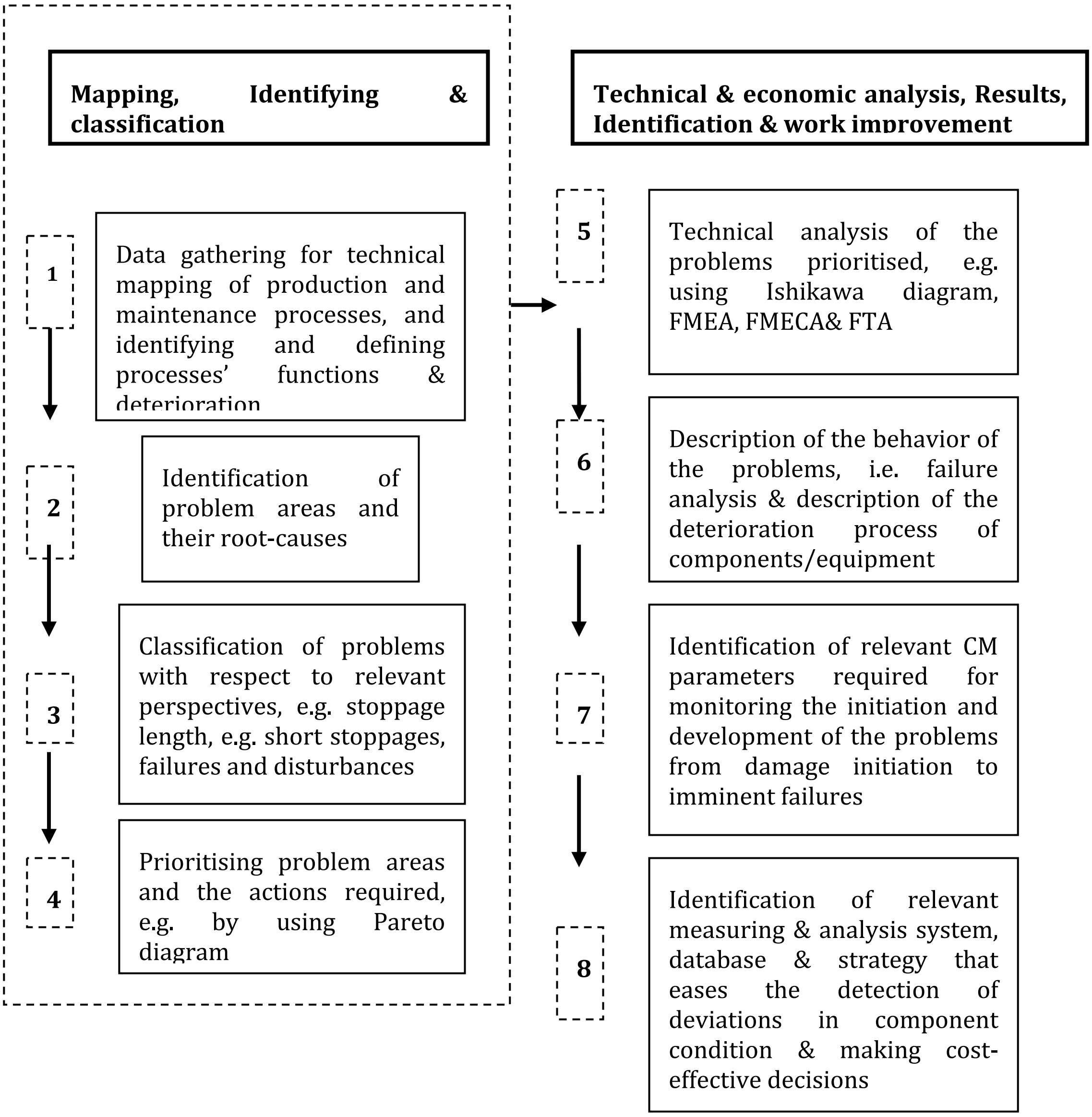

FIGURE 1. Identify& analysis towards cost-effective decision-making process

These three steps are to convert maintenance impact to a measure, such as money, that every one in a company from the floor workers to the chef manager can easily understand and use for comparison between maintenance inputs and outputs and judgement of maintenance cost-effectiveness. Maintenance actions can be planned cost-effectively through selecting the most proper moment for the task, i.e. when all the cost are low, which in turn increases maintenance economic impact. Also, it will not be difficult to assess maintenance activities' costs and how much maintenance has generated income (savings and profit). To highlight this point we introduce in FIGURE 2 two cases showing the logic flow of cause-result.

a) Fewer disturbances, e.g. failures, in a production process ----*results in*---- Reducing delay in the delivery schedule ----*which in turn*---- Accomplishes company strategic objectives

b) Fewer failures and shorter downtime ---- *yields* ---- Longer production time ------ More production ---- *and consequently* ---- Better profit margin ----*which leads to*---- More profit ---- *and* ---- Better competitiveness

FIGURE 2. Logic flow of cause-result of maintenance impact is described in two cases

From industrial everyday experience, it is, in many cases, possible to tell what has happened in a component/equipment, where and why, but it is more preferable to know more about the situation, for example more information about:

1. What is the residual time (the probable time that has been left until failure)?
2. What is the probability of failure during the coming period?
3. What is the predicted value of the CM parameter in the next future, e.g. next measuring opportunity or next planned stoppage?
4. What are, if there any, alternative solutions for the problem in question?
5. How much will cost to solve the problem?
6. What is the most cost-effective maintenance solution for the problem in hand?
7. Is the selected solution really profitable?
8. What are the most profitable areas for investments in maintenance?
9. What is maintenance contribution in company profit?
10. According to which factors/parameters maintenance is profitable?

Dynamic e-maintenance that is realised in eMDSS introduces four different strategies for continuously improving the cost-effectiveness of maintenance and production processes:

1. Accurate maintenance decisions
2. Selection of the most cost-effective solution
3. Follow up maintenance investments and performance
4. Identify, classify and assess losses in production time, see also TABLE 1.

Assessing the residual time of a component is always necessary for a production manager to check the possibility of fulfilling delivery schedule. While, the probability of failure of the same component is important to understand the chance of proceeding running the production without increasing the risk of failure. Prediction of, e.g. the vibration level during the next future, is for describing the ability of machine to run in the near future without exposing the machine security, operator safety, product quality, working environment and may be even production cost to dramatic or catastrophic changes, Al-Najjar (2009). Having a problem, it is almost always possible to suggest several alternative solutions, but the selection of the appropriate, i.e. the most cost-effective, solution is always not trivial while it is important to increase the certainty in doing things right from first time. Furthermore, theoretical selection of the most cost-effective can, in many cases, not securing achieving the most profitable solution. This is why following up implementation results and maintenance performance for pinpointing the profitability of the chosen solution in addition to assessing maintenance contribution in company business, Al-Najjar (2007, 2009 and 2010). Thus, it would be possible to identify the most beneficial area for future investments in maintenance and which maintenance measure stands behind increasing or reducing its profits.

The additional information that we are asking about above in addition to the economic failure consequences will enhance appreciably the context of the holistic view of the situation and eases making cost-effective maintenance decision. Furthermore, following static rules for judging dynamically changed situation makes the process of decision making rigid and unable to suit different situations. This is why this additional information increases the possibility of applying dynamic and cost-effective maintenance.

In many cases, it is necessary to realise the importance of the changes in the technical parameters, e.g. stoppage hours, number of failures, average stoppage time per each short stoppage, lower quality rate, productivity, etc. on the economic scale. For example, what is the economic impact of increasing or reducing the number of failures by a number m? Finally when all these technical information parameters and measures have been converted to the economic scale it will be easy to assess losses and profit of every investment and action, Al-Najjar (2007). Also, it helps to allocate necessary investment in the most places of high payoff and consequently more profitable maintenance and production.

4. SCENARIO OF ACHIEVING DYNAMIC AND COST-EFFECTIVE MAINTENANCE

eMDSS can be used for the same component and machine. Also, it is applicable for different components in the same machine or in different machines, Holmberg et al. (2010). It is not prepared to replace available systems rather than to be a complementary part which adds new function other available systems do not provide. In order to utilise all the services provided by eMDSS, relevant data are necessary to have. These data are usually available at the company data bases, i.e. eMDSS does not demand more data than that available in the company database, such as:

1. Technical data: Times and number of stoppages, type of stoppages, planned and real production, production rate, defective items, investment depreciation period.
2. Economic data: Profit margin, maintenance direct costs, user defined expenses, maintenance investments.
3. Human resources data: Impact of competence, commitments and communication on the production time, i.e. classification of stoppages with respect to the above mentioned factors.

A dynamic decision is considered as; the decision which is made using dynamic rules instead of a general model does not matter the changes that may have happened in the situation of a production process. For example, damage initiation cannot in any way means termination of a component/equipment ability to perform its function measured in the operational, economic or safety basis, Holmberg et al. (2010). Also, the operating conditions, e.g. production speed and loading, ambient temperature, pressure, humidity, etc. cannot be kept constant in time. Given that the data required for mapping, analysis and controlling the condition of a component are available and accessible. The rules for making a decision of stopping a machine to replace damaged component should be dynamic in a way that a maintenance engineer can follow up the development of damage development with high certainty. In other words, damaged component should not be replaced as soon as the damage is detected because what it should be considered in this context is the impact of the damage on safety, production, quality and cost. Rules for dynamic decisions will make it possible to reduce failures and utilise as much as possible of the component life without increasing the risk of failure. It also means that ability to perform the maintenance action required at any time the risk of failure approached a significant level. This is what eMDSS offer as a possibility, i.e. to maintenance a machine cost-effectively in a dynamic (real) environment without increasing the risk of failure.

Assume that we monitor a rotating machine, e.g. compressor, pump, gearbox, CNC, etc. using vibration signal analysis. The scenario of dynamic and cost-effective maintenance will be described by the following steps, see also FIGURE 3 and FIGURE 4:

1. Vibration measurements are already picked up and analysed. Diagnosis of these measurements provide information concerning;
   - What has happened?
   - Where is it happened?
   - Why is it happened?
2. Primarily judgement of the damage severity can be done using alerts stated in the CM software programme. As long as the vibration level of the interesting component according to a particular fault is still fluctuating around the normal level (the level when no damage is initiated) there is no worry
3. As soon as the vibration level approach or exceeds warning level we should worry because we cannot know the behaviour of it in the close future. This is why many replacements are done as soon as the level exceeds the normal value which in turn costs more economic losses, Al-Najjar (1998).
4. In order to avoid unnecessary replacement and additional production losses, the vibration level in the next convenient date is predicted. This date can be decided by the user, such as, next measuring moment, next planned stoppage, delivery datum, etc. To predict the vibration level use PreVib, see TABLE 1, FIGURE 3&4, and Al-Najjar and Ciganovic (2009).
5. The assessment of damage severity using vibration level may acquire less certainty due to the nature of the deterioration process and vibration signals, i.e. randomness. This is why it is important to reduce this uncertainty by applying statistical tools for assessing the probability of failure and

residual time using historical data from the same machine or identical components, see TABLE 1 and FIGURES 3&4.

6. Then, the existence of an imminent failure/problem is confirmed, it naturally in turn demands solution.
7. Maintenance solutions/actions can be many and of different types for the same problem. The major problem is then how to select the most cost-effective solution. In order to handle this threshold apply AltSim, see TABLE 1 , FIGURES 3&4 and Al-Najjar (2010).
8. Implementing the solution selected by AltSim demands following up for checking whether the solution was really the most cost-effective. Also, following up maintenance performance, its economic contribution to company profit, identification of the most beneficial investment areas in maintenance and judging the profitability of previous investments in maintenance. MainSave is prepared for performing all these functions, see TABLE 1, FIGURES 3&4 and Al-Najjar (2009).
9. The fourth strategy for enhancing the cost-effectiveness is a means to identify problems and classify the root-causes with respect to the losses in the production time, see TABLE 1 & FIGURE 3.
10. When a problem is identified, classified and weighted using its share in generating losses in the production time, it would be possible to go back to AltSim (Step 7) for selecting the solution and (Step 8) for following up the investment using MainSave, see TABLE 1 & FIGURE 3.

To summarise these steps, eMDSS can be used differently for different situations to identify, localise and prioritise problems, simulate solutions, select the most cost-effective and provide in advance judgement concerning the cost-effectiveness of the investments suggested, and finally follow up the investment results whether it contributes in more profit for the company.

TABLE 1. Description of the toolsets and tools included by eMDSS.

Toolsets	**Tools**	**Features & Function**	**Toolsets**
Toolset 1 Maintenance decision accuracy	**(a)** PreVib	**(a)** To predict the vibration level of a component/ equipment at the next planned maintenance action or measuring moment for avoiding sudden and dramatic changes in the vibration level and catastrophic failures.	**Toolset 1** Maintenance decision accuracy
	(b) ProFail	**(b)** To assess the probability of failure of a component (using machine past data) at need or when its vibration level is significantly high. It can also be used separately from CM techniques.	
	(c) ResLife	**(c)** To assess the residual life of a component. It is to avoid failures and delivery delays, ResLife can be used to control whether it is possible for the production process to proceed according to the production schedule or not. The probability of failure and residual life are assessed using a modified form of Total Time on Test plots.	
Toolset 2 Cost-effective solution	AltSim	To simulate technically applicable alternative solutions suggested for a particular problem, and to select the most cost-effective solution using an intelligent motor. It is important to improve the cost-effectiveness of maintenance investments and planned actions. The selection is done using well-defined criteria, such as the proportion of maintenance savings to the invested capital, total maintenance profit.	**Toolset 2** Cost-effective solution
Toolset 3 Maintenance Savings	MainSave	To monitor, map, analyse, follow up and assess maintenance cost-effectiveness, i.e. maintenance contribution in company profit (maintenance savings & profit), and investments in maintenance. It is a reliable	**Toolset 3** Maintenance Savings

		tool for securing cost-effective maintenance actions.	
Toolset 4 Problem identification & prioritisation	Man-Machine-Maintenance-Economy (MMME)	To identify and prioritise problem areas and to assess the losses in the production time. It is beneficial to plan maintenance actions according to a prioritising list.	**Toolset 4** Problem identification & prioritisation

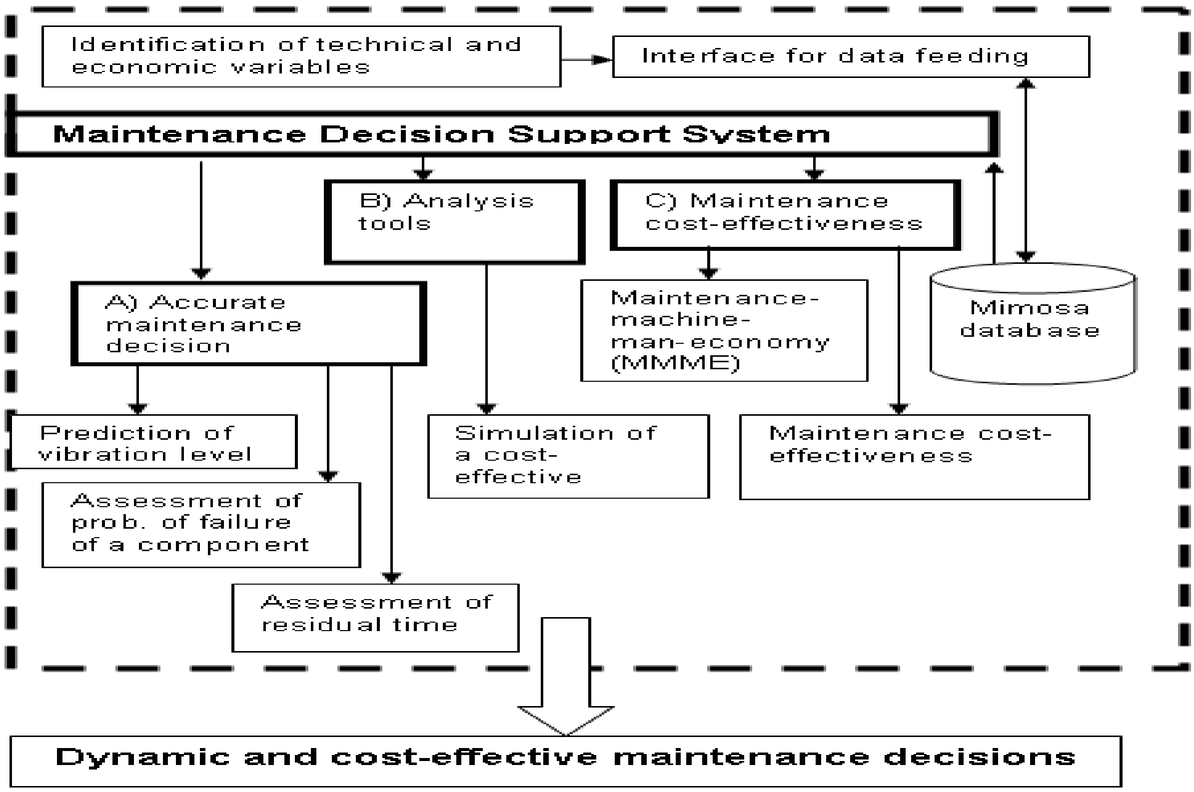

FIGURE 3. Conceptual model of eMDSS, Holmberg et al. (2010)

5. EMDSS TEST AND RESULTS

In order to test the conceptual model shown in FIGURE 3 and the software programme introduced in FIGURE 4 and also to test the applicability and functionalities of eMDSS for dynamic and cost-effective maintenance decisions, sets of real industrial data have been gathered for testing all eMDSS's tools. In this section, we illustrate the tests that have been conducted and the final results of the tests. All the six tools included by toolsets 1, 2, 3 and 4 in eMDSS, see TABLE 1, have been tested using industrial data from Goratu (CNC-machine manufacturer) and FIAT/CRF (car manufacturer). The data have provided by FIAT/CRF were used for testing AltSim, MMME and MainSave (toolsets 2, 3 and 4), for more details see Holmberg, et al. (2010).

The data (vibration measurements and life data of the components) gathered from Goratu have been used for testing the tools (software modules) PreVib, ProFail and ResLife (toolset 1, Accurate Maintenance Decisions). The data gathering was partly performed by using the database user-interface.

The machine at FIAT/CRF that was considered for eMDSS test is a CNC-milling machine. It produces engine heads. The operation that is performed by the machine is milling. This machine is considered to be a bottleneck in the production line which makes it critical for the whole production process. The data were collected at two periods (8^{th} of Jan. 2007 – 7^{th} of June 2007) and (8^{th} of June 2007-8^{th} of Jan. 2008).

Failure data have been collected with high precision.

Losses in the production time, due to decreased production speed, management problems, human recourses related problems, machine characteristics, etc. were initially collected in one huge category called **Waste** without any notation of the real causes and the associated losses in the production time. This happened because the company has not any previous necessity for gathering these types of data. eMDSS demands sorting out the different types of losses accumulated in the **Waste** category with respect to the real root-causes. This means that the losses in the production time estimated per each root-cause is not an exact measurement, because of the deviations in the distribution of **Waste** into different root-causes, such as measuring error, human error, incompatible measuring system and technique, and measuring procedures. In this way, eMDSS has been tested in FIAT (Car manufacturer) in Italy, and at GORATU (CNC-Machine manufacturer) in Spain. The test has shown that:

It is important for approaching accurate and cost-effective maintenance decisions

1. It can be suited for different situation dynamically
2. It assists identification, classification and prioritising problems
3. A reliable tool in identifying the most beneficial areas for investments in maintenance
4. It is also effective in following up previous investments and assessing its profitability

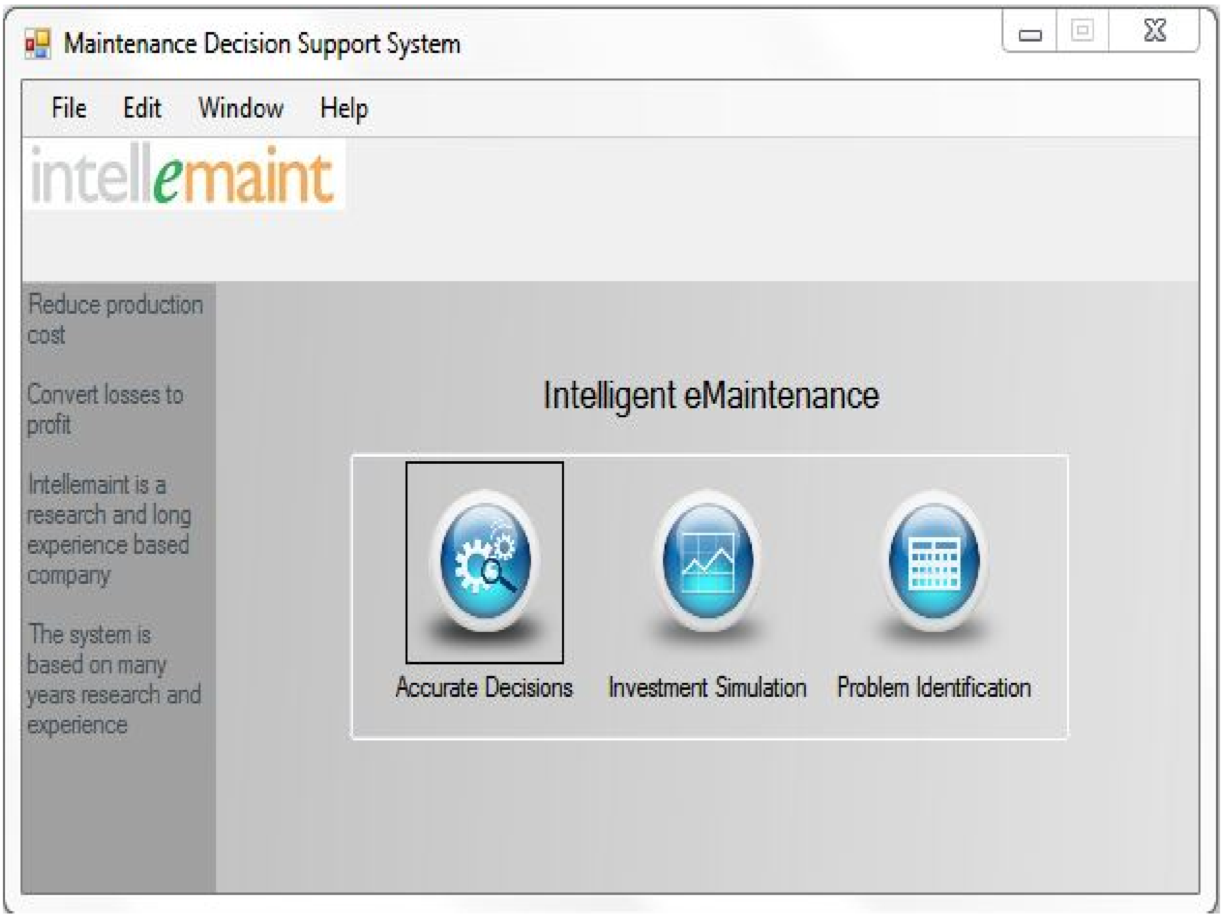

FIGURE 4. Main menu, user-interface of eMDSS.

To check whether it is correct that the tests of eMDSS has shown clearly the potentials and benefits of achieving dynamic and cost-effective maintenance decisions, the following features have been distinguished:

- **Dynamic:** following up technical changes in the condition of the component/machine, process and improvement results.
- **Selective:** simulating relevant solutions & selecting the most cost-effective.
- **Supportive:** supporting continuous and cost-effective improvements in maintenance and production processes.

- **Cost-effective:** following up previous and on-going investments in maintenance for detecting deviations in its cost-effectiveness.

CONCLUSIONS

Using MDSS, it is possible to act at an early stage in both tactical and strategic levels for fulfilling company's strategic goals in continuous improvement of its profitability and competitiveness. Applying MDSS makes it possible to handle real-time data, analysis and decisions and give necessary information about maintenance and other working areas to the decision maker.

It provides better data coverage and quality which are essential for improving knowledge and experience in maintenance and thereby aid in increasing the competitiveness and profitability of a company. Predicting the CM parameter level at the next planned measuring time or next planned stoppage reduces the risk of an unexpected deviation in the condition of significant components. This means that the probability of failure of a component, such as a rolling element bearing can be kept very low (close to zero) until damage is initiated and under development, given that damage can be detected at an early stage through using an efficient CM system. This would reduce the number and duration of planned and unplanned stoppage that has a direct impact on the company's productivity, and hence, its competitiveness.

Using MDSS different tools (software modules), there is no duplication of data gathering. Also, MDSS's modules are flexible and can used in different companies, for different machines, components and products. It is also possible to show how maintenance affects the profit of a company in a way that is hard to do with the available tools and techniques even if the data required are available. Development of relevant and traceable KPIs for technical and economic maintenance control has made this possible. All these functionalities can be done when high quality data can be collected using advance techniques in data gathering, transmission and analysis.

ACKNOWLEDGEMENTS

The results of this study were part of the result achieved in an EU-IP DYNAMITE (Dynamic Decisions in Maintenance) during th eperiod 2005-2009.

REFERENCES

Al-Najjar, B. (1998) Improved effectiveness of vibration monitoring of rolling element bearings in paper mills. Journal of Engineering Tribology, IMechE, Proc. Instn Mech Engrs part J, 212:111-120

Al-Najjar, B. (2007) The lack of maintenance and not maintenance which costs: A model to describe and quantify the impact of vibration-based maintenance on company's business. Int. J. of Production Economics (IJPPM)107, 55:260-273

Al-Najjar, B. (2009) A computerised model for assessing the return on investment in maintenance: Following up maintenance contribution in company profit. To appear in the proceedings of WCEAM 2009, Athens, Greece

Al-Najjar, B. and Ciganovic, R. (2009) A model for more accurate maintenance decisions (MMAMDec). To appear in the proceedings of WCEAM 2009, Athens, Greece

Al-Najjar, B. (2010) Computerised Maintenance Decision Support System (MDSS) for Simulating and Selecting the most Cost-effective Production and Maintenance Solution: Case Study in FIAT/CRF, Italy. Proceedings of the 23rd Internatonal Congress on Condition Monitoring and Diagnostic Engineering

Management (COMADEM), June 28-July 2, 2010, Nara, Japan. p. 843-851, edited by Susumu Okumura, Tadao Kawai, Prng Chen & Raj B.K.N. Rao, Sunrise Publishing Limited, Hikone, Japan.

Barlow, R.E. and Proschan, F. (1967) *Mathematical Theory of Reliability*. John Wiley & Sons, Inc., New York, 1967.

Bloch, H.P. and Geitner, F.K. *Machinery failure, analysis and troubleshooting*. Gulf Publishing Company, London 1994.

Cerrada, M. Cardillo, J. Aguilar, J., Faneite, R. (2007) Agent based design for fault management systems in industrial processes. Computers in Industry 58. 313-328.

Collacott, R.A. (1977) *Mechanical Fault Diagnosis and condition monitoring*. Chapman and Hall, London.

Cox, D. R. *Renewal Theory.* Barnes & Noble Inc., London, 1967.

Djurdjanovic, D, Lee, J., Ni, J. (2004). Watchdog Agent- An infotronics-based prognostic approach for performance degradation assessment and prediction. Advanced Engineering Informatics, Vol. 17, 109-125.

Fu, C., Ye, L.Q., Liu, Y.Q. Iung, B. (2002). MAS-based model of intelligent control-maintenance management system (ICMMS) and its applications. Proceedings of International Conference on Machine Learning and Cybernetics. Vol. 1, 376-380

Garg, A., and Deshmukh, S.G. (2006). Maintenance Management: literature review and directions. Journal of Quality in Maintenance Engineering. Vol.12, No. 3, 205-238.

Holmberg, K., Jantunen, E., Adgar, A., Mascolo, J., Arnaiz, A. and Mekid, S. (2010) E-Maintenance. Sprinder-Verlag London Limited 2010.

Jardine, A.K.S. *Maintenance replacement and reliability.* Pitman Publishing 1973.

Jardine A K S, Lin D, Banjevic D (2006) A review on machinery diagnostics and prognostics implementing condition-based maintenance. Mechanical Systems and Signal Processing 20:1483-1510

Liyanage, J.P. (2007) Integrated eOperation-maintenance: Applications in North Sea offshore assets. Book chapter in Complex Systems Maintenance, Murthy, P. and Kobbacy, K. USA, Springer, 585-609

Nadakatti, M., Ramachandra, A., Kumar, A.N.S. (2008) Artificial intellingence-based condition monitoring for plant maintenance. Assembly Automation. Vol.28, No. 2, 143-150.

Pintelon L (1997) Maintenance performance reporting systems: some experiences. Journal of Quality in Maintenance Engineering 3:4-15.

Sloan, T.W. and Shanthikumar, G.(2000) Combined production and maintenance scheduling for a multiple-product, single-machine production system.Production and operations management, Vol.9, No.4, 2000.