Dynamic e-Maintenance: Applying eMaintenance Decision Support System (eMDSS) in Case Companies

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Abstract
In order to maintain and improve company profitability especially during financial crises and lower profit-margin, it is necessary to reduce economic losses. This can be achieved through maintaining and improving the quality of the elements involved in the production process. Therefore, the maintenance strategy applied should be dynamic to suit the changes occur in a production process cost-effectively. Therefore, it is essential for maintenance and production managers to have a system providing the data required to achieve dynamic and cost-effective maintenance decisions. In this paper, a new Maintenance Decision Support System (eMDSS) for achieving dynamic and cost-effective maintenance decisions is introduced, tested and discussed. It consists of three toolsets and five software modules for performing six services to; enhance accuracy of maintenance decisions, select the most cost-effective maintenance solutions, identify and prioritise problem areas, and assess losses in production time, and map, follow up and assess maintenance cost-effectiveness (maintenance savings and profit) to achieve continuous & cost effective improvement. The major result of this tsudy is verfication of a new innovative Mainteance Decision Support System (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 and maintenance processes, identify and prioritise problems, select the most cost-effective maintenance investment and follow up and control investments results. **Key words:** Dynamic eMaintenance, Cost-effective and Accurate Decisions, Maintenance Savings, Profit & Risk Capital Investment, Return on Investment in Maintenance, Prediction of Vibration Level, 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 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). 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 more frequently. 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. Dynamic e-Maintenance

Maintenance influences many working areas in a producing company. Therefore, an estimation of maintenance impact, i.e. savings generated due to maintenance, is interesting because it means lower production cost, and highlights maintenance role in the company's business (Al-Najjar 2007). In this paper, we considered a cost-effective decision is that which increases maintenance savings due to reducing failures, & shorter stoppages, and improving quality, etc. In the economic terms, it is the decision which contributes in more profit for a company.

2.1 Maintenance Modelling

Applying only the deterministic (Engineering) approach, such as problem identification, analysis and diagnosis of failures and following up development of fault using condition monitoring (CM) technologies, can be counted as one of the shortages in condition-based maintenance (CBM) applications. Due to randomness in a deterioration process, the real damage or changes in the condition of a component is hardly to be expressed, described and assessed effectively by only the deterministic approach. Probabilistic modelling of the residual time or the assessment of the probability of failure of a component by converting CM measurement to the time scale without considering analysis, diagnosis and prognosis cannot either give a reliable picture of the condition of the component. This is because there is inbuilt appreciable uncertainty in each statistical model does matter how robust it is as long as the spread of the time to failure is large, i.e. the standard deviation is big, which is the case in mechanical components and systems. In these types of components the spread in the time to failure can be between months and years. From everyday experience, more relevant and accurate data concerning the deterioration process under consideration the less need for probabilistic modelling. Keeping in mind the probabilistic approach cannot be eliminated as long as the deterioration process is a stochastic process. This is why we believe that the probabilistic modelling is a natural complementary to the deterministic approach when there are no more accurate data can be provided by the latter and that are required for enhancing the certainty of the decision-making process.

When the CM parameter value is increased significantly, the assessment of the probability of failure of a component, its residual time, etc. in addition to the historical and current CM measurements and diagnosis would enhance the description of the previous, current and future state of the deterioration process and component life behaviour (Al-Najjar 2003, Jardine et al. 2006). In order to approach an accurate mapping and assessment of the condition of a component/equipment several variables should be considered simultaneously, such as previous measurements and their trend, current measurement, deterioration rate, maximum allowable limit for the CM value, diagnosis and prognosis results, failure rate, residual time, probability of failure, etc. Usually, only the first three variables or the last two variables are used (Al-Najjar and Wang 2001, Jardine et al. 2006), respectively. Therefore, in eMDSS we use additional information parameters to describe the situation of a component/equipment with more details. In addition to the trend data and current measurement that reflect the past and current condition of a component/equipment, eMDSS predict the vibration level during the next future, the next planned stoppage or measuring opportunity, the probability of failure utilising past data from the same machine/component and the residual life of the component in question. 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 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)**

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. Thus, maintenance actions can be planned cost-effectively through selecting the most proper moment for the task 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).

2.2 Strategies for Cost-effectiveness

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, e.g.:

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.

Assessing the residual time of a component is always necessary for the 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 lower 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, is always not easy 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 maintenance investments and performance for pinpointing the profitability of the chosen solution in addition to assessing maintenance contribution in company business is important, Al-Najjar (2007, 2009 and 2010). Thus, it would be possible to identify the most beneficial area for future investments in maintenance and which causes stand 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 dynamically changed situations. This is why these additional information parameters increase the possibility of applying dynamic and cost-effective e-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 maintenance investment and action, Al-Najjar (2007). Also, it helps to allocate necessary investments in the most places of high payoff and to consequently achieve more profitable maintenance and production.

3. Test and Results of eMDSS

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. It is not prepared to replace available systems rather than to be a complementary part which adds new functions 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 company data bases, i.e. eMDSS does not demand more data than that available in the company database, such as: **Technical data:** Times and number of stoppages, type of stoppages, planned and real production, production rate, defective items, investment depreciation period. **Economic data:** Profit margin, maintenance direct costs, user defined expenses, maintenance investments. And **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, see also Fig.1. eMDSS has been tested in FIAT (Car manufacturer) in Italy, and at GORATU (CNC-Machine manufacturer) in Spain, see Al-Najjar and Ciganovic (2009), Al-Najjar (2009) and Al-Najjar (2010). The tests have shown that: **It** is important for approaching accurate and cost-effective maintenance decisions. **It** can be suited for different situation dynamically. **It** assists identification, classification and prioritisation of problems. **It** is a reliable tool for identifying the most beneficial areas for investments in maintenance. And **it** is also effective in following up previous investments and assessing its profitability.

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

When using a CM system for following changes in the condition of a component/equipment, it is necessary to have more information about future development of CM parameter value in addition to the past and current data. For that PreVib is developed to predict the value of the vibration level in the next future, e.g. next planned measuring moment or stoppage, Fig.2. The red curve and blue curves represent predicted and real measurement values. When the CM parameter value in the close future is predicted, it would be necessary for increasing the certainty in the results obtained to assess the probability of failure and the residual live of the component in question. The major reason of these additional assessments is the randomness in CM measurements. ProFail and ResLife can be used when a CM system is involved or not. Applying PreVib, ProFail and ResLife, Fig.3, make planning and performing a maintenance action dynamic, basically based on the condition of the component without increasing the risk of failure. When a problem is identified and the severity of the damage is assessed, a plan for maintenance actions is then necessary. For every problem several solutions can be suggested. The selection of the most suitable solution is not trivial. Using AltSim, it is possible to select the most cost-effective maintenance solution using data from production process, see Fig.4. But, it might be difference between selecting a maintenance solution and its real application. Therefore, applying MainSave shown in Fig.5 eases following up the impact of the selected solution, maintenance performance, identifying the most cost-effective investing areas in maintenance and follow up it and indentify the causes behind technical and economic losses in production.

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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. 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 profit of the company. Predicting the CM parameter level at the next planned measuring time or next planned stoppage reduces the risk of failures. This means that the probability of failure of a component, such as a rolling element bearing can be kept very low 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 productivity. 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.

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Fig.1. Main menu, user-interface of eMDSS

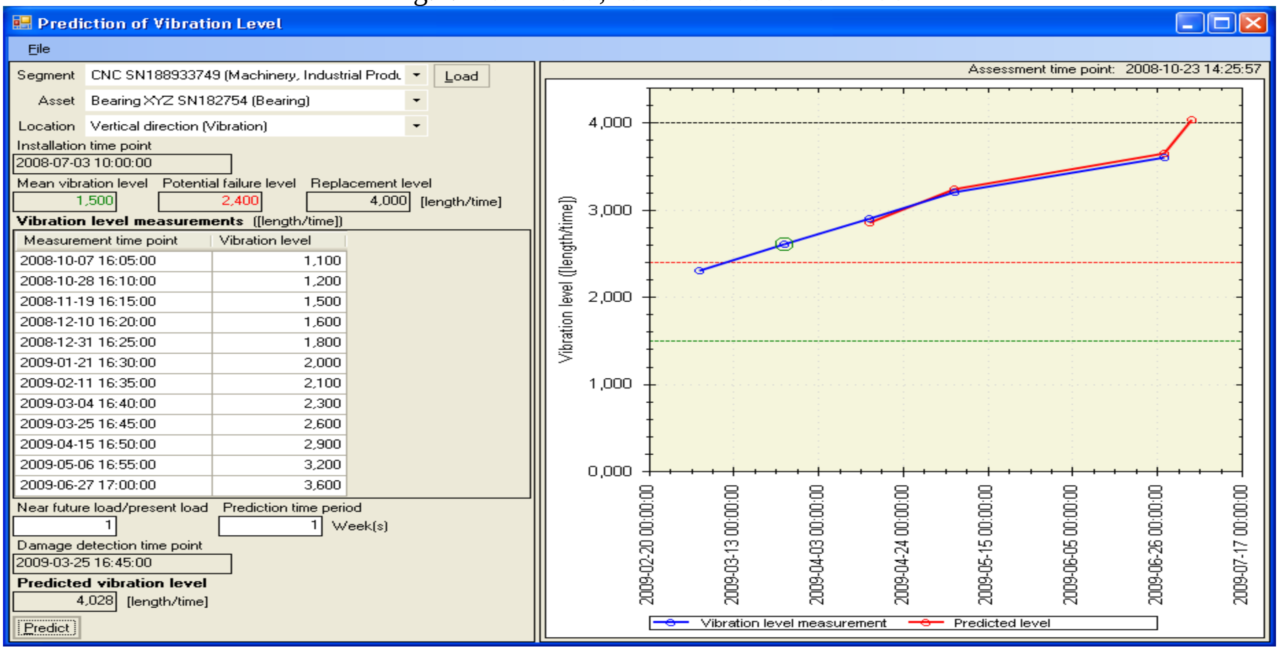

Fig.2. User-interface of PreVib module.

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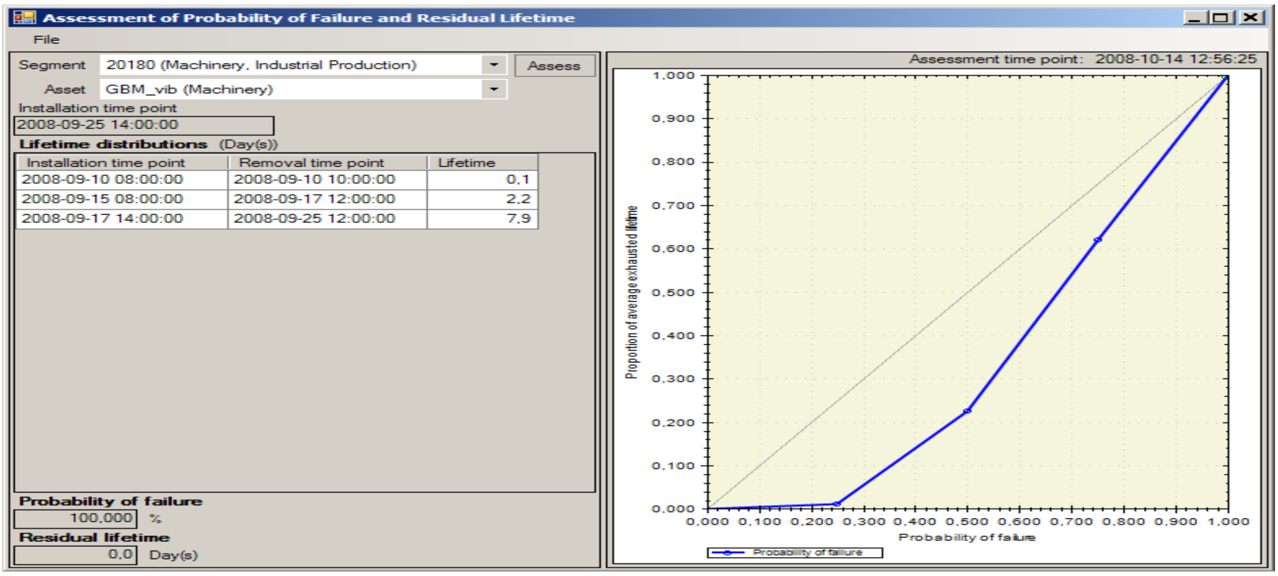

Fig.3. User-interface of ProFail and ResLife module

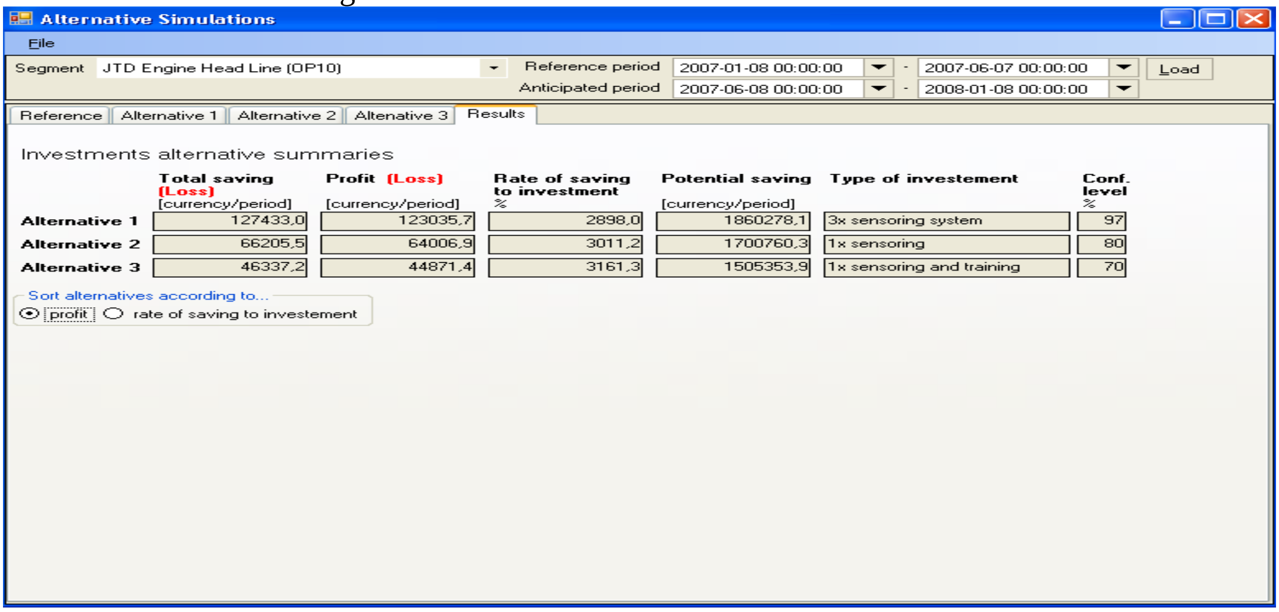

Fig.4. User-interface of AltSim module

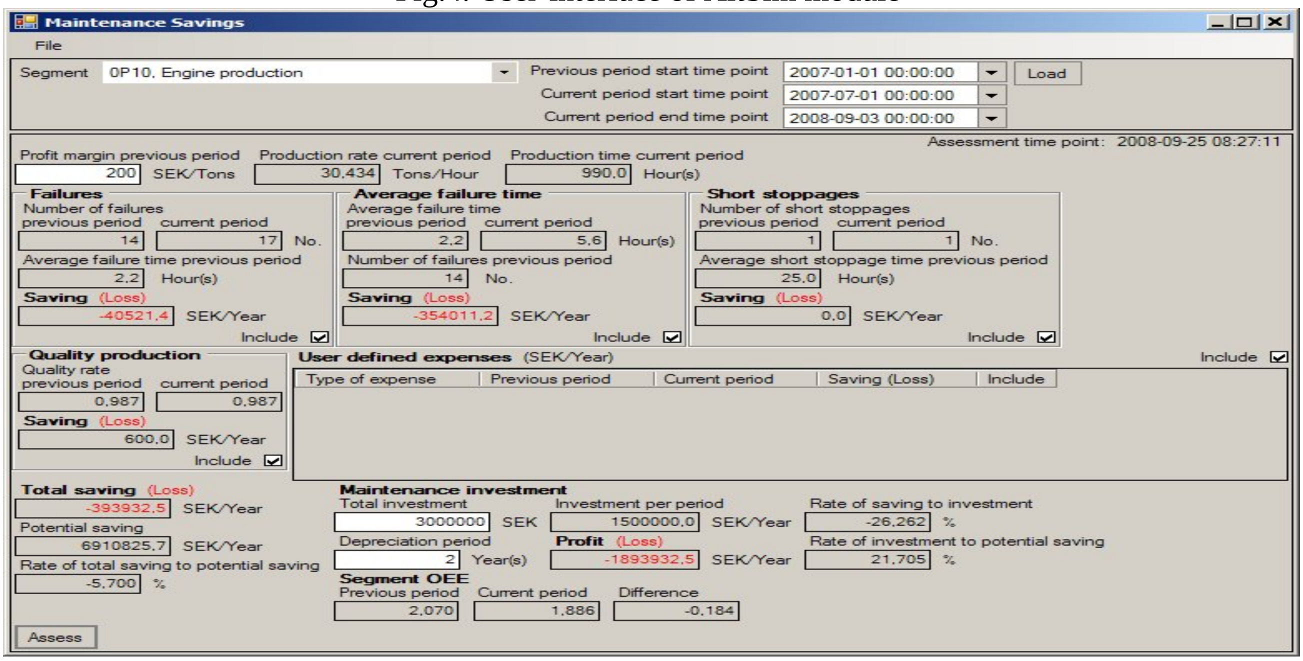

Fig.5. User-interface of MainSave module