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SYSTEM FOR MONITORING MACHINES FINANCIAL AND TECHNICAL EFFECTIVENESS

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ABSTRACT

The positive effects of maintenance on product quality, machine, ability to deliver the expected production on time and on production costs are well accepted in the scientific community. Never the less, a survey made in Swedish industry indicates that the positive contribution of maintenance is in general still not recognised or fully understood. Maintenance is still to a great extent seen as an unnecessary cost. To make it possible to recognise the impact of maintenance on the production process, a simple to use and reliable system for assessing its impact is required. This system should assist in distinguishing effects from actions taken in different working areas such as maintenance and logistics to enhance process performance. In this article a simple and transparent system for monitoring the performance of a production process in financial terms with respect to maintenance effect is presented. This system is based on a model describing how performance of the production can be related to vibration-based maintenance. The main result presented in this paper is a simple, transparent and user-friendly system for monitoring and assessing the performance of the production process with respect to maintenance. The main conclusion is that using this system makes the hard task of monitoring maintenance impact on the production process easier and faster and thereby also easier follow up the cost-effectiveness of investment in maintenance.

KEYWORDS
PRODUCTION PROCESS MONITORING, PERFORMANCE MEASURE, CONTINUOUS IMPROVEMENT, MAINTENANCE

INTRODUCTION

The positive financial effects of maintenance is widely recognised in the scientific community, for example (De Groote 1995), (Ollila and Malmipuro 1999), (Markeset and Kumar 2001), (Mitchell et al. 2002) and (Al-Najjar and Alsyouf 2004). (Mitchell et al. 2002) conducted a study in north east of England
during 1997 and 1998 including 298 companies followed by a smaller study among 23 companies and they found that companies systematically adopting best practices in maintenance do achieve higher performance. Yet, a study conducted among Swedish industry gave as a result that 70% is considering maintenance only as a cost, (Alsyouf 2004). This illustrates a possible difference in the apprehension of maintenance between the academic research community and the industry, which indicates that the industry are losing money simply because it is not accepting or believe that maintenance can contribute positively and because of that do not use it in an effective manner. Development in maintenance and a more holistic view on maintenance is enabled by sophisticated information technology, (Pintelon et al. 1999). However, in general, maintenance is a complex, partly stochastic process, and it is difficult to quantify the output of the process itself, (Nikolopoulos et al. 2003). Although, maintenance is still to a great extent considered as a cost, adding little value to business, more and more companies realise that an effective maintenance strategy can contribute significantly to companies profitability, see for example (Nikolopoulos et al. 2003) and (Al-Najjar and Alsyouf 2004). Furthermore, according to (Fachy 1993) companies are experiencing increased global competence. Because the possible impact of maintenance on availability, performance efficiency and quality rate and as a consequence of the profitability of a company a better use of maintenance is a way to meet this situation. However, in order to be able to use maintenance as a cost-effective tool to increase the profitability of a company a system for monitoring the financial consequences, showing both costs and savings of maintenance, is required. Such a system will enable cost-effective decisions regarding maintenance, make it possible to follow up actions and support continuous improvement of the maintenance, (Al-Najjar and Alsyouf 2004). In this paper we introduce a simple, transparent and user-friendly system for monitoring and assessing the performance of the production process with respect to maintenance.

MAINTENANCE

There are several approaches to maintenance, ranging from reactive, preventive maintenance to advanced approaches involving condition monitoring techniques, see for example (Al-Najjar 1997; Kelly 1997; Sherwin 2000).

According to (Kans 2005) maintenance concepts can be classified in the following way:

- Reactive. Maintenance activities are not planned beforehand. However, resources in form of spare parts and personnel must be at hand to avoid long stoppage times and therefore the cost for this type of maintenance is in many cases very high. The main goal of maintenance is to restore production to a functional state after a breakdown.
- Preventive. When using this type of maintenance, time (calendar or operational) between maintenance actions is optimised using statistical methods.
- Predictive. When using this type of maintenance condition monitoring techniques are used to predict the best time to do maintenance.
- Proactive/predictive. A more holistic view on maintenance is adopted, not only considering the mechanical part. The quality of all crucial elements in the entire production process is considered.

In this paper we consider a broader definition of maintenance, described in Total Quality Maintenance (TQMain), not only considering the machinery but all working areas that are relevant for the output of the production process such as: working environment, operations, quality and competence (Al-Najjar 1997), (Al-Najjar and Alsyouf 2000).

TECHNICAL AND FINANCIAL IMPACT OF MAINTENANCE

The costs related to maintenance are often divided into direct and indirect costs, where direct costs are related to spare parts, direct labour etc. that can be comparable easily related to maintenance. Also some of the indirect costs can relatively easily be linked to maintenance, see for example (Cavalier and Knapp 1996). This is why, in general the savings and profit generated by maintenance are not considered. Also
some savings due to maintenance is seen over the entire life cycle of the equipment. Therefore, to estimate the effect of maintenance it is necessary to use the concept of life cycle costs (LCC) and life cycle income (LCI).

LCC is defined as the sum of research and development costs, production and construction costs, operation and maintenance support costs and retirement and disposal costs, (Fabricky and Blanchard 1991). Maintenance is covered in one of the LCC-factors but influence of maintenance can be found in all other LCC-factors as well, (Al-Najjar and Alsyouf 2004). It is also often necessary to estimate LCI, although it may be difficult. A way is to directly assess the savings achieved due to maintenance in other areas such as production, quality and inventory. These savings are achieved through for example reducing the downtime due to failures and short stoppages and reducing number of rejected items due to poor quality, (Al-Najjar and Alsyouf 2004). A model describing how performance of the production can be related to vibration based maintenance, transferred into financials terms, and the mechanisms for impact on other areas of the business was developed and verified, (Al-Najjar 2006). The model describes qualitatively and quantitatively the technical and financial impact of investments in maintenance on the operative and strategic levels in a company, see Fig. 1. Investments in maintenance can in the model, logically, be followed to its technical impact on the operative level concerning: Less unplanned stoppages, Shorter time to repair, Less short stoppages, Better working environment, Higher performance efficiency and Higher availability. An improvement in any of these areas can have a consequential effect on other costs in the company so the investment in maintenance is then followed further to its logical financial impact on the operative level concerning: Less expenses of personnel and environment damage, Lower insurance premium, Lower direct maintenance cost, Lower production cost and Less tied up capital due to less redundancy. Lastly the investment in maintenance is followed to its impact on the strategic level of the company concerning: More savings, More profit, Less delivery delay and penalties, Satisfied customer, Increased market share and Higher stake value.

Figure 1 Schematic view of model describing the impact of investments in vibration based maintenance

In order to see the effect of an investment in vibration based maintenance the saving in all areas of impact must be assessed and summed. When quantifying the model some of the areas of impact disappear because the effect of these can be found in other areas. For example, availability disappears because it increases when number of failures and short stoppages decrease.

The areas that is considered when quantifying the financial impact from an investment in condition based maintenance are: Failures per year, Average stoppage time, Short stoppage per year, Quality production per hour, Expenses of personnel and environment damage, Insurance premium, Direct maintenance cost, Tied up capital due to redundancies and WIP and Delivery delay penalties. Data required to assess the impact of maintenance in these areas can usually be found in the companies' databases and by applying the model it is possible to monitor the most important factors affecting the cost and the profit related to maintenance. The quantified model monitor changes over a period of one year.

SYSTEMS FOR MONITORING MAINTENANCE PERFORMANCE

In order to take full advantage of maintenance, a system for monitoring, assessing and following up the performance of maintenance is required. This is why relevant performance measures should be utilised. The system should consider that effects of maintenance also could be found in other related working areas such as operations and quality. The requirement on systems used to support the maintenance function depends on how developed the view on maintenance is, e.g. if it is seen as an isolated activity performed
when something is broken or something that is done to remove causes of problem and thereby avoiding failures. If the maintenance is carried out in a reactive way, with out any planning or efforts to increase its effectiveness then the system requirements will be low. A maintenance management system that deals with spare-parts might be sufficient, (Kans 2005). However, if an organisation has a more developed view on maintenance the demands on the maintenance management system will increase and it is required to also include functionality for planning maintenance and for condition monitoring, (Kans 2005).

On the market there exist many computerised maintenance management systems (CMMS). However, most CMMS only deal with technical and financial information related directly to maintenance such as spare parts, failure reports, condition monitoring in a technical sense (i.e. vibration, temperature, etc) and overall performance effectiveness (OEE). In addition, about 10 percent of the available Enterprise Resource Planning (ERP) systems on the market includes a module for maintenance, most of these with similar functionality as can be found in the CMMS. A few of the ERP systems also contain information such as mean time to repair (MTTR) and mean time between failure (MTBF) that can be used for maintenance optimisation. Also OEE can be found in some ERP systems, (Kans 2005).

In literature several models for how to monitor maintenance performance have been suggested. (Nagarur and Kaewplang 1999), (Duffua et al. 2001), (Komonen 2002) and (Al-Najjar et al. 2003) among others have presented models for maintenance systems including sets of performance indicators. (Nikolopoulus et al. 2003) has described a model for how functions for managing and follow up on maintenance can be integrated into an ERP system. (Kans 2005) describes the lack of systems for technical and financial monitoring of maintenance impact.

This indicates that there is need for a simple, flexible, user-friendly, system for mapping, analysing, assessing and following up maintenance performance that could support the managers of companies to use the resources in a more cost-effective way.

**SYSTEM FOR MAPPING, ANALYSING, ASSESSING AND FOLLOW UP MAINTENANCE PERFORMANCE**

In order to fill this gap we develop and present a user-friendly system for monitoring maintenance performance in this section. We have chosen to develop this first version of the system using excel since this is well known for most of the possible users, thereby giving a minimal start-up time. Also, this system for mapping, analysing and following up maintenance performance requires relatively few input-data.

**Elements Of The System**

First, all required technical and financial input data to the system should be identified, see (A) in Fig. 2. The technical data is required to assess number of failures, types of failures and short stoppages, length of failures, production rate and amount of quality production. In this stage it is also determined where to find the various required input data. The next steps are to classify data describing the status of the machine as either failure or short stoppage (B1) and also relate data to different working areas such as maintenance and logistics (B2). Step B2 makes it possible to filtering out the signals (disturbances) related to a specific working area. The third step (C) is to start collecting data. This is done using a real time device for monitoring a production process. When data are collected for a decided period of time the savings or losses compared with the previous period is shown, (D).
To investigate the causes behind the savings or losses it is possible to go to individual causes, (E), to see exactly what is behind changes in cost. The following step is to improve the production performance and the system can be used to prioritise individual causes based on how much each contributes to the losses (F). It is also possible to examine in what working area it is best to work with improvements (G). The last step is to improve the use of the system by identifying additional causes of failures to be monitored. Thereby continuously decreasing the short stoppages, (H).

System Development

The system in this section is called EcoCon, is composed of two parts:

1. An industrial commercial system for collecting data regarding disturbances in a production process called Maskintidsuppföljning i realtid (MUR)
2. A model for how these disturbances can be related to maintenance and transferred into financial terms, (Al-Najjar 2006)

A conceptual view of the EcoCon can be seen in Fig. 3. MUR can register the status of a production process. It can register 10 automatic signals, from sensors or from control systems, and 10 manually entered signals. Each signal representing a certain type of disturbance and the user decide how many of these to use. The data are stored in log files. Besides registering disturbances the system also registers production rate, temperature, pressure, etc. MUR is designed and produced by Adductor AB.
EcoCon is using a generalisation of the model described by (Al-Najjar 2006). It is not restricted to only vibration-based maintenance. Regardless of type of maintenance the technical and financial impact on the operative level and impact on the strategic level (market) can be mapped, analysed, assessed and monitored. Furthermore, in the original model the period used to follow up was one year, we have modified this to follow up over any period of time.

![Figure 4. Periods used when following up performance](image)

In EcoCon changes in cost factors between periods decided by the user are monitored. In Fig. 4, when using the system at time \( t_2 \) the increases or decreases of the cost factors between current period, \( t_1 - t_2 \), and previous period, \( t_0 - t_1 \), are assessed. The cost factors used in EcoCon are denoted with \( S_1 \) to \( S_{14} \). Four major cost factors are monitored, \( S_1 \) Number of failures, \( S_2 \) Average failure time, \( S_3 \) Short stoppages and \( S_4 \) Amount of quality production, and up to ten additional related cost factors. The first two factors that are monitored and assessed are regarding losses due to failures. Failures affect this kind of losses in two ways, the number of failures and the average length of the stoppages due to the failure. Actions in maintenance can influence one or both of these factors and consequently we use one cost factor, \( S_1 \), to follow the changes in the losses due to the changes in the number of failures and one cost factor, \( S_2 \), to follow the changes in the losses due to changes in the average failure time. When adding \( S_1 \) and \( S_2 \) we got the total changed loss due to changes in failures.

**Number of failures**

\[
S_1 = [(Y-y) \times L_1] \times PR \times PM \tag{1}
\]

where \( Y \): number of failures during the previous period, \( y \): number of failures during current period, \( L_1 \): average failure time during previous period, \( PR \): Production rate during current period, \( PM \): Profit margin during previous period.

Because we are interested in filtering out the change in the losses due to change in the number of failures, the average failure time from previous period is used.

**Average failure time**

\[
S_2 = [(L_1-l_1) \times Y] \times PR \times PM \tag{2}
\]

where \( L_1 \): Average failure time during previous period, \( l_1 \): Average failure time during current period, \( Y \): number of failures during the previous period, \( PR \): Production rate during current period, \( PM \): Profit margin during previous period.

In this case we are interested in filtering out the change in the loss due to the change in the average failure time and consequently we are using the number of failures from previous period in calculating the change. For short stoppages we are only using one cost-factor to monitor the change in the losses. It can be argued that there should be two factors, one for the number of short stoppages and one for the average short stoppage time as for the failures, see Eqn. 1 and 2, but short stoppages are by definition short and in most cases not properly registered. Because of that we only use one cost factor including changes in both number of short stoppages and changes in stoppage time.

**Short stoppages**

\[
S_3 = [(B-b) \times L_2] \times PR \times PM \tag{3}
\]
where $B$: Number of short stoppages during previous period, $b$: Number of short stoppages during current period, $L_2$: Average short stoppage time, $PR$: Production rate during current period, $PM$: Profit margin during previous period.

The last of the cost-factors that have a major impact on company’s business we are using is the losses due to bad quality generated due to inefficient maintenance.

Quality production (could be weight, number of items, length, volume, etc)

$$S_4 = (p-P) \times WH \times WD \times PM \quad [4]$$

$$S_4 = (p-P) \times PrP \times PM \quad [5]$$

where $p$: Production of high quality per time unit during current period, $P$: Production of high quality per time unit during previous period, $WH$: Work hours per day, $WD$: Work days per year, $PrP$: Production time during current period, $PM$: Profit margin of previous period.

Compared with the original formula, which can be seen in Eqn. 4, see (Al-Najjar 2006), we have modified this formula to be able to calculate change in the costs due to the changes in quality over any period of time and not just for one year. Apart from these four major cost factors it is also possible to follow up costs related to failures, shorts stoppages and level using EcoCon, for example: Personal compensation due to accidents $S_5$, Environmental damage penalties $S_6$, Insurance premium $S_7$, etc, see Fig 4. EcoCon in it self is flexible it is availability of data that decide what is possible to follow up. The efforts required to collect more data have to be balanced against the increased accuracy. The total change in costs related to maintenance between previous and current period is then given by:

$$Total \ change = \sum_{i=1}^{n} S_i \quad [6]$$

Besides the technical data provided by MUR, EcoCon also requires the user to input a profit margin and amount of bad quality products produced during the period of interest. We use profit margin for assessing the financial losses due to disturbances and poor quality in production due to inefficient maintenance. This might not be completely accurate for comparison since the profit margin may be increased if the production runs with fewer losses. Because of this it is the profit margin estimated for the previous period that is used when assessing the savings/losses. Also it might be argued that it is not possible to sell everything if more is produced. We have chosen to use Excel as a platform for the prototype of EcoCon because it makes it relatively simple to make changes and Excel is well known by most of the companies that can help us testing the Eco Con and this makes it simple to install and test it at the host companies. It is also important that the user can see and understand how the system is working; everything should be as transparent as possible. As a consequence we are not hiding any data, all data used to assess the changed costs are available for the user. Simplicity for the user is in focus when developing EcoCon.

The user can reach all the functionality introduced by EcoCon easily see Fig. 5. Before starting to monitor a production process the system must be prepared, this is done through Setup, where it is decided what signals should be used to indicate failure and what signals should be used to indicate short stoppage. During Setup it is also decided to what working areas different signals should be related, i.e. Status number 4, No material can be classified as Logistic and Status number 5, Repair, can be connected to Maintenance. During Setup it is also decided what production process or machine to monitor and the value of the profit margin is entered. It is possible to start EcoCon using only two signals, one representing failure and one representing short stoppages.
This to make it possible to identify where investments will have the best effect. To illustrate the use of EcoCon an example is used.

Example

In the example only S1 Number of failures, S2 Average failure time, S3 Number of short stoppages, S4 Quality production and S8 Direct maintenance costs are considered related to a production machine. The length of a period is set to eight weeks. The first time it is used is at t1, 2005-09-30, at this time the cost factors for the period 2005-08-05 to 2005-09-29 was assessed. The data that was gathered in the end of each period can be seen in Table 1. To prepare EcoCon data for one period must be entered, in this case regarding the period 2005-06-10 to 2005-08-04. This can be done immediately before time t1, where the actual use of EcoCon starts.

<table>
<thead>
<tr>
<th>Period</th>
<th>2005-06-10</th>
<th>2005-08-05</th>
<th>2005-09-30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of failures</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Average failure time</td>
<td>6 hr</td>
<td>5 hr</td>
<td>4 hr</td>
</tr>
<tr>
<td>Number of short stoppages</td>
<td>60</td>
<td>55</td>
<td>56</td>
</tr>
<tr>
<td>Average stoppage time for short stoppages</td>
<td>5 min</td>
<td>5 min</td>
<td>5 min</td>
</tr>
<tr>
<td>Average number of quality production per hour</td>
<td>24</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Direct maintenance costs</td>
<td>160 000 SEK</td>
<td>160 000 SEK</td>
<td>156 000 SEK</td>
</tr>
<tr>
<td>Production hours during period</td>
<td>320</td>
<td>320</td>
<td>320</td>
</tr>
<tr>
<td>Production rate</td>
<td>23,5</td>
<td>23,5</td>
<td>23,5</td>
</tr>
<tr>
<td>Profit margin SEK/production unit</td>
<td>1800</td>
<td>1800</td>
<td>1800</td>
</tr>
</tbody>
</table>

Table 1 Data used in the example

The data collected at this point only serve as a base for assessing changes in cost factors. In this example the first use of the system is at time t1, when data is collected for the period 2005-08-05 to 2005-09-29. In Table 2 the output from using EcoCon at time t1 and t2 can be seen.

<table>
<thead>
<tr>
<th></th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
<th>S8</th>
<th>Total savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>t1</td>
<td>253800</td>
<td>126900</td>
<td>17625</td>
<td>576000</td>
<td>0</td>
<td>974325</td>
</tr>
<tr>
<td>t2</td>
<td>211500</td>
<td>84600</td>
<td>-3525</td>
<td>0</td>
<td>4000</td>
<td>296575</td>
</tr>
</tbody>
</table>

Table 2 Output from EcoCon

In Table 2, a positive number always means a saving and a negative number, i.e. S3 at time t2, means increased costs. Besides the possibility of seeing changes in each cost factor and total savings, it is useful to be able to see more in detail what has caused the changes. In Fig. 6, a dialog showing the number of different failures types categorised as failures. Also the total lost time and the change in total lost time caused by each failure can be seen.
The output from EcoCon is the changed costs compared with previous period. It is also interesting to see the development over more than one period for each cost factor. This can be seen in a diagram showing the cumulative savings over more than one period. In Fig. 7 it is possible to see that during the two periods concerned in this example the savings increase both totally and because of reduced number of failures, S1. However there are increased costs due to changed number of short stoppages between the periods.

To be able to work with improvements it is also important to see in what working area, i.e. maintenance, organisation logistics, the causes of the losses can be found. If the different machine statuses that are gathered in to EcoCon from MUR is linked to working areas this is possible. It is possible both to prioritise working areas and individual causes of losses based on lost profit, Fig. 8.

EcoCon can be used to map the situation, monitor changes in the production process due to maintenance and be used when analysing the situation in order to continuously and cost-effectively improve the performance of production and maintenance process. EcoCon is flexible, meaning that it is only necessary to define two machine statuses, failures and short stoppage, before starting to use it. It is then possible to refine the monitoring process by including more factors to monitor. This makes it easier to start using EcoCon and it will show where it is justified with further analyses, i.e. if the number of short stoppages will be un-proportionally large, this indicate that this requires more analyse to separate individual causes to follow up. Also it is possible to include additional cost factors that are consequences of the stoppages to increase the accuracy of the model. Because MUR, providing EcoCon with data regarding the status of the production process is a real time system it is possible to see deviations at an early stage and react fast thereby avoiding unnecessary costs. Because EcoCon is based on a broader, more holistic view on maintenance described by TQMain, it allows for cost effective improvements of the production considering all relevant aspects and not only the technical aspects of maintenance. EcoCon is transparent.
since it is possible for the user to see the individual data used in calculations, no hidden data. This should make it easier to accept the system by the user.

EcoCon is in a preparation stage to be tested for a period in real industrial environment at two companies. Then after analysing the result from the test period, EcoCon will be updated and improved. The goal is to develop EcoCon into a more stable and reliable system for monitoring machines financial and technical performance using another platform that give more stability and more possibilities.

REFERENCES


