A COMPUTERIZED MODEL FOR ASSESSING THE RETURN ON INVESTMENT IN MAINTENANCE; FOLLOWING UP MAINTENANCE CONTRIBUTION IN COMPANY PROFIT

Basim Al-Najjar [a]

[a] *Terotechnology, School for Technology and Design, Växjö University, Sweden, basim.al-najjar@vxu.se*

In order to reduce as much as possible the economic losses that are generated due to lack or inefficient maintenance, it is necessary to map, analyse and judge maintenance performance and act on deviations before it is too late. It is always necessary for a company to act for increasing profit and consequently enhance its competitiveness. In this paper, a software model (MainSave) has been developed for mapping, monitoring, analysis, following up and assessing the cost-effectiveness of maintenance (and maintenance investments). MainSave can be used for assessing savings and profit/losses due to maintenance performance, identify problem areas and primarily plan for new beneficial investments in maintenance. The module has been tested at Fiat/CRF in Italy. The major conclusion is; applying MainSave it would be possible to identify, assess and follow up maintenance contribution in company business.

Key words: Maintenance Savings, Maintenance Profit, Maintenance Risk Capital Investment, Return on Investment in Maintenance

INTRODUCTION

Manufacturing industries realize the importance of monitoring and following up the performance of production and maintenance processes by simultaneously using economic and technical key performance indicators (KPIs). These indicators establish a bridge between the operational level in terms of, e.g. productivity, performance efficiency, quality rate, availability and production cost, and the strategic level expressed by company profit and competitiveness. Also, these key indicators are important to follow up the maintenance role in a sustainable manufacturing, [1]. In the past, the survival of manufacturing companies was mainly connected to how much a company was able to push into the market. This situation has changed and today's strategies imply cost minimization and differentiation and the ability to use available resources in a cost-effective way with reduced pollution to the surroundings. The focus on customer needs puts great demands on the production and maintenance systems to meet the goals of high product quality, production safety and delivery on time at a competitive price, [2,3].

Properly identified KPIs are required for following up the work done to achieve company strategic objectives and daily competition survival. Also, integration of the KPIs with the knowledge and database can provide a manager the required information, knowledge and ability to monitor and interpret the performance measures for making cost effective decisions, [4]. Furthermore, such KPIs can be utilised for benchmarking, which is one of the tools for never-ending improvements, [1,5].

THEORETICAL BACKGROUND

Traditionally and faulty maintenance costs are divided into direct and indirect costs. Direct cost, i.e. the costs that can easy be related directly to maintenance, consists of direct maintenance labor, consumable maintenance material, outsourcing in maintenance and overheads to cover the expenses of, for example such as tools, instruments, training, administration and other maintenance related expenses. Indirect-costs, i.e. the costs that can be related indirectly to maintenance inefficiency, cannot all be easily related to maintenance as the losses in the production due to machine failures can be related. For example, indirect-cost/profit that is related to losing/gaining of customers and shares of market are not that easy related to maintenance inefficiency/efficiency, respectively. Also, it would not be easy (or sometimes impossible) to find these costs in the current accountancy systems without being confused with other costs, [6]. In order to assess the economic importance of an investment in maintenance, it is often necessary to find the Life Cycle Income (LCI) of a machine/equipment, which is usually not an easy task either. It is easier to asses the savings that have been achieved by more efficient maintenance, such as reduced downtime, number of rejected items, capital tied in inventories and operating costs [4,6].

To be able to monitor, assess and improve the outcome of different maintenance actions it is necessary to use a model for identifying and localizing/retrieving both technical and economic data from company databases. In order to make the process of data gathering and analyzing even easier and more cost-effective, the model should be computerized, [7,8]. Using MIMOSA database reduces technical difficulties and disturbance that may be induced in the current IT-systems of a company, [9]. This would allow following up maintenance KPIs more frequently and easily, thereby be able to react quicker on disturbances and avoid unnecessary costs. It will also be easier to identify and trace the causes behind deviations. The model should also help in interpreting the measurements of relevant basic variables and KPIs in order to achieve cost-effective decisions in planning and executing maintenance actions and to identify where an investment in maintenance may have the best financial payoff, [1,6,10].

In order to evaluate the economic importance of maintenance activities and consequently the Return on Investment in Maintenance (ROIIM), it is necessary to assess the savings achieved by a more efficient maintenance policy. It can be done by analyzing the life cycle cost (LCC) and the transactions between maintenance and other disciplines within the plant, such as production/operation, quality and inventories expenses using system theory. Analysis and assessment of the transactions between maintenance and other working areas can be used to highlight the real maintenance role in the internal effectiveness of a producing company. Maintenance savings are usually achieved through reducing; downtime, number of rejected items, operating/production costs, expenses of different fees/penalties, such as those due to failure-related accidents or failure-related-environment violation and cost of tied up capital, i.e. less unnecessary components and equipment in inventories, [2,4]. Assessment of the savings achieved by more efficient maintenance is less influenced by irrelevant factors compared with the assessment of LCI when company profit is generally considered for assessment, [4]. In this case, several external factors, such as the amount of the product sold, currency course, wars, crises and product price that are irrelevant to the maintenance role but have an appreciable effect on the assessment of the company's LCI.

Discussing solely direct and indirect maintenance costs imply that maintenance is a cost-centre. Therefore, during recessions, companies generally reduce maintenance budget/costs regardless of the benefits that maintenance activities may generate. While the investments in maintenance during these periods can be one of the best investments in the company, see [6]. The economic benefits that could be gained by more efficient maintenance can be found as enhancements in the results of other working areas, such as production, quality and investments, through reducing losses of profit happened due to;

a) Losing production time (and production),
b) More tied up capital and expenses
c) Losses of customers,
d) Loss of reputation and consequently
e) Loss of market share.

These losses are usually generated mainly due to lack of (or inefficient) maintenance. In general, the majority of the indirect costs listed above are due to failures and short stoppages resulting from maintenance performance deficiencies, as discussed in [11]. In this paper, maintenance-related economic factors considered when evaluating the economic role of maintenance are;

1. Maintenance direct cost,
2. Economic losses (which can be considered as Potential Savings or Maintenance Income when using more efficient maintenance)
3. Maintenance savings,
4. Risk capital investments in maintenance for enhancing its performance and achieving better accuracy in maintenance decisions, and
5. Maintenance results (maintenance profit/losses)

Part of the economic losses (potential savings), those are due to unavailability and expenses of delivery delay, that a manufacturing company may encounter can be recovered by implementing more efficient maintenance policy, [4,6,12]. This is why we label the economic losses as potential savings or maintenance income. The latter represents the resource for savings and consequently maintenance profit that can be generated by more efficient maintenance.

MODELING COST-EFFECTIVENESS WITH RESPECT TO MAINTENANCE

A maintenance policy is considered cost-effective if and only if its return on investment is greater than the capital invested in maintenance. But, the benefits of the improvements in maintenance are usually collected in other working areas but hardly in maintenance as long as its accountancy system shows just costs. For example, identifying and relating the benefits generated by more efficient vibration-based maintenance (VBM) is not that easy task to perform if the mechanisms of transferring maintenance impacts, and technical and economic KPIs are not well identified, [4].

In order to justify investments in maintenance, the cost-effectiveness (C_e) of each investment in improving maintenance performance can be examined by using the proportion of the difference between the average cost per high quality product before and after the improvement to that before. This means that all the savings (and possible increments) in the expenses of production, tied-up capital, insurance premiums, etc., including the maintenance cost resulting from a more efficient maintenance policy should be assessed. At the beginning the cost-effectiveness can be ≥ 0 due to the extra expenses incurred by the learning period. This period can be defined on the basis of the nature of each improvement. But beyond this learning period it should be bigger than zero. C_e indicates the percentage of the reduction in the total production cost due to the maintenance impact and can thus be used as a measure of the cost-effectiveness of the improvements, [4].

A model shows the links between maintenance actions and their economic results has been developed at Växjö University, [4]. In order to make the model industrially applicable, we tried to make it transparent by avoiding the idea of Black Box, i.e. the end user feed in the data required in the software and get the results by pushing particular buttons without knowing any thing about what has happened inside the software.

Changes and improvements in the production conditions, production and maintenance processes usually lead to appreciable changes in the performance of production and/or maintenance processes. Therefore, the formulas that have been developed, see [4], are used for assessing the impact of maintenance on the company economics during two different periods to highlight changes in production and maintenance performances and results, i.e. savings or losses achieved due to better or worse usage of the available maintenance technologies, [4]. These formulas can be applied independent of the maintenance technique being used. Denote five of the most popular sources generating savings/losses by S_i, for i = 1, 2,…, 5. These popular sources are changes in; number of failures & short stoppages, stoppage time, bad quality production due to inefficient maintenance and additional expenses that can be defined by the user. These formulas are derived to underlying an inference motor constitute a new software tool that is given the name MainSave as it is shown in Fig.5. Then, the total savings or losses can simply be expressed as

$$\text{Total saving} = \sum_{i=1}^{i=5} S_i$$

where $S_1, S_2, \dots, S_5$ are assessed using the following formulas:

I. Failures; the saving or loss in the production cost has been generated due to less or more failures (S_1) can be expressed by;

S_1 = Number of failures avoided * average stoppage time* production rate * profit margin (PM)

$$S_1 = [(Y - y) * L_1] * \Pr * P_M$$

Where Y and y are the numbers of failures during the previous and current period, respectively, L_1 is the failure average stoppage time and Pr is the production rate.

II. Average stoppage time; the saving or loss that has been generated due to shorter or longer stoppages (S_2), i.e. longer/shorter production time, is expressed as;

S_2 = Difference in failure average stoppage time * number of failures * production rate * profit margin

$$S_2 = [(L_1 - l_1) * y] * \Pr * P_M$$

Where L_1 and l_1 are failure average stoppage times during the pervious and current period, respectively

III. Short stoppages; the saving or loss in the production cost has been generated by less short stoppages (S_3) can be expressed by;

S_3 = [short stoppages in previous period (B) – short stoppages in current period (b)] * average stoppage time (L_2) * production rate * profit margin

$$S_3 = [(B - b) * L_2] * \Pr * P_M$$

IV. Quality production. The saving or loss generated due to higher production quality (S_4) is expressed by:

S_4 = [Current period high quality production per hour – Previous period high quality production per hour] * Number of production hours per day (Ph) * Number of production days per period (Pd) * profit margin

$$S_4 = (p - P) * P_h * P_d * P_M$$

where P and p are amount (in tons, meters, etc.) of high quality product produced per hour in the previous and current year, respectively

V. User defined expenses paid by the company to cover, for instant, personnel compensation due to accidents, environmental damage penalty, insurance premium, direct maintenance costs (that includes labor, spare parts and overheads), tied up capital in spare parts and equipment and penalty expenses of delivery delay. Denote the expenses before and after the improvement, i.e. previous and current period, by E_b and E_a, respectively. Then, the sum of the reduction or increment in these expenses can be expressed by

$$S_5 = \sum_j \left(E_b - E_a\right)_j$$

where j =1, 2,…, n denotes the n types of the expenses that can be expressed by the user.

SOFTWARE PROTOTYPE FOR INDUSTRIAL APPLICATION

One of the major reasons behind the lack of techniques for controlling and assessing maintenance economic impact on company profitability and competitiveness is the lack of clear and robust theory, methods and tools required for performing that task easily and properly, [4]. Also, the difficulties in finding and processing the data required for mapping, monitoring, controlling, following up, analysis and assessing maintenance economic impact. This is why a software-tool may make it is possible to perform this task easily and cost-effectively. The software module aims to sum all the economic losses (potential savings which represent maintenance future income) that are generated due to lack of (or inefficient) maintenance. Also, it assesses the savings and consequently the profit generated by applying more efficient maintenance. Furthermore, the KPIs, such as total savings, potential saving and profit, and ratios, such as maintenance savings to potential savings, savings to investments, investments to potential savings, investments per period, etc. are automatically assessed by the model using the above mentioned equations. The investment is assessed per the period of time that has been passed until the analysis is done instead of the whole depreciation period. The same thing can be said about Overall Equipment Effectiveness (OEE) that is assessed using the traditional equation, i.e.

OEE = Availability * Performance efficiency * Quality rate

The above mentioned ratios and measures are considered in this study as parts of the important KPIs that are required for mapping, monitoring, analysis and controlling maintenance performance and its economic impact. The main objective of using MainSave is to enable the user to easily and at demand assess and control the economic impact of maintenance as well as the potentials for further improvements. In other words, it can be utilized to assess the current situation, identify problem areas, assess technical and economic losses, and motivate investments in maintenance. The latter is important for providing objective evidences demanded to convince the company's executives about the necessity of these investments for enhancing the productivity and effectiveness of a production process. All these results cannot be achieved without high quality and relevant coverage data, [4,6]. Also, the data required for applying MainSave should be easily retrieved by the system.

An investment in maintenance often has a relative short payoff time compared to other investments if it has been made using right information and knowledge, [13]. Usually, it is hard to show the economic advantages of such investments due to the fact that the savings are spread out in many working areas in a company, and cannot be found easily in the current accountancy systems.

DATA DEFINITION AND GATHERING

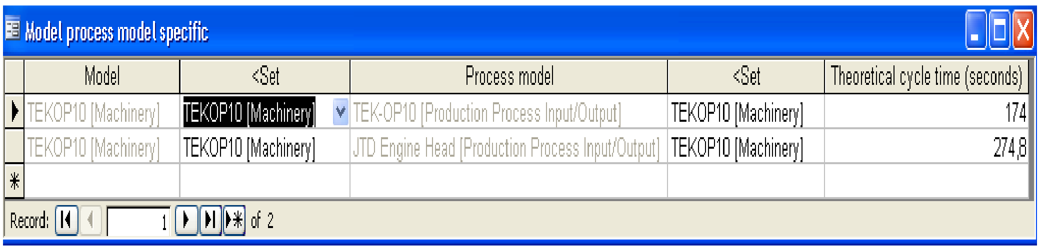
The data required for applying and running MainSave can be divided in two major categories: Database datasets and Non-database datasets. From Fig.5, it is easy to distinguish non-database datasets from those which are database datasets. The former have white colored boxes while the latter have grey colored boxes. The data described by non-database datasets are defined below:

- Profit margin per high quality item, ton, meter or cubic meter, etc.
- Total investment in maintenance for improving its performance
- Depreciation period, i.e. the period that was decided as the investment life length

The data described by database datasets are defined below in Fig.s1-4;

- Data gathered concern one production machine and product.
- The data cover two production periods, i.e. before and after an improvement in maintenance or production process or any two well distinguished periods.
- Numbers of unplanned stoppages, such as failures and short stoppages and their causes.
- Average time of the stoppages
- Production rate, production time and theoretical and actual cycle time.
- Quality rate, i.e. the share of high quality product out of the total production during the periods of analysis

The rest of the information shown in Fig.5, such as savings, investment per period, ratios and OEE are assessed by MainSave.


Model process model specific

Model	<Set	Process model	<Set	Theoretical cycle time (seconds)
TEKOP10 [Machinery]	TEKOP10 [Machinery]	TEK-OP10 [Production Process Input/Output]	TEKOP10 [Machinery]	174
TEKOP10 [Machinery]	TEKOP10 [Machinery]	JTD Engine Head [Production Process Input/Output]	TEKOP10 [Machinery]	274,8

Record: 1 of 2

Fig.1. Production theoretical cycle time.

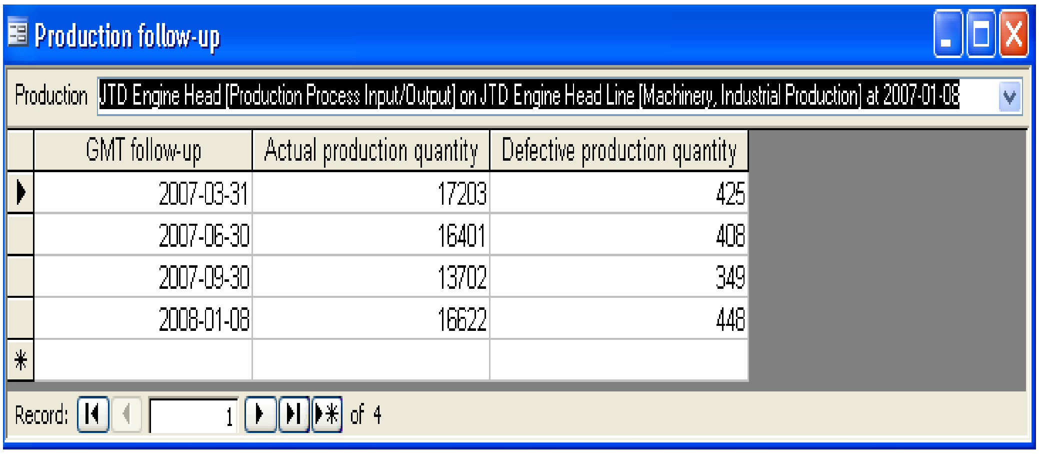
Production

Segment: JTD Engine Head Line [Machinery, Industrial Production]

Process model	<Set	GMT production start	GMT production end	Planned production time (hours)
JTD Engine Head [	TEI	2007-01-08	2008-01-08	4880

Record: 1 of 1

Fig.2. Planned production time.



Production follow-up

Production: JTD Engine Head [Production Process Input/Output] on JTD Engine Head Line [Machinery, Industrial Production] at 2007-01-08

GMT follow-up	Actual production quantity	Defective production quantity
2007-03-31	17203	425
2007-06-30	16401	408
2007-09-30	13702	349
2008-01-08	16622	448

Record: 1 of 4

Fig.3. Production follow up.

MAINSAVE TEST

The tests were done using industrial data gathered from FIAT/CRF in Italy. Technical and economic data from production and maintenance processes and economy department have been collected and feed in the MIMOSA database located in IBK, Tallinn. A CNC machine at FIAT/CRF, was considered for MDSS test. 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 (previous/first and current/second period) of 6 months each (8th of Jan. 2007 – 7th of June 2007) and (7th of June 2007-8th of Jan. 2008). The periods were selected are considered to be long enough so that they include several events, such as production speed changes, shorts stoppages, failures, disturbances or any other stoppages that are generated by organization, man or environment. In general, the periods can be selected as;

a) Two periods were planned for producing two orders of the same product in the same machine, or
b) Two periods that have been selected from the machine register representing the time before and after a particular improvement has been done to the maintenance policy.

The non-database dataset, i.e. profit margin, investment and depreciation period are given in the white colored boxes; 10 units, 30000 units and 4 years, respectively, Fig.5. The savings (or additional losses) that maintenance has generated due to its original performance or due to a particular performance improvement are assessed using different losses categories. The losses are classified in two groups of categories;

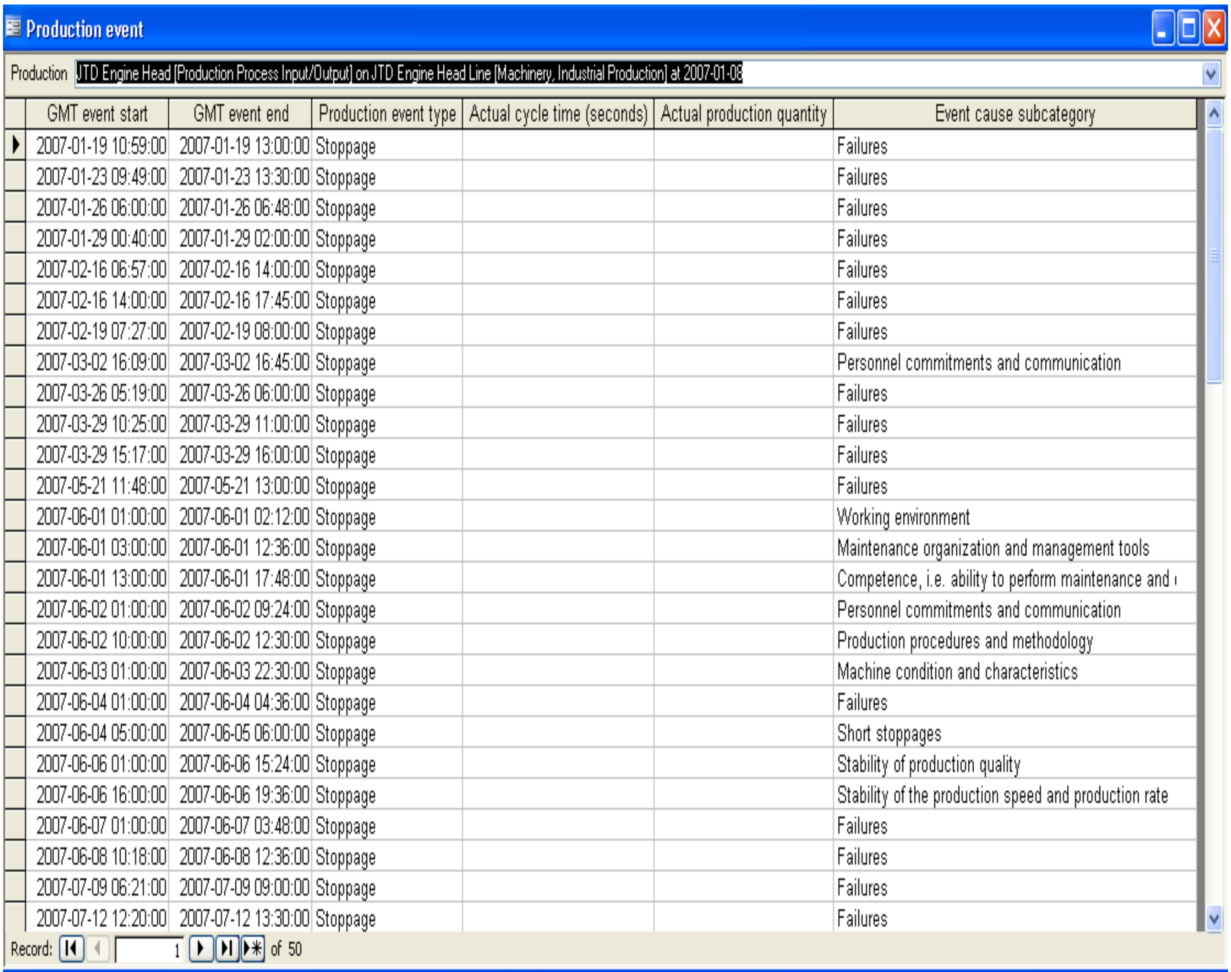
- o defined categories of losses, and
- o user defined category of losses, see Fig.5.

In general, it is not necessary that companies have the same types of losses. Therefore, in order to accommodate MainSave for each particular application, machine and company, any of the defined losses can be included or excluded in MainSave. In MainSav, we tried to use the most usual categories of losses and left a wide window for the user defined expenses. MainSave converts all technical data, such as number of failure and downtimes to a measure on the economic scale, i.e. money. In this test, all the defined categories of losses expressed by MainSave are used and no user defined expenses were found.

In Fig.5, it is clear that there is an obvious increase in the losses of the production time in the current (second) period compared with the previous (first) period. The major part of this increment was due to increased failures and short stoppages.

This increment was, according to the company, happened because of using spar parts from another supplier than that they used to have. The major conclusion that can be drawn from this test is; using MainSave, it is possible to map, identify, analysis and assess the economic losses and savings in the production process and identify the causes behind that, which eases the localization of next investments required for improving maintenance performance to reduce losses.

The number of failures was increased and the stoppage times were also prolonged. This resulted in more economic losses (-15372.9 units) despite the investment (30000 units) was done. These losses are distributed among the major areas that are; more failures ((-4142.7 units), longer stoppage time (-10723.5 units), more bad quality expenses (-506.6 units). The biggest part of the losses is due to the longer stoppage time which represents about 70% of the total losses. Assessing the losses belonging to different category helps to primarily estimate and judge the size of the risk capital that should be invested for solving the problem. Notice that the saving with the (-) sign means losses. Also, the Overall Equipment Effectiveness (OEE) has been increased due to unknown reasons.

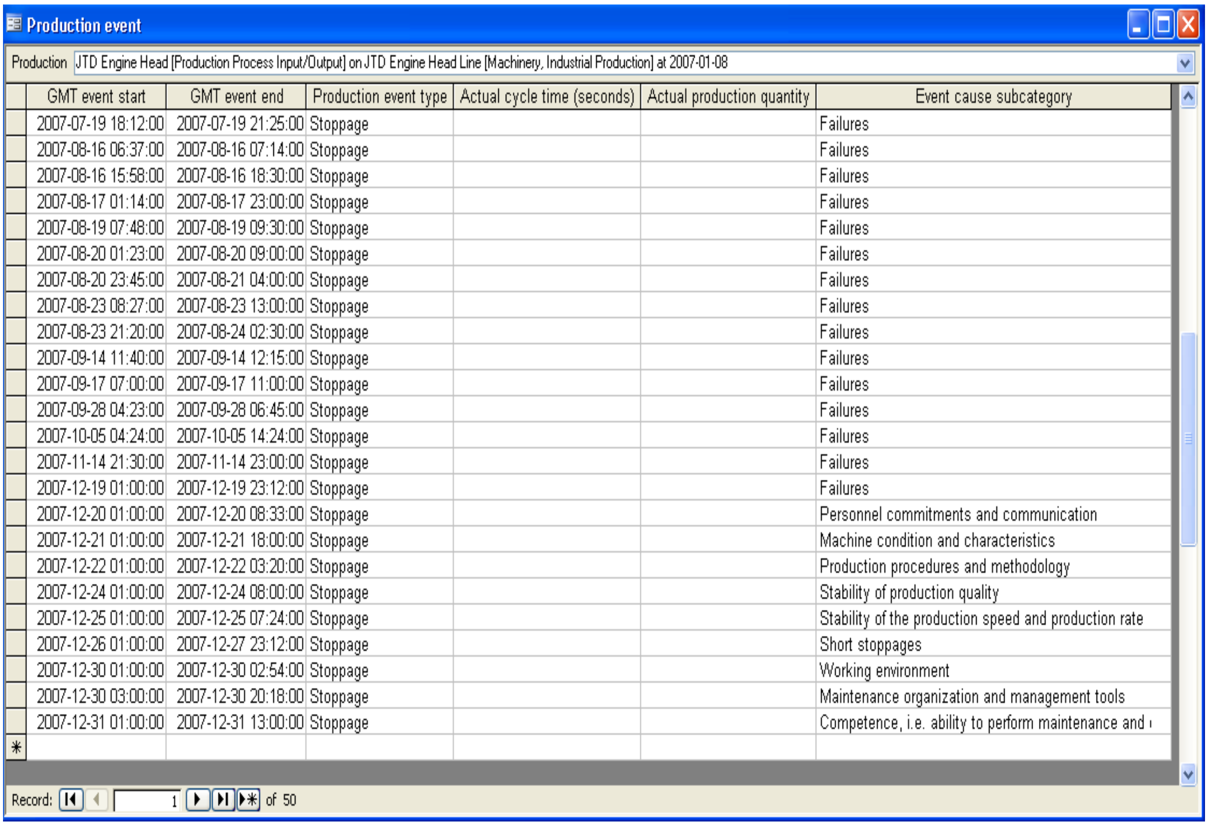

Production event

Production: JTD Engine Head [Production Process Input/Output] on JTD Engine Head Line [Machinery, Industrial Production] at 2007-01-08

GMT event start	GMT event end	Production event type	Actual cycle time (seconds)	Actual production quantity	Event cause subcategory
2007-01-19 10:59:00	2007-01-19 13:00:00	Stoppage			Failures
2007-01-23 09:49:00	2007-01-23 13:30:00	Stoppage			Failures
2007-01-26 06:00:00	2007-01-26 06:48:00	Stoppage			Failures
2007-01-29 00:40:00	2007-01-29 02:00:00	Stoppage			Failures
2007-02-16 06:57:00	2007-02-16 14:00:00	Stoppage			Failures
2007-02-16 14:00:00	2007-02-16 17:45:00	Stoppage			Failures
2007-02-19 07:27:00	2007-02-19 08:00:00	Stoppage			Failures
2007-03-02 16:09:00	2007-03-02 16:45:00	Stoppage			Personnel commitments and communication
2007-03-26 05:19:00	2007-03-26 06:00:00	Stoppage			Failures
2007-03-29 10:25:00	2007-03-29 11:00:00	Stoppage			Failures
2007-03-29 15:17:00	2007-03-29 16:00:00	Stoppage			Failures
2007-05-21 11:48:00	2007-05-21 13:00:00	Stoppage			Failures
2007-06-01 01:00:00	2007-06-01 02:12:00	Stoppage			Working environment
2007-06-01 03:00:00	2007-06-01 12:36:00	Stoppage			Maintenance organization and management tools
2007-06-01 13:00:00	2007-06-01 17:48:00	Stoppage			Competence, i.e. ability to perform maintenance and
2007-06-02 01:00:00	2007-06-02 09:24:00	Stoppage			Personnel commitments and communication
2007-06-02 10:00:00	2007-06-02 12:30:00	Stoppage			Production procedures and methodology
2007-06-03 01:00:00	2007-06-03 22:30:00	Stoppage			Machine condition and characteristics
2007-06-04 01:00:00	2007-06-04 04:36:00	Stoppage			Failures
2007-06-04 05:00:00	2007-06-05 06:00:00	Stoppage			Short stoppages
2007-06-06 01:00:00	2007-06-06 15:24:00	Stoppage			Stability of production quality
2007-06-06 16:00:00	2007-06-06 19:36:00	Stoppage			Stability of the production speed and production rate
2007-06-07 01:00:00	2007-06-07 03:48:00	Stoppage			Failures
2007-06-08 10:18:00	2007-06-08 12:36:00	Stoppage			Failures
2007-07-09 06:21:00	2007-07-09 09:00:00	Stoppage			Failures
2007-07-12 12:20:00	2007-07-12 13:30:00	Stoppage			Failures

Record: 1 of 50

Fig.4a. Production events.



Production event

Production: JTD Engine Head [Production Process Input/Output] on JTD Engine Head Line [Machinery, Industrial Production] at 2007-01-08

GMT event start	GMT event end	Production event type	Actual cycle time (seconds)	Actual production quantity	Event cause subcategory
2007-07-19 18:12:00	2007-07-19 21:25:00	Stoppage			Failures
2007-08-16 06:37:00	2007-08-16 07:14:00	Stoppage			Failures
2007-08-16 15:58:00	2007-08-16 18:30:00	Stoppage			Failures
2007-08-17 01:14:00	2007-08-17 23:00:00	Stoppage			Failures
2007-08-19 07:48:00	2007-08-19 09:30:00	Stoppage			Failures
2007-08-20 01:23:00	2007-08-20 09:00:00	Stoppage			Failures
2007-08-20 23:45:00	2007-08-21 04:00:00	Stoppage			Failures
2007-08-23 08:27:00	2007-08-23 13:00:00	Stoppage			Failures
2007-08-23 21:20:00	2007-08-24 02:30:00	Stoppage			Failures
2007-09-14 11:40:00	2007-09-14 12:15:00	Stoppage			Failures
2007-09-17 07:00:00	2007-09-17 11:00:00	Stoppage			Failures
2007-09-28 04:23:00	2007-09-28 06:45:00	Stoppage			Failures
2007-10-05 04:24:00	2007-10-05 14:24:00	Stoppage			Failures
2007-11-14 21:30:00	2007-11-14 23:00:00	Stoppage			Failures
2007-12-19 01:00:00	2007-12-19 23:12:00	Stoppage			Failures
2007-12-20 01:00:00	2007-12-20 08:33:00	Stoppage			Personnel commitments and communication
2007-12-21 01:00:00	2007-12-21 18:00:00	Stoppage			Machine condition and characteristics
2007-12-22 01:00:00	2007-12-22 03:20:00	Stoppage			Production procedures and methodology
2007-12-24 01:00:00	2007-12-24 08:00:00	Stoppage			Stability of production quality
2007-12-25 01:00:00	2007-12-25 07:24:00	Stoppage			Stability of the production speed and production rate
2007-12-26 01:00:00	2007-12-27 23:12:00	Stoppage			Short stoppages
2007-12-30 01:00:00	2007-12-30 02:54:00	Stoppage			Working environment
2007-12-30 03:00:00	2007-12-30 20:18:00	Stoppage			Maintenance organization and management tools
2007-12-31 01:00:00	2007-12-31 13:00:00	Stoppage			Competence, i.e. ability to perform maintenance and

Record: 1 of 50

Fig.4b. Production events.

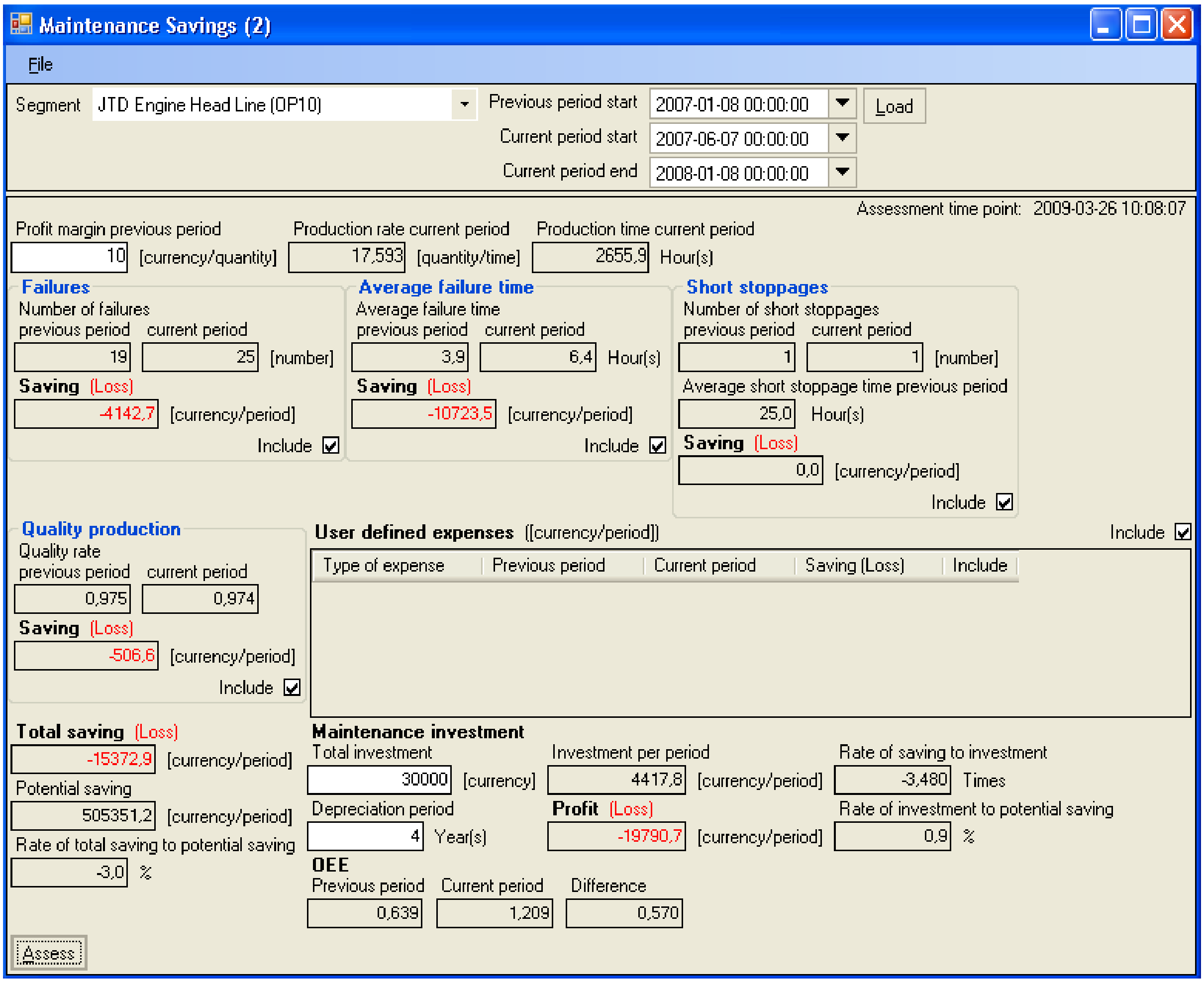


Fig.5. Test results of MainSave.

RESULTS, DISCUSSIONS AND CONCLUSIONS

When the profit margin of a plant decreases, the need for reliable and efficient maintenance policy becomes more important, because it will be more important to reduce the economic losses, i.e. pressing down production cost per high quality item, ton or meter, and consequently increases the profit.

The major result of this study is the development of a new model and software prototype (MainSave) for enhancing maintenance cost-effectiveness, performance and economic impact on company business. The test of the model has shown clearly the potentials and the benefits of application.

Using MainSave, it is possible to monitor, analyze, assess maintenance activities and 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 which is hard to achieve using available tools and techniques even if the data required are available. Development of relevant and traceable technical and economic KPIs has made maintenance performance control more possible. Also, it makes it possible to handle real-time data gathering, analysis and decision making. Further necessary information about maintenance and other working areas is also provided to the decision maker. MainSave is developed using new and flexible model that can be accommodated to each production process without big difficulties for enhancing its accuracy. 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.

ACKNOWLEDGE

This paper is part of the work done within DYNAMITE and the author would like to thank EU for supporting EU-IP DYNAMITE.

REFERENCES

[1] Al-Najjar, B., Hansson, M-O and Sunnegårdh, P. (2004). Benchmarking of Maintenance Performance: A Case Study in two manufacturers of furniture. IMA Journal of Management Mathematics 15, 253-270.

[2] Al-Najjar, B. Condition-based maintenance: Selection and improvement of a cost-effective vibration-based policy in rolling element bearings. Doctoral thesis, ISSN 0280-722X, ISRN LUTMDN/TMIO—1006—SE, ISBN 91-628-2545-X, Lund University, Inst. of Industrial Engineering, Sweden, 1997.

[3] Al-Najjar, B. (1998). Improved Effectiveness of Vibration Monitoring of Rolling Element Bearings in Paper Mills. Journal of Engineering Tribology, IMechE 1998, Proc Instn Mech Engrs Vol 212 part J, 111-120.

[4] Al-Najjar, Basim (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. International Journal of Production Economics IJPPM Vol. 55 No. 8.

[5] Pintelon, Liliane, (1997), Maintenance performance reporting systems: some experiences. Journal of Quality in Maintenance Engineering. Vol 3 No. 1, pp 4-15.

[6] Al-Najjar, B., Alsyouf, I., Salgado, E., Khosaba, S., Faaborg, K., (2001), Economic Importance of Maintenance Planning when using vibration-based maintenance policy, project report, Växjö University.

[7] Al-Najjar, B. and Kans, M. (2006). A Model to Identify Relevant Data for Accurate Problem Tracing and Localisation, and Cost-effective Decisions: A Case Study. The International Journal of productivity and performance measurent (IJPPM), Volume 55, Issue 8.

[8] Kans, Mirka (2008). On the utilisation of information technology for the management of profitable maintenance. PhD thesis, 2008, Department of Terotechnology, Växjö University, Sweden

[9] MIMOSA, (2006). “Common Relational Information Schema (CRIS) Version 3.1 Specification”, http://www.mimosa.org/.

[10] Al-Najjar, B., Kans, M., Ingwald, A. Samadi, R. (2003), Förstudierapport - Implementering av prototyp För Ekonomisk och Teknisk UnderhållsStyrning, BETUS. Växjö University.

[11] Al-Najjar, B. (2000). Accuracy, effectiveness and improvement of Vibration-based Maintenance in Paper Mills; Case Studies. Journal of Sound and Vibration (2000), 229(2), 389-410.

[12] Al-Najjar, Basim, (1999), Economic criteria to select a cost-effective maintenance policy, Journal of Quality in Maintenance Engineering, Vol. 5, No. 3.

[13] Al-Najjar, B. and Alsyouf, I. (2004). Enhancing a Company's Profitability and Competitiveness using Integrated Vibration-based Maintenance: A Case Study. Journal of European Operation Research, 157, 643-657, 2004.