Framework for Self-Maintenance Machine

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Abstract

Rapid developments in computer science have significantly contributed to the improvement of maintenance practice and organization's competitiveness. Many available computerized maintenance management systems have currently incorporated, to a certain extend with a model based decision support capabilities. Next, decision making grid and fuzzy logic models can be formed by combining the risk factors. In this paper, a maintenance framework is proposed for machineries self maintenance capabilities. The models are capable of generating more sensible maintenance strategies. For continuous maintenance improvement, this study also proposed few decision making models to embed with computerized maintenance systems.

1. Introduction

Current economic depression worldwide make a strong and urgent need to develop better controls and accountability by every department in manufacturing lines. Align with that, industries start to reduce headcount, especially service sectors such as maintenance department. They start to outsource maintenance task, because they believed that outsourcing are able to:

i) Lower down the maintenance costs;
ii) Allow them to focus on other salient core business;
iii) Reduces staff recruitment headaches; and
iv) Eliminates uncertainty, as contractors have to give full attention on the machinery problems.

This rose on other issues on how to benchmark the outsourcing contractors. These are few process can be used to benchmark contractors:

i) Choose list of contractors,
ii) Collect data on their maintenance history,
iii) Model data,
iv) Best practise comparison, and
v) Make recommendations on available alternatives.

There are rapid growths on maintenance new era on business intelligent, where maintenance information moves from transactional systems to a database, with online analyzing capabilities. The systems equipped with structured query languages statement to extract data and generate reports automatically. It is vital for maintenance department in manufacturing to acquire all maintenance data, to process information instantaneously, and subsequently transform them into a useful knowledge. Later, from computerized systems, they have to continuously revise and improve their maintenance strategies. Computerized Maintenance Management Systems (*CMMS*) should speak in the maintenance language, with visualization, graphics or words and concepts familiar to the end-user, rather than solely based on software engineering-oriented terms.

2. Study of Literature

There has been a long journey of maintenance techniques since 1940 until now, to measure and estimate downtime in the production lines. Downtime is defined as the time from the moment a machine failed to operate as expected until the moment it is fully repaired and re-operate again. Some repairing activities will take place in between the unit's failure time and the time it is reassembled. [1] defined maintenance as:

i) Team work between maintenance crew and operators in the production floor;
ii) When any failures occurs, ability to redesign the equipment with a much greater emphasis on reliability or introducing backup and standby strategies;
iii) Decision support tools, such as failure modes, effects analysis, reliability studies; and
iv) Expert systems development using artificial intelligence techniques. Automatic maintenance monitoring capabilities can be implemented using the techniques.

[2] proposed some structures for maintenance policy decision strategies, *i.e.* when to practice use-based maintenance, condition-based maintenance or failure-based maintenance at any phase of the machine life cycle. [3] suggested more measurement of service processes studies using mathematical models. [4] and [5] used systematic mathematical measurements on covariates illustrated with the use of the semi-parametric, multistate hazards model for transition and reverse transition among more than one transient state emerged from follow-up studies. [5] used the proportional hazards model to analyze transitions in human contraceptive recovery over time and illustrate the score test on testing the equality of parameters for models on transitions and repeated transitions. Then, [6] employs the competing risk model proposed by [5] to estimate the risk factors that delay the equipment downtime. [6] estimated the relationship between repair time and various risk factors of interest including underlying characteristics of the technicians, *i.e.* their age, experiences and qualifications. [7] analyzed downtime of the machines by exploring the general renewal process for repairable systems. They use Kijima Model *II* to model complex repairable systems. A general likelihood function formulation for single and multiple systems with the time truncated data and failure truncated data is applied to estimate parameters using Weibull++7. However, [7] used only one parameter, failure time in their analysis.

[8] and [9] have described an application of analytical hierarchical process (*AHP*) for selecting the best maintenance strategies. [8] proposed Decision Making Grid (*DMG*) analysis based on downtime and frequency of failures, which are very important measure prior to the *AHP* analysis. [10] defined DMG as a control chart by itself in 2 dimensional matrix forms. The columns of the matrix show the 3 criterion of the downtime. While the rows of the matrix show another 3 criterion of the frequencies of the failures. A better maintenance model for quality management can be formed by handling both, the rows and columns of the matrix respectively. The matrix offers an opportunity to decide what maintenance strategies is needed for decision making such as to practice fixed-time maintenance, condition-based maintenance or design-out maintenance. The matrix is also can be used to decide what maintenance concepts are useful for each defined cell of the matrix such as total productive maintenance or reliability centered maintenance approaches. [11] listed the reason on why company should have *CMMS* as follows:

i) Improved data integrity: data is more accurate, consistent and up to date;
ii) Increased security: different passwords can be used to share specific information between selected users;
iii) Data maintenance: easy to edit data into their field at anytime; and
iv) Data redundancy: backup strategies to ensure the availability of data in case of any failures and disasters of the primary data sources.

There are always numbers of feedbacks on production parts complaint from the customers after the sales. For instance, the researchers seek to understand on the reason why the warranty period of the parts are given two years but there are still cases on parts failure within eight months of the products deployment. From the discussion with few multi-national bearing technology manufacturers in Malaysia, 14% of the parts failure before warranty is due to the contamination in the equipment usage area. 34% is due to a fatigue where equipment usage is too long. 16% of these defects are due to poor fitting during installation. The highest reason is due to a routine maintenance, which is 36%, due to:

i) Low quality of the lubrication oil;
ii) Lubrication quantity is too little or over the given specification limit;
iii) Preventive maintenance frequency is either too frequent or very rare;
iv) Incorrect tools used for repair and preventive maintenance; or
v) Poor technician skills.

In fact, self-maintenance on this routine maintenance job could reduce technician responding time tremendously. There are almost 35 industries have been contacted in the present study to understand their maintenance practice. When the machines deploy in the industries, its follow few important phases in their life cycle as given in Figure 1. The company purchases the machine and install in the production floor. Then mounting and lubrication is checked and prepared before the operation. Alignment is adjusted based on the production requirement. Then the machine will run testing and ready for full operations. Re-lubrication and adjustment is needed depends on the machine specification. From the observation, most of the industries use basic condition monitoring involves four human sense of sight, sound, touch and smell to predict a failure. If there is any failure, then troubleshooting procedure is used to repair the equipment. Any failure parts are repaired or replaced. Once completed, the machine is back to the operation and it follows this life cycle again until scrapped.

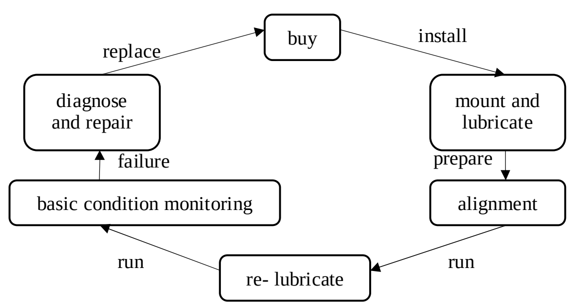

Figure 1: Machine Life Cycle

The present work discovered that the maintenance team can learn from the defect during diagnose and repair phase to continuously restructure some improvement strategies at other phases. More cause and effect on how bad is the defect characteristics can be analyzed and few recommendations can be given to improve the equipment reliability during their life span. Further studies on diagnostic and repair automation are essential. Few underlying factors on maintenance delay can be identified using Ishikawa analysis as example shown in Figure 2.

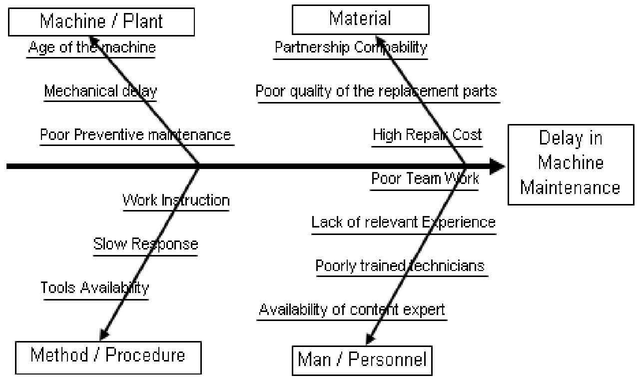

Figure 2: Ishikawa Analysis

Here, maintenance delay can be reduced by:

i) Improving preventive maintenance strategies,
ii) Using better quality of the replacement parts,
iii) Use good tools for repair and collaboration, or
iv) Restructure man-hours on repairing the equipment.

Strategic direction in maintenance from *CMSS* to Decision Support System (*DSS*) is essential. These are few steps taken to explore decisions from the *CMMS* database as shown in Figure 3.

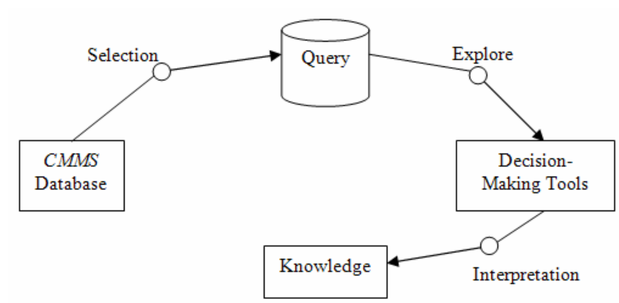

Figure 3: Decision Support Steps in CMMS

Next, certain rules created from the knowledge and able to trigger machine sensors. Then the actuators are able to react and perform certain self maintenance. With this automation, perhaps contractor and technician respond time could be reduced or eliminated.

3. Maintenance Model Development

[12] listed the important of *CMMS*, but it appears to be used less often as a tool for analysis and maintenance coordination. Its happen to be only a data store to keep equipment information and their maintenance activities. Thus, [8] make a very good improvement in *CMMS* by using a formalized decision analysis approach based on multiple criteria using *DMG* to find the worst production machines. The policy emphasizes the fact that the best policy is the one that maximize the profit. [13] designed computer-aided integration of maintenance in their model. Later [14] embedded [8] *DMG* approach as a visual tool in their *CMMS* to obtain good *DSS*.

The *CMMS* should provide some decision support capabilities on doing the right things at the right time rather than only do the things right. [8] consider top ten worst production machines based on two criteria, downtime and frequency of failures. Then those machines are mapped into *DMG* and appropriate maintenance strategies are recommended, depend on the location of the machines in the grid. The analysis takes into consideration the top ten worst production machines criterion *i.e.* low, medium and high boundaries with the formulae given by[15].

Those machines that met both criteria are then associated in the grid as shown in Table 1 with respect to the multiple criteria as follows [14]:

i) Operate to failure (*OTF*): Machine is very seldom failed. Once failed, the downtime is short;
ii) Fixed time maintenance (FTM_1, FTM_2, FTM_3, FTM_4 and FTM_5): Failure frequency and downtime are almost at the moderate cases;
iii) Skill levels upgrade (*SLU*): Machine is always failed, but it can be fixed very fast;
iv) Condition-based maintenance (*CBM*): Machine is very seldom to fail. But once failed, it takes a long time to bring it back to the normal operation; and
v) Design out maintenance (*DOM*): Machine is always failed. Once failed, it takes a long time to bring it back to the normal operation.

Table 1: Decision Making Grid [14]

Frequency	Downtime: Low	Medium	High
Low	*OTF*	FTM_1	*CBM*
Medium	FTM_2	FTM_3	FTM_4
High	*SLU*	FTM_5	*DOM*

Note that those machines in *OTF*, FTM_2 and *SLU* regions are candidate for self-maintenance implementation. This is because their downtime is low. Therefore, repairing those machines are simpler than the machines in medium and high downtime regions. [14] have implemented the *CMMS* with *DMG* in one of the brake pad manufacturing companies in England. [16] identified the important of the study by measuring relationship with maintenance strategies and performance. He discovered strong positive relationship between the maintenance strategies and performance. By having the impact studies, manufacturing managers may have more comfortable in making investment in maintenance. [17] applied [14] and [8] approaches by implementing *DMG* in one of the food processing companies in Malaysia. They discovered that DMG analysis create more opportunities in *CMMS* to be transparent to production personnel instead of only maintenance personnel. The increased usage of data mining and *DMG* analysis in *CMMS* by personnel outside maintenance function may have a good potential to improve maintenance strategies and equipment utilization.

To be more generalized, this study introduced maintenance framework with three important rings as given in Figure 4. Outer ring is the continuous process for maintenance effectiveness. This is the iterative process of extracting the data, studying its patterns, producing the results and verifying the models. Then, provide the feedback, execute, and update the database accordingly. Middle ring is the life cycle to manage the maintenance task. Appropriate tools, techniques and maintenance speed are required to manage the technology efficiently in the ring. There are six cycles (*DAVADI)* in the decision support cycle to follow, which includes:

i) Data (*D*) selection from *CMMS* database using standard query languages,
ii) Analyze (*A*) data periodically on 3 factors *i.e.* cost, frequency of failures and downtime of the machines,
iii) Visualize (*V*) the results using *DMG*,
iv) Associate (*A*) the result with decision mapping,
v) Display (*D*) the analysis using indicator boards in the production lines, and
vi) Implement (*I*) the strategies.

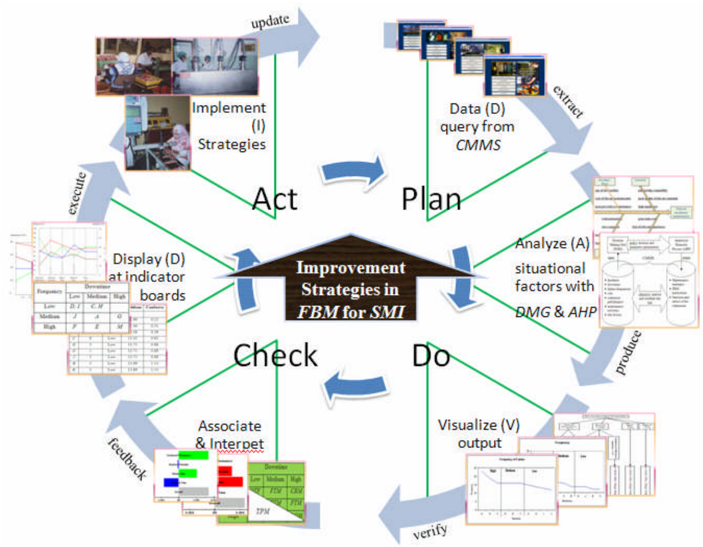

Figure 4: Proposed Framework

Inner ring is the important cycle, and involves participation and commitment from every level of the production people for continuous improvement. This study proposes a qualitative cycle to monitor machine performance in the production lines, using a plan-do-check-act approach as follows:

i) Proper planning of maintenance activities;
ii) Analyse and carry out all maintenance work as planned;
iii) Check by conducting detailed and systematic inspections;
iv) Act by implementing appropriate action to the right machine and make necessary corrections at the right time; and
v) Repeat the cycle periodically for continuous improvement.

Here, we can embed, [18] model to integrate between intelligent maintenance and intelligent manufacturing systems as shown in Figure 5. The model is able to reconfigure itself as a response to uncertain condition *i.e.* machine breakdown. It can specify whether at any time to produce part at certain rate or to do maintenance *i.e.* preventive maintenance task. It is developed with three intelligent subsystems, which are the fuzzy logic controller *I*, fuzzy logic controller *II* and fuzzy maintenance using DMG system. Fuzzy Logic Controllers *I* and *II* are developed based on hedging point theory to control a failure prone manufacturing system [19], while fuzzy maintenance and *DMG* are based on the work on maintenance specification process [8]. The fuzzy logic controller for failure prone manufacturing system has the capability to determine the production mode of the system. It is also capable of determining when the machine should produce part or not to produce part when the machine is in operational state. Based on this fact, opportunity maintenance is proposed to make use of the time when the system is operational but not producing parts or idle, as the time for the maintenance should take place.

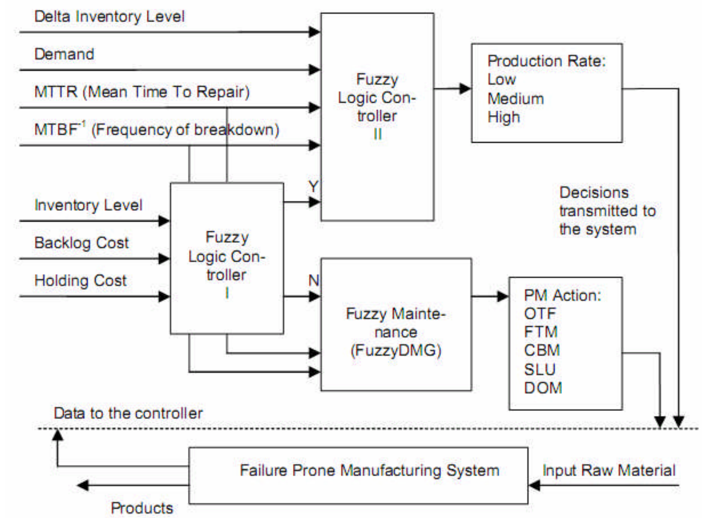

Figure 5: Maintenance Model and Intelligent manufacturing [18]

There are two types of data for the proposed fuzzy logic controller, which are production system data (Delta inventory level, demand, inventory level, back log cost and holding cost) and maintenance system data, Mean Time to Repair (*MTTR*) and Mean Time Between Failure (*MTBF*). The first fuzzy logic controller (*FLCI*) evaluates its inputs (back log cost, inventory level and holding cost) and makes decision whether the system should produce the requested part or not. If the decision is to produce part (YES to produce part) then it will trigger the second fuzzy logic controller (*FLCII*). The *FLCII* then specifies at what rate the requested part should be produced. When the decision of the *FLCI* is NO to produce part then it will trigger the fuzzy logic maintenance and DMG controller to prescribe what the appropriate maintenance action should be taken based on the current value 1 (frequency of breakdown). Then the decision is of *MTTR* (downtime) and *MTBF* transmitted to the shop floor to be executed while the machine is still in operational state but not producing requested part. In other words, when the machine is idle. When the maintenance action is successful in reducing the downtime and the frequency of breakdown (the objective of all maintenance activities) then the new value of down time and frequency of breakdown are feedback to the fuzzy logic controller and a new cycle of controlling and maintenance is started. This model is a closed loop system and it enables the failure prone manufacturing system to continuously improve its performance.

4. Example of Self-Maintenance Machines

[20] defined a self-maintenance machine as a machine that can maintain its own functions for a while even though faults occur. In general, a self-maintenance machine requires the following six capabilities:

i) Monitoring;
ii) Fault judging;
iii) Diagnosis;
iv) Repair planning;
v) Repair execution; and
vi) Reporting.

In simple word, we are trying to take over technicians role by automate certain troubleshooting activities. To achieve these capabilities, [20] architecture for self-maintenance machine is depicted in Figure 6. In this architecture, the monitoring capability, fault judging and diagnosis are performed by sensors. Then the repair planning and procedures are obtained from the computers. Next, the repair executed by actuators and reporting generated by computers.

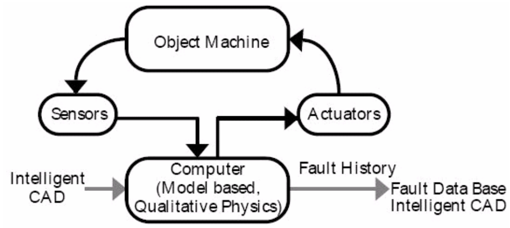

Figure 6: Self-maintenance Machine Architecture

One of the key issues of self-maintenance machine is how to actually execute repairs. Here, we introduce three types of repair strategy:

i) Control;
ii) Learning from previous repair activities; and
iii) Functional redundancy.

Here, we can use artificial intelligence techniques such as artificial neural networks to learn failure behaviour and diagnose the machines. Next, fuzzy rules are followed for troubleshooting decision.

5. Conclusion and Future Research

This paper proposed a framework on maintenance system for the machines. Then few artificial intelligence methods are proposed to study failure behaviour and improve the performance of the reasoning such as fuzzy qualitative reasoning and the imitational fault method. We provide the idea on self maintenance strategy for the next generation of maintenance engineering. Here, we are trying to mimic human body at the state of relaxation, sleep or in idle time, the body performs some self-maintenance tasks. Our approach in maintaining a machine when it is idle can be considered as a step towards self-maintenance and future direction in the maintenance field. This needs to be further developed and compared with human activities in self-maintenance capabilities.

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References

[1] Moubray, J. “Reliability-Centered Maintenance”. New York: Industrial Press Inc. 1997.
[2] Water, H.V. “A Maintenance model for quality management”. International Journal of Quality and Reliability Management. Vol. 17, No.7, pp. 756-770. 2000.
[3] Mustafa, G. “Reliability of service systems and an application in student office”. International Journal of Quality and Reliability Management. Vol. 1, pp. 58-66. 2002.
[4] Cox, D.R. and Oakes, D. “Analysis of Survival Data”. New York: Chapman and Hall. 1984.
[5] Islam, M.A. “Multistate Survival Models for Transitions and Reverse Transitions: an Application to Contraceptive Use Data”. Journal of the Royal Statistical Society A. Vol. 157, Part 3, pp. 441-455. 1994.
[6] Burhanuddin, M.A. “Reliability analysis of delay in repair time using hazards model”. Integrating Technology in the Mathematical Sciences Conference. Universiti Sains Malaysia. Part A, pp. 113-122. 2003.

[7] Adamantios, M. and Zhao, W. "Modeling and Analysis of Repairable Systems with General Repair". IEEE Annual Proceedings of Reliability and Maintainability. 0-7803-8824-0, pp. 1-8. 2005.
[8] Labib, A.W. "World-class maintenance using a computerized maintenance management system". Journal of Quality in Maintenance Engineering. Vol. 4, No. 1, pp. 66-75. 1998.
[9] Bevilacqua, M. and Braglia, M. "The analytic hierarchy process applied to maintenance strategy selection". Reliability Engineering and System Safety. Vol. 70, pp. 71-83. 2000.
[10] Labib, A.W. "A decision analysis model for maintenance policy selection using a CMMS. Journal of Quality in Maintenance Engineering". Vol. 10, No. 3, pp. 191-202. 2004.
[11] Williams, K.B. and Sawyer, S.C. "Using Information Technology". New York: McGraw-Hill. 2006.
[12] Swanson, L. "Computerized maintenance management systems: A study of system design and use". Production and Inventory Management Journal. Vol. 1, pp. 99-107. 1997.
[13] Leger, J.B. and Movel, G. "Integration of maintenance in the enterprise: towards an enterprise modeling based framework compliant with proactive maintenance strategy". Journal of Production Planning Control. Vol. 1, Part 2, pp. 341-352. 2001.
[14] Fernandez, O., Walmsley, R., Petty, D.J. and Labib, A.W. "A decision support maintenance management system development and implementation". International Journal of Quality and Reliability Management. Vol.20, No.8, pp. 965-979. 2003.
[15] Burhanuddin, M.A. and Ahmad, A.R. "An Improved Decision Making Grid Model for Food Processing Small and Medium Industries". Proceedings towards Excellence in Computer Science Postgraduate Research (PARS'08). Universiti Teknologi Malaysia, Johor. Vol. 1, No. 3, pp. 1-6. 2008.
[16] Swanson, L. "Linking maintenance strategies to performance". International Journal Production Economics. Vol. 70, pp. 237-244. 2001.
[17] Burhanuddin, M.A, Ahmad, A.R. and Desa, M.I. "Maintenance Decision Making Using Multiple Criteria Analysis for Small and Medium Industries". Journal of Information Technology. UTM, Johor, Malaysia. Vol. 19, No. 2, pp. 35-46. 2007.
[18] Labib, A.W. and Yuniarto, M.N. "Maintenance Strategies for Changeable Manufacturing". New York: Springer-Verlag Inc. Chapter 19, pp. 337-351. 2009.
[19] Kimemia, J.G. and Gershwin, S.B. "An Algorithm for the Computer Control of Production in Flexible Manufacturing Systems". Massachusetts Institute of Technology Laboratory for Information and Decision Systems Report. LIDS-P-1134. 1983.
[20] Yoshiki, S., Sadao, T., Yasushi, U. and Tetsuo, T. "Development of Self-Maintenance Photocopiers". AI Magazine. Vol. 16, No. 4, pp. 41-53. 1995.