Maintenance Decision Support System in Small and Medium Industries: An Approach to New Optimization Model

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Summary
Maintenance management is one of the main focuses in industrial sector. Many maintenance functions with varieties optimization models have been proposed to aid maintenance management. However, there are limited models have been implemented in small and medium industries (SMIs). The data problems and the gap between theory and practice have always become a reason. In this paper, a new maintenance optimization model has been used to carry out the computations for calculating frequency of failures and downtime as the maintenance data problems using decision making grid (DMG) with fuzzy logic in maintenance decision support system (DSS). Next, SMIs can use this system to support their maintenance decision process.
Key words:
Small and medium industries, decision making grid, fuzzy logic, maintenance decision support system.

1. Introduction

The importance of maintenance functions for maintenance management in commonly industries has growing rapidly. A lot of researches and publications in the field maintenance decision models have been published to improve the effectiveness of maintenance process. As a part of research project for maintenance decision support system in small and medium industries, we have collected the related publications in those areas.

The trends shown there are limited models have been implemented in industrial maintenance process. Although the improvement of IT (both software and hardware) can support to easy develop of the system with lower cost and systematic modules, it is limited work has directed toward developing into operational applications such as computerized maintenance management system (CMMS) or DSS. It can be said that the impact of decision making within a maintenance organization has so far been limited. The data problems and the gap between theories and practice have always become the reason.

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In order to increase the effectiveness of the units, DSS is needed to simplify the analyzing process and to reduce the time needed for make a maintenance decision. The aim of this paper is to propose a new optimization technique for maintenance decision support system for analysis CMMS data to support SMIs maintenance decision process. Choosing and optimizing maintenance strategies is of for most importance in maintenance management. The paper established DMG with fuzzy logic for maintenance strategy and introduces a decision support system in CMMS application. Figure 1 shows the steps to discover decision and knowledge from CMMS database.

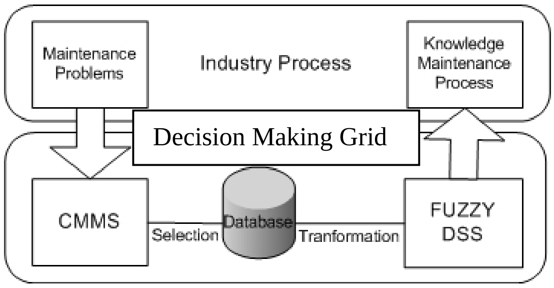

Fig. 1 Fuzzy-DSS process.

2. Related Work

Maintenance optimization is the process to attempt the balance of maintenance requirement such as legislative, economic, technical or others. The goals is to select the appropriate maintenance technique for each piece of equipment in the system and identifying the periodicity that the maintenance technique should be conducted to achieve the best requirement, maintenance target concerning safety, equipment reliability, and system availability/costs. Reference [1] has presented various resources in the field of maintenance optimization models as shown in figure 2.

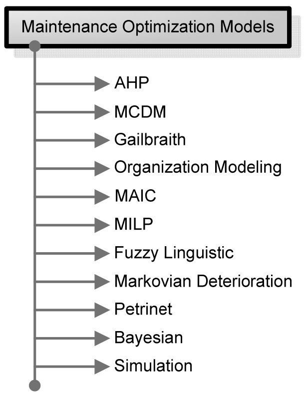

Fig. 2 Maintenance optimization classification.

Each classification and available literature of maintenance optimization models has been described as follow:

1. *Analytical Hierarchy Process (AHP):* It was developed by [2] as mathematical decision making model to solve complex decision making problems when there are multiple objectives or criteria considered. It's requires the decision makers to provide judgments about the relative importance criterion for each decision alternative ([3], [4]).

   AHP can be using to model a hierarchy of levels related to objective, criteria, failure category, failure details and failed components as described in figure 3. AHP divided the priorities related to every element priorities in the same level. With AHP, every decision variety can be compared according in manner adaptive to shop floor realities.

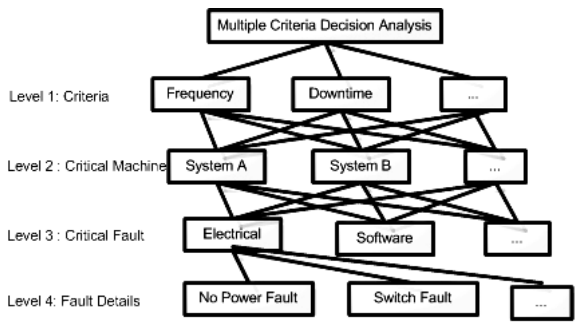

Fig. 3 AHP decision support.

2. *Multiple Criteria Decision Making (MCDM):* Ranking and selecting between alternates is a relatively common, yet often difficult task. MCDM refers to the solving of decision and planning problems involving multiple and generally collecting requirements. The decision makers (DM) one reasonable alternative from among a set of available ones ([5], [6]).

3. *Gailbraith:* The theory believes that "the greater uncertainty of the task, the greater amount of information that must be processed between decision makers during the execution of the task to get a given level of performance". Industries can reduce uncertainty through better planning and coordination, often by rules, hierarchy, or goals [7].

4. *Organization Modeling:* Reference [8] reviews maintenance organization models, e.g. advanced terotechnological model (ATM), Eindhoven University of Technology model (EUT), total quality management (TQM), total productive maintenance (TPM), reliability centered maintenance (RCM) model etc., and suggest maintenance can be contributor to profits by use of information technology (IT) and showed that integrated IT permits co-planning of production with maintenance.

5. *Materially per Apparencchiature de Impiariti Chemiei (MAIC):* Reference [9] has presented a knowledge-based decision support system, MAIC for maintenance of a chemical plant.

6. *Mixed Integer Linear Programming (MILP):* It is very general framework for capturing problems with both discrete decisions and continuous variable. This includes assignment problems, control of hybrids system, piecewise-affine (PWA) system (including approximation of nonlinear system), and problems with non-convex constrains [10].

7. *Fuzzy Linguistic:* Fuzzy logic was introduced by [11] as a superset of conventional or Boolean logic that has been extended to handle the concepts of partial truth – truth values between "completely true" and "completely false". It was described as a means to model the uncertainty of natural language. Zadeh stated that rather than regarding fuzzy theory as a single theory, we should regard the process of "fuzzyfication" as a methodology to generalize any specific theory from crisp or discrete to a continuous or fuzzy form. By the term "fuzziness" Zadeh meant classes in which there is no sharp transition from membership. For example, the class of tall men is fuzzy set.

   In general, fuzzy logic is a form of AI that can deal with non-quantifiable concepts. It enables software developers to program easily computer that can simulate the vagueness and uncertainty of term like "old" and "smart" – terms inherent in human reasoning and thought-processes ([12], [13], [14], [15]). In fuzzy logic, unlike standard conditional logic, the truth of any statement is a matter of degree. For example, for the rule if (weather is cold) then (heat is on), both variables, cold and on, map to ranges of values. Fuzzy systems rely on membership function to explain to the computer how to calculate the correct value between zero and one. The degree to which any fuzzy statement is true is denoted by a value between zero and one. A typical fuzzy system consists of a rule base, membership function and an inference procedure, as presented in figure 4.

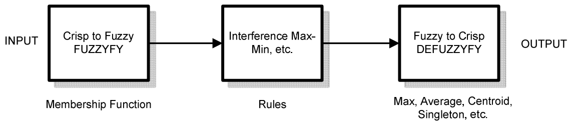

Fig. 4 A typically fuzzy system.

8. *Markovian Deterioration:* Markovian deterioration is a mathematical model for the random evolution of a memoryless system. Often the property of being 'memoryless' is expressed such that conditional on the present state of the system, it's future and past are independent ([16], [17], [18], [19]).

9. *Petri Net:* It is one of several mathematical modeling languages for the description of discrete distributed system. A petri net is a directed bipartite graph, in which the nodes represent transitions (i.e. discrete events that may occur), places (i.e. conditions), and directed arch (that describe which places are pre – and/or post conditions for which transitions) [20].

10. *Bayesian*: Bayesian statistic is based on Bayes' rule or conditional probability. It is well known that probability of events *A* and *B* both occurring can be written as the probability of *A* occurring multiplied by probability of *B* occurring given that *A* has occurred ([21], [22]). This is written as,

$$P(A \text{ and } B) = P(A)\, P(B|A)$$

11. *Simulation:* Reference [23] and [24] use the Monte Carlo simulation to determine optimum maintenance policy and for modelling on continuously monitored systems. Reference [25] has used simulation model to reduce maintenance and inventory cost for a manufacturing system with stochastic item failure, replacement and order lead times. Reference [26] demonstrates application of simulation models to evaluate maintenance policies for an automated production line in a steel rolling mill.

3. Theoretical Review

Fuzzy decision support system is the system that combining DSS with fuzzy logic. This research used analytical hierarchy process (AHP) combining with fuzzy logic to render DMG. Next, the new-DMG will be applied into fuzzy decision support system to create decision analysis.

3.1. Fuzzy decision support system

Nowadays, decision making has become very important for the organization in industries. This trend necessitates DSSs are able to organize and process all the information and data that managers need to make effective decisions. In the process of decision making, decision makers combine different types of data (i.e. internal and external data) and knowledge (i.e. tacit and explicit knowledge) available in various forms in the industries or its external environment. However their task is made extremely difficult by the uncertainty affecting decision making processes. The ability to manage uncertainty and fuzzy value turns out to be a crucial issue for DSS. There are several research has been proposed with the fuzzy value in DSS. Reference [27] discussed the past research and future prospect about integrating fuzzy logic into DSS in several areas, those are business sectors, industries, social sectors, and other sectors.

Reference [28] has built vertical handover decision making algorithm using fuzzy logic for integrated radio and optical wireless system. Moreover, reference [29] has presented fuzzy group DSS for project assessment and reference [30] proposed DSS of ventilation operator based on fuzzy method applied on interpretation and processing of gas dynamic images. In 2008, reference [31] presented a novel biological and psychologically inspired fuzzy decision support system hierarchical complementary learning.

Based on all of the references above, CMMS application is a typical problem to which decision support fuzzy system can be successful applied. To develop a decision-support fuzzy system for this problem, we can represent the basic concept of maintenance data in fuzzy term, then implement the concept in prototype system using an appropriate fuzzy tool, and finally test and optimize the system with selected test case [32].

3.2. Decision making grid

Reference [4] proposed DMG model as a map on which the performances of the worst machine are mapped according to multiple criteria. Then reference [33] defined DMG in control chart on two dimension model. First model is downtime with low, medium and high criterion, and the second is frequency of failure as low, medium and high criterion. The methodology has implemented as follows:

(i) Criteria analysis: Establish Pareto analysis of the criterion;

(ii) Decision mapping: Mapped the criterion in the matrix; and

(iii) Decision support: Identifying a focused action to be implemented.

Reference [34] applied the model to improve maintenance strategies in SMIs in Malaysia. They have developed a system to select both of frequency and downtime data in CMMS and mapped them into each criterion in DMG. Based on their research, the criterion analysis is embedded to describe fuzzy sets input for fuzzy decision support system in the present study.

Both references ([33], [34]) are two publications that mostly related to this paper.

4. Methodology

The historical data is extremely needed for analysis and decision making to maintain the systems at optimum or desire level. It should be selected from real CMMS database in SMIs. As a case study, we selected data maintenance measurement from reference [34], who was collected dataset from one SMI in Malaysia as shown in figure 5.

ID Machine	Frequency		Downtime	
	No. Off	Criteria	Hour	Criteria
A	1	Low	2	Low
B	3	Low	89	Med
C	8	Med	193	High
D	2	Low	13	Low
E	5	Low	33	Low
F	16	High	249	High
G	5	Low	129	Med
H	30	High	737	High
J	5	Low	73	Low
K	3	Low	54	Low
L	1	Low	8	Low
M	19	High	188	Med
N	9	Med	63	Low
P	2	Low	33	Low

Fig. 5 Data measurement.

The data have been categorized by selecting top ten machines having highest frequency of failure and downtime from CMMS, and then divided in using these formulae:

Let: h is the highest value in the list.

l is the lowest value in the list.

High boundary = h

Medium/high boundary = $h - {}^{1}/_{3}\,(h)$

Low/medium boundary = $h - {}^{2}/_{3}\,(h)$

Low boundary = l

Reference [34] also has developed both frequency and downtime into two dimension matrix as shown in figure 6, which includes two steps as follows:

1. Those machines that meet both criteria and ranked in formulae, are then mapped in the two dimensional matrix, and

2. Once mapping have been finalized, the decisions is developed by comparing two dimensional matrixes with the appropriate maintenance strategies for each criterion.

Criteria		Downtime		
		Low	Med	High
Frequency	Low	OTF [J][K]	FTM [G][B]	CBM
	Med	FTM [N]	FTM	FTM [C]
	High	SLU	FTM [M]	DOM [H][F]

Fig. 6 Data mapping.

The objective from data measurement is to implement appropriate strategies that will lead the movement of machine toward an improvement machine stages, divided to multiple criterion decision that has mentioned by [33] as:

(i) Operate to Failure (OTF): This strategy is implemented when the machine is seldom failed, and once failed the downtime is short;

(ii) Fixed Time Maintenance (FTM): This strategy used preventive maintenance schedule, implemented when failure frequency and downtime are almost at the moderate cases;

(iii) Skill Level Upgrade (SLU): Upgrading skill level of operator, because machine has been visited many times (high frequency) and but easily can be fixed (low downtime);

(iv) Condition-Based Maintenance (CBM): This is used to analyze the breakdown event and closely monitor its condition when the machine not breakdown often but take longer time to fix;

(v) Design Out Maintenance (DOM): DOM is the most crucial area in the grid. Machines in this region are recommended to go for major design out project. This is because the machines experience high downtime and high frequency.

In practice, however, there were two cases founded from DMG models that need to refine. The first is when the performance makers of two machines are located near to each other on the grid but on different sides of boundary between two criteria, and the second is when two such machines are on the extreme side of a quadrant of a certain criteria. For both cases, a new model DMG with fuzzy logic could be applied to smooth the boundary and to apply the rules simultaneously with varying weight [33].

5. Implementation

Commonly CMMS application in SMIs is aims to enhance the effectiveness of industry process. All of maintenance process should be recorded and stored in CMMS data base. Machine downtime and frequency of machine failure is normally the standard criterion that must be included in maintenance data. Next, both data is analyzed with fuzzy decision support system.

To define membership function from maintenance data as shown in figure 7 and 8, we can estimates from all of data as shown in Figure 5 in the decision making grid over period of time. The scope/domain of membership function is the range over which a membership function is mapped. Here the domain of fuzzy set medium frequency is from 5 to 16 and its scope is 9 (16-5), whereas the domain of medium downtime is from 73 until 199 and the scope is 126 (199-73) and so on. Triangular and trapezoidal membership function can adequately represent the problem of the maintenance.

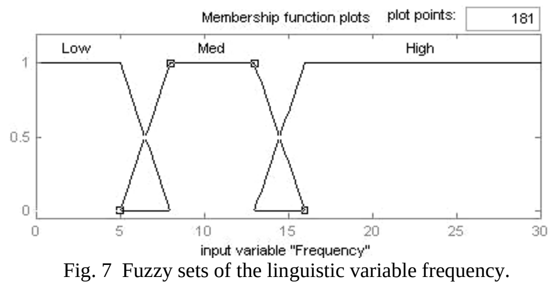

Fig. 7 Fuzzy sets of the linguistic variable frequency.

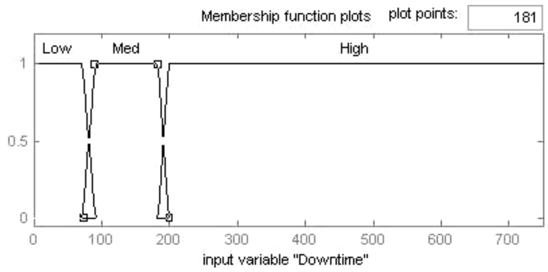

Fig. 8 Fuzzy sets of the linguistic variable downtime.

The output strategies that shown in figure 9 have assumed as cost or benefit and have a membership function that linear and follows the relationship – DOM > CBM > SLU > FTM > OTF.

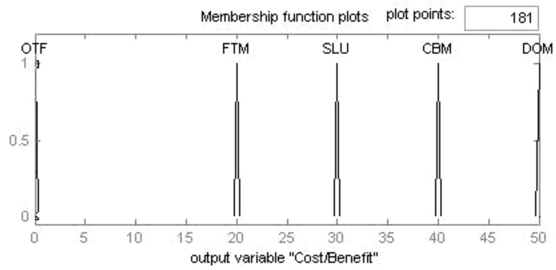

Fig. 9 Fuzzy sets of the linguistic variable output.

Next, fuzzy rules are obtained based on DMG. In our case, we simply adapt the basic rules used by reference [33]. These rules are shown in figure 10.

- If (frequency is low) and (downtime is low) then (maintenance strategy is OTF);
- If (frequency is low) and (downtime is medium) then (maintenance strategy is FTM);
- If (frequency is low) and (downtime is high) then (maintenance strategy is CBM);
- If (frequency is medium) and (downtime is low) then (maintenance strategy is FTM);
- If (frequency is medium) and (downtime is medium) then (maintenance strategy is FTM);
- If (frequency is medium) and (downtime is high) then (maintenance strategy is FTM);
- If (frequency is high) and (downtime is low) then (maintenance strategy is SLU);
- If (frequency is high) and (downtime is medium) then (maintenance strategy is FTM);
- If (frequency is high) and (downtime is high) then (maintenance strategy is DOM);

Fig. 10 Rule based maintenance strategy evaluation.

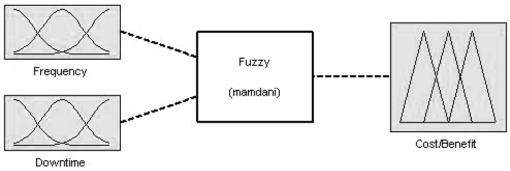

Fig. 11 Hierarchical fuzzy model.

Complex relationships between all variables used in fuzzy system can be represented by the hierarchical structure as shown in figure 11.

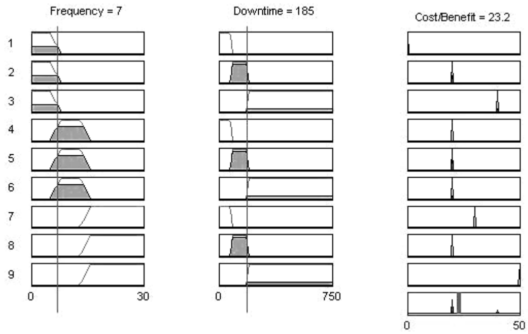

Fig. 12 Outputs example.

The system is built with MATLAB fuzzy logic toolbox. The last phase in the development of a prototype system is its evaluation and testing. In examples, for a 7 times frequency and a 185 hour downtime, the output is 23.2 as shown in figure 12. Its means the suggested strategy is FTM. It can be noticed from that the relation – DOM > CBM > SLU > FTM > OTF can be maintained.

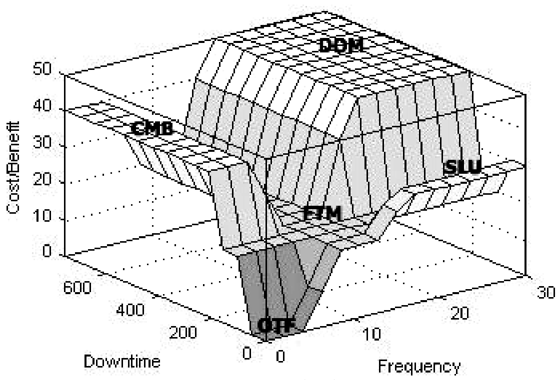

Fig. 13 Three-dimensional plots for frequency and downtime.

To analyze the performance of fuzzy system, three-dimensional plots output can be used as provided in figure 13. Finally, the output can determine the most appropriate strategy to follow from any combination of frequency and downtime.

6. Conclusion

The main idea is based on the fact that DSS is needed for CMMS in industries. A model has been proposed with combining the AHP with fuzzy logic concept to render DMG. The DMG is very suitable to be embedded with CMMS to identify different strategies of maintenance based on their utilization.

As mentioned earlier, in practice, however, there were two cases that the DMG model needs to refine. The first is when the performance makers of two machines are located near to each other on the grid but on different sides of boundary between two criteria, and the second is when two such machines are on the extreme side of a quadrant of a certain criteria. For both cases, a new model DMG with fuzzy logic could be applied to smooth the boundary and to apply the rules simultaneously with varying weight.

The basis problems are usually easy to find in existing CMMSs from SMIs. It is therefore proposed that decision support fuzzy system could be attached as an intelligent module for existing CMMSs in SMIs to support decision analysis and to reduce the time needed for make a maintenance decision.

Acknowledgments

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