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A New Fuzzy Multi Criteria Model for Maintenance Policy

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Abstract: This paper aims to evaluate different maintenance strategies (such as corrective maintenance, time-based preventive maintenance, condition-based maintenance and predictive maintenance) for different equipment. A new fuzzy multi criteria model is introduced and it is used for the optimization decision making of the complex system maintenance strategy with five Criteria. In this paper maintenance strategies has been modeled with consideration of four fuzzy parameters in the figure of Multi Criteria Decision Making. One of the Criteria elaborates minimization of total Completion time. The second Criteria has been considered in this model due to describe minimize cost. The other Criteria are in regards to minimization of risk and working man and maximize retrieval parts.

Key words: Maintenance · Fuzzy · Multi criteria

INTRODUCTION

In the literature, maintenance can be classified into two main types: corrective and preventive [1, 2]. Corrective maintenance is the maintenance that occurs after systems failure and it means all actions resulting from failure; preventive maintenance is the maintenance that is performed before systems failure in order to retain equipment in specified condition by providing systematic inspections, detection and prevention of incipient failure [3]. Based on the development of preventive maintenance techniques, three divisions of preventive maintenance are considered in this paper, i.e. time-based preventive maintenance, condition-based maintenance and predictive maintenance. These maintenance strategies will be introduced in detail in the next section. Most plants are equipped with various machines, which have different reliability requirements, Risk levels and failure effect. Therefore, it is clear that a proper maintenance program must define different maintenance strategies for different machines. Thus, the reliability and availability of production facilities can be kept in an acceptable level and the unnecessary investment needed to implement an unsuitable maintenance strategy may be avoided. For example, for the pump with a standby, the corrective/time-based maintenance may be more cost-effective than the condition-based/predictive maintenance strategy in a production environment with a relatively low reliability requirement.

Although the selection of the suitable maintenance strategy for each piece of equipment is important for manufacturing companies, few studies have been done on this problem. In [4] Luce, Okumura and Okino [5] showed the methods to select the most effective maintenance strategy based on different production loss and maintenance costs incurred by different maintenance strategies. Although the calculation theories for the related costs presented by them are reasonable, the money spent on maintenance is only one of the factors that should be taken into account when choosing maintenance strategies in many cases. In [6] Azadivar and Shu presented the method to select a suitable maintenance strategy for each class of systems in a just-in-time environment, exploring 16 characteristic factors that could play a role in maintenance strategy selection. But this method is not applicable to process plants because of the difference between discrete manufacturing plants and process plants. In the report of Bevilacqua and Braglia [7], the original method for the selection of maintenance strategies in an important Italian oil refinery was given and the application of the analytic hierarchy process (AHP) for selecting the best maintenance strategy was described. The criteria they considered seem sufficient, but a crisp decision-making method as the

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traditional AHP is not appropriate because many of the maintenance goals taken as criteria are non-monetary and difficult to be quantified. In [8] Al-Najjar and Alsyouf, Sharma *et al*. [9] assessed the most popular maintenance strategies using the fuzzy inference theory and fuzzy multiple criteria decision-making (MCDM) evaluation methodology. The application of the fuzzy theory for this problem is a good solution. However, only a few failure causes were considered as the criteria in their studies. In [10] Mechefske and Wang, the authors proposed to evaluate and select the optimum maintenance strategy and condition monitoring technique making use of fuzzy linguistics. The fuzzy methodology based on qualitative verbal assessment inputs is more practical than the formers, because many of the overall maintenance objectives of the organization are intangible. However, the method of Mechefske and Wang [10] is very subjective to directly assess the importance of each maintenance goal and the capability of each strategy to achieve each maintenance goal. Considering the shortcomings of the existing methods above, it is necessary to develop a new evaluation scheme for maintenance strategies. This scheme should include different aspects of maintenance goals, be able to model uncertainty and imprecise judgments of decision makers (i.e. maintenance managers and engineers) and be easy to use.

Alternative Maintenance Strategies: Four alternative maintenance strategies considered in this paper are introduced as following:

Corrective Maintenance: This alternative maintenance strategy is also named as fire-fighting maintenance, failure based maintenance or breakdown maintenance. When the corrective maintenance strategy is applied, maintenance is not implemented until failure occurs [11]. Corrective maintenance is the original maintenance strategy appeared in industry [12, 10]. It is considered as a feasible strategy in the cases where profit margins are large [9]. However, such a firefighting mode of maintenance often causes serious damage of related facilities, personnel and environment. Furthermore, increasing global competition and small profit margins have forced maintenance managers to apply more effective and reliable maintenance strategies.

Time-Based Preventive Maintenance: According to reliability characteristics of equipment, maintenance is planned and performed periodically to reduce frequent and sudden failure. This maintenance strategy is called time-based preventive maintenance, where the term ‘‘time’’ may refer to calendar time, operating time or age. Time-based preventive maintenance is applied widely in industry. For performing time-based preventive maintenance, a decision support system is needed and it is often difficult to define the most effective maintenance intervals because of lacking sufficient historical data [13]. In many cases when time-based maintenance strategies are used, most machines are maintained with a significant amount of useful life remaining [10]. This often leads to unnecessary maintenance, even deterioration of machines if incorrect maintenance is implemented.

Condition-Based Maintenance: Maintenance decision is made depending on the measured data from a set of sensors system when using the condition-based maintenance strategy. To date a number of monitoring techniques are already available, such as vibration monitoring, lubricating analysis and ultrasonic testing. The monitored data of equipment parameters could tell engineers whether the situation is normal, allowing the maintenance staff to implement necessary maintenance before failure occurs. This maintenance strategy is often designed for rotating and reciprocating machines, e.g. turbines, centrifugal pumps and compressors. But limitations and deficiency in data coverage and quality reduce the effectiveness and accuracy of the condition-based maintenance strategy [8].

Predictive Maintenance: In the literature, predictive maintenance often refers to the same maintenance strategy with condition-based maintenance [9, 14]. In this paper, considering the recent development of fault prognosis techniques [15, 16], predictive maintenance is used to represent the maintenance strategy that is able to forecast the temporary trend of performance degradation and predict faults of machines by analyzing the monitored parameters data. Fault prognostics is a young technique employed by maintenance management, which gives maintenance engineers the possibility to plan maintenance based on the time of future failure and coincidence maintenance activities with production plans, customers’ orders and personnel availability. Recently, the intelligent maintenance system was described by Djurdjanovic *et al*. [17], focusing on fault prognostic techniques and aiming to achieve near-zero-downtime performance of equipment.

Comparing Criteria: When different maintenance strategies are evaluated for different machines, the manufacturing firms must set maintenance goals taken as comparing criteria first. Different manufacturing

companies may have different maintenance goals. But in most cases, these goals be divided into five aspects analyzed as follows:

Risk: Risk levels required are often high in many manufacturing actories, especially in wood industry and power plants. The relevant factors describing the Risk are:

Personnel: The failure of many machines can lead to serious damage of personnel on site, such as high pressure vessels in power plants.

Facilities: For example, the sudden breakdown of a water-feeding pump can result in serious damage of the corresponding boiler in a power plant.

Environment: The failure of equipment with poisonous liquid or gas can damage the environment.

Cost: Different maintenance strategies have different expenditure of hardware, software and personnel training.

Hard ware: For condition-based maintenance and predictive maintenance, a number of sensors and some computers are indispensable.

Soft ware: Software is needed for analyzing measured parameters data when using condition-based maintenance and predictive maintenance strategies.

Personnel Training: Only after sufficient training can maintenance staff make full use of the related tools and techniques and reach the maintenance goals

Time: Different maintenance strategies need different times. Minimized times of stop in continuios systems production minimized times of stop are one of the important goals.The dependent factors included:

Corrective Activities: Times consumed to repair after failure occurs.

Inspection: Total times needed for inspection of production line and other equipments.

Lost Production Capacity: Total times that equipment is downtime and in those times we can not produce.

Service: It is included total times that need for lubrication and other services.

Human Source: We often confront lack of experts in many factories. The dependent factors included:

Human Source Existent in Factory: It is consisted of man that employed fulltime inside factory.

Human Source Existent in Contract: It is consisted of men that employed as contract with factory when does not enough time or enough experts.

Retrieval: In some production systems especially in continuous production system, for reducing of stop time in some sensitive equipment that have the capability of retrieval, it is proposed aided equipment. When failure occurs in the shortest time it is replaced with breakdown equipment and it will be retrieved. The dependent factors included:

Reliability: That means the retrieval equipment can work with high reliability.

Value: It clearly shows that the cost of purchasing is more than the cost of retrieval and then it will be selected.

Methodology: In this paper we have introduced fuzzy multi criteria mathematical programming with generalized triangular fuzzy number and it is applied as objective coefficients to a reliability problem subject to complex system design.

Conventional optimization methods assume that all parameters and goals of an optimization model are precisely known. But for many practical problems there are incompleteness and unreliability of input information. This is caused to use fuzzy multi criteria optimization method with fuzzy parameters. In many practical design situations, maintenance strategies selecting is complicated because of the presence of several conflicting objecting objectives and imprecise cost of components of the system. For instance, a designer is required to minimize the system cost while simultaneously maximizing the part retrieve. Therefore multi criteria functions become an important aspect in the maintenance strategies selecting.

In this paper it is supposed that time, cost, risk and retrieval are triangular number that first convert them to crisp value and then input them into the model.

Defuzzification of Fuzzy Number: The aggregation defined by a triangular or trapezoidal number very often has to be expressed by a crisp value which represents best the corresponding average. This operation is called defuzzification.

First consider the defuzzification of A = (m1;mM;m2) given It looks plausible to select for that purpose the value mM in the supporting interval [m1;m2] of A; mM has the highest degree (one) of membership in A. In other words, A attains its maximum at xmax = mM which we call maximizing value. However the operation defuzzification can not be defined uniquely.

Here we present three options for defuzzifying A = (m1; mM; m2) which are essentially statistical average formulas:

$$X = (m1 + mM + m2)/3 \quad (1)$$

$$X = (m1 + 2mM + m2)/4 \quad (2)$$

$$X = (m1 + 4mM + m2)/6 \quad (3)$$

The defuzzification of the trapezoidal number A = (m1; mM1, mM2; m2) can be performed by an extension of 1 and 2 amd 3.

Here we present three options for defuzzifying triangular number A= (m1; mM1, mM2; m2) which are essentially statistical average formulas:

$$x = (m1 + (mM1 + mM2)/2 + m2)/3 \quad (1)$$

$$x = (m1 + mM1 + mM2 + m2)/4 \quad (2)$$

$$x = (m1 + 2(mM1 + mM2) + m2)/4 \quad (3)$$

Mathematical Model:

T_{ij} : The needed time for performance of jth maintenance policy on the ith part.
C_{ij} : The needed cost for performance of jth maintenance policy on the ith part.
R_{ij} : The risk of performance of jth maintenance policy on the ith part.
Re_{ij} : Retrieval possibility of ith part if jth maintenance policy will be selected.
M_{ij} : The number of man material needs for performance of jth maintenance policy on the ith part.
λ_k : Weight of kth criteria.
θ_i : Weight of time for ith part.
η_i : Weight of cost for ith part.
γ_i : Weight of risk for ith part.
μ_i : Weight of man material for ith part.
α_i : Weight of retriaval for ith part.

$$Z = \begin{cases} 1 & \text{if jth maintenance policy will be selected for ith part..} \\ 0 & \text{otherwise} \end{cases}$$

L : Maximum of man material exited in factory.
S_i : Maximum time feasible for performance of maintenance policy in ith part.
Oi : Maximum money unit that is be cost for ith part.
P_i : Maximum acceptable of risk for ith part.

$$\min z = \lambda_1 \sum_{i=1}^{n} \theta_i \left((\sum_{j=1}^{m} Z_{ij} T_{ij}) / (\sum_{i=1}^{n} \sum_{j=1}^{m} Z_{ij} T_{ij}) \right)$$
$$+\lambda_2 \sum_{i=1}^{n} \eta_i \left((\sum_{j=1}^{m} Z_{ij} C_{ij}) / (\sum_{i=1}^{n} \sum_{j=1}^{m} Z_{ij} C_{ij}) \right)$$
$$+\lambda_3 \sum_{i=1}^{n} \gamma_i \left((\sum_{j=1}^{m} Z_{ij} R_{ij}) / (\sum_{i=1}^{n} \sum_{j=1}^{m} Z_{ij} R_{ij}) \right)$$
$$+\lambda_4 \sum_{i=1}^{n} \mu_i \left((\sum_{j=1}^{m} Z_{ij} M_{ij}) / (\sum_{i=1}^{n} \sum_{j=1}^{m} Z_{ij} M_{ij}) \right)$$
$$+\lambda_5 \sum_{i=1}^{n} \alpha_i \left((\sum_{i=1}^{n} \sum_{j=1}^{m} Z_{ij} \mathrm{Re}_{ij}) / (\sum_{j=1}^{m} Z_{ij} \mathrm{Re}_{ij}) \right)$$

s.t.:

$$\sum_{j=1}^{m} Z_{ij} \geq 1 \quad i = 1,\ldots,n \quad (1)$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} Z_{ij} M_{ij} \leq L \quad (2)$$

$$\sum_{j=1}^{m} Z_{ij} T_{ij} \leq S_i \quad i = 1,\ldots,n \quad (3)$$

$$\sum_{j=1}^{m} Z_{ij} C_{ij} \leq Oi \quad i = 1,\ldots,n \quad (4)$$

$$\sum_{j=1}^{m} Z_{ij} R_{ij} \leq P_i \quad i = 1,\ldots,n \quad (5)$$

$$Z_{ij} \in \{0,1\} \quad i = 1,\ldots,n;\ j = 1,\ldots,m \quad (6)$$

$$M_{ij} \in Integer \quad (7)$$

The constraint (1) shows that for each part, at least one maintenance Policy must be selected.

The constraint (2) shows that at most existence man material must be L.

The constraint (3) shows that maximum consumed time for ith part is S_i .

The constraint (4) shows that maximum consumed cost for ith part is *Oi*.

The constraint (5) shows that maximum acceptable risk for ith part is P_i.

This objective function contains of five criteria. Z_{ij} is a binary variable and when multiplied in T_{ij} shows the time that is consumed in ith part when jth maintenance policy is selected and it is multiplied by θ_i (weight of time for ith part) and divided by the sum of times in all parts, it is transferred into standard variable and then by multipling in weight of self criteria against other criteria, the objective function of time is obtained. Similarly, the objective function of cost, risk and human source is obtained. In the retrieval criteria whereas the objective is maximum and total objective function is minimum then the objective function of retrieval must be converted.

CONCLUSION

In one equipment, its different parts with respect to introduced criteria may need different maintenance policies. Thus it is important for different parts of equipment with respect to their Sensitivity suitable maintenance policies can be selected.

In this paper, the problem of maintenance policy selection had been modeled in the form of fuzzy multi criteria.

In the real world, maintenance policy selection criteria usually are more than one. On the other hand, usually criteria are not crisp. Thus in this paper a new fuzzy multi criteria mathematical model has been considered for selection of maintenance policy for parts.

It is proposed to use, multi objective criteria or integrated AHP and GP or integrated DEA and multi objective porograming for futures research.

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