Selecting optimal maintenance strategy using Qualitative - Quantitative Model and Multi-Criteria Decision Making approach

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Abstract_ **By the passage of the time, Incremental population needs more and more to get industrial products, Energy, food, etc. All the sets and human artifact's life times are limited. Because they have made by a collection of electrical and mechanical components, any time, their breakdowns and so failure of set or the whole system are possible. The more dangerous breakdown, the higher importance of maintenance activities, it is undeniable fact. To consider the maintenance activities, it's necessary for systems whose breakdowns are so undesirable. In this situation, selection of maintenance optimal strategies has a special importance. In this paper, by considering systemability, a quantitative-qualitative model is developed which spite of optimal strategy selection, it gives optimal time to strategy changing. One of the most important advantages of this model is consideration of both quantitative-qualitative criteria and also this strategy selection is dynamic. For this, it uses Multi Criteria Decision Making approach by considering cost criteria. Finally, a factory of automotive parts manufacturer is selected as case study and diagrams as user friendly tools are utilized to sensitivity analysis of results.**

Keywords_ Maintenance strategies, Quantitative-qualitative approach, Systemability, Multi Criteria Decision Making.

1. Introduction

Maintenance of industrial machinery has long been one of the major issues in the industry. Maintenance costs in the industry is typically 5 to 6 percent of fixed assets and in heavy industries reaches to 12 percent [1].

Growing importance of maintenance has created a keen interest in the development and implementation of optimal maintenance strategies to improve the reliability of the system that includes preventing the occurrence of defects and reduce the maintenance costs of the system. This is an inescapable fact that as well as the damage is more serious the maintenance activities are more important too. Maintenance activities on systems that their failure or interruption can be very unpleasant, are necessary. Maintenance activities like systems that will provide the desired services for society, such as power plants, defense and support (military systems) , and so on[2].

In recent years the importance of maintenance and maintenance management has been developed. Fast development of technology and automation, reduced energy production labor and increased the number of capital employed for production equipment and development structures. Existence of an optimum maintenance strategy that aligns with the organization's capacity, causing a significant role in reducing the cost of maintenance

2. Literature review

Today maintenance activities are done to improve machine performance, reducing the need of them to perform repairs and remove all causes of damage. Comprehensive Efficient maintenance strategy, world class maintenance, etc. in this time are extremely useful. Choosing the best set of maintenance policies for various forms of failure is a difficult issue. This choice requires science and knowledge in areas such as safety, environment issues, cost and budget constraints, staffing efficiency, MTBF[1] and MTTR[2], etc. for each piece of equipment [3]. Researchers considering various criteria, strategies properties, and industry conditions, are following to choose the most optimal maintenance strategy.

In this regard, in 2000 Bevilacqua and Braglia [4] found the optimal strategy of the five preventive, predictive, condition based, corrective and

[1] Mean time between failures
[2] Mean time to repair

opportunistic strategies at an oil refinery in Italy. Criteria used in the survey included damage, constructability, added value and cost. Also in this study, using Analytic Hierarchy Process (AHP[1]) optimality is investigated. In 2007, Wang and colleagues [5] investigated optimal strategy in a thermal power plant in China using fuzzy AHP method. In this research standards of safety, added value, cost and availability are considered. Preventive strategies, based on conditions, the Time-based Preventive Maintenance and corrective are research's candidates.

In 2011 Baba Esmaili and colleagues [6] using the strategic planning process and a fuzzy ANP2 method, a ranking for strategies of SWOT matrix in a tile company acquired and use these rankings to choose an optimal strategy. The strength of this study is to quantify the SWOT matrix components and taking into account the dependence between its components.

In 2012 Sadeghi and Alborzi Manesh [7] obtained the optimal strategy in Isfahan Mobarakeh Steel Company. In this paper, researchers at first formed a thirteen -member team of professors, professionals and industry experts and considering conditions of the industry on the one hand, selected safety, delivery, quality, cost and availability criteria. Each of these criteria, have some sub-criteria. Dependence between these criteria and sub- criteria has a great impact for the selection of optimal solutions. In the other hand, three strategies of World-class maintenance systems (WMS), Total productive maintenance (TPM) and Traditional maintenance (TM) was selected as a candidate. Finally, establishing a relationship between the properties of desired strategies and capabilities of the industry using fuzzy analytical network process (FANP), the model was developed and World-class maintenance systems was chosen as the optimal strategy.

Persona et al. drew charts of preventive replacement time and cost of preventive replacement by taking a new three-dimensional measurement called systemability. Reliability is considered in these graphs follow Weibull distribution with parameters γ and λ and environment criterion is modelled using Gamma distribution with parameters α and β.
With preventive replacement cost, emergency replacement cost, Weibull distribution parameters and Gamma distribution parameters, the optimal switching time and optimal preventive cost easily obtained from the graph [8].

Faccio and colleagues [9] presented a framework which focusing on two strategies of maintenance and based on failures maintenance (FBM[3]) and maintenance before and at the same time of failure (UBM[4]) investigated the optimal maintenance strategy. Technical managers using and decision diagrams and with high-speed, get the desired policy and change time. In this paper, a graph based on costs and considering the Weibull distribution as the reliability of the system was developed. This chart's surface using a curve is divided into two parts that if the point of optimality be in the bottom of the graph UBM strategy and if the optimality point be at the top of the graph
FBM strategy is selected as the optimal maintenance strategy.

3. The selection of optimal maintenance strategy

Implementation of the strategy in an organization requires a coordination of that strategy with the interests of its stakeholders. Selecting maintenance strategy is no exception. At each step the expert's opinions have utmost priority.
In maintenance strategy issues in one side strategies and on the other side criteria acceptable by experts are examined then the researchers creating different models trying to select optimal maintenance strategy. The following qualitative quantitative model of the study is described.

3.1 Modeling

This research by considering two criteria: the cost and availability that simultaneously influence of environment parameter is seen within and also using a multi-criteria decision making approach, trying to select optimal maintenance strategy with qualitative quantitative approach. Phases of this research are as follows:
The first phase is concerned with the analysis equipment, the most important system, known component or components. The main methods that can be used at this stage include: AHP, ANP and FMEA[5], quality model applied in this area.
In the second phase the data required to obtain the parameters of the model through databases and relevant forms can be obtained. Statistical Software such as MINITAB is among the most important tools in this process.

[1] Analytic hierarchy process
[2] Analytical Network Process
[3] failure-based maintenance
[4] use-based maintenance
[5] Failure Mode and Effects Analysis

The third phase is to decide on the choice of optimal maintenance strategy through qualitative quantitative model and then using switch, strategies shifts are examined.

3-2-The set of indices and parameters of the model

c_p	Preventive replacement cost
C_f	Emergency replacement or correction cost
R(NT)	System or component reliability
F(NT)	Cumulative distribution function for a syst
MTTR	Mean time to failure
α	Shape parameter of the gamma distributio
β	Scale parameter of the gamma distribution
γ	Shape parameter Weibull distribution
λ	Scale parameter Weibull distribution (so lifetime)

3-3- The decision variable

N = number of substitutions (substitutions at the N-th time)

3-4-Criteria Cost

Cost factor is always one of important factors affecting the choice of maintenance policy in organizations. Most maintenance researchers and engineers when considering maintenance policies looking for a policy to minimize this factor. Then the importance of considering this factor has been established as a major factor in organizations.

In Equation 1, if NT is change time based on the number of change period UEC (N) is change cost rate in the N -th change time. Equation 1 shows the maintenance cost of UBM mode [10].

$$UEC(N)=\frac{C_pR(NT)+C_f[1-R(NT)]}{\int_0^{NT} R(S)\,ds} \quad (1)$$

The numerator is equal to the total expected costs and denominator equals to the average distribution of reliability.

In the maintenance strategy be FBM, because the attribute of this strategy, the reliability goes to zero by placement of R (NT) = 0 in Equation 1, the maintenance cost of the relationship 2 is obtained.

$$UEC(NT=\infty)=\frac{C_f}{\int_0^{\infty} R(s)ds} \quad (2)$$

Availability

The probability that a certain outfit can do a certain work under the specified conditions in the particular moment, has been defined as accessibility. Equation 3 shows the availability based on the number of change periods [11].

$$A(N)=[1+\frac{T_fF(NT)+T_pR(NT)}{\int_0^{NT} R(s)ds}]^{-1} \quad (3)$$

Systemability

It is possible that a system can perform its tasks at a certain time in a random environment conditions [10].

Generally, the purpose isn't the environmental conditions such as temperature, pressure, etc., but it is about conditions effective on the operation of the system (in this study Factory Machinery). Conditions such as staffing, production methods, processes, materials used, etc., which are not considered in simple reliability estimate.

The relationship 4 shows system reliability that f(s) and h(s) are respectively the density function of failure and the failure rate.

$$R(t)=\int_t^{\infty} f(s)ds = e^{\int_0^t h(s)ds} \quad (4)$$

Given the above equation, the system reliability can be obtained by considering the circumstances of the equation 5. That ŋ is a random variable that shows the operating environment of the system (machinery) and follows the gamma distribution (G).

$$R_s(t)=\int_{\eta} e^{-\eta \int_0^t h(s)ds} dG(\eta) \quad (5)$$

The relationship 5shows a new function of the complex and random operating environment that is based on the failure rate function. If Assume ŋ is a gamma distribution with parameters α and β (~ γ (α, β) ŋ) ŋ density function is obtained using Equation 6.

$$f_{\eta}(x)=\frac{\beta^{\alpha}x^{\alpha-1}e^{-\beta x}}{\Gamma(\alpha)} \quad \text{for } \alpha,\beta>0;\ x\geq 0 \quad (6)$$

Finally, acquiring Laplace from the equation 6, the system reliability can be achieved by considering the environmental conditions that shown in Equation 7.

$$R_s(t)=\left[\frac{\beta}{\beta+\int_0^t h(s)ds}\right]^{\alpha} \quad (7)$$

The combination model of the two measures of cost and availability considering Systemability

$$C(N)=\frac{C_p+\left[\frac{\beta}{\beta+\lambda(NT)^{\gamma}}\right]^{\alpha}+C_f\times\left[1-\left(\frac{\beta}{\beta+\lambda(NT)^{\gamma}}\right)\right]}{\int_0^{NT}\left[\frac{\beta}{\beta+\lambda(s)^{\gamma}}\right]^{\alpha}ds} \quad (8)$$

$$A(N)=\frac{\int_0^{NT}R(s)ds}{\int_0^{NT}R(s)ds+T_f\left[1-\left(\frac{\beta}{\beta+\lambda(NT)^{\gamma}}\right)^{\alpha}\right]+T_p\left(\frac{\beta}{\beta+\lambda(NT)^{\gamma}}\right)} \quad (9)$$

$$Z(N)=w_1\frac{C(N)}{C^*(N)}-w_2\frac{A(N)}{A^*(N)} \quad (10)$$

First, the value of the relationship 10 for FBM and UBM strategies is obtained. Value of Z (N) for each of these strategies is less, the same as the optimal strategy is chosen. If FBM strategy is selected, the system works to be corrupted and then replace to be done but if UBM strategy is chosen, two basic questions arise:

1. When preventive replacement should be undertaken?
2. When the strategy should be changed?

By taking the derivative of the equation 10, the optimal time for preventive replacement is obtained. Based on the number of replacement cycles and some mmanagement considerations, the answer to the second question is obtained.

4. Case study

In this section to describe the model's function a numerical example is presented in an automobile parts factory.

Availability parameters (Day)		Cost parameters (Rials)	
T_p	T_f	C_f	C_p
0.0243	0.110727	687304	30500

Table 1: data of the real example

First, the costs of UBM and FBM strategies are compared. If FBM strategy be selected the device or system works to failure and finally change is done, but if UBM strategy is chosen two basic question arises:

- ✓ When is the preventive replacement time?
- ✓ When is the time to change strategies?

Table 1 and 2, Includes the information needed for one of the most sensitive machines of the factory.

Weibull distribution Parameters		gamma distribution Parameters	
γ	λ	α	β
0.7504	21.337	3.10	1.42

Table 2: data of the real example

Table 3 shows the results of performing of the model. Preventive replacement time is 137 days and time to change strategy is 200 days. This number is obtained from the difference between failure-based maintenance cost and use-based maintenance cost, in addition, management decisions are influenced.

Parameters	Measure
T	1
λ	0.07427
γ	0.80118
α	3.10
β	1.42
C_p	30500
C_f	687304
T_f	0.110727
T_p	0.024375
FBM	1.03
UBM	1.0426
Selection maintenance	UBM

Table 3: the results of performing of the model

5. Conclusion

Profitability and cost reduction in an organization is the most important thing for management to follow. One important aspects effective in the productivity and reducing manufacturing cost is technical management or the maintenance department. In various industries by selecting optimal maintenance strategies and closer to reality, in addition to increasing productivity, production costs are also reduced. In this study using a qualitative quantitative framework and taking into account the cost criterion, the optimal strategy is chosen between two maintenance policies of FBM and UBM. According to the calculations shown in Table 2, UBM strategy was chosen as the optimal strategy.

For future studies environmental conditions can be modelled in other forms performed, such as the beta distribution etc. or add a third strategy to the equation.

5. Biography

Naser Mollaverdi is an Assistant Professor, in the Department of Industrial Engineering at the Isfahan University of Technology, Isfahan, Iran. He earned B.S. in Industrial Engineering from Isfahan University of Technology, Iran, Masters in Industrial Engineering from Tarbiyat Modarres University, Iran, Tehran and PhD in Operations Research from Moscow State University M.V. Lomonosov. He has published journal and conference papers. Dr Naser has done some research projects at Isfahan, Yazd and Tehran. His research interests include optimization, manufacturing, simulation, reliability, maintenance and statistical quality control.

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