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Robust Design of Maintenance Scheduling Considering Engineering Insurance Using Genetic Algorithm

S. Molaei[*]**, K.M. Cyrus**
Department of Industrial Engineering Amirkabir University of Technology, Tehran, Iran.

A R T I C L E I N F O

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A B S T R A C T

Preventive maintenance is a broad term that encompasses a set of activities aimed at improving the overall reliability and availability of a system. Designers of the preventive maintenance schedules attempt to minimize the overall cost of system operation. There is no substitute for perfection in maintenance to ensure zero breakdowns in machine; therefore it is necessary to get a machinery breakdown insurance against the risks that might occur at business. Previous researches didn't consider the effect of engineering insurance on maintenance scheduling while it affect the cost function of maintenance scheduling seriously. Engineering insurance pays for all repair costs of machinery, therefore the cost function of maintenance scheduling is affected. This paper presents a new cost function for maintenance scheduling by considering the effects of engineering insurance. Due to the uncertainty in the cost parameters related to the cost function which are very common in application, the paper proposed the application of the scenario-based approach for robust design of maintenance scheduling. Then, genetic algorithm is developed for obtaining the optimal solution of the proposed robust model and the effectiveness of this model is illustrated through a numerical example.

1. Introduction

Maintenance Planning and Scheduling are key elements that influence the true success of any organization. Many times we have a planner or planner/scheduler, but do not know how to use him or her effectively or efficiently. When we talk about maintenance planning, we are talking about higher wrench time. At this time of economic uncertainty, a higher wrench time equals lower cost, which results in job security for all. The application of preventive maintenance scheduling has been widely used in manufacturing and production systems. Past studies have shown that most companies do not perform maintenance planning effectively thus impacting negatively work effectiveness, wrench time, equipment uptime, equipment reliability, and cost. If we were "Effective in Maintenance Planning", it would result in higher Wrench Time and higher Equipment Reliability. Preventive maintenance is defined as a set of activities aimed at improving the overall reliability and availability of a system. All

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[*] Corresponding author
E-mail address: molaei@aut.ac.ir

types of systems, from conveyors to cars to overhead cranes, have prescribed maintenance schedules set forth by the manufacturer that aim to reduce the risk of system failure. Preventive maintenance activities generally consist of inspection, cleaning, lubrication, adjustment, alignment, and/or replacement of subcomponents that wear-out. In general, preventive maintenance activities can be categorized in one of two ways, component maintenance or component replacement. It is clear that preventive maintenance involves a basic trade-off between the costs of conducting maintenance and replacement activities and the cost savings achieved by reducing the overall rate of occurrence of system failures. Designers of preventive maintenance schedules must prioritize these individual costs to minimize the overall cost of system operation. They may also be interested in maximizing the system reliability, subject to some sort of budget constraint. Many researches have been done to optimize maintenance scheduling economically. Reference [1] determines optimal cost of maintenance policies by defining the average cost rate of system operation, in this study it is assumed that an increasing failure rate is based on the Weibull distribution function. Reference [2] develops a model to minimize the total relating to preventive maintenance schedules. Exact algorithms reach exact optimal solutions of mathematical models, while approximation algorithms seek an approximation that is close to the true optimal solutions. Reference [3] presents a model that optimizes the preventive maintenance scheduling in semiconductor manufacturing operations. They optimize this model via a mixed-integer linear programming model. Reference [4] presents a preventive maintenance optimization model in order to minimize the total maintenance costs in a production system. Reference [5] determines an optimal preventive maintenance schedule by considering the time value of money in all future costs. Reference [6] defines the summation of maintenance activities cost along with cost of unsupplied demand due to failures of components in the objective function to optimize maintenance strategy. Reference [7] presents a model in order to optimize the maintenance policy for a component with random failure rate. Reference [8] presents an optimization model to schedule a preventive maintenance. He considers the total cost relating to operations as the objective function and solves the model using Bender's decomposition. Reference [9] present two mixed-integer linear programming models for preventive maintenance scheduling problems and use CPLEX to implement the optimization models for a case study of railway maintenance scheduling. Reference [10] develops an age based nonlinear optimization model to determine the optimal preventive maintenance schedule for a single component system. Reference [11] develop three nonlinear optimization models, one that minimizes total cost subject to satisfying a required reliability, one that maximizes reliability at a given budget, and one that minimizes the expected total cost including expected breakdown outages cost and maintenance cost.

Because of complexity of maintenance scheduling metaheuristic algorithms have been used in several researches ([12]). Reference [13] uses genetic algorithms with simulated annealing in order to optimize a large-scale and long-term preventive maintenance and replacement scheduling problem. Reference [14] uses an ant colony algorithm to optimize the maintenance scheduling. Reference [15] proposes several techniques to represent the decision variables in preventive maintenance scheduling models that use heuristics and metaheuristics optimization algorithms. Reference [16] use a genetic algorithm combined with simulated annealing to optimize maintenance scheduling. Reference [17] develops a novel multi-objective genetic algorithm in order to optimize preventive maintenance schedule problem.

In the area of application of preventive maintenance in manufacturing and production systems, many researchers are done. Reference [18] presents an application of combination of maintenance scheduling and job assignment in distribution systems. Reference [19] present an integrated preventive maintenance and inventory control simulation model for a production line with multi-component. Reference [20] presents an optimization model of integrated preventive maintenance planning and production scheduling for a single machine. Reference [21] present comprehensive research in area of integrating preventive maintenance and production scheduling.

Previous researches didn’t consider the cost due to engineering insurance while the engineering insurance in real application of industry is noticeable and in many cases it affects the decision making about the maintenance scheduling. Engineering insurance policy pays for all repair costs of machinery; therefore the cost function of maintenance scheduling is affected. So, it is necessary to rewrite the cost function by assuming the cost of maintenance which is compensated by engineering insurance. Also the previous researches optimized maintenance by considering only one scenario while it is possible that the machine faces with different scenarios. In addition we should be aware that under these conditions, the input parameters are not deterministic. This study revised the cost function of maintenance scheduling and optimized it under different scenarios for input parameters using genetic algorithm. The organization of the paper is as follows: In Section 2, engineering insurance is illustrated and in Section 3 the optimization models which minimize the total cost are presented. The structure of the robust design is demonstrated in section 4, in Section 5 the genetic algorithm is presented, the optimal variables are calculated in section 6 and finally, conclusions and the future researches are discussed in section 7.

2. Engineering Insurance

Engineering involves significant risk – for us, our business, our clients and the wider community. Building and engineering insurance cover the builder against any issues which can arise with a construction. This type of insurance also covers engineering equipment that can cost millions of dollars and liability against the work of contractors. Engineering insurance covers the cost of repair of those items of plant where there is an element of breakdown. Machinery Breakdown (MB) insurance offers protection against sudden and unforeseen physical loss or damage to machinery which has been erected and is operational or at rest. It is basically an accident insurance and cannot be construed as a "life insurance" for machines. This is because machines have only a limited life span due to wear and tear. Therefore, machinery owners must depreciate their machines annually and establish reserves for replacement. Warranties and service contracts are important but they don't cover many of the common causes of machinery breakdowns. Maintenance contracts cover routine service such as cleaning or adjustment, but they don't pay for damage due to operator error, the cause of over 35% of machinery breakdowns, but machinery breakdown insurance does. Warranties and maintenance contracts also don't pay for business interruption or income loss resulting from breakdown. They don’t pay for spoilage, damage to surrounding property or extra expenses to restore operations. Machinery Breakdown insurance can cover all these risks. The amount of premium paid is calculated basis the type of equipment insured and their capacity. Every different machinery type attracts a different premium rate.

3. Formulation

3.1.Notation

N: Number of components
T: Number of periods
J: Number of intervals
□i: Scale parameter of component i
βi: Shape parameter of component i
αi: Improving facter of component i when the preventive maintenance is done
Tri: Time required to replace component i
δi: Percent of premium which is paid when the component i is replaced
τi: Percent of maintenance cost which is compensated by engineering insurance when the component i is maintained.
Fi: Unexpected failure cost of component i
Mi: Maintenance cost of component i
Ri: Replacement cost of component i
xij: Effective age of component i at the start of period j
yij: Effective age of component i at the end of period j
mij=1 if component i at the start of period j is maintained otherwise mij=0
rij=1 if component i at the start of period j is replaced otherwise rij=0
$N_{i,j}$: Number of failures of component i in period j
$f_i(t)$: Probability distribution function (PDF) of component failures
Fij: Total cost due to failure of component i in period j
P_i: Premium of component i
R_{ij}: Cost due to replacement of component i in period j
M_{ij}: Cost due to maintenance of component i in period j
Z: Fixed cost of system

The interval [0, T] is segmented into J discrete intervals, each of length T/J. At the end of period j, the system is either, maintained, replaced, or no action is taken. If the maintenance activity occurs at the end of the period for component i, the effective age of it at start of next period is as follow:

$$x_{i,j+1} = \alpha y_{i,j}$$

$$0 \leq \alpha \leq 1 \qquad (1)$$

When α=0 the component seems replaced, also following equation is true:

$$x_{i,j+1} = \alpha_i y_{i,j} = x_{i,j} + r_{ij}T_{r,i} + \frac{T}{J}$$

(2)

To option the cost function of maintenance scheduling we categorized related costs as follow:

i) Unexpected failure cost: we must account for the inevitable costs due to unplanned component failures, therefor we compute the expected number of failures of component i in period j, as:

$$E\left(N_{i,j}\right) = \int_{x_{i,j}}^{y_{i,j}} f_i(t)dt$$

$$f_i(t) = \lambda_i \beta_i t^{\beta_i - 1} \qquad t \geq 0 \tag{3}$$

Therefore the total cost of failures attributable to component i in period j is as follow:

$$F_{ij} = F_i E\left(N_{i,j}\right) \tag{4}$$

ii) Replacement cost: we assume that the replacement cost is the initial purchase price of the component. If we replace component i in period j, the related cost is as follow:

$$R_{ij} = r_{ij}R_i + \delta_i P_i \tag{5}$$

iii) Maintenance cost: if we maintain component i in period j, the related cost is as follow:

$$M_{ij} = m_{ij}M_i(1 - \tau_i) \tag{6}$$

$(1 - \tau_i)$ Represent the percentage of maintenance cost which the owner must be pay.

iv) Fixed cost: a fixed cost of downtime equal to Z be charged in period j if any component (one or more) is maintained or replaced in that period.

3.2.Cost function

Summation the previous costs results the final cost function

$$C = \sum_{i=1}^{N}\sum_{j=1}^{T}\left[F_{ij} + R_{ij} + M_{ij}\right] + \sum_{j=1}^{N}[Z(1 - \prod_{i=1}^{N}(1 - m_{ij} - r_{ij}))]$$

$$C = \sum_{i=1}^{N}\sum_{j=1}^{T}\left[(F_i \int_{x_{i,j}}^{y_{i,j}} \lambda_i \beta_i t^{\beta_i - 1} dt) + r_{ij}R_i + \delta_i P_i + m_{ij}M_i\right] + \sum_{j=1}^{N}[Z(1 - \prod_{i=1}^{N}(1 - m_{ij} - r_{ij}))] \tag{7}$$

The purpose is to optimize a schedule of future maintenance and replacement actions for each component over the period [0, T].

4. Robust Optimization

Imprecision in the input parameters is one of the reasons for lack of confidence in the economically designed of maintenance variables. This shows the necessity of robust design procedures for maintenance scheduling. In this respect considering the impreciseness in estimating the parameters will reduce the cost of the operation. Specifically the maintenance and replacement costs are not deterministic; also the premium and other parameters of engineering insurance may have been under different scenarios. Robust economic designs aim at reducing the monetary losses occurring as a result of departure of the model from basic assumptions. The non-availability of precise estimates of cost and process parameters for use in the cost function indicates the need for robust designs in maintenance scheduling. Some robust optimization methods such as simple weighting method considering the probability of occurrence, regret value and min-max regret model are the most significant among others. One of the robust optimization approaches is scenario-based approach in which cost parameters are defined by different scenarios. The scenario defines as a set of model parameters that can be realized in the production environment. When there is more than one scenario, maintenance scheduling should not be designed for one particular scenario. Since maintenance plan which is designed for one scenario may results in higher costs when the other scenario is realized. The optimum maintenance scheduling is to be obtained in such a manner that the cost of operating the process with all possible scenarios is minimized. Reference [22] proposed a framework for robust discrete optimization, which seeks to find a solution that minimizes the worst case performance under a set of scenarios for the data.

Three different designs have been suggested based on the following discrete optimization measures:

a. Absolute robustness: The absolute robustness criterion is explained as a measure that selects the design that minimizes the objective across all scenarios.

b. Robust deviation: The robust deviation is explained as a measure that selects the design that has the smallest deviation from the best possible performance for each scenario.

c. Relative robustness: Relative robustness is explained as a measure that selects the design that has the smallest percentage deviation from the best possible performance for each scenario.

4.1.Robust optimization approach

Minimize C

Subject to:

$$m_{ij} + r_{ij} \leq 1$$

$$x_{ij} \text{ and } y_{ij} \text{ must be positive}$$

$$\lambda_i\ \beta_i\ \alpha_i\ \tau_i\ \delta_i \text{ are belong to different scenario} \quad (8)$$

5. Genetic Algorithm

One of algorithms to solve the cost function of maintenance scheduling is genetic algorithm (GA). GA algorithm is a global search and optimization tool in biological system ([23]). The algorithm is based on Darwin's evolutionary theory and has been structured by [24].This algorithm is different from the other optimization tools because it considers many points in a search space simultaneously and works directly with a set of parameters characterized as strings of chromosomes instead of parameters themselves. In addition, it uses the probabilistic rules for the search of solutions. Because of the complexity of the cost function in the maintenance scheduling model, the GA algorithm is more suitable than exact algorithms and can lead to better results in comparison with the classical optimization tools.

The GA used in this paper is explained as follows:

Step1. Twelve initial solutions (chromosome) are generated.

Step2. Fitness function value for each answer can be computed by equation (7).
Step3. After selecting chromosomes with high fitness function (parent), the crossover operator is applied to the parent chromosomes as follows:

$$D_1 = 0.4R + 0.6M$$
$$D_2 = 0.6R + 0.4M \tag{9}$$

Where D_1 and D_2 are new chromosomes after crossover operator on the parent chromosomes R and M.
Step4. Operator mutation with rate of 0.1 will work on population; to do this we use a non-uniform method.
Step5. After repeating steps 2 to 4 for 100 times (Generation) we stop the algorithm.

6. Results

Results are shown in Table 1, 2 and 3.

Table1. Optimal values of variables under first scenario

component	λ_i	β_i	α_i	τ_i	δ_i	**Failure cost**	**Maintenance cost**	**Replacement cost**
1	0.000348	2.4	0.787401	0.8	0.1	200	30	210
2	0.000387	2	0.761577	0.8	0.1	190	27	220
3	0.000395	2.1	0.74162	0.8	0.1	220	60	255
4	0.000384	1.8	0.707107	0.8	0.1	160	37	190
5	0.000379	1.5	0.69282	0.8	0.1	170	45	215
6	0.000367	2.2	0.806226	0.8	0.1	230	33	245
7	0.000322	2.5	0.866025	0.8	0.1	150	40	185
8	0.00031	1.6	0.824621	0.8	0.1	235	25	225
9	0.000358	1.7	0.72111	0.8	0.1	225	44	220
10	0.000341	2.3	0.818535	0.8	0.1	205	50	260

Table2. Optimal values of variables under second scenario

component	λ_i	β_i	α_i	τ_i	δ_i	**Failure cost**	**Maintenance cost**	**Replacement cost**
1	0.000274	2.6	0.687356	0.7	0.15	181	39	231
2	0.000294	2	0.672684	0.7	0.15	172	35.1	242
3	0.000297	2.15	0.661174	0.7	0.15	200	78	280.5
4	0.000292	1.7	0.640896	0.7	0.15	145	48.1	209
5	0.000289	1.25	0.632358	0.7	0.15	154	58.5	236.5
6	0.000284	2.3	0.697901	0.7	0.15	210	42.9	269.5
7	0.000261	2.75	0.730605	0.7	0.15	137	52	203.5
8	0.000255	1.4	0.708087	0.7	0.15	213	32.5	247.5
9	0.000279	1.55	0.649182	0.7	0.15	205	57.2	242
10	0.000271	2.45	0.704729	0.7	0.15	187	65	286

Table3. Optimal values of variables under third scenario

component	λ_i	β_i	α_i	τ_i	δ_i	Failure cost	Maintenance cost	Replacement cost
1	0.000316	3.8	0.687356	0.8	0.2	315	30	277
2	0.000339	3	0.672684	0.8	0.2	330	24	290
3	0.000343	3.2	0.661174	0.8	0.2	382.5	90	336
4	0.000337	2.6	0.640896	0.8	0.2	285	44	250
5	0.000334	2	0.632358	0.8	0.2	322.5	60	283
6	0.000327	3.4	0.697901	0.8	0.2	367.5	36	323
7	0.000301	4	0.730605	0.8	0.2	277.5	50	244
8	0.000294	2.2	0.708087	0.8	0.2	337.5	20	297
9	0.000322	2.4	0.649182	0.8	0.2	330	58	290
10	0.000312	3.6	0.704729	0.8	0.2	390	70	343

7. Conclusions

In this research, the cost function of maintenance scheduling is revised and a part of cost due to maintenance and replacement is compensated by machinery breakdown insurance. After that, we solved a numerical example in which the cost parameters are considered not deterministic, therefore; a robust model of maintenance is proposed. To compute the optimal results, a genetic algorithm is developed. Finally the effect of machinery breakdown insurance is investigated on structure of the optimal preventive maintenance and replacement scheduling. Results show that the Machinery Breakdown insurance affects the optimal maintenance scheduling seriously.

In future researches we can utilize this approach when the reliability of plant should be taken into account and solve the model using another optimization method. Also we can consider the time value of money in all future costs and revise the cost function.

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