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Research Paper

MAINTENANCE COST OPTIMIZATION FOR THE PROCESS INDUSTRY

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Proper maintenance of plant equipment can significantly reduce the overall operating cost, while boosting the productivity of the plant. Therefore Maintenance planning is carried out in a area where the frequent failure occurs. The raw mill section is chosen due to its critical failure nature. The various subsystems of the raw mill system are: air slide, conveyor assembly, impact crusher, separator, elevator and gear assembly. The objective is to determine the optimal maintenance policy by means of Analytical Hierarchy Process (AHP) and it is combined with Goal Programming (GP) to minimize the total maintenance cost.

Keywords: Optimization, Maintenance, Reliability, Priority, Goals

INTRODUCTION

Maintenance activities are those use resources in physically performing those action and tasks attendant on the equipment maintenance functions for test, servicing, repair calibration, overhaul, and modification so on. It can be performed on an individual machine or entire group of machines simultaneously. Realizing the need for continuous improvement most companies have initiated the focused program covering various aspects of maintenance. The need for the hour is to offset the continual increase in input cost through optimized maintenance operations.

Optimization is an effective tool for improving the effectiveness of the system and hence, the cost will be reduced. Proper maintenance of plant equipment can significantly reduce the overall operating cost, while boosting the productivity of the plant. Management personnel often consider plant maintenance an expense, yet a more positive approach is to view maintenance work as a profit centre. In consideration of this new perspective, the requirements for maintenance management have change drastically from the old concept of ‘fix-it-when-broken’ to a more complex approach, which entails adopting a maintenance strategy for a more integrated

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approach and alignment. Furthermore, the high level of complexity of today's industrial plants requires an elevated level of availability and reliability of such systems. The development of new technologies and managerial practices means that maintenance staff must be endowed with growing technical and managerial skills.

The Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a structured technique for dealing with complex decisions. Rather than prescribing a "correct" decision, the AHP helps the decision makers find the one that best suits their needs and their understanding of the problem.

The AHP provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions.

Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analysed independently. The elements of the hierarchy can relate to any aspect of the decision problem tangible or intangible, carefully measured or roughly estimated, well- or poorly-understood anything at all that applies to the decision at hand.

Once the hierarchy is built, the decision makers systematically evaluate its various elements by comparing them to one another two at a time. In making the comparisons, the decision makers can use concrete data about the elements, or they can use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations.

The AHP-GP model for maintenance policy selection the combined AHP-GP model embodies AHP results in the GP model. In particular, in the model described here the AHP analysis provides the priority vector of the possible maintenance Policies (corrective, preventive and predictive) for each failure type revealed.

The use of AHP allows defining a three level hierarchical structure: the top level represents the goal of the analysis (in this case the maintenance policy definition), the second level is relative to the relevant criteria used (maintenance time, replacement period), and the third one defines the possible alternatives.

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The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. This capability distinguishes the AHP from other decision making techniques.

LITERATURE REVIEW

Naikan (1995) discusses the relationship between plant availability and maintenance expenditure and their limiting features. Achieving higher plant availability always necessitates a higher maintenance budget and may not be economically feasible in many cases. Through a mathematical modelling the variation of net income with respect to plant availability has been studied and the limiting availability values have been established. Expressions for optimum availability and maintenance cost have also been obtained. An illustrative example has been worked out.

Sun (2010) Tools used in a machining process are vulnerable to frequent wear-outs and failures during their useful life. Maintenance is thus considered essential under such conditions. Additionally, it is widely recognized that the maintenance of manufacturing equipments and the quality of manufactured product are highly interrelated. However, few detailed study has been found in the literature dealing with the effects of maintenance policies on the operational performance of such a system, especially the long-term average cost. The need for a method to determine the optimal tool maintenance policy has become increasingly important. Since the multiple tools in a multi-station machining system generally have significant interactive impacts on the product quality loss, the optimal multi-component maintenance models for several policies are investigated to address the interdependence among these tools. Three distinctive multi-component maintenance policies, i.e., age replacement, block replacement, and block replacement with minimal repair, are identified and analysed. The proposed approach focuses on these maintenance policies with consideration of both component catastrophic failures, and the interdependence of component degradations on the product quality loss as well as the obsolescence cost. The effects of various maintenance policies on the system performance are simulated, and they are used to determine the best policy for a given system.The results presented a comparative analysis of specified maintenance policies with respect to the total maintenance cost with consideration of the product quality loss and the obsolescence cost.

Adriaan (2002) proposed due to widespread automation and the high capital tied up in production equipment, the importance of maintenance is ever-increasing. This makes maintenance an investment opportunity to be optimized, not a cost to be minimized. Academics have recognized this and many maintenance optimization models have been published over the years. Most of these models focus on one optimization criterion or objective, making multi-objective optimization models an under explored area of maintenance optimization. Moreover, there is a big gap between academic models and application in practice. It is very difficult for industrial companies to adapt these models to their specific business context. This paper reviews the literature on maintenance optimization models, with special focus on the optimization criteria and objectives used. To overcome flaws in present optimization models, a generic survey of maintenance optimization models is presented. All factors that have an influence on the optimization model will be made explicit and their links will be established.

Ilangkumaran (1994), the purpose of this paper is to focus on the use of Analytic Hierarchy Process (AHP) under fuzzy environment and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to select an optimum maintenance strategy for a textile industry. First by using improved AHP with fuzzy set theory, the weight of each criterion is calculated to overcome the criticism of unbalanced scale of judgments, uncertainty, and imprecision in the pair-wise comparison process. Then this paper introduces a model that integrates improved fuzzy AHP with TOPSIS algorithm to support maintenance strategy selection decisions. An efficient pair-wise comparison process and ranking of alternatives can be achieved for maintenance strategy selection through the integration of AHP with fuzzy set theory and TOPSIS.

Jianrong (2001) concluded maintaining the reliability of aircraft engines in an acceptable level requires an optimal maintenance strategy and planning for each entity in the network. This paper proposes an Analytic Hierarchy Process (AHP) and Genetic Algorithm (GA) hybrid model to deal with the maintenance scheduling problem of aircraft engine, which is an optimization problem formulated with respect to multiple objectives and soft constraints. GA, using an integer representation, is applied to obtain the best solution resulting in a minimal value of maintenance costs and time and maximal value of available cycles after maintenance in the analysed period. AHP handles the decision-maker's attitude toward preferences of the multiple objectives. The proposed method was tested using a maintenance company data for PW4077D engines and the obtained results show the feasibility and effectiveness of the approach for engine maintenance scheduling applications.

Srividya (2005) gives A fuzzy version of prioritization from among several alternatives under different decision criteria of Saaty's pair wise comparison method is presented in this paper. Each ratio expressing the relative significance of a pair of factors is displayed in a matrix from which suitable weights can be extracted. Since these ratios are essentially fuzzy, they express the opinion of a decision-maker on the importance of a pair of factors. This method is used in such a way that information from experts, who are asked to express their opinions in fuzzy numbers with triangular membership functions, is embedded in it. The method is applied at two levels: beginning with the finding of fuzzy weights for the decision criteria, followed by finding the fuzzy weights for the alternatives under each of the decision criteria. Fuzzy scores for the alternatives are obtained. Using the fuzzy scores, experts will be able to prioritize the alternatives for maintenance activities based on the listed criteria. The method is illustrated for outlet feeders in a nuclear power plant with representative values.

METHEDOLOGY

Steps involved in AHP

- The AHP converts the evaluations to numerical values that can be processed and compared over the entire range of the problem.
- A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable

elements to be compared to one another in a rational and consistent way.

- This capability distinguishes the AHP from other decision making techniques.
- In the final step of the process, numerical priorities are calculated for each of the decision alternatives.
- These numbers represent the alternatives' relative ability to achieve the decision goal, so they allow a straightforward consideration of the various courses of action.

Scoring of the Equipments

The values of the previous matrix is obtained by the earlier method, now by using the formula we are going to obtain the weight age for the each and every equipment in which the maintenance schedule should be framed to minimize the maintenance cost.

$$s = \sum_{j=1}^{m} (r * w)$$

where as;

r = Rating factor;

w = Weightage factor;

The different priority levels reflect the hierarchical relationship between the targets in the objective function where they are arranged in order of decreasing priority ($P1 > P2 > Pm$).

Goal Programming

Goal programming is a well-known modification and extension of linear programming, however it allows for multiple goals to be satisfied at the same time. Allows for the multiple goals to be prioritized and weighted to account for the DM's utility for meeting the various goals.

Components of GP

- Goal constraints
- Variable
- Concerned with target values
- Can be changed/modified
- Example desire to achieve a certain level of profit.

Objective Function

- Minimizes the sum of the weighted deviations from the target values—this is ALWAYS the objective for Goal Programming.
- Not the same as LP (which was maximize revenue/minimize costs).

Goal Programming Terms

Decision Variables are the same as those in LP formulations (represent products, hours worked).

Deviational Variables represent overachieving or underachieving the desired level of each goal:

- d+ Represents overachieving level of the goal.
- d– Represents underachieving level of the goal.

Economic Constraints

- Stated as <=, >=, or =.
- Linear (stated in terms of decision variables).

Goal Constraints

- General form of goal constraint:

– d + + d – = These are the upper deviation and lower deviation.

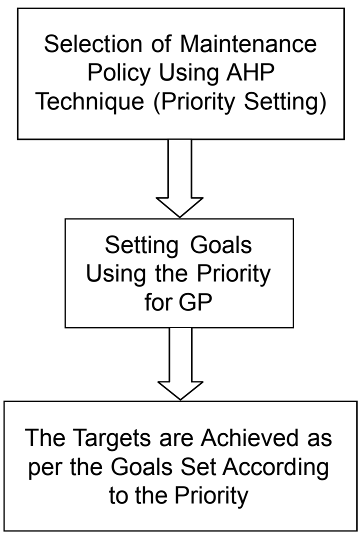
Linear programming deals with only one single objective to be minimized or maximized, and subject to some constraint; it, therefore, has limitations in solving a problem with multiple objectives. Goal programming, instead, can be used as an effective approach to handle a decision concerning multiple and conflicting goals. Also, the objective function of a goal programming model may consist in non-homogeneous units of measure. In particular, it has been successfully used to solve several Multi Criteria Decision (MCD) problems, such as the design of a quality control procedure in service organizations; the selection of the optimal set of service quality control instruments; regarding information system selection and the identification and development in the mathematical model for information system project selection in health service institutions; and, finally, to help the facility planning authorities to formulate viable location strategies in the volatile and complex global decision environment.

The different goal programming models available to assess MCD problems include the non-linear and linear GP with Archimedean weights (i.e., weighted GP), the Interactive Weighted Tchebycheff Procedure (IWT), the MINMAX (Chebyshev) GP, the Reference Point Method (RPM), the Compromise Programming (CP), and the Lexicographic Linear GP.

Lexicographic goal programming is actually one of the most significant devices in tackling MCD problems: the different goals can be ranked according to different priority Levels that reflect the target allocated to them by the decision maker. The lexicographic approach defines different priority levels *Pj* for the goals of the analysis. The different priority levels reflect the hierarchical relationship between the targets in the objective function where they are arranged in order of decreasing priority ($P1 < P2 < Pm$).

In order to identify the solution to the problem, the highest priority goals and constraints are considered first; if more than one solution is found in the first step, another goal programming problem is formulated which takes into account the second priority level targets. The procedure is repeated until a unique solution is found, gradually considering Decreasing priority levels. The lexicographic optimization can then avoid the estimate of the different deviation weights, but the results of the analysis may be biased by the analyst's personal opinion. The objective function reported in shows that the goal of the problem consists in the minimization of the unwanted deviations from the target.

Figure 1: The AHP-GP Model for Maintenance Policy Selection



Various terms used in the goal programming are as follows;

- d^-_j the negative deviation from the value desired or constrained, of the j^{th} objective;
- d^+_j the positive deviation from the value desired or constrained, of the j^{th} objective;
- P_j factors reflect the problem hierarchy (i.e., $P1$ represent the highest level, $P2$ the second priority level, and so on);
- B_j the objective target of the j^{th} resource;
- a_{ji} the usage of j^{th} resource of every possible alternative i^{th} decision;
- x_i the alternative i^{th} decision (i.e., xCORR is the corrective maintenance policy);
- w_k the weights of the k^{th} criteria (i.e., w_k is the weights of occurrence criteria);
- C_{CORR} the cost for the corrective policy;
- C_{PREV} the cost for the preventive policy;
- C_{ABP} the cost for the predictive policy;
- MT_{CORR} the maintenance time for the corrective policy;
- MT_{PREV} the maintenance time for the preventive policy;
- MT_{COND} the maintenance time for the predictive policy;
- TC the availability of the maintenance budget resources;
- PMT the availability of the maintenance time resources;
- dk–; dk+ the deviations from the target for each criterion (i.e., dc–; dc+ are the negative and positive deviations for the maintenance cost, dmt–; dmt+ are the negative and positive deviations for the maintenance time);
- MT_{CORR} the overall corrective maintenance time;
- MT_{PREV} the overall preventive maintenance time;
- MT_{COND} the overall predictive maintenance time;
- $T_{FAILURE}$ the single item repair time (T_{PREV} is the item;
- Repair time in preventive policy and T_{ABP} is the item repair time in predictive policy);
- $N_{FAILURE}$ the expected number of failures of the item during the observation period (N_{PREV} is the number of programmed interventions in preventive maintenance;
- N_{abp} is the number of programmed interventions in age based maintenance.

As per the priority we constructed the GP model will be as follows:

The objective function of the GP in the general form is as follows

$$\text{Min}z = P1(dr+) + P2(dc+) + P3(dmt+)$$

The objective function aims at minimizing the sum of the deviations associated to each.

Specified goal, taking into account only the unwanted deviations.

Subjected to the constraints,

$$C_{corr}X_{corr} + C_{prev}X_{prev} + C_{abp}X_{abp} + dc^- - dc^+ \leq TC$$

$$MT_{corr}X_{corr} + MT_{prev}X_{prev} + MT_{abp}X_{abp} + dmt^- - dmt^+ \leq TMT$$

$$RP_{corr}X_{corr} + RP_{prev}X_{prev} + RP_{abp}X_{abp} + drp^- - drp^+ \leq TRP$$

The estimate of the preventive and corrective maintenance times for the failure types considered for raw mill.

$MT_{corr} = T_{failure} * N_{failure}$

Where MT_{corr}, $T_{failure}$, $N_{failure}$ are the overall corrective maintenance time, the single item repair time and the expected number of failures of the item during the observation period. As far as preventive maintenance policy is considered, the Number of programmed interventions was hypothesized as equal to the mean number of failures increased by one and the maintenance time was determined as a fixed percentage as α = 70% of the corresponding corrective maintenance time, as:

Shown in Equation

$MT_{PREV} = T_{PREV} * N_{PREV}$;

$T_{PREV} = T_{FAILURE} * \alpha$;

$N_{PREV} = N_{FAILURE} + 1$

For a age based replacement maintenance we suppose that:

$MT_{ABP} = T_{ABP} * N_{ABP}$;

$T_{ABP} = T_{FAILURE} * \alpha$;

$N_{ABP} = N_{FAILURE}$;

In the final step of the process, numerical priorities are calculated for each of the decision alternatives. These numbers represent the alternatives' relative ability to achieve the decision goal, so they allow a straightforward consideration of the various courses of action. The AHP-GP model for maintenance policy selection and the combined AHP-GP model embodies AHP results in the GP model. In particular, in the model described here the AHP analysis provides the priority vector of the possible maintenance Policies (corrective, preventive and predictive) for each failure type revealed.

The use of AHP allows defining a three level hierarchical structure: the top level represents the goal of the analysis (in this case the maintenance policy definition), the second level is relative to the relevant criteria used (occurrence, severity and detect ability), the third one defines the possible alternatives. AHP for multi criteria decision making, mainly based on the lack of a strong normative foundation.

The results of AHP are as follows and their priorities in decreasing order

From the Table 1 the priorities has been ranked in the decreasing order so it comes the first priority is age based replacement policy ,then it comes preventive maintenance policy, finally it comes the corrective maintenance policy.

Table 1: AHP Results

Ranking	Terms	Prioririty Values
1.	Age based replacement policy	0.30722
2.	Preventive maintenance policy	0.30573
3.	Corrective maintenance policy	0.30124

In order to identify the solution to the problem, the highest priority goals and constraints are considered first; if more than one solution is found in the first step, another goal programming problem is formulated which takes into account the second priority level targets. The procedure is repeated until a unique solution is found, gradually considering Decreasing priority levels. By using the lexicographic optimization the different deviation weights has been avoided, but the results of the analysis may be biased by the analyst's personal opinion. The objective function reported in shows that the goal of the problem consists in the minimization of the unwanted deviations from the target has been achieved.

As per the data's obtained the goal programming is formulated with the objective function and constraints as per the priority results obtained from the AHP the formulations are as follows,

The objective function is,

$\text{Min}z = P1(dr+) + P2(dc+) + P3(dmt+)$

Subjected to the constraints,

$20000X_{corr} + 206X_{prev} + 228X_{abp} + dc^{-} - dc^{+} \leq 100000;$

$280X_{corr} + 206X_{prev} + 228X_{abp} + dmt^{-} - dmt^{+} \leq 614;$

$156X_{corr} + 56X_{prev} + 70X_{abp} + drp^{-} - drp^{+} \leq 300;$

The results of the above formulation are presented in Table 2,

Table 2: Goal Programming Results

S. No.	Terms	Values
1.	XABP	1.22
2.	Xcorr	1.42
3.	dc+	134
4.	dmt+	165

CONCLUSION

The application of the GP technique combined with AHP methodology proved to be a flexible tool to optimally select different maintenance strategies, a feature that is particularly important in situations where the decision maker can choose between different objectives subject to several constraint conditions. The method here presented can provide a framework to guide future investigations. In particular, in future works other kinds of goals and/or constraints could be potentially considered and added to the original model proposed. In this paper, the GP model is applied and the objective function reported that the goal of the problem consists of the minimization of the unwanted deviations from the target. The deviations analyzed in this work are the total maintenance cost, maintenance time, replacement period. The usage of AHP provides priority in selecting the various maintenance policies and by linking this with GP various goals has been achieved. In future the work can be extended by including manpower planning, repair time, minimization, and the inventory cost minimization can also be carried out.

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