CHAPTER 6

MAINTENANCE STRATEGY SELECTION USING AHP-TOPSIS-LP MODEL

6.1 INTRODUCTION

The development of AHP-TOPSIS integrated with Linear Programming (LP) model for selection of maintenance strategy is detailed in this chapter. The problem description is presented in section 6.2. The hierarchical structure development using AHP procedure and formulation of objective function from closeness coefficient of alternatives are detailed in section 6.3. The software development for the application of proposed AHP-TOPSIS-LP model as an integrated tool is detailed in section 6.4. The proposed model is exemplified with a case study from tea industry and is detailed. The summary of the chapter is presented in section 6.5.

6.2 PROBLEM DESCRIPTION

In a maintenance strategy decision making problem, there are ‘A’ maintenance strategy alternatives, ‘C’ evaluation criteria and ‘J’ number of resource limitations. The alternatives are denoted as ‘Ai’ (for \(i = 1, 2, 3\ldots, M\)), criteria as \(C_j\) (for \(j = 1, 2, 3\ldots, N\)) and resource limitations \(J_k\) (for \(k = 1, 2, 3\ldots, M\)). The ‘A1’ denotes predictive maintenance strategy similarly the \(A_2\), \(A_3\) and \(A_4\) denote Condition-Based Maintenance, Time-Based Maintenance and Corrective Maintenance respectively. The ‘C1’ denotes the influencing criterion ‘safety’. Similarly \(C_2\), \(C_3\) and \(C_4\) represented ‘Equipment’, ‘Value Added’ and ‘Feasibility’ respectively for maintenance
strategy evaluation. The $J_1$ denotes ‘Production Capacity (PC)’, similarly $J_2$, $J_3$, $J_4$ and $J_5$ represent ‘Depreciation (D)’, ‘Spare Part Cost (SPC)’, ‘Break Down Cost (BDC)’ and ‘Wages of labours (W)’ respectively. The problem is to determine the best maintenance strategy and the optimal maintenance cost.

### 6.3 AHP-TOPSIS AND LP

The proposed AHP-TOPSIS integrated with LP procedure for solving MSS is shown in Figure 6.1. The steps of proposed model for the MSS identify the criteria, weights by AHP procedure, closeness coefficients of maintenance alternatives using TOPSIS procedure and evaluation of alternatives with linear programming. The influencing criteria on maintenance strategy have been analyzed and fixed by the experts from the industry through questionnaire. The weight of the criterion is computed through the pair-wise comparison. Decision matrix of TOPSIS is constructed using weights of alternatives. The procedural steps to calculate the closeness coefficient of maintenance alternatives are explained as section 4.3 of chapter 4. The linear programming model is built from closeness coefficients derived from the TOPSIS procedure to find the best maintenance strategy and its optimum maintenance cost.

The LP model is constructed as below:

**Notations:**

- $CC_i$ - Closeness coefficient of each maintenance strategy
- $D_i$ - Depreciation value of $i^{th}$ maintenance strategy
- $S_i$ - Spare parts cost of $i^{th}$ maintenance strategy
- $BD_i$ - Break down cost of $i^{th}$ maintenance strategy
- $x_i$ - Maintenance cost for $i^{th}$ maintenance strategy
- $w_i$ - wages of $i^{th}$ maintenance strategy
Min (Maintenance cost) = \sum_{i=1}^{n} CC_i X_i \quad \text{(Objective function)}

Figure 6.1 Proposed AHP-TOSIS integrated with LP model for MSS
Subject to:

\[ \sum_{i=1}^{n} X_i \geq PC \]  
(Production Capacity constraint)

\[ X_i \geq D_i \]  
(Depreciation value constraint associated with cost)

\[ X_i \geq S_i \]  
(Spare part constraint associated with cost)

\[ X_i \geq 0_{i=1,2,...,n} \]  
(Non-negativity constraint)

\[ \sum_{i=1}^{n} X_i Bd_i \geq BD \]  
(Break down constraint associated cost)

\[ \sum_{i=1}^{n} X_i w_i \geq w \]  
(Wages constraint for labors)

### 6.4 SOFTWARE DEVELOPMENT

As the number of criteria increase, the dimension of the problem expands. This could lead to a number of mathematical operations. Therefore, the aid of software may be very useful to automatically carry out the proposed model computation. Software Computer Aided MCDM Tool (CAMCDMT) was developed using VisualBasic (VB) 6.0. This system helps in computation of AHP, TOPSIS and VIKOR procedures. The user can make use of the stand alone models such as AHP, TOPSIS and VIKOR or the hybrid models such as AHP-TOPSSIS and AHP-VIKOR. The operation sequence is based on the sequence of the steps shown as in the section 3.3 of chapter 3, section 4.3 of chapter 4 and section 5.2 of chapter 5. Initially, the user must select the required MCDM tool for the evaluation process. The snapshot of the main screen is shown in Figure 6.2. The user input the selected evaluation criteria and maintenance strategy alternatives. The software access a database about criterion and maintenance alternatives to perform the comparison analysis.
The required evaluation criterion and alternatives are fed by the user. The snapshot of input for criterion is shown in Figure 6.3.

**Figure 6.2** Main screen of the proposed CAMCDMT software

**Figure 6.3** Snapshot of input for criterion in CAMCDMT
Next, the user has to fill in the pair-wise comparison matrix for the criteria. Once the comparison matrix is entirely filled with important values, the system provides the eigenvector, eigenvalue and consistency ratio. If total consistency is proved, the system will provide the ranking of the criterion according to the information input by the user. The user must input the pair-wise comparisons between two specific maintenance alternatives. This task is made according to each of the considered criterion (Figure 6.4). In the final screen of the system, the results of global weights and the best ranking are shown in Figure 6.5. The user can integrate the results of AHP with TOPSIS or VIKOR.

Figure 6.4  Comparison matrix of maintenance strategy for each one of the criteria developed in CAMCDMT
The company wishes to adopt a suitable maintenance strategy with resource limitations in order to increase the productivity. The company has installed a unit having the capacity of 10,000 kg tea leaf processing per day. The leaf has to undergo several phases such as weathering, crushing, CTC (Cut, Tear and Curl), fermenting, drying, shifting, and pulverizing before it is completely made as a fine tea dust powder. The tea manufacturers decide to chose the best maintenance strategy with resource limitations such as breakdown cost, maintenance cost and spare parts cost. The proposed AHP-TOPSIS integrated with linear programming model is described as follows using software development. The hierarchical structure of the problem is established and shown in Figure 6.6.

The AHP is selected for computation of criteria weights and maintenance alternatives. The user has to enter the number of main criteria and their name. The snapshot of evaluation criterion is shown in Figure 6.7. In
the next stage of developed software, the user has to enter the number of subcriteria for each main criterion. Here, the number of subcriteria is taken as zero. The proposed model is validated through functionality and usefulness. The functionality of the model is tested through the validation of data and comparison of results with judgment of experts.

Figure 6.6 Hierarchical structure of MSSP for AHP-TOPSIS-LP

Figure 6.7 Number of main criteria for the evaluation in CAMCDMT
In the next stage, the user input the number of alternatives and their names. Figure 6.8 shows the number of alternatives and their name.

![Image of alternatives input screen]

**Figure 6.8 Maintenance alternatives for the selection process in CAMCDMT**

The next step of the developed software shows the pair-wise comparison matrix of main criterion. The decision maker completes the matrix using satty nine point scales. The priority weights, Eigen value and consistency ratio are computed and the results are shown in Figure 6.9. Similarly the remaining computation process of alternatives with respect to each criterion is computed. Figure 6.10 shows the pair-wise comparison matrix of alternatives with respect to evaluation criteria feasibility. The pair-wise comparison matrix and relative weights of alternatives are shown in Appendix 5.
Figure 6.9  Screenshot of the relative weights of main criteria in CAMCDMT

Figure 6.10  Snapshot of the relative weights of maintenance alternatives with respect to feasibility in CAMCDMT
The relative weights of each maintenance alternative are calculated based on the same procedure. The TOPSIS is used for further integration with AHP. The TOPSIS decision matrix is created from the global weights obtained from the AHP. The next step is to calculate the ideal and negative ideal solutions of maintenance alternatives and the results are shown in Figure 6.11. The ideal and negative ideal solutions of maintenance alternatives are separated. Figure 6.12 shows the results of closeness of maintenance alternatives. The closeness coefficient of maintenance alternatives are framed as the objective function for linear programming model.

The production capacity, breakdown cost, wages for labour, cost of depreciation and cost of spare part are observed from the records. The number of spare parts consumed by similar type of four machines with four different maintenance strategies for two production cycles in a year are tabulated in Tables 6.1 and 6.2.

![Global weights]

Figure 6.11 Snapshot of the ideal and negative ideal solutions of maintenance alternatives in CAMCDMT
Figure 6.12  Snapshot of relative closeness of maintenance alternatives in CAMCDMT

Table 6.1 Bearing changes observed for first production cycle (24 cycles)

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<tr>
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<th>PM</th>
<th>CBM</th>
<th>TBM</th>
<th>CM</th>
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Table 6.2  Bearing changes observed from second production cycle (28 cycles)

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The breakdown occurrence of machines for the same year is tabulated in Table 6.3. The labour wage is the cost expenditure considered for the persons who are involved in changing the spare parts as well as rectifying the breakdown.

Table 6.3  Occurrences of breakdown per annum

<table>
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<tr>
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<th>TBM</th>
<th>CM</th>
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The resource constraints are identified. The objective function for the selection of the best maintenance strategy is built using closeness coefficient of TOPSIS as follows:

\[
\text{Min (Maintenance Cost)} = 0.104X_1 + 0.492X_2 + 0.824X_3 + 0.636X_4
\]

Subject to:

\[
X_1 + X_2 + X_3 + X_4 \geq 2600000 \quad \text{(Production capacity constraint)}
\]

\[
\begin{align*}
    X_1 & \geq 35000 \\
    X_2 & \geq 15000 \quad \text{(Depreciation values constraint associated with cost)} \\
    X_3 & \geq 3000 \\
    X_4 & \geq 85000
\end{align*}
\]

\[
\begin{align*}
    118X_1 & \geq 100000 \\
    117X_2 & \geq 95000 \quad \text{(Spare part constraint associated with cost)} \\
    90X_3 & \geq 60000 \\
    122X_4 & \geq 105000
\end{align*}
\]

\[
4X_1 + 3X_2 + X_3 + 4X_4 \geq 25000 \quad \text{(Break down constraint cost)}
\]

\[
21700X_1 + 20550X_2 + 14500X_3 + 22300X_4 \geq 14500
\]

(Wages constraint for labors)

This LP problem is solved using Microsoft Excel Solver. The snapshot of Excel Solver is shown in Figure 6.13. \( (\text{Min } Z) = 1977; X_3 = 666, X_2 = 811, X_4 = 860, X_1 = 4613 \). The Time-Based Maintenance is the best strategy with minimum cost of 667.
The AHP-TOPSIS integrated with linear programming model is proposed and developed for MSS with resource constraints. The software is developed using VisualBasic to make easy computations. The developed software is demonstrated with a case study for the selection of a suitable maintenance strategy in tea industry equipment. The AHP procedure is applied to analyze the hierarchical structure of the MSSP and determine the weights of the criteria. The criteria weights are computed through pair-wise comparison matrix. The closeness coefficients of alternatives are computed using TOPSIS. The linear programming model is proposed and integrated to find the best maintenance strategy with optimum maintenance cost.