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Modelling For Maintenance Job Cost - An Approach

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Abstract **- Prime mover maintenance plays an important role in cost effective approach in production planning and material transportation system. Any engine run by petrol, diesel or gases used for heavy power drive in material transportation system or to drive the stationary unit need planning to upkeep the production or the jobs being installed for application for required jobs. The cost of equipment is increasing day by day and maintenance of the prime mover like engine is very vital for smooth operation of the manufacturing and haulage system. This study aims to study the major factors influencing the maintenance system and its effect on maintenance cost. The effect of these factors on the various types of maintenance jobs with regard to their complexity has also been examined. The constraints in such analytical exercise have been formulated on the basis of some prioritised key jobs. The model development and the scope for application of the linear goal programming technique for maintenance system evaluation have been presented. This study for maintenance job cost is common for the prime mover consisting of engine, power transmission, fuel, lubrication and cooling, braking and electrical circuits.**

1. INTRODUCTION

The prime movers play a major role for the haulage of minerals and other bulk materials in mining and earthmoving industry. A large fleet of prime movers are deployed at the mining and construction projects to perform various tasks. An effective utilization of the prime movers would be only possible if the equipment availability can be improved. The maintenance of prime movers at the workshops often suffers due to limited manpower resource. This leads to an increased downtime of the machines and as a result the equipment availability gets reduced. The maintenance of prime movers is influenced by a number of factors like type of job, quality of supervision, availability of logistics, etc. The maintenance times for the different subsystems of prime movers would vary depending on the type and complexity of the job. An attempt has been made in this paper to optimise the breakdown maintenance times for the different subsystems of prime movers commensurate with the complexity level of maintenance jobs. Knowledge on the optimum maintenance times for different jobs would help considerably to arrive at the rationale for planning the manpower resource at the maintenance workshop[10-24].

A number of researchers have worked in the field of maintenance management with a view to improving the maintenance system performance.

Ahmed et al [1] has presented a model for optimal determination of job evaluation for maintenance planning to carry out routine maintenance work. Brosh et al [2] have presented the optimal maintenance and replacement policy for a fleet of vehicles whereas Czjikiewcz [3] has worked on' Optimisation of Maintenance Process. Gupta et al [4] have developed a goal programming approach for job evaluation based on different factors.

Optimal scheduled maintenance policy based on multiple criteria decision making has been modelled by Hwang et al [5]. Ignizio[6] has introduced Linear Goal Programming approach in maintenance. An Evolution of the Maintenance Practice for a Fleet of Prime movers working in mining system has been formulated by Kumar et al [7]. Again, Kumar et al [8] have published maintenance Job Evaluation of Heavy Earthmoving Machines - A Goal Programming Approach.

Lee [9] has worked and formulated Goal Programming for Decision Analysis model in different areas and application.

Although many quantitative studies have been carried out for the improvement of maintenance systems, an in-depth study on the evaluation of maintenance jobs for proper manpower planning in breakdown maintenance is really lacking. While deciding the strategies for an optimal maintenance planning, the functional aspect of the maintenance system cannot be ignored. Indeed, the effect of manpower resource in the functioning of maintenance system has not been analysed with an aim to determine the optimal maintenance times for various jobs. It is felt that a comprehensive study in this line should be carried out to evolve strategies for an optimal maintenance planning with due consideration to manpower groups that form a major part of the maintenance system.

With the increasing complexity in industrial sectors, it has become imperative in many situations to apply an appropriate model for multi-criterion decision making. The maintenance management personnel often have to set the goals although the same may not be attainable due to the limitation of available resources. However, such problems can be tackled easily with the help of Goal Programming Technique. The objective function of the maintenance system model can be defined in a manner that its optimisation would call for the closest possible achievement of the goals, while the constraint incorporated in such models can be regarded as the goals.

Further, the multiple goals in any maintenance management problem may be often in conflict and one goal would be achieved only at the expense of the other. Thus, it would be necessary to establish the hierarchy of importance amongst the incomparable goals to have a solution for such problems. The maintenance manager has to determine the priority for each of the goals and rank them in a sequence so that the lower priority goals are considered only after the higher priority goals are satisfied or have reached the point beyond which no further improvement is feasible. Thus, the maintenance planner has to make an ordinal ranking of the goals in terms of their contribution or importance. Moreover, the deviations between the goals within the given set of constraints in a goal programming model are to be minimized rather than trying to maximise or minimise the objective function directly.

Although various research works has been carried out for the optimisation of systems using the goal programming technique, its application for an optimal manpower planning in maintenance workshop is yet to be observed. The maintenance planning for proper manpower utilization is the critical problem in prime mover maintenance workshop. The maintenance systems at such shops generally suffer from improper planning, irregular job distribution, undue priority assignment, etc. and the managers decide the maintenance methodology for necessary implementation as per their convenience. This paper aims to provide a direction for optimal manpower planning in the breakdown maintenance of a fleet of prime movers.

2. BREAKDOWN MAINTENANCE MODEL

The breakdown maintenance job of a prime mover pertains to five major subsystems namely Electrical circuit, Braking device, Hydraulic circuit, Transmission unit and Engine. The engine is the source of motive power and the transmission unit is responsible for the transfer of power from the source to the driving wheels for vehicle movement. The hydraulic subsystem enables the operation of the steering assembly, transmission unit and serves to raise or lower the dump body. The braking device is responsible for the stoppage or retardation of vehicle motion as and when necessary and any failure of this unit may stop the vehicle or endanger safety particularly when the vehicle is on a downhill run. The Electrical subsystem helps to start the engine and provides for necessary illumination facility. The breakdown of the vehicle may happen due to the failure of any of these subsystems.

The maintenance time required for a particular job corresponds to component failure of any of the above subsystems. The time required to perform the maintenance task has to be estimated by time study method taking into account the allowances for arranging the logistics. It has been considered that the spare parts are generally available at the workshop store located near the maintenance area.

Now, $\mathbf{T_{ij}}$ = N X D manhours.

$\mathbf{T_{ij}}$ = Maintenance time required for completing the Job (Kij) pertaining to i^{th} subsystem i.e. Job level and K^{th} Job complexity level (man-hours)

N = Number of personnel engaged for a maintenance Job

D = Time needed to complete the maintenance Job Kij (hours)

The maintenance time related to each of such subsystems may be categorised under six different complexity levels. Each of the above subsystems i.e. Job levels can be grouped further into six sublevels to be represented as Kij, i = 1, 2, …, 5; j = 1, 2, …, 6. Thus, the maintenance Jobs for each machine subsystem pertaining to the different complexity sublevels would be as in Table1.

The Jobs for the electrical circuit are identified by $\mathbf{K_{1j}}$ having $\mathbf{K_{11}, K_{12}, K_{13}, K_{14}, K_{15}, K_{16}}$ types of Jobs corresponding to different Job complexity levels. The maintenance times required for such Jobs would correspond to the level wise Job complexity meaning that T_{11} is the man-hour needed for the least complex Job K_{11} and that for the highest Job complexity would be T_{16} man-hours. Similarly, the other subsystems are also categorised as in Table 1. Needless to mention, the Job K_{21} would need more maintenance time than that required to perform the Job K_{11}. Similarly, the time required in maintenance for the Job K_{31} would be more than that for the Job K_{21} and so on. Thus, the ascending order of the Job level pertaining to the machine subsystems as shown in Table1 signifies light to heavy maintenance requirement.

TABLE 1 : PRIMEE MOVER SUBSYSTEMS

Job Level K_i	Job Complexity Sublevel Kij					
	1	2	3	4	5	6
Electrical circuit, K_{1j}	K_{11}	K_{12}	K_{13}	K_{14}	K_{15}	K_{16}
Braking device, K_{2j}	K_{21}	K_{22}	K_{23}	K_{24}	K_{25}	K_{26}
Hydraulic circuit, K_{3j}	K_{31}	K_{32}	K_{33}	K_{34}	K_{35}	K_{36}
Transmission Unit, K_{4j}	K_{41}	K_{42}	K_{43}	K_{44}	K_{45}	K_{46}
Engine, K_{5j}	K_{51}	K_{52}	K_{53}	K_{54}	K_{55}	K_{56}

The breakdown maintenance of prime mover may comprise of one or more of such maintenance Jobs requiring necessary maintenance time. Thus, the total maintenance time required for the repair of different subsystems would be the sum of all the individual maintenance times. It is necessary to arrive at a rationale for determining the Key jobs to develop the maintenance system model. The maintenance manager has to suggest such elemental mix for the Key jobs considering the quality and complexity of the Jobs. These Key jobs would be used as the basis for evaluating the worth of other Jobs to arrive at the maintenance strategy. This aspect should be carefully considered in identification and determination of the score of Key jobs. A proper selection of the Key jobs can only yield a precise solution from the model. The system analyst may have to interrogate the maintenance management personnel to gather sufficient knowledge on the Job factors that make up a specific Key job pertaining to an appropriate Job level or machine subsystem.

The total score of the Key job would be the sum of the scores of its constituent elements that should be decided carefully to obtain an acceptable model performance. The larger the number of Key jobs included in the model, the better would be model output results. Further, the scores of the Key jobs in breakdown maintenance operation may change without showing any regularity commensurate with the contents of breakdown maintenance Job linked to different Job complexity sublevels.

The maintenance times for the Key jobs of the prime movers are estimated in man-hours by time study. The actual scores obtained from the field study can be rounded to a value at the higher or lower side in the usual manner. These Key jobs are having different constituent elements one each under a particular level of Job complexity of a given subsystem considering that all such elements has failed simultaneously. While selecting the Key jobs it is considered that the failures occur at all the five Job levels (or machine subsystems) on a random basis. In order to help in evaluating the worth of Jobs pertaining to the different sublevels, the maintenance manager has to provide the minimum and maximum values of maintenance time required to perform the task pertaining to a given subsystem. The difference in maintenance time corresponding to the consecutive sublevels depends on the change in complexity level of the Job. Now, the maintenance times for the five Key jobs are estimated as:

$$\mathbf{T_{11} + T_{23} + T_{32} + T_{43} + T_{56} \leq 100 \text{ man-hours}} \quad \ldots (1)$$
$$\mathbf{T_{11} + T_{23} + T_{32} + T_{42} + T_{55} \leq 85 \text{ man-hours}} \quad \ldots (2)$$
$$\mathbf{T_{12} + T_{22} + T_{32} + T_{43} + T_{53} \leq 75 \text{ man-hours}} \quad \ldots (3)$$
$$\mathbf{T_{14} + T_{22} + T_{31} + T_{44} + T_{51} \leq 60 \text{ man-hours}} \quad \ldots (4)$$
$$\mathbf{T_{11} + T_{21} + T_{31} + T_{44} + T_{51} \leq 50 \text{ man-hours}} \quad \ldots (5)$$

It is unlikely that the score structure in a maintenance system would fully satisfy the in equations (1) - (5). However, these are the goals for each of the Jobs and there may exist some deviations arising out of the time study procedure and the structure of the maintenance system. Indeed, these should be the permissible deviations from the goals for a maintenance system to function smoothly. The other constraints as given below are for lower limit, higher limit and deviation in maintenance Job scores between two consecutive sublevels:

$$\mathbf{T_{i1} \geq 6 \text{ man-hours}} \quad \ldots \quad (6)$$
$$\mathbf{T_{i6} \leq (25 + 5\,i) \text{ man-hours}} \quad \ldots \quad (7)$$
$$\mathbf{T_{iK} - T_{i(K-1)} \geq (4 + i) \text{ manhours}} \quad \ldots \quad (8)$$

Where, i = 1, 2, ..., 5; K = 2, 3, ..., 6 for each i.

The positive deviational variables e.g. $\mathbf{p_1}$, $\mathbf{p_2}$, $\mathbf{p_3}$, $\mathbf{p_4}$ and $\mathbf{p_5}$ are introduced to indicate that the total scores of the maintenance Jobs expressed in equations (1)-(5) are the maximum acceptable scores in respective cases. To develop the goal programming model these constraints can be written as below:

$$
\left.
\begin{aligned}
\mathbf{T_{11} + T_{23} + T_{32} + T_{43} + T_{56} - p_1} &= \mathbf{100 \ldots} \\
\mathbf{T_{11} + T_{23} + T_{32} + T_{42} + T_{55} - p_2} &= \mathbf{85 \ldots} \\
\mathbf{T_{12} + T_{22} + T_{32} + T_{43} + T_{53} - p_3} &= \mathbf{75 \ldots} \\
\mathbf{T_{14} + T_{22} + T_{31} + T_{44} + T_{51} - p_4} &= \mathbf{60 \ldots} \\
\mathbf{T_{11} + T_{21} + T_{31} + T_{44} + T_{51} - p_5} &= \mathbf{50 \ldots}
\end{aligned}
\right\} \quad \mathbf{(A)}
$$

The equation set **(A)** indicates that each Job level should be duly evaluated so that each of the above equations must satisfy for a minimum value of deviation. It would be necessary to meet the goals of the Key jobs as close as possible to their assigned scores.

Apart from the deviations in score for the Key jobs, there would be some deviation in relation to the individual score of a given maintenance Job. Such constraints may be represented as:

$$\mathbf{T_{i1} + n_{i+5} = 6 \quad \ldots \quad (B)}$$

$$\mathbf{T_{i6} - p_{i+10} = (25 + 5\,i) \quad \ldots \quad (C)}$$

$$\mathbf{T_{ij} - T_{i(j-1)} + n_{\{5(i-1)+(j+14)\}} = (4 + i) \quad \ldots \quad (D)}$$

Where, p_i and n_i are the positive and negative deviational variables

The breakdown maintenance model incorporates the predetermined minimum maintenance Job times as the datum. Any maintenance Job needing repair time lesser than the minimum Job time would be considered as a running repair activity. The equation set (B) indicates that the lowest value of maintenance Job time $\mathbf{T_{i1}}$ for each Job level should be at least 6 man-hours and negative deviational variables are associated with the constraints. When the maintenance time requirement for any Job is below 6 man-hours the same would be done by the running repair groups. The equation set (C) indicates that the highest possible value of maintenance Job time for each Job level or machine subsystem should not exceed the limit value in respective cases and positive deviational variables are associated with these constraints. Such limit values would correspond to the highest Job complexity. It may be noted that the maintenance Job time increases by 5 man-hours from one Job level to the other due to the change in Job complexity. The equation set (D) indicates that the difference in man-hours related to maintenance Jobs for any particular Job level would incorporate the negative deviational variables. Also, the difference in maintenance Job times for the consecutive sublevels remains the same for any particular Job level. When the Job level number goes higher, the time required for the maintenance Job of a given complexity sublevel would also be more in comparison to that for the Job of preceding Job level. Consequently, the difference in maintenance Job times (i.e. man-hours) for the respective sublevels would also go higher due to increased work content as the Job level goes higher.

The achievement function of the goal programming model may be formulated as:

Minimize,

$$\mathbf{Z = \{ P_1\Big(\sum_{j=1}^{5} pj\Big), P_2\Big(\sum_{j=6}^{10} nj\Big), P_3\Big(\sum_{j=11}^{15} pj\Big), P_4\Big(\sum_{j=16}^{40} nj\Big)\} \quad \ldots. \quad (E)}$$

Subject to satisfying the constraints (A), (B), (C) and (D).

In equation (E), P_i (i = 1, 2, 3, 4) indicates the priority level. These priority levels are assigned in respect of the different sets of positive or negative deviational variables. The model assigns the highest priority with regard to minimising the deviations from the goals for Key jobs. The next priority has been assigned to minimise the deviations from goals for the lowest values of maintenance times related to different subsystems and so on. With the priority structure given in the model, there exists an inevitable competition amongst the goals and the optimum solution would satisfy the goals as much as possible.

The pre-emptive goal programming model has been formulated for arriving at the optimal maintenance times in relation to breakdown maintenance Jobs of prime movers. The model has been developed based on the maintenance tasks identified in relation to different major subsystems of the prime mover keeping in view the Job complexity sublevels.

3. NUMERICAL RESULTS

The optimum values of breakdown maintenance time as presented in Table 2 and the deviations from the goals as shown in Table 3 have been computed by solving the pre-emptive linear goal programming problem.

TABLE 3 : OPTIMUM BREAKDOWN MAINTENANCE SCORES

SUBSYSTEM	Job Complexity Sublevel K					
Job Level (i)	1	2	3	4	5	6
Electrical circuit (T_{1j})	6	10	15	20	25	30
Braking device (T_{2j})	6	11	17	23	29	35
Hydraulic circuit (T_{3j})	6	12	19	26	33	40
Transmission Unit (T_{4j})	6	10	18	26	34	42
Engine (T_{5j})	6	11	20	29	38	47

TABLE 3 : GOAL ATTAINMENT IN BREAKDOWN MAINTENANCE

Key jobs	Allotted score	Goal achieved	Goal under achievement
1	100	100	0
2	85	83	2
3	75	71	4
4	60	58	2
5	50	50	0

It may be observed from Table 3 that there exists some goal underachievement for the Key jobs 2, 3 and 4; whereas the allotted scores are just achieved for the other Key jobs 1 and 5.

The optimal maintenance times obtained for each of the Job levels corresponding to different complexity sublevels would enable to understand the elemental maintenance times for the desired maintenance Jobs. This would help to determine the total maintenance time requirement for a given Job.

This model has aimed to compute the maintenance times for different maintenance tasks pertaining to any particular Job level within the limitations of lowest and highest possible maintenance times that may be allowed for such Jobs. It would help to prioritise the maintenance work for a given prime mover based on the minimum man-hour requirement in breakdown maintenance for achieving the maximum availability of the equipment at the site of operation. Also the results of the model would help to understand the workload in breakdown maintenance for the different manpower groups.

4. SENSITIVITY ANALYSIS

In order to examine the sensitivity of the pre-emptive goal programming model, different scores are assigned to the Key jobs to observe the extent of deviations from the allotted scores in respective cases. The score of first Key job is kept unaltered and the scores of the rest of Key jobs are marginally varied on the lower or higher side of the scores obtained from time study. It is observed that the deviation in score ranges from a minimum to the maximum. However, the minimum value of total deviation does not provide uniformity in the values of decision variables. Hence, the higher value of total deviation is considered that satisfies the requirements of constraints and provides uniformity in the values of decision variables.

The number of Key jobs is increased successively to observe the deviation in scores. The actual scores of the Key jobs have been considered as the basis to understand the extent of deviation. Additional Key jobs are also introduced between the consecutive Key jobs successively with a marginal variation in score. It is noted that the total deviation is minimum and the values of decision variables get changed in a regular manner sublevel wise for the different subsystems of the machine. As the first Key job has shown minimum deviation, the chosen set of Key jobs with the scores allotted in respective cases are considered acceptable.

Further, the values of the lower limit, higher limit and those for the difference in maintenance time for the consecutive sublevels of the system are varied marginally on the lower or higher side of the base scores. It is observed that the values of the variables vary uniformly for the minimum value of total deviation. This is contrary to the other cases where the total deviation in score values does not provide any regular trend in the values of decision variables. Thus, the model is acceptable for further application.

The pre-emptive goal programming model is formulated mainly to obtain the optimum maintenance times for the breakdown maintenance Jobs. Although sensitivity analysis of the goal programming output results has been carried out for the purpose of model validation, it enables to explore the possibility of improving the optimum maintenance times still further.

5. MODEL APPLICATION

As an extension of the exercise, the model has been applied for analysing the breakdown maintenance system of prime movers of lower capacity rating. The study has been undertaken at another maintenance workshop in the region. The modified formulation of the Key jobs for such application is given below:

$$T_{11} + T_{23} + T_{32} + T_{43} + T_{56} \leq 100 \text{ man-hours} \quad \dots (9)$$
$$T_{11} + T_{23} + T_{32} + T_{42} + T_{55} \leq 85 \text{ man-hours} \quad \dots (10)$$
$$T_{12} + T_{22} + T_{32} + T_{43} + T_{53} \leq 75 \text{ man-hours} \quad \dots (11)$$
$$T_{14} + T_{22} + T_{31} + T_{42} + T_{52} \leq 60 \text{ man-hours} \quad \dots (12)$$
$$T_{11} + T_{21} + T_{31} + T_{44} + T_{51} \leq 50 \text{ man-hours} \quad \dots (13)$$

While the constraint for lower limit of maintenance Job score remains unchanged, the constraints for higher limit and differ in maintenance Job scores between two consecutive sublevels have been formulated with minor modifications for the prime movers as presented below:

$$T_{i1} \geq 6 \text{ man-hours} \quad \dots (14)$$
$$T_{i6} \leq (25 + 5\,I) \text{ man-hours} \quad \dots (15)$$
$$T_{ij} - T_{i(j-1)} \geq (4 + i) \text{ man-hours} \quad \dots (16)$$

Where, i = 1, 2, ..., 5; j = 2, 3, ..., 6 for each i.

Now, the goal programming model has been developed with the incorporation of positive and negative deviational variables in the similar manner as has been discussed earlier. Also the formulation of achievement function of the goal programming model for such application remains unaltered. This goal programming problem has been solved to compute the optimum values of breakdown maintenance times required for the different maintenance Jobs as shown in Table 4. Further, the deviations from the goals in this case are shown in Table 5.

TABLE 4 : OPTIMUM MAINTENANCE SCORES

SUBSYSTEM	Job Complexity Sublevel J					
Job Level (i)	1	2	3	4	5	6
Electrical circuit (T_{1j})	6	9	13	17	21	25
Braking device (T_{2j})	6	10	15	20	25	30
Hydraulic circuit (T_{3j})	6	11	17	23	29	35
Transmission Unit (T_{4j})	6	12	19	26	33	40
Engine (T_{5j})	6	13	21	29	37	45

TABLE 5 : GOAL ATTAINMENT IN MAINTENANCE

Key jobs	*Allotted score*	*Goal achieved*	*Goal under achievement*
1	100	96	4
2	85	81	4
3	75	70	5
4	60	58	2
5	50	50	0

The Table 5 shows the goal underachievement values for the Key jobs 1, 2, 3 and 4. However, the allotted score is fully achieved for the Key job 5. The result of the model as shown above establishes that the approach made in this exercise is fully acceptable for other possible applications.

6. CONCLUSION

The maintenance system analysis for a fleet of prime movers is based on the study carried out at the maintenance workshops of the regional coal industry. A study on the manpower evaluation in prime mover maintenance would help to provide an idea as to whether the current maintenance policy would need any modification. A proper manpower utilisation can only help to perform an effective maintenance of critical machine subsystems for minimising the duration of equipment breakdown. A pre-emptive goal programming model has been developed to estimate the optimal maintenance times for the engagement of manpower groups in the maintenance of prime mover fleet.

The prime movers are deployed at the mining and construction projects in a large fleet for the off-highway haulage of bulk materials. This paper has aimed to develop the optimum breakdown maintenance plans for a fleet of prime movers and study the scope for an optimum utilization of maintenance manpower. A study in this area would help to reap the benefit of formulating an economic maintenance strategy. Inevitably, the approach would help to develop the maintenance plans in a much lesser time results an improved availability of the equipment so as to cater to the requirements of the physical operating system. An estimation of the optimal breakdown maintenance times under the prevailing conditions would help to assist in a proper manpower planning for possible reduction in manpower cost in maintenance and to plan the maintenance budget in future. The approach made in this paper would hopefully provide the opportunity to improve the breakdown maintenance system for a fleet of prime movers on an overall basis.

An optimum utilization of manpower in maintenance would help to reduce the breakdown time of prime movers. Further, it would be possible to maintain a balance between the manpower available for maintenance and that actually required at the working area to maintain each subsystem of the machine.

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