Decision tree analysis for economic maintenance and replacement of heavy haul railway track.

The trains used for heavy haul would be among the heaviest and longest trains operating in the system with axle loads up to 30 tonnes. The track deterioration rate is high. Worldwide the trend towards higher axle loads and train speeds has increased the deterioration rate of track and vehicles, particularly rails .Consequently, expensive rail maintenance and replacement programmes have to be carried out to ensure safe and reliable rail service.

Major rail maintenance problems are fatigue fracture, severe wear and plastic deformation of rail heads. Fatigue fracture is caused by cyclic loading of very heavy axle loads which generate high wheel/rail contact shear stresses. At present, these defects are detected by the extensive use of ultrasonic detection methods and regular visual inspections by track inspectors. If a fatigue defect is not detected, a rail break will occur leading to a possible derailment. Wear pattern in curved portion of track is different from that in straight track. In particular, curved track is subject to heavy side wear, which necessitates much more frequent replacement than straight track**.** When an outer rail is condemned on the basis of excessive side wear, the inner rail is still in good condition. To save replacement cost, it is current practice to interchange outer rail to inner rail and vice versa. Rails in the straight portion of track of a heavy haul railway are more likely to generate fatigue defects. When fully developed, this form of failure can cause rail break, which can very likely lead to a derailment. Because of the catastrophic consequence of a derailment (i.e. high cost and possible loss of life), extensive preventive maintenance are used to detect and repair fatigue defects before they fracture. At the same time, extensive research internationally has resulted in the development of maintenance options, such as rail grinding, which reduce deterioration.

This paper explores the possibility of application of the decision network method in determining minimum cost maintenance and replacement policies for rails in heavy haul rail track.

Management Decision:
The following alternatives are available with the managers for maintenance and replacement of rails in heavy haul tracks.

→ Do nothing
→ Interchange
→ Rail Grinding
→ Through Rail Renewal

"Do nothing" means resorting to intensive inspection and regular maintenance to avoid failures. At the same time rate of deterioration is faster in wheels as well as in rails. There are costs associated with risk of fatigue failure and consequent derailment in addition to cost of wear in wheels and rails.

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Other actions such as interchange, rail grinding, TRR as the name indicate are proactive preventive measures having certain costs associated.

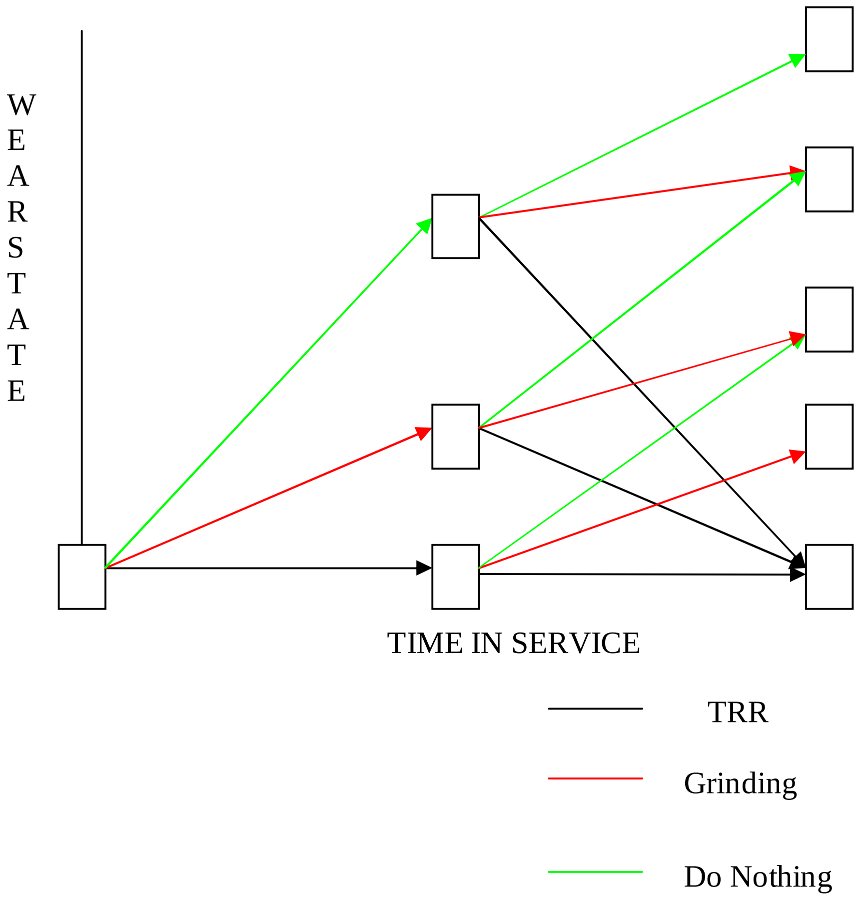


Fig-1

Engineering Functions governing the decision:

Rail wear function: Generally, track properties vary slightly between one curve and another, but experience and research have shown that radius of curvature is the predominant factor causing curve wear and defect characteristics. Maintenance decisions are required for discrete regular intervals or periods.

S. T. Lamson[1] defines the following variables;

WR = % loss of rail head area to date;

WL_n = the wear level after n maintenance periods since the last grinding;

DELT = the traffic per period in million gross tonnes.

[1] Lamson S. T., Hastings N. A. J., Willis R. J. (1983). Minimum Cost Maintenance in Heavy Haul Rail Track. The Journal of the Operational Research Society, Vol. 34, No. 3, pp. 211-223.

The wear level increments by one unit per period since the last grinding.
From research on wear rates researchers have found the formula
$WR = 0.0012\ (DELT x WL_n)^2$
This formula is used to show the effect of various maintenance options on wear level in Table-1.

Defect function: The rate of occurrence of fatigue defects is dependent on the level of traffic carried by the rails.
Let DR = number of fatigue defects;
TL_n = tonnage level at maintenance period n.

From research on defect rates, researchers[2] have found that
$DR = 0.000723\ (DELT \times TL_n)^2$
The tonnage level increments by one unit per maintenance period.

Grinding requirements : The number of grinding passes required to restore a rail at a wear level WL_n to the special profile is given by
$NP = 1.5\ DELT \times WL_n$
Where NP = number of grinding passes. For example, if the rail profile is 3 months old, the monthly tonnage is 4 MGT and the maintenance period is 1 month, then the number of grinding passes required is: NP = 1.5 x4x 3 = 18 passes.

Special constraints for Rail maintenance and renewal: As per Indian Railway Permanent Way Manual ,the rail shall be planned for renewal after it has reached following levels:

(i) 800 GMT for 60Kg/m, 90 UTS rails and 550 GMT for 52 Kg/m,90 UTS rails.

(ii) When loss in rail section reaches 6% for 52 Kg/m rails.

(iii) Vertical wear is 13mm and 8 mm for 60Kg and 52 Kg rails respectively.

(iv) Lateral wear is 8mm for curves and 6mm for straight.

(v) Wear due to corrosion is also a criterion for replacement. Corrosion beyond 1.5 mm in web is the limit

(vi) Incidence of fatigue failures more than 5 per 10 Km stretch.

Action taken at the start of stage n	Wear level at the start of stage n	Wear level at the end of stage n	Amount of rail wear during stage n
Do Nothing	WL_n	WL_{n+1}	$.0012[(WL_{n+1})^2-(WL_n)^2]xDELT^2$

[2] Lamson S. T., Hastings N. A. J., Willis R. J. (1983). Minimum Cost Maintenance in Heavy Haul Rail Track. The Journal of the Operational Research Society, Vol. 34, No. 3, pp. 211- 223.

Grind Rail	WL_n	WL_1	$.0012x\ DELT^2 + \Delta G_n$
Interchange or TRR	WL_0	WL_1	$.0012x\ DELT^2$

Table-1

$\Delta G_n =$ % head loss due to grinding a wear n level.

Factors involved in the application of the decision network method to rail grinding and replacement planning:

The various engineering functions and financial factors have been tabulated in following table-2.

Cost Data	Engineering Data	Management Data
Wear cost	Rail wear characteristics	Do nothing
Defect Cost	Fatigue defect characteristics	Grind
Interchanging Cost	Grinding effect	Interchange
Interest Rates	Interchange effect	TRR
Escalation	Safety limits on Wear and GMT	Maintenance and replacement policy
TRR cost		

Table -2

Rail wear cost: Rail wear causes wheel wear, track geometry deterioration and some increase in derailment risk. These damages result in costs associated with wheel maintenance, track maintenance and derailment.

Cost coefficients for rail wear can be derived from maintenance cost records using a procedure which ensures that only costs relevant to the optimization are extracted. Researchers[3] found the pattern of distribution of cost for a 2.3 degree curve as under;

(i) 89.5% wheel wear cost;
(ii) (ii) 9.9% track geometry damage cost;
(iii) (iii) 0.6% derailment cost.

Defect cost: Transverse defects have to be found and repaired before rail breakage occurs causing possible derailment. Currently, nearly half of the cost associated with each transverse defect is spent on inspection, and the remainder is spent on repair. Only a small proportion is spent on derailment, since the probability of derailment is very small.

Grinding cost: The cost of grinding can be determined on the basis of the operating charge per hour, the grinding rate and efficiency. As the grinding work can only be carried out when the track is cleared of traffic, a significant amount of time is often spent waiting for track clearance. This cost represents a fixed sum associated with each grinding session. Thus, the grinding cost can be calculated as:

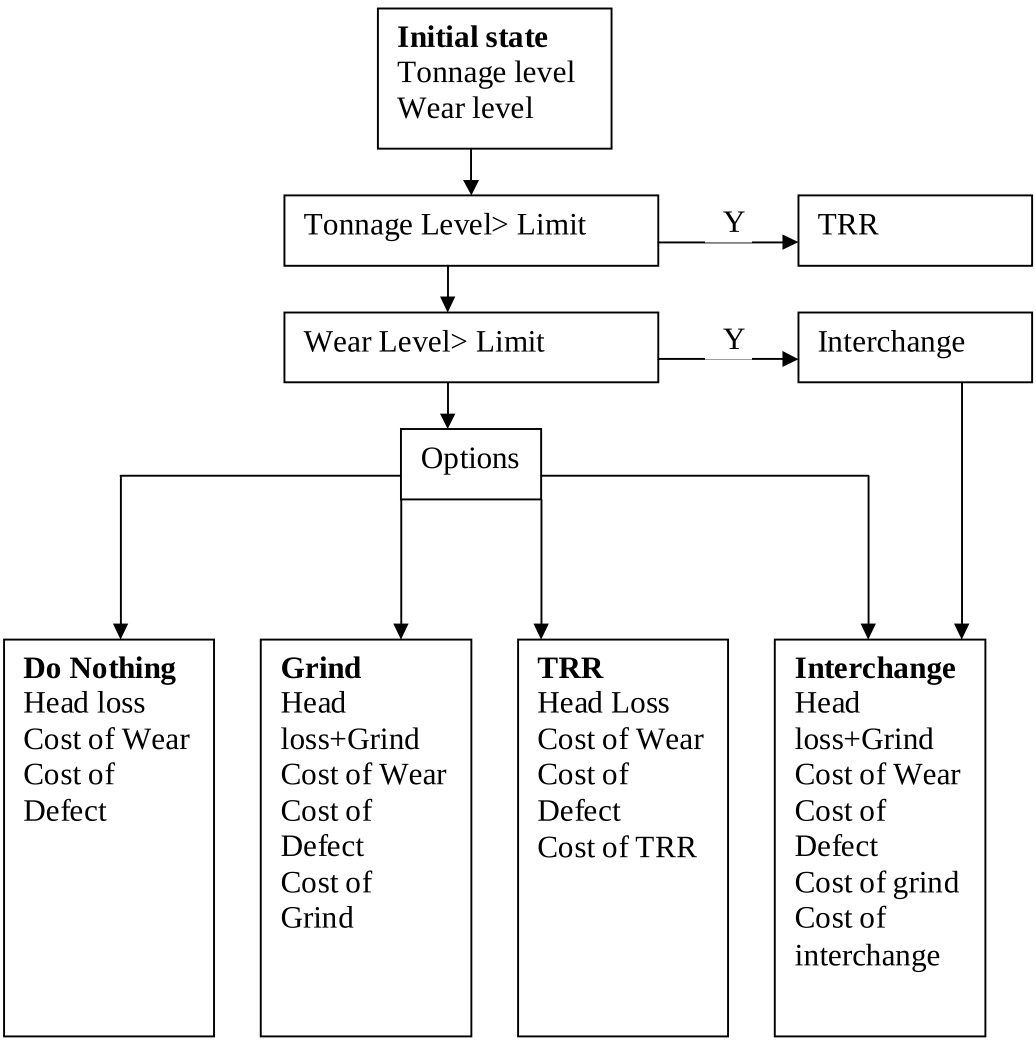
[3] Lamson S. T., Hastings N. A. J., Willis R. J. (1983). Minimum Cost Maintenance in Heavy Haul Rail Track. The Journal of the Operational Research Society, Vol. 34, No. 3, pp. 211- 223

Grinding cost = Fixed cost + Cost per pass x Number of grinding passes.

Interchanging Cost: When a high rail is condemned on the basis of excessive side wear, and low rail is still in good condition ,to save replacement cost, it is current practice to transpose high rail to low rail and vice versa. The interchange cost normally includes labour, delay of traffic and extensive grinding to recondition the rail profile.

Replacement cost: Replacement cost consists of materials, labour and traffic disruption costs. This is usually a large investment and is sensitive to financial factors such as taxation, interest rate and inflation.

Flow Chart for Analysing the Data: The various engineering functions and cost data can be processed by using suitable computing program to produce optimal plan which can be used to derive the grinding /replacement policy.



Conclusion: One of the main applications of the model is to examine the effect of changes in the financial and technical conditions on the optimal policy. The optimization model based on the decision network method is effective in minimizing rail management costs through rational planning of maintenance and replacement policies for rails in the whole track. The flexibility of the decision network method enables the evaluation of a wide range of management options, engineering conditions and cost variations.

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