Decision Support System (DSS) for Rail Maintenance in Heavy Haul Line

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ABSTRACT

Rail wear and rolling contact fatigue (RCF) in rails are major contributors of operational and maintenance cost in heavy haul lines. Collection of data, modelling degradation and estimation of parameter for failure models is necessary for accurate prediction of asset conditions. Failure to do so can lead to undetected rail breaks and unsafe track leading to derailments. There is a need for developing effective maintenance strategies for cost and risk reduction.

This paper focuses on collection and analysis of field data over a period of time for maintenance cost model, estimation of parameter and decision support system applicable to heavy haul lines.

Keywords: Rail Wear, Rolling Contact Fatigue (RCF), DSS, Maintenance Cost Model.

1. INTRODUCTION

Rail wear and fatigue are important factors behind rail degradation and therefore, for budgeting rail maintenance and replacements. In 2000, the Hatfield accident in UK killed 4 people and injured 34 people and has lead to the cost over £ 733 million for repairs and compensations. In 1977, the Granville train disaster in Australia killed 83 people and injured 213 people. These are related to problems associated to rail maintenance decisions. Train speed, axle load, rail-wheel material type, size and profile, track construction, characteristics of bogie type, Million Gross Tonnes (MGT), curvature, traffic type, weather and environmental conditions. Collection of data, modelling degradation and estimation of parameter for failure models is necessary for accurate prediction of asset conditions. Failure to do so can lead to undetected rail breaks and unsafe track leading to derailments. There is a need for developing effective maintenance strategies for cost and risk reduction.

This paper focuses on collection and analysis of field data over a period of time for maintenance cost model, estimation of parameter and decision support system applicable to heavy haul lines. Risk based cost benefit model is developed and built into the system for enhancing network performance, reducing costs and operational risks.

Outline of this paper is as follows: Section 1 introduces an overview of rail wear and fatigue modes and mechanism. Section 2 proposes a model for predictive model. In Section 3 field data are collected for analysis and development of integrated system for maintenance decision. The concluding section discusses summary and scope for future work.

2. PROPOSED RAIL WEAR AND FATIGUE PREDICTION MODEL

The rail life is determined by head loss limit, which is a relative measure of the ratio of a worn rail head to the area of a new rail head [1]. Kumar et al. [2, 3] followed by McEven and Harvey [4] proposed wear prediction model based on full scale testing. Danks and Clayton [5] conducted test on gauge face wear of rail under unlubricated conditions. In line with this Markov's [6] tests include

- longitudinal slippage,
- constant friction force,
- lateral slippage and
- pure sliding friction

The wheel load is transmitted to the rail through a tiny contact area in heavy haul lines resulting high contact stresses. Repeated loading beyond the elastic limit causes plastic deformation [7] and influenced by hardness of the rail and wheel, MGT and the radius of the curves [8, 9]. Excessive gauge face wear and plastic flow on curves for heavy haul railway tracks is a problem for rail life [10]. This is also a problem for metropolitan rail network of the public transport corporation, Victoria [11]. Kalousek [12] indicated that gauge face wear of high rails in curves as a dominating problem. Zakharov et al. [13] conducted twin-disc experiments at different loads and lateral creep levels. They found that the product of contact pressure and creep are relevant parameters for determining wear regimes. Wear is predicted by considering material response to combined tangential and normal stresses and slippage. Wear coefficients were used in dynamic simulations of vehicle/track interaction. Corrugations, resulting significant increase in wear & noise emissions called 'roaring rail' was studied by Ekberg et al. [14].

Figure 1. Head Checks (RCF)

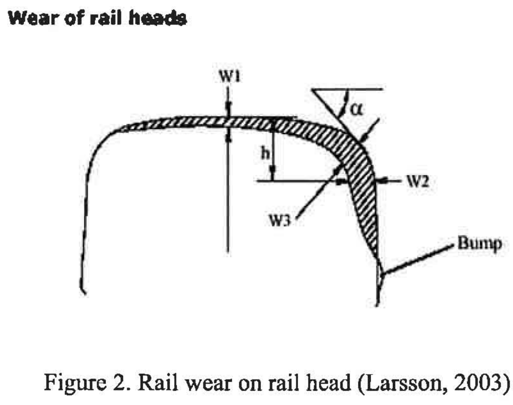

Figure 2. Rail wear on rail head (Larsson, 2003)

Wear occurs due to sliding in the contact area under poorly lubricated conditions. In addition to that microstructure, hardness and temperature influence wear rate [15, 16].

Clayton [17] analyzed laboratory and field data to predict rail wear at higher axle loads. He concluded that general wear models are unlikely to produce the practical benefits in the field. The existing models are restricted to particular application under limited conditions. Better results were achieved with field and experimental data. The wear rate was evaluated using material hardness, microstructure and contact pressure. Warra [18] analyzed lubricant influence on flange wear in sharp curves. Nilsson [19] (2003) investigated lubricated and unlubricated rail under different weather conditions. He found that wear rate vary over the year due to the changing weather conditions. Extensive measurements of wheel and rail wear during a service period of three and a half years of the Stockholm commuter traffic have been reported and analyzed by Nilsson [7, 19, 20] and Olofsson and Nilsson [21]. There is a need for improvement in maintenance activity, positioning, dedicated maintainer, aging lubricator and careful in selection of lubricants. Level of lubrication performance depends on:

- Traffic type
- Millions Gross Tonnes (MGT)
- Lubrication Strategy (Each depot may varies)
- Weather Condition (Season changes)
- Maintenance Activity

3. DECISION SUPPORT SYSTEM FOR RAIL MAINTENANCE

Field data were collected and analysed according to factors as classified in Figure 3 for a predictive simulation model and maintenance decision.

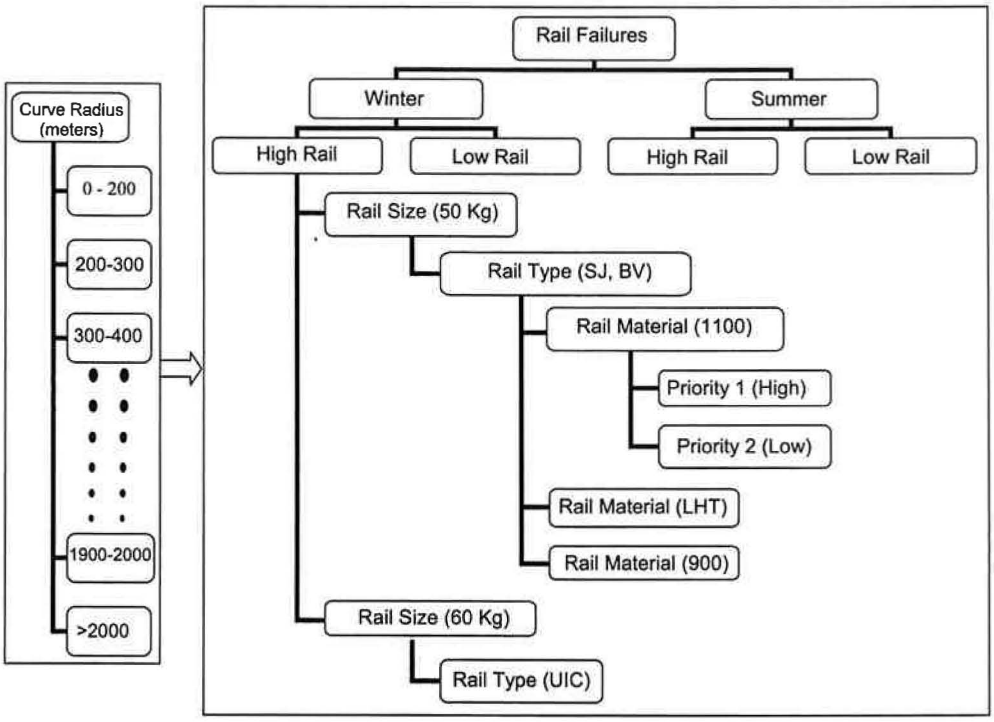

Figure 3. Rail Failure data Classification [22]

Wear rate is estimated using field data. From profile measurement data a stochastic rail wear model is developed using effect of traffic wear and grinding wear. The area after ith period modelled as:

$$A_i = A_0 - \sum_{j=o}^{i}\left((RC_w + RG_w)TD_j + (RC_w + RG_w)GD_j\right) \tag{1}$$

Where, A_0 is the cross sectional profile area of a new rail, RC_w is Rail Crown wear width, RG_w is Rail Gauge wear width, TD is from Traffic, GD is the Grinding Depth due to grinding. It can be expressed as:

$$A_i = A_0 - \sum_{j=0}^{i} A_{TW_j} + A_{GW_j} \tag{2}$$

Where, A_{TW_j} is the area loss due to traffic wear i.e.

$$A_{TW_j} = (RC_w + RG_W)TD_j \tag{3}$$

And, A_{GW_j} is the area loss due to grinding wear in period j.

$$A_{GW_i} = (RC_W + RG_W)GD_j \tag{4}$$

A_c is the critical railhead for rail replacement based on safety recommendation. A_i is the cross sectional rail profile area at ith interval. Real life field data was analyzed. The worn out level of rail after ith period as percentage of wear limit is given by:

$$WOL_i = 100 * \frac{A_0 - A_i}{A_0 - A_c} \tag{5}$$

The relative % area head loss for cross sectional rail head area A_i to A_{i+1} can be expressed as

$$\% \text{ Area head loss} = \frac{A_i - A_{i+1}}{A_i} * 100 \tag{6}$$

It can be further expressed considering MGT that is mm^2/MGT is:

$$\text{Area head loss per MGT} = \frac{(A_i - A_{i+1})}{(M_{i+1} - M_i)} = \frac{\Delta w}{\Delta MGT} \tag{7}$$

Costs related to the rail-wheel wear can be modelled as annuity for lubrication, risk, safety, noise, grinding, maintenance and replacement of worn-out rails and wheels. Life consumed can be expressed in terms of depth of wear and fatigue or material removal. Expressions for converting any one of the measures to another is possible using profile parameters and curve profile details. Jendel [23] discussed that for 300-400 m the wear rate is about 10-15 times lower in a lubricated curve than non-lubricated curves. For curves radius around 600 m the wear rate is about two-five times lower in lubricated curve than non-lubricated curve. From the analysis, by comparing the field data and the findings show that rail wear rate is 3-4 times higher for non-lubricated curve than lubricated curve.

Failure due to fatigue is analysed as shown in Figure 4. Technical input data is expected to be from simulated test rig and filed observations. Rail and wheel wear data are collected for development of prediction model. Cost data on annuity, risk, safety, noise problems, grinding, maintenance and replacement can be used in the model. Area loss/MGT due to traffic and grinding, track length and track curvature is also used. Then the model is to estimate expected area loss/MGT based on the field data.

Estimation of total maintenance cost in terms helps the rail infrastructure owners for budgeting rail replacements. Average area head loss for the curve 236.7 m radius is considered low with 17.6 mm2 per year. Standard STD/0077/TEC shows wear limit for 50kg SC radius for less than 500 m allows 856.6 mm2 area head loss. AUD $ 2,312,978 per annum in 2006 was re-railing for 10000 km. However, these values changes with the operating, weather conditions, traffic conditions and accuracy of data.
Factors influencing head loss rates include number of axle passes, curve radius, rail-wheel profile and material, hardness of material, rail/wheel interaction, rail-wheel grinding intervals, and lubrication at rail-wheel interface and maintenance decision. Proposed integrated rail wear fatigue prediction model could be able to monitor and control rail head loss due to wear and fatigue, and help finding out reasons behind abnormal degradation for corrective and preventive actions.

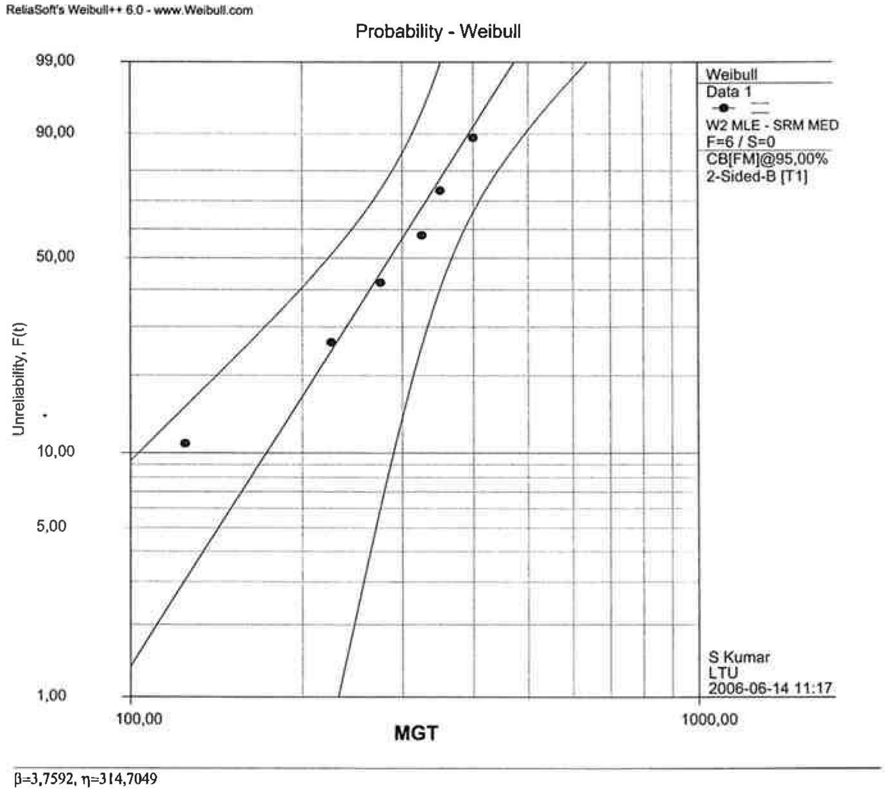

Figure 4. Analysis of rail break data for curve radius 500-600 metres [22]

Some of the tools for monitoring and control are as follows:

1. Identification of best curve and worst curve for application of lessons learnt
2. Application of statistical analysis of wear and fatigue rate and costs using mean and standard deviation (limit) for monitoring and control
3. Economic evaluation of maintenance decisions
    a. using wear fatigue rate model considering curve radius and curve length
    b. using above rail (rolling stock/wheel) and below rail wear and fatigue

Integrated Model proposed by Chattopadhyay and Reddy [24] and Chattopadhyay [25] are used for rail maintenance decision combining rail grinding, lubrication, inspection and rail replacement costs.

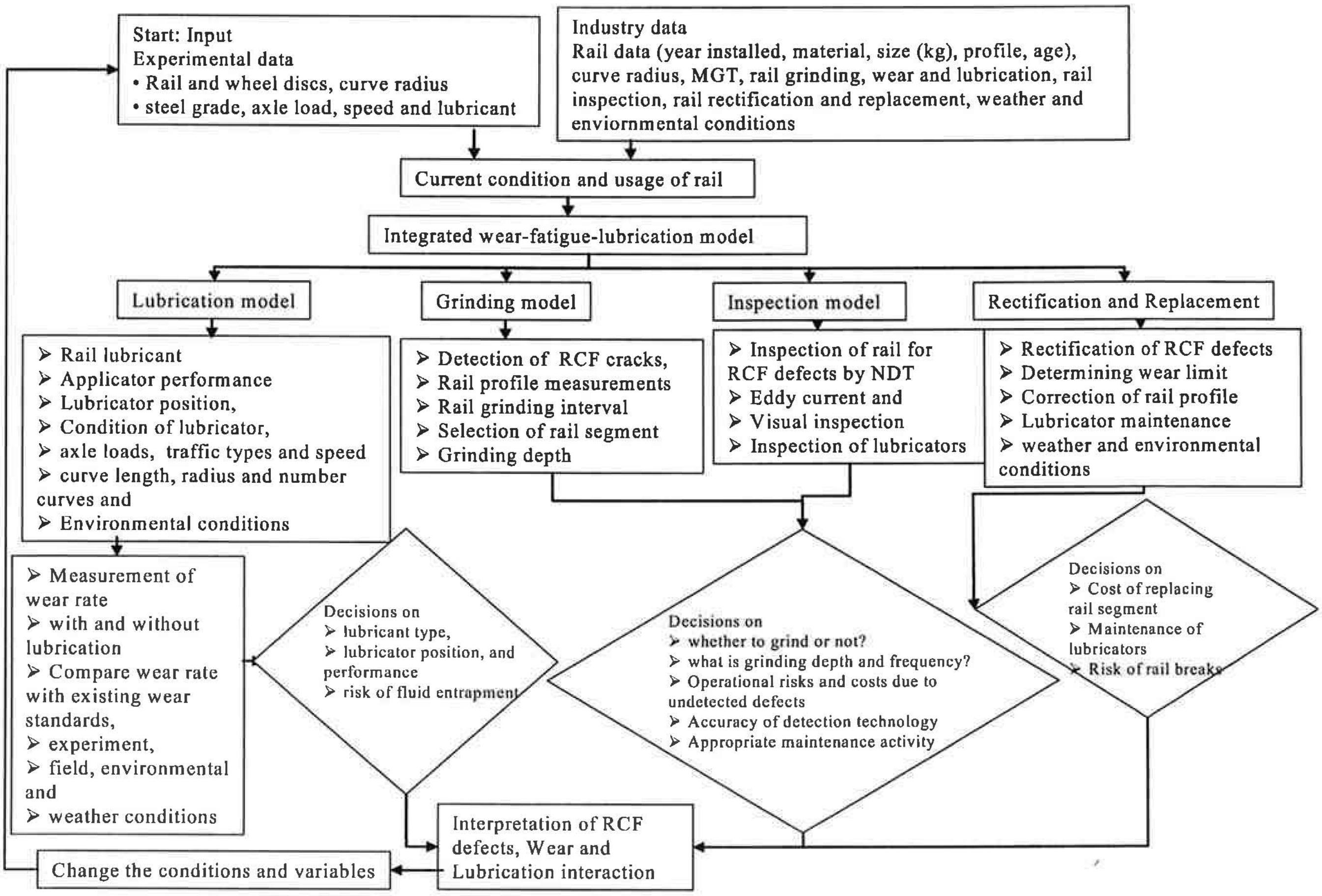

Figure 5: Integrated Maintenance Model [24, 25]

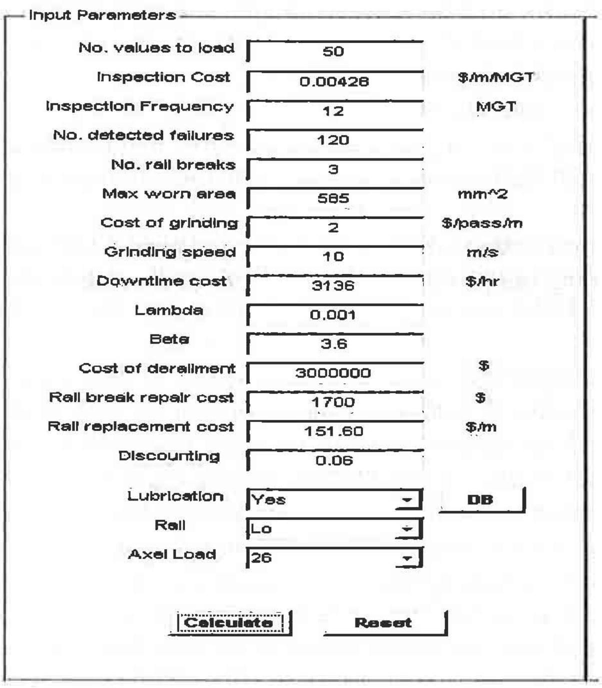

Figure 6: Prototype Decision Support System (input)

Output Results

	9 MGT	10 MGT	11 MGT	12 MGT	13 MGT	14 MGT	15 MGT	
Grinding annuity cost	3.07873e+006	2.84499e+006	3.04988e+006	2.21341e+006	3.105e+006	3.15251e+006	3.08685e+006	$
Inspection annuity cost	6348.52	6348.85	6351.6	6357.36	6364.77	6370.78	6380.1	$
Risk annuity cost	16.34	22.4786	43.1529	55.575	72.6123	65.6716	54.7827	$
Down-time annuity cost	241373	223047	239111	173531	243432	247156	242009	$
Replacement annuity cost	2.38819e+006	2.39026e+006	2.40745e+006	2.44351e+006	2.48988e+006	2.52747e+006	2.58583e+006	$
Lubrication annuity Cost	30498.5	30498.5	30498.5	30498.5	30498.5	30498.5	30498.5	$
Sum total annuity cost	5.71466e+006	5.46467e+006	5.70284e+006	4.83686e+006	5.84475e+006	5.93357e+006	5.92113e+006	$

	16 MGT	17 MGT	18 MGT	19 MGT	20 MGT	21 MGT	22 MGT	
Grinding annuity cost	2.98273e+006	3.11673e+006	2.99377e+006	3.05527e+006	3.05507e+006	3.25844e+006	3.21013e+006	$
Inspection annuity cost	6414.61	6427.8	6417.44	6428.93	6477.8	6584.38	6493.43	$
Risk annuity cost	99.4234	92.3658	96.5219	117.233	114.712	139.866	95.0006	$
Down-time annuity cost	233846	244351	234712	239534	239517	255462	251674	$
Replacement annuity cost	2.64683e+006	2.74924e+006	2.81949e+006	2.8914e+006	3.02551e+006	3.2165e+006	3.16696e+006	$
Lubrication annuity Cost	30498.5	30498.5	30498.5	30498.5	30498.5	30498.5	30498.5	$
Sum total annuity cost	5.86992e+006	6.11683e+006	6.05448e+006	6.19275e+006	6.32669e+006	6.73713e+006	6.63535e+006	$

Figure 7: Prototype Decision Support System (output)

Decision support system developed by using weighted field and lab data for prediction of wear and fatigue loss by measuring the traffic wear and grinding wear using Miniprop before and after grinding. Total cost is sum of grinding, lubrication, inspection, replacement, downtime and risks. Screen shots of prototype system are shown in Figure 6 and 7 for illustration. Decisions on whether to lubricate or not, inspection interval to reduce risks, appropriate traffic and grinding wear loss and replacement decisions are based on total cost of combination decisions.

4. SUMMARY AND CONCLUSIONS

This paper proposed a hierarchy for analysis of field data over a period of time for maintenance cost model. Risk based cost benefit model is developed and built into the system for enhancing network performance, reducing costs and operational risks. It has proposed rail wear prediction model which looks into area loss/MGT due to traffic and grinding wear as a function of MGT, track length and curve radius. There is huge scope on future work on developing best curve and worst curve models for managerial decisions. The prototype developed is being investigated by one of the rail operators in Australia.

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