International Symposium of Research Students on Material Science and Engineering
December 20-22, 2004, Chennai, India
Department of Metallurgical and Materials Engineering, Indian Institute of Technology Madras

DEVELOPMENT OF FRAMEWORK FOR INTEGRATED PREDICTION MODELS FOR ANALYSIS OF OPERATIONAL RISKS DUE TO ROLLING CONTACT FATIGUE (RCF) AND RAIL/WHEEL WEAR

V. Reddy
Queensland University of Technology School of MMME 2, George Street P.O Box 2434
Brisbane QLD 4001, AUSTRALIA, phone +61 73864 5106, fax +61 73864 1469

ABSTRACT

Rolling contact fatigue (RCF) and rail/wheel wear are problems for railway companies leading to rail degradation, rail breaks and derailments. These problems result in huge loss of revenue, service and lives. Cost of repairs and compensation payments after the Hatfield, UK (2000) accident was £580 Million. The main cause was RCF. Increasing speed, axle loads and tonnages increases risks in railtrack under various operating conditions. Review of current research shows that most of the predictive models are based on Million Gross Tonnes (MGT). This research looks into development of a framework for integrated prediction models for mitigation of operational risks due to RCF and rail/wheel wear.

KEYWORDS: Rolling contact fatigue (RCF), Rail/Wheel Wear, Risk Analysis.

1. INTRODUCTION

Despite advances in maintenance, inspection and rail manufacturing technology, increased axle load and frequencies results in surface fatigue and traffic initiated wear. Literature review shows that rolling contact fatigue (RCF) such as squats and head check defects have been increasing due to introduction of longer and heavier trains with increased axle loads and speed (Railtrack Plc, 2001). European Union estimated that premature rail removal, renewal and maintenance costs due to these problems amount to 300 Million Euros ($US 319 Million) per year (Sawley and Reiff, 2000). Railtrack Degradation modelling is complicated due to the large number of variables and their interactions. Predicting degradation is extremely important for safety and reliability of rail infrastructure. Researchers in modelling rail degradation have looked into total Million Gross Tonnes (MGT), lubrication, rail and wheel grinding and other factors in isolation which has limited the effectiveness of prediction of models. There is a need for integrated studies to improve the accuracy of predictive models (Clayton, 1996). This paper focuses on development of a framework for integrated prediction models for mitigation of operational risks due to RCF and rail/wheel wear. Section 1 introduces the effect of rolling contact fatigue (RCF) and variables that led to rail degradation, rail defects and rail breaks and derailments. Section 2 discusses the modelling risk cost of rail breaks and derailments and research analysis. Section 3 provides a frame work for integrated prediction models for mitigation of operational risks. In concluding section summary and future work are discussed.

2. MODELLING RISK COST OF RAIL BREAKS AND DERAILMENTS

In spite of aggressive grinding programs along with frequent onboard non-destructive measurements rail breaks happen. Increasing demand of speed, axle loads, tonnages, revenue and productivity leads to increasing risks in rail track under various operating conditions. Risk analysis of rail track and wheel is a complex process. Rail operating conditions depend on train speed, axle loads, number of axle passes, tonnage, curve radius, rail wheel profile, material, hardness, interaction, grinding lubrication and maintenance factors.

The cost of due to rail breaks and derailments is considered as risk cost. For infrastructure players it is essential to measure and estimate these risks by implementing cost effective traffic and maintenance management strategies. Questions commonly asked are:

- How much is the current risk of rail break and derailment on a specific track section?
- Will the current risk change with changed maintenance strategies in the future? and
- What is the cost-benefit ratio of various strategies in terms of maintenance costs and risk costs?

The total cost of maintaining any segment of rail is modelled as the sum of costs for, rail grinding, down time due to rail grinding (loss of traffic), rectification and associated costs of rail breaks, derailment, inspection and replacement of worn-out rails. Using the statistical data on derailments, rail breaks and rectifications initiated by routine inspections the expected costs are estimated. Finally the total costs for different traffic situation and grinding strategies are analysed using annuity method.

Rail track is made operational through repair or replacement of the failed segment and no action is taken with regards to the remaining length. Since the length of failed segment replaced at each failure is very small relative to the whole track, the rectification action can be viewed as having negligible impact on the failure rate of the track as a whole, see Barlow and Hunter, (1960). Then the expected number of failures over period i and (i+1) is given by:

$$E[N(M_{i+1}, M_i)] = \lambda^{\beta}((M_{i+1})^{\beta} - (M_i)^{\beta}) \qquad (1)$$

Where M_i is the total accumulated MGT of the section studied up to decision i [$kg \cdot 10^6$]
N is the total number of periods up to safety limit for renewal, $N(M_{i+1},M_i)$ Number of failures over M_i and M_{i+1}. β, λ are Weibull parameters.

Let cost per rectification of rail breaks on emergency basis, C_r be modelled through $G(c)$, and is given by

$$G(c) = P[C_r \le c] \qquad (2)$$

For an example, if $G(c)$ follows exponential distribution (Crowder et al., 1995), then it is given by

$$G(c) = 1 - e^{-\rho c} \qquad (3)$$

where $\bar{c}$ denote the expected cost of each rail break repair on emergency basis and is given by

$$\bar{c} = [1/\rho] \qquad (4)$$

Let k be the expected cost of repairing potential rail breaks based on NDT in a planned way and a be the expected cost per derailment. Then k and a could be modelled in similar manner. The risk cost associated with rail break and derailment is based on the probability of NDT detecting potential rail breaks, rail breaks not detected by NDT, derailments and associated costs. Let $P_i(B)$ be the probability of detecting potential rail break in NDT, $P_i(A)$ be the probability of undetected potential rail breaks leading to derailments, n_{NDT_j} be the number of NDT detected potential rail breaks, n_{RB_j} be the number of rail brakes in between two NDT inspections and n_{A_j} be number of accidents in period. Then the risk cost is given by:

$$c_r = \{\sum_{i=0}^{N} E[N(M_{i+1}, M_i)] * [P_i(B) * k + (1 - P_i(B)) * (P_i(A) * a + (1 - P_i(A)) * \overline{c}] / \\ (1+r)^i\} * (1 - (1/(1+r_y))) * (1+r_y) / (1 - (1/(1+r_y)^y)) \qquad (5)$$

where $P_i(B)$ and $P_i(A)$ could be estimated based on n_{NDT_j} the number of NDT detected potential rail breaks, n_{RB_j} the number of rail brakes in between two NDT inspections and n_{A_j} be number of accidents in between two NDT inspections over *j* periods. Figure 1 shows the probability of failures.

Research analysis that the annuity cost/meter for 9 and 18 MGT intervals is higher compared to 23 and 12 MGT intervals. This is due to excessive grinding. The data on risk cost based on very small number of derailment incidents and there is enough scope for estimating actual risk cost based on real life derailment data.

3. INTEGRATED APPROACH AND FRAME WORK FOR PREDICTION MODELS

Figure 2 shows an integrated approach proposed in this research to improve rail-wheel maintenance effectiveness and reduce cost. It provides the frame work, assumptions needing to be considered to develop new models to enhance rail-wheel life.
Most of the researchers have been used Million Gross Tonnes (MGT) for predicting rail/ wheel condition. They have not considered many of the factors influential to predict risk for prevention of conditions leading to rail breaks and derailments.

This research will look into the important factors associated with operational risks modelled in Figure 3. Mathematical models and Management system and decision support system for predicting operational risks will be developed and validated using field and lab experiments.

4. CONCLUSION AND SCOPE FOR FUTURE WORK

Rolling contact fatigue and rail wear problems were analysed. Rail degradation and risk models due to rail breaks and derailments are discussed. Data collected from Swedish Rail and Queensland Rail for illustration. Risk cost model considering rail breaks and derailments are presented. Research analysis shows that rail players can save with 12 MGT intervals compared to 23, 9, and 18 MGT intervals. Author is currently working in developing integrated economic models to identify and assess operational risks in rail track and results will be published in the near future.

5. REFERENCES

1. Barlow, R. E. and Hunter, L. Optimum Preventive Maintenance Policies, “Operations Research 8”, (1960) pp. 90-100.
2. Chattopadhyay, G., Reddy, V., Hargreaves, D. and Larsson, P. O., “Assessment of Risks and Cost Benefit Analysis of Various Lubrication Strategies for Rail Tracks Under Different Operating Conditions”, Published in TRIBOLOGIA – Finnish Journal of Tribology, Norway, September 2004.
3. Chattopadhyay, G., Reddy, V. and Larsson, P. O., “Integrated Model for Assessment of Risks in Rail Tracks under Various Operating Conditions”, International Journal of Reliability and Applications, 4.4, (2003) 183-190.
4. Chattopadhyay, G., Reddy, V. and Larsson, P. O., (2003) “Mathematical modelling for optimal rail grinding decisions in maintenance of rails”, Condition Monitoring and Diagnostic Engineering Management (COMADEM 2003) Proceedings of the 16th International congress, (2003) 565-572.

5. Chattopadhyay, G., Reddy, V., Larsson, P. O. and Hargreaves, D., "Development of Optimal Rail Track Maintenance Strategies based on Rolling Contact Fatigue (RCF), Traffic Wear, Lubrication and Weather Condition", Published in Proceedings of the 5th Operations Research Conference on Operation Research in the 21st Century, the Australian Society of Operations Research, Sunshine coast, Australia, 9-10 May, (2003) P 54-66.
6. Chattopadhyay, G., Reddy. V., Hargreaves, D. and Larsson, P. O. "Comparative Evaluation of Various Rail-Wheel Lubrication Strategies". Published in Condition Monitoring and Diagnostics Engineering Management. Proceedings of the 17th International Congress and Exhibition on Condition Monitoring and Diagnostic Engineering Management, (COMADEM 2004) The Robinson College, Cambridge, UK, ISBN 0-954 1307-1-5, (2004) 52-61.
7. Chattopadhyay, G., Reddy. V., Ong, T. K., and Hayne, M. "Development of a Low Cost Data Acquisition System for Condition Monitoring of Rail Tracks". Published in Condition Monitoring and Diagnostics Engineering Management. Proceedings of the 17th International Congress and Exhibition on Condition Monitoring and Diagnostic Engineering Management, (COMADEM 2004) The Robinson College, Cambridge, UK, ISBN 0-954 1307-1-5, (2004) 62-69.
8. Reddy. V., Chattopadhyay, G. and Ong. P. K., "Modelling & analysis of risks due to broken rails & rail defects". Full paper accepted for publication by VETOMAC-3 & ACSIM-2004 Conference, 6th – 9th December 2004, New Delhi, India.
9. Reddy, V., Chattopadhyay, G. and Larsson, P. O., "Technical vs. Economical decisions: A case study on preventive rail grinding". Full paper accepted for publication in proceedings of The Fifth Asia-Pacific Industrial Engineering and Management Systems Conference & The Seventh Asia-Pacific Division Meeting of the International Foundation of Production Research, December 12-15, 2004, Gold coast, Australia.
10. Chattopadhyay, G., Reddy. V., Hargreaves, D. and Larsson-Kraik, P. O., "Integrated Rail & Wheel Maintenance Model for Cost sharing by Rail Players". Full paper submitted for review to VETOMAC-3 & ACSIM-2004 Conference, 6th – 9th December 2004, New Delhi, India. (Full paper submitted on 051004).
11. Clayton, P. (1996), "Tribological aspects of wheel-rail contact: a review of recent experimental research", Wear, Vol. 191, (1996) pp. 170-183.
12. Crowder, M. J., Kimber, A. C., Smith, R. L. and Sweeting, T. J., "Statistical Analysis of Reliability Data", Chapman & Hall, London SE1 8HN, UK (1995).
13. Sawley, K., and Reiff, R., "Rail Failure Assessment for the Office of the Rail Regulator", "An assessment of Rail track's methods for managing broken and defective rails". Transportation Technology Center, Inc. A subsidiary of the Association of American Railroads, Pueblo, Colorado USA (2000) P-00-070.

FIGURES

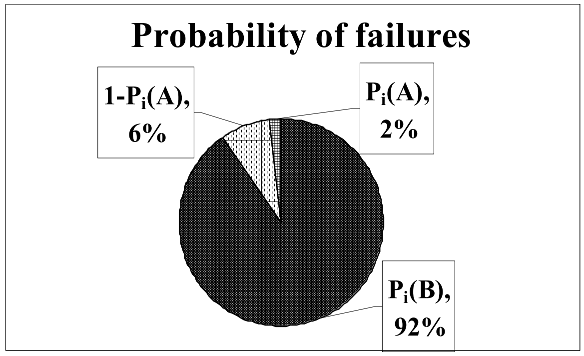

Figure 1: Probabilities of failures

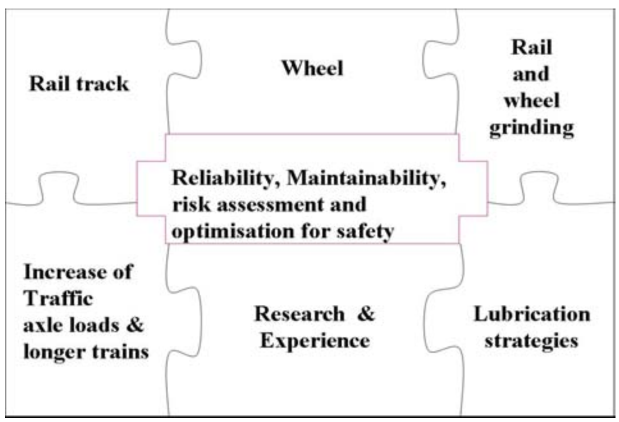

Figure 2: Integrated approach to improve rail and wheel maintenance strategy

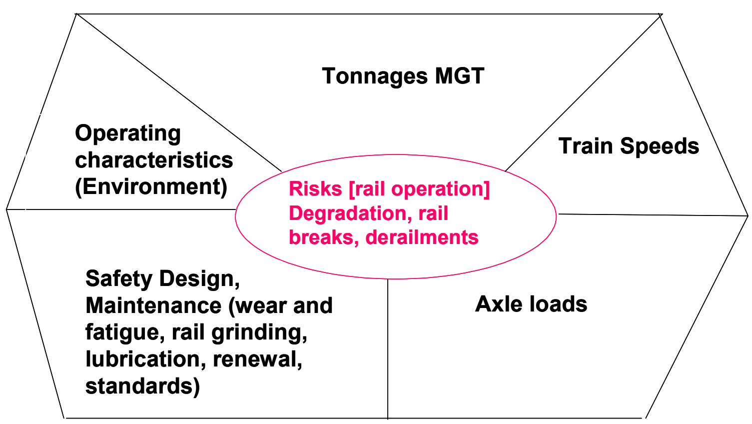

Figure 3: Integrated model for operational risks (Chattopadhyay et al., 2003)