

Mechanics-Based Model to Predict Ballast-Related Maintenance Timing and Costs

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Summary

The AAR has developed a mechanics-based model (BALLAST2) which predicts the timing of required ballast maintenance based on track settlement and roughness. With this model, track maintenance costs and increased track roughness may be minimized by considering alternative ballast-related maintenance and purchasing decisions.

BALLAST2 calculates cost on the basis of all activities associated with the ballast life cycle. Track roughness is calculated on the basis of uneven settlement of the ballast, subballast, and subgrade: in short, the sub-structure layers.

With user-defined track material properties, loading characteristics, and maintenance techniques to be applied, the model determines the rate of track roughness increase and applies the desired maintenance when such roughness exceeds a user defined limit. This analysis is continued, usually over the life of the ballast, and the related life cycle cost is calculated. For another ballast material or maintenance technique, a lower or higher cost may be realized. This allows the model user to observe the effect upon ballast maintenance and cost of using concrete rather than wood ties, a heavier axle load, or increasing the track stiffness. Because the life cycle cost is used, purchasing decisions based upon the least present costs can be avoided. Instead, the model allows the user to optimize by considering all the associated costs incurred during the ballast life.

Copies of the model will be available for AAR members and non-members in November 1993. Contact the individual listed at the end of this digest to obtain a copy.



Association of American Railroads
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INTRODUCTION AND CONCLUSIONS

Class 1 railroads in the United States each spend millions of dollars annually on the purchase of ballast material and ballast-related maintenance activities. The selection of maintenance technique and timing of such maintenance is often determined by precedent and the need to work within existing maintenance budgets. BALLAST2 was developed to provide a more rational way of deciding the timing and selection of ballast maintenance techniques.

The model is based on data from laboratory and field measurements of strains and settlements of the sub-structure layers. Track structure and material characteristics were analyzed to determine how changes in their properties affect the settlement rates of the sub-structure layers. From this, non-uniform settlement (track roughness) arises which is calculated on a yearly basis and displayed by the model.

The following items describe features of the model:

- Track settlement from the strain of the sub-structure layers can be reliably predicted based on the physical characteristics of these layers and the track super-structure.
- The track super-structure material characteristics can strongly influence the substructure rate of settlement and, therefore, the track maintenance requirements and costs.
- Track recording car data can be used to characterize track roughness in terms of the standard deviation of mid-chord vertical offsets (σ_{vo}) for a length of track.
- Track settlement is converted to roughness. Based on the observed relationship between the two parameters, one inch of track settlement results in approximately 0.2 inches σ_{vo} .

- The model can help determine the most economical ballast maintenance technique and ballast material selection based on the minimum life cycle cost.

MAINTENANCE STRATEGIES

The model user may choose from three possible maintenance strategies:

1. **Renew** the ballast in the present by:

- a) undercutting-cleaning (U/C) or
- b) plowing

2. **Tamp** the existing ballast in the present **then renew** the ballast later when the life of the current ballast is expired by:

- a) U/C or
- b) plowing.

3. **Tamp** the existing ballast in the present and as needed in the future **without renewal** of the ballast, but with added increments of new ballast.

Substructure Layer Settlement and Associated Track Roughness

The model is unique in that it considers the mechanisms causing strain in the substructure layers. The strains (ϵ) of the ballast and subballast layers are multiplied by the respective layer heights (H) and added to the calculated subgrade compression (δ) resulting in the equation:

$$S_L = \epsilon_{ball} * H_{ball} + \epsilon_{subball} * H_{subball} + \delta_{subgrade}$$

where S_L is average track settlement. S_L is then multiplied by a factor found to relate the average settlement to associated uneven settlement or track roughness. The rate of track roughness growth with average settlement is:

$$\sigma_{vo} = (\sigma_{vo}) + 0.2 S_L$$



where $(\sigma_{vo})_{min}$ is the roughness value just after tamping, and 0.2 is the ratio of σ_{vo} increase to average settlement increase. When the σ_{vo} equals or exceeds a user-input limiting value, the model determines that track smoothing is required.

Example output in Exhibit 1 shows how the track roughness (standard deviation) is displayed on an annual basis. Also displayed is the percent of ballast life remaining for that year of the analysis. The ballast life is determined using the CP Rail approach. CP Rail relates ballast life to (1) the ballast gradation and (2) to the results from the Los Angeles Abrasion and Mill Abrasion tests. In this way, ballast life is defined by the amount of open void space between the particles and the rate of void filling due to particle breakdown.

	Year	STD. DEV. (in.)	% Ballast Life Used
For this maintenance strategy & the data as input, the EAC (\$/mile) = \$4,700	1993	0.10	10
	1994	0.18	14
	1995	0.22	18
	1996	0.26	22
	1997	0.30	26
	1998	0.34	31
	1999	0.38	35
	1999	0.10	36
	2000	0.16	40
	2001	0.20	44
	2002	0.24	48
	2003	0.28	52
	2004	0.32	57
	2005	0.36	61
	2005	0.10	63
	2006	0.16	67
2007	0.20	71	
2008	0.24	76	
2009	0.28	80	
2010	0.32	84	
2011	0.38	88	
2011	0.10	90	
2012	0.19	95	
2013	0.29	99	
2014	0.38	103	

Exhibit 1. Example Output Page of Model Showing Track Roughness & Ballast Life Remaining per Year.

MODEL OUTPUT

With the end of the maintenance requirement analysis, the model computes the cost of the initial maintenance and that of the maintenance performed during the ballast life. All costs are converted to a series of uniform yearly payments (or equivalent annual cost, EAC) made over the ballast life. This EAC is displayed in the worksheet along with the calculated yearly track roughness and remaining ballast life data as shown in Exhibit 1. The yearly track roughness and EAC is shown by the model as in Exhibit 2 for the maintenance strategy of undercutting in the present and tamping when required. Note the upper and lower roughness limits indicated by the horizontal lines.

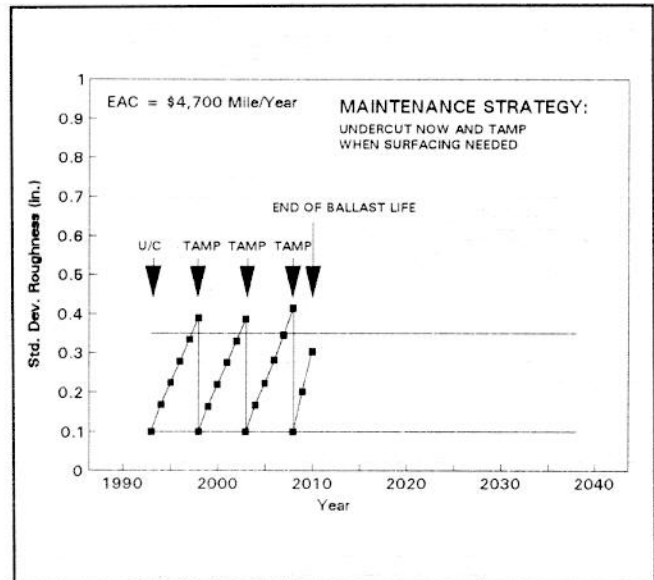


Exhibit 2. Top-of-Rail Longitudinal Roughness with Traffic & Maintenance.

Comparisons between ballast maintenance techniques and ballast material choices may be made on an economic basis. As shown in Exhibit 3, the model can be run repeatedly to determine the ballast maintenance technique and ballast material selection which results in the most cost effective solution. For the example data used, maintenance strategy 2a is the least cost option.

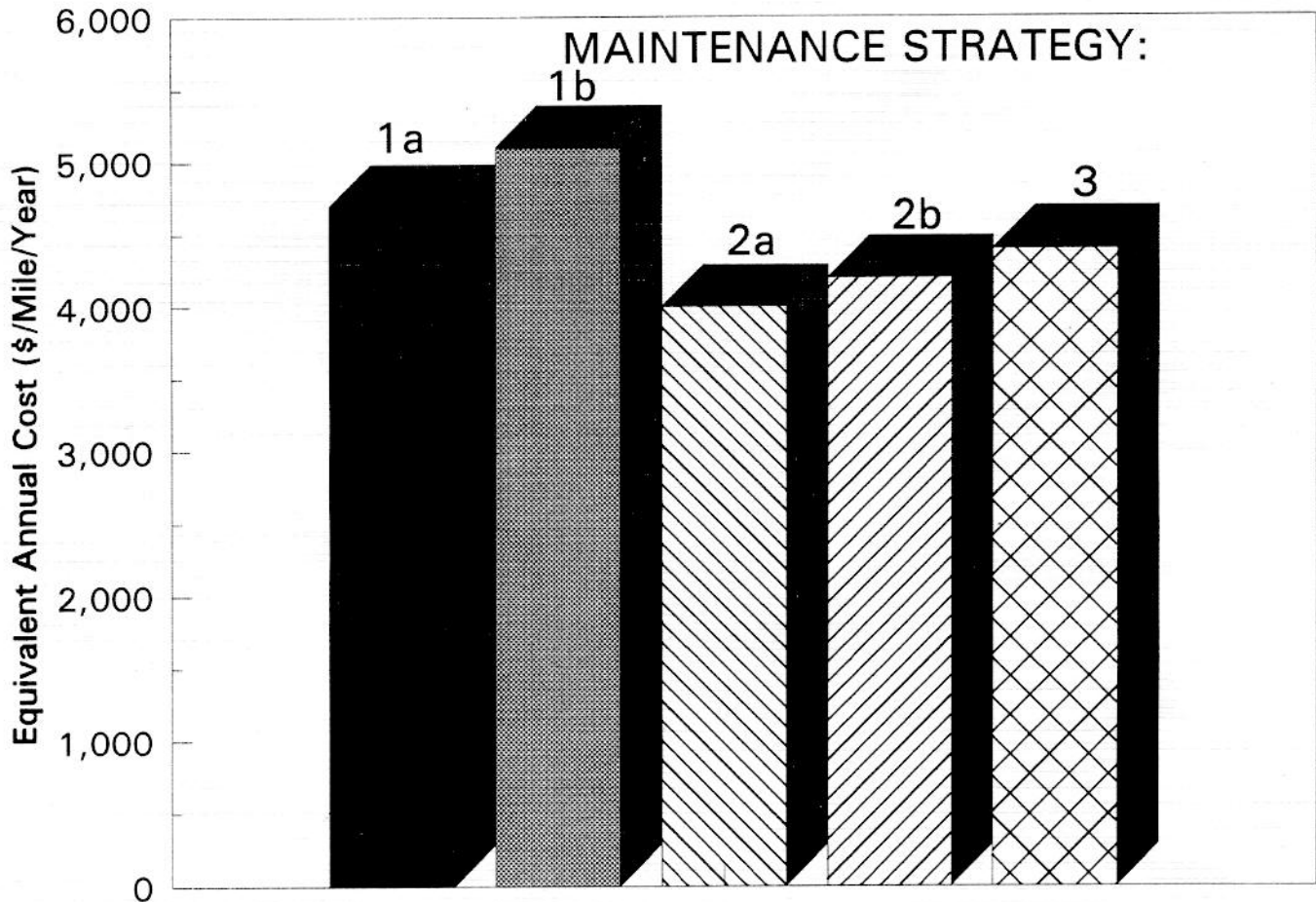


Exhibit 3. Comparative Costs for Different Maintenance Strategies.

Note: Contact S. M. Chrismer at (312) 808-5848 with questions or comments about this document.

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