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Economic Effect of Imbalanced Loads on Bridges

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Summary

As part of an effort initiated in 2006 to reduce the stress state of the North American railroad system by reducing imbalanced car loads, the Transportation Technology Center, Inc. (TTCI), a wholly owned subsidiary of the Association of American Railroads (AAR), Pueblo, Colorado, completed an economic analysis of the effects of imbalanced loads and overloads on bridges in 2007.

The simulations indicate that correction of all imbalances would save from about 2 to nearly 4 percent of overall annual bridge (capital and operational) costs for some routes. Correcting imbalances of 5 percent or greater would save from about 1.0 to 2.5 percent. If applied to all North American bridge costs at the rates predicted, correcting imbalanced loads of 5 percent or above could result in a savings of over \$1 million per year.

A normalized cost per imbalanced load car mile operated was established by TTCI for each of the imbalanced load ranges considered. Although imbalanced loads greater than 16 percent had the greatest impact per car mile, because there were relatively few cars operating at these high levels, their overall effect was minimized.

Imbalanced loads in traffic carrying coal, steel slabs, and rock were simulated operating over hypothetical AAR eastern and western coal routes that were developed as part of the 1995 heavy axle load economic study.¹ End-to-end and side-to-side imbalanced loads and overloads were considered separately.

A series of hypothetical trains was assembled for the simulation with imbalanced loads imposed based on as-measured conditions for each commodity. Four imbalance correction scenarios were developed with thresholds at 16 percent or greater imbalance, 10 percent or greater imbalance, 5 percent or greater imbalance, and all imbalances corrected (0 percent). A fifth scenario, with all overloads corrected, was also considered.

Bridge fatigue life was estimated using a bridge loading model in conjunction with a bridge and economics model by the AAR.

Data from different Wheel Impact Load Detector sites was used to characterize typical commodity in-service load imbalances for typical commodity loads, which were chosen as worst performers based on interviews with mechanical officers of several member railroads.

Results of this effort will be combined with results of similar efforts exploring the effects of imbalanced loads on track, fuel, and vehicle costs.

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INTRODUCTION AND CONCLUSIONS

As part of an effort to reduce the stress state of the North American railroad system by reducing imbalanced car loads, TTCI completed an economic analysis of the effects of imbalanced loads and overloads on bridges in 2007. North American Class I railroads typically spend over \$700 million on bridges annually (combined capital and operating costs).

Imbalanced loads in traffic carrying coal, steel slabs, and rock were simulated operating over hypothetical eastern and western coal routes.¹ End-to-end and side-to-side imbalanced loads and car and truck overloads were simulated. Effects of correcting imbalances of 16 percent or greater, 10 percent or greater, and 5 percent or greater, correcting all imbalanced loads (0 percent), and overloads were considered.

The simulations indicate that correction of all imbalances would save from about 2 to nearly 4 percent of overall annual bridge capital and operation costs for some routes. Correcting imbalances of 5 percent or greater would save from about 1.0 to 2.5 percent. If applied to all North American bridge capital and operation costs at the rates predicted, correcting imbalanced loads of 5 percent or above could result in savings of over \$1 million per year.

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TYPICAL ROUTES AND TRAFFIC

The typical western coal route was assumed to be 547 miles in length, with 26 feet of steel bridges and 5.3 feet of timber bridges per mile. It was assumed to carry 100 million gross tons (MGT) per year. The typical eastern coal route was 144 miles in length with 52.3 feet of steel bridges and 4.1 feet of timber bridges per mile with 50 MGT per year.

Data from Wheel Impact Load Detector (WILD) sites was used to characterize typical load imbalances for coal, steel slabs, and rock. This data was used to establish typical traffic for each of the commodities considered and a base case annual cost. A series of progressively restrictive correction cases was then considered, starting at a value that would likely affect vehicle performance, to an ideal case where all imbalances were corrected. Annual costs were predicted for correction of imbalances 16 percent or greater, 10 percent or greater, 5 percent or greater, 5 percent or greater. Also, correction of all car and truck overloads was considered.

RESULTS

Figure 1 shows the predicted base case overall bridge cost of operating typical commodity traffic over each of the routes. The large difference between the eastern and western routes reflects the difference in route length. These base case costs were used to estimate savings at the various correction levels.

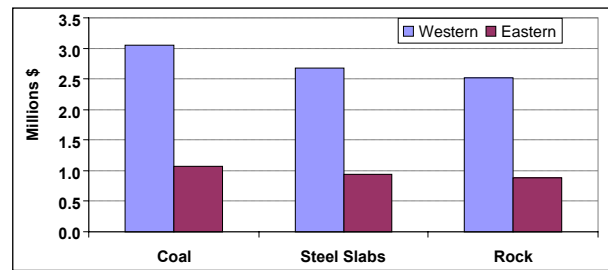


Figure 1. Base Case Annual Bridge Cost by Commodity

Figures 2 to 5 show the predicted savings for each commodity. Savings for correcting all imbalanced loads range from about 2 to nearly 4 percent. The greatest savings were predicted for correction of all steel slab side-to-side imbalances on the western route. This was followed by coal at about 3.5 percent, steel slabs end-to-end imbalances at about 3 percent, and rock.

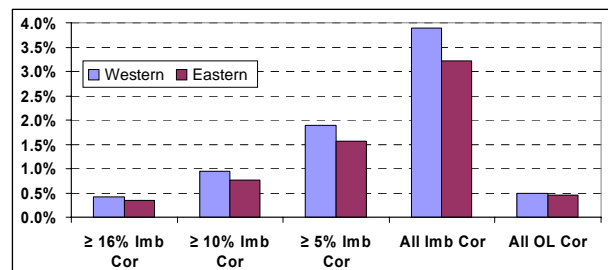


Figure 2. Overall Annual Bridge Cost Savings - Steel Slabs Side-to-side

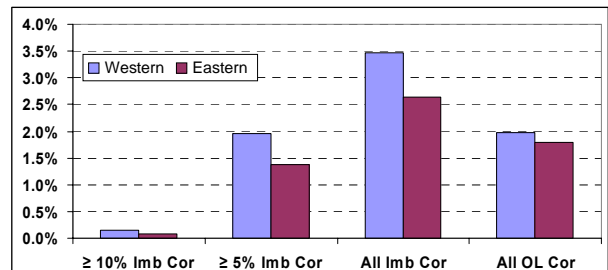


Figure 3. Overall Annual Bridge Cost Savings - Coal

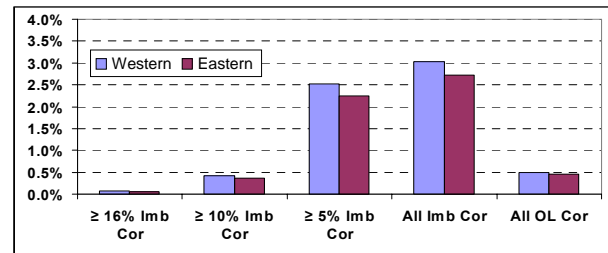


Figure 4. Overall Annual Bridge Cost Savings - Steel Slabs End-to-end

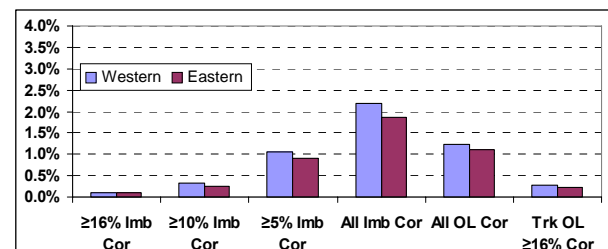


Figure 5. Overall Annual Bridge Cost Savings - Rock

A more realistic goal may be to correct all imbalances above 5 percent. At this level, the greatest saving, about 2.5 percent, was predicted for end-to-end imbalanced loads on steel slabs, followed by coal, rock, and side-to-side imbalanced loads on steel slabs. The greatest savings for correction of overloads was for coal at about 2 percent. Costs of correcting imbalances were not considered within this effort.

Figures 6 and 7 show predicted normalized bridge cost per imbalanced car mile for each route for the following bands:

- Imbalance \geq 16 percent
- 16 percent > imbalance \geq 10 percent
- 10 percent > imbalance \geq 5 percent
- 5 percent > imbalance > 0 percent

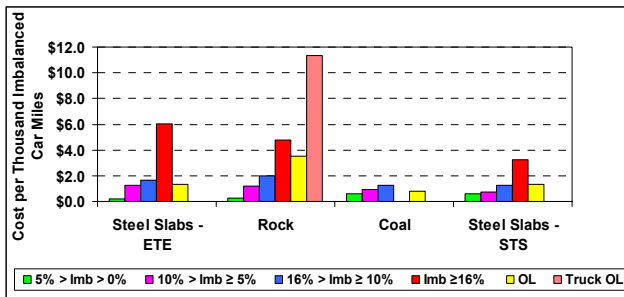


Figure 6. Predicted Bridge Cost per Imbalanced/Overloaded Car Mile — Eastern Route

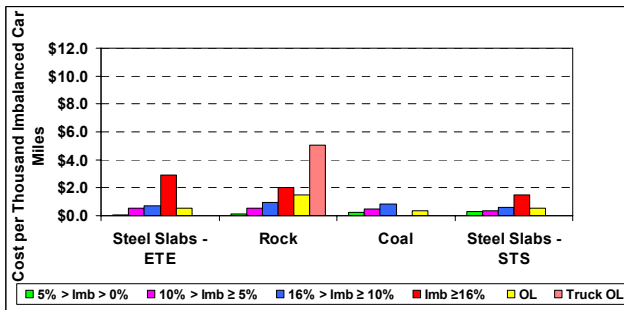


Figure 7. Predicted Bridge Cost per Imbalanced/Overloaded Car Mile — Western Route

Truck overloads on rock cars had the greatest impact per imbalanced car mile. Because there were relatively few cars operating at these high imbalance levels, their overall effect was minimized. The greatest normalized cost was predicted for truck overloads operating on the eastern route — about \$11 per thousand car miles. Data for coal traffic indicated that no cars with an imbalance greater than or equal to 16 percent were present.

METHODOLOGY

Bridge fatigue was dependent upon cyclic stress range and the effect of the applied load on each component, as well as the influence line length of each component.² Therefore, a detailed fatigue analysis on the component level was required. This analysis relied heavily on the 1995 heavy axle load (HAL) economic model by the AAR and fatigue analysis methods for steel bridges recommended by the American Railway Engineering and Maintenance-of-Way Association (AREMA).^{1,3}

It was assumed that the effect of imbalanced loads on concrete bridges was negligible, due to the relatively new age of the concrete bridge population.

Timber bridges were affected by cyclic load effects as well as by environmental factors. A fatigue curve, developed by TTCI and Texas A&M University based on a series of destructive tests, was used to estimate fatigue damage of timber stringers.⁴ Economic analysis of the effects of imbalanced loads and overloads on bridges was carried out as follows:

1. A series of hypothetical trains was assembled for simulation with imbalanced loads and overloads imposed based on as-measured conditions for each commodity. The imbalanced loads were randomly distributed throughout the train so that stress-cycle effects of two adjacent heavy or light trucks would be properly accounted for. The orientation of heavy/light trucks was preserved.
2. Five correction scenarios developed with thresholds at:
 - 16 percent imbalance
 - 10 percent imbalance
 - 5 percent imbalance
 - 0 percent, all imbalanced loads
 - All overloads
3. Each of the correction scenarios was applied to the series of trains. For example, for the 16 percent imbalance threshold, all cars with imbalanced loads at 16 percent or above were theoretically corrected to a no-imbalance condition and returned to the train. So that each condition can be considered separately, corrections for imbalanced loads preserved any overloads that occurred and corrections for overloads still had proportional imbalances.
4. A fatigue life was estimated at a component level for bridge populations established for the typical eastern and western routes.
5. Bridge costs were established for each scenario, commodity, and route. The 1995 HAL economic model was used for steel bridges. An analysis based partly on expert opinion was used for timber bridges.¹

TTCI used a specialized FORTRAN program to determine the stress effect of passing each of the hypothetical trains over each major component in the 35 steel bridges and stringers for a typical timber bridge.⁵ Given axle load and spacing for a hypothetical train, the model produces a stress time history for a given component. More than 1,200 trains were simulated over 64 individual components. Results were used to estimate fatigue life using methods recommended by AREMA for steel bridge components and by Uppal, et al. for the timber bridge stringers.^{1,2}

TTCI then used the 1995 HAL economic model to estimate route bridge costs. The model was configured to include the number and type of bridges established for typical eastern and western routes. Fatigue factors for each component were modified based on the change in fatigue life from 286,000-pound traffic from the analysis described above.

Timber bridge fatigue life was influenced by environmental factors as well as load-based factors. Based on input from

several chief bridge engineers, it was assumed that 50 percent of bridge deterioration on the western route and 75 percent of bridge deterioration on eastern route were due to environmental factors with the remaining deterioration due to fatigue.

MEASURED DATA

Data from different WILD sites was used to characterize in-service imbalance for typical commodity loads, which were chosen as worst performers based on interviews with mechanical officers of several AAR members. The sites/commodities chosen were in the following locations:

- Powder River Basin — 286,000-pound gross rail load (GRL) coal traffic
- Pennsylvania — large volume of 263,000-pound GRL mill gondolas carrying steel slabs
- Texas — large volume of 286,000-pound GRL hoppers carrying rock

Car data from each of the sites was filtered and analyzed. Figure 8 shows the measured end-to-end imbalance for each commodity considered. All commodity distributions were similar, with the greatest variation in the rock cars. Figure 9 indicates the side-to-side imbalance, with steel slab cars showing a large number of imbalanced loads, with a significant number greater than 20 percent imbalanced. Similarly, Figure 10 shows overloads for the commodities considered.

Based on the measured distributions exhibited in Figures 6 through 8, it was decided to consider end-to-end and overloads on all three commodity groups and to consider side-to-side imbalance on steel slab cars due to the longer tail in the side-to-side distribution.

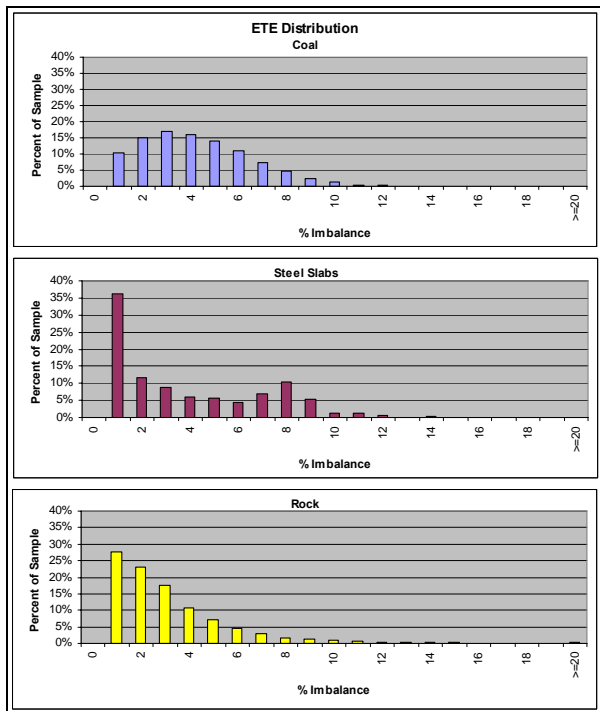


Figure 8. End-to-end Imbalanced Loads by Commodity

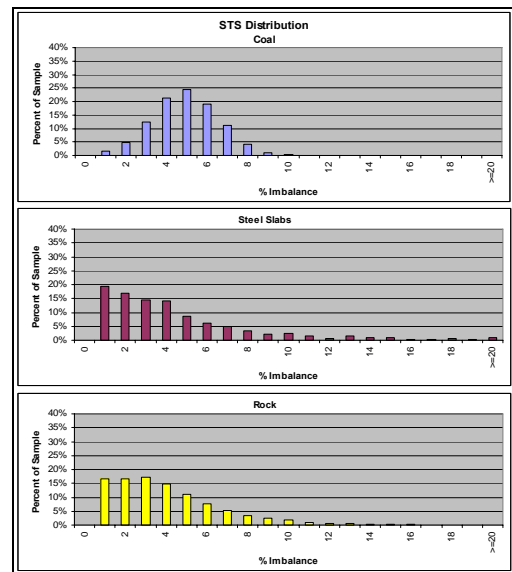


Figure 9. Side-to-side Imbalanced Loads by Commodity

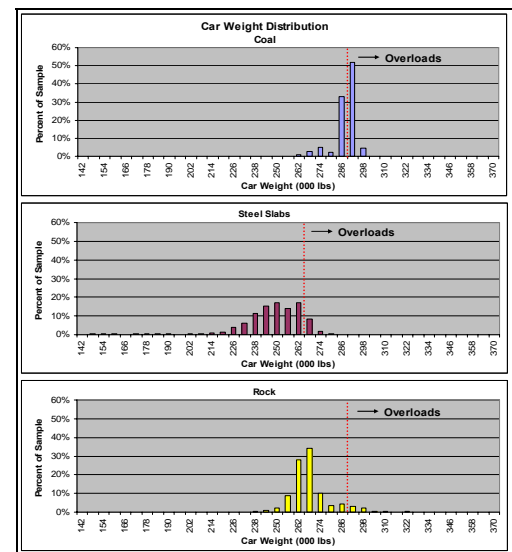


Figure 10. Overloads by Commodity

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