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Crossing Diamond Life-Cycle Analysis: Tools for Development of a Speed Policy for Crossing Diamonds

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Summary

Under sponsorship of the Association of American Railroads' Strategic Research Initiatives Program, Transportation Technology Center, Inc. (TTCI) has developed the tools needed to analyze life-cycle costs (LCC) of crossing diamonds. This work is conducted in support of an industry initiative to develop rational, uniform policies for establishing allowable speeds on crossing diamonds.

Using industry average service life records, cost data, and previous studies of train delay at crossing diamonds,¹ a parametric study of crossing diamond LCCs was conducted. Findings from the study include:

- The effect of speed on crossing-diamond frog-service life is significant. The predicted life of a frog in 60 mph service is 56 percent of the predicted life for the same frog in 40 mph service.
- For most mainline cases, train delay costs dominate LCCs. The optimal diamond speed will be the one that minimizes train delay costs.
- Maintenance costs can affect optimal operating speed. Industry average costs were used in this analysis. Further analysis is needed for determining factors that affect maintenance cost.
- First (purchase) cost of the crossing diamonds affects LCCs, but is relatively unimportant in determining optimal operating speed.

Key analysis tools now available:

- Running surface-condition measurement tools. The effect of running surface profile can be captured by measuring the effective gap at the flangeway. Effective gap is the distance a wheel is unsupported going across a flangeway. TTCI developed a prototype gage to measure the effective gap.
- Vehicle-track dynamic analysis tools. The wheel/rail forces generated by a freight car in crossing a frog can be modeled using NUCARS®. The predicted forces for various operating speeds, crossing angles, and conditions are used as inputs for predicting frog degradation.
- Frog degradation model. A model of a crossing diamond frog casting was developed to predict service life from known operating conditions. The model predicts the amount of tonnage required to initiate a fatigue crack in the casting.

Development of a rational policy for crossing diamond speeds is a long-standing goal of the Engineering Department of each railroad. Higher crossing diamond speeds, where technically feasible, may benefit the railroad in lower operating and train delay costs. However, the costs of higher speeds are borne almost exclusively by the Engineering Department. Thus, the trade-offs should be well understood by the railroad when setting a crossing diamond speed policy.



INTRODUCTION AND CONCLUSIONS

Crossing diamonds can be traffic bottlenecks by design (e.g., single track in double-track territory) and by condition (e.g., condition-related speed restrictions). These restrictions can have significant effects on train operations, line capacity, and railroad operating costs. Crossing diamond related train delay costs are estimated at more than \$100-million annually. These costs estimates are conservative in that they only include the direct costs of additional operating time for trains.

Development of a crossing diamond LCC model must include operating costs as well as track costs. To optimize either track costs or train delay costs alone would produce speed policies detrimental to the railroad. An existing train delay cost model for crossing diamonds was combined with a new crossing diamond fatigue model to produce a LCC model.

Optimal crossing diamond operating speed was determined for an example case and for a demonstration of the capabilities of these analysis tools. Findings from the parametric analysis conducted include:

- The effect of speed on crossing-diamond frog service life is significant. The predicted life of a frog in 60 mph service is 56 percent of the predicted life for the same frog in 40 mph service.
- For most mainline cases, train delay costs dominate LCCs. The optimal diamond speed will be the one that minimizes train delay costs.
- Maintenance costs can affect optimal operating speed. Industry average costs were used in this analysis. Further analysis is needed for determining factors that affect maintenance cost.
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Demonstration Case

To demonstrate the capabilities of the model, a parametric study of crossing diamond speed was conducted for a heavy haul operation. Table 1 lists the key model inputs.

Table 1. Crossing Diamond Life-Cycle Model Demonstration Case Input

Input	Main Line	Crossing Line
Line speed (mph)	40	40
Diamond Speed (mph)	40	40
Traffic (MGT)	80	20
No. Trains (per day)	27	12
Train Delay costs:		
Fuel (/gal)	\$1.90	\$1.90
Crew (/hr)	\$275	\$275
Maintenance (\$/MGT)	700	700
Discount Rate (%)	12	12

Diamond speed was varied from 10 mph to 60 mph. For each diamond speed, the effects on diamond service life, maintenance costs, and train delay costs are calculated. These costs are tabulated for a long-term, steady-state situation (99 years) and converted to Net Present Value (NPV) for comparison. This allows equitable comparison of assets with different service lives.

Parametric Analysis

To assess the effects of various elements, Figure 1 shows the NPV LCC versus crossing diamond speed results for the demonstration case. The figure illustrates that train delay dominates LCCs, if low speeds are selected for the diamond. As higher diamond speeds are selected, diamond capital costs increase until they dominate costs. Above 40 mph, the line's track speed in this simulation, the train delay costs are nil because train delay in this study is defined as the additional time and fuel required to slow and then accelerate the train for a speed restriction at the diamond.

Additionally, Figure 2 shows the relative effects of train delay costs on optimal crossing diamond speed. Shown are NPV costs for the base case operation with train delay labor and fuel costs, with only train delay fuel costs (no train delay costs). If only track costs (capital and maintenance) are considered, the optimal speed is 10 mph. If train delay costs are also considered, the optimal speed is 40 mph. However, at 40 mph, the cost to the Engineering Department is 250 percent of the cost at 10 mph. Further, there may be strategic reasons, such as capacity constraints, for raising diamond and surrounding line speeds above current line speeds.

Sensitivity analysis of key engineering input variables was conducted. As the cost of new crossing diamonds and the maintenance costs increase, the lower the optimal speeds become. This would also be the case if the train delay costs per delayed train decrease. Figures 3 and 4 show the relative effects of increasing diamond capital costs and diamond maintenance costs by 100, 200 and 400 percent.

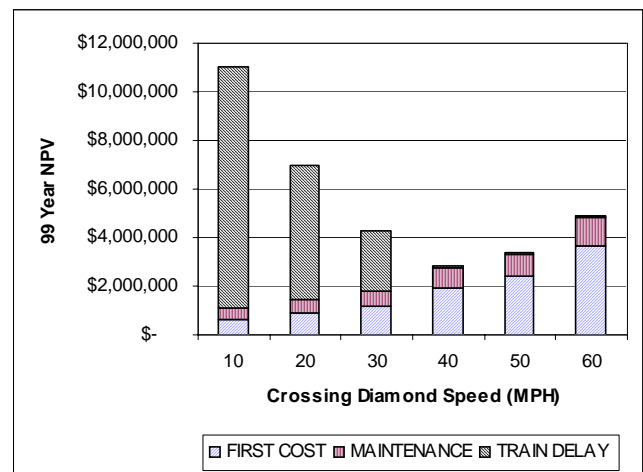


Figure 1. Crossing Diamond LCC vs. Speed by Source

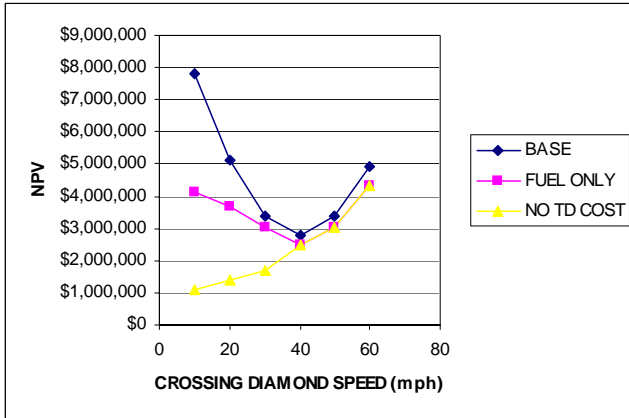


Figure 2. Crossing Diamond LCCs With and Without Train Delay Costs

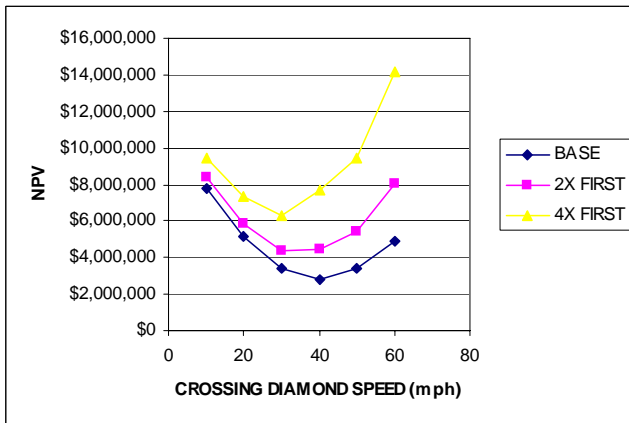


Figure 3. Effect of Varying Diamond Capital Cost on LCC

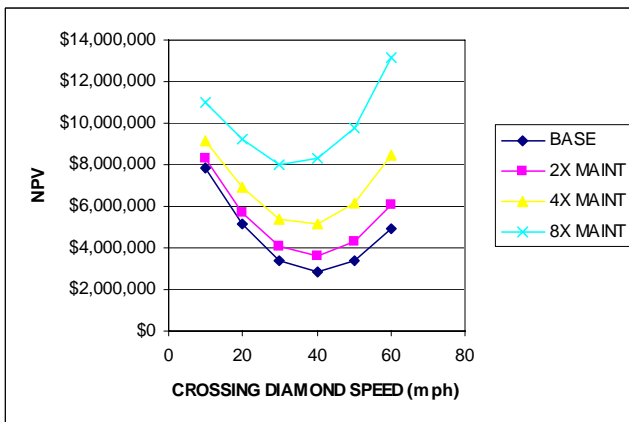


Figure 4. Effect of Varying Diamond Maintenance Cost on LCC

Figure 5 shows the effect of reducing train delay costs by 50, 75, and 100 percent. For purposes of this digest, train delay labor is the additional time spent in going across the diamond (including the time to slow down and speed back up). Additionally, the model stops crossing line traffic based on the amount of time the mainline is occupied. Many railroads may discount this train delay figure due to the nature of operations

on a particular line. This is a recognition of the fact that the additional time may not add any additional labor cost, depending on labor agreements and/or other bottlenecks on the same line. However, one can view the model predicted train delay cost as the theoretical train delay or the opportunity cost of crossing diamond related train delay. In Figure 5, the optimal train speed is affected by train delay cost, with higher labor costs resulting in higher optimum speed. The no-train delay cost case shows only the track related expenses. For this case, a diamond operating speed of 10 mph produces the lowest LCC. For train delay costs of 25 percent, the theoretical labor and fuel costs for diamond speed restrictions, a minimum LCC speed is 30 mph. For higher rates of train delay costs, the optimal diamond speed is the mainline speed (40 mph in this case).

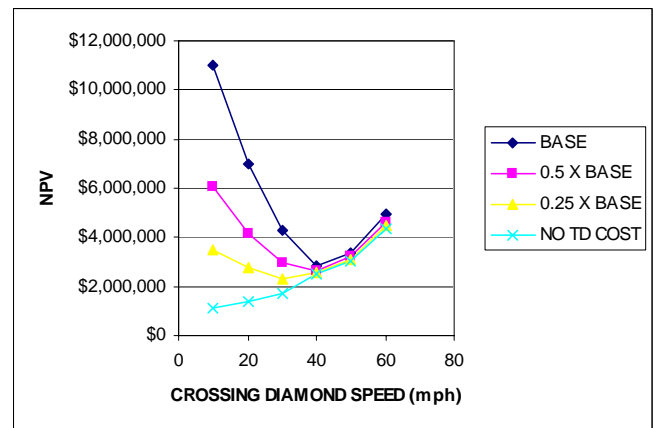


Figure 5. Effect of Varying Train Delay Costs on LCC

Life-Cycle Cost Modeling

Train delay costs consist of two major factors: fuel and crew labor. Additional delay cost elements, such as equipment ownership costs, were ignored for this analysis. The model, based on previous crossing diamond specific operating simulations,¹ determines the additional time and fuel required for a train to change from mainline track speeds to the specified crossing diamond speed, cross the diamond, and resume mainline speeds. Additionally, the model assumes a proportion of trains on the crossing route must stop for mainline traffic. The proportion is based on the amount of time the crossing is occupied by mainline trains. The model can calculate crew labor and fuel for each route. Any or all four can be considered in the LCC calculations.

The predicted service life of the diamond was calculated from frog material specific stress analysis (unpublished data). NUCARS® (vehicle-track dynamics modeling) was used to develop the dynamic wheel load speed relationships used as input to the frog stress analysis. Figure 6 shows a typical dynamic load versus frog angle-condition-speed relationship developed from NUCARS. The lower curve represents conditions for new crossing diamonds. The upper curve represents conditions for worn diamonds, nearing replacement.

TTCI has developed a flangeway gap gage that can measure the effective gap a wheel jumps going across a frog. In terms of this analysis, the gage helps determine where, between the lower and upper curves, a diamond resides, providing dynamic load inputs to the frog degradation model.

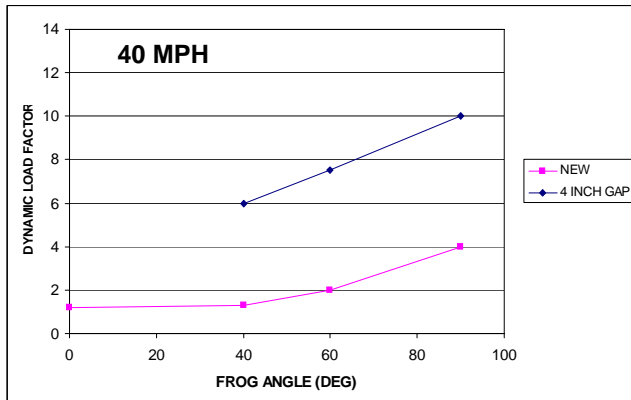


Figure 6. Effect of Speed, Angle, and Running Surface Condition on Predicted Dynamic Forces

Figure 7 depicts the effective gap gage in use on a crossing diamond. The gage is shaped like a freight car wheel. It is applied by placing it on the frog to be measured and reading the effective gap scale. This device gives a more accurate measure of the actual gap a wheel encounters in rolling across a flangeway. The effective gap of a frog is dependent on the angle and the running surface condition.

This input produces a prediction of the crack initiation life and, from that, a prediction of the service life of the frog castings in a diamond. Figure 8 shows the relationship developed for mainline bulk commodity train loading. The effect of train speed is significant on the predicted service life of the diamond. The predicted service life of a casting in 60 mph service is only 56 percent of the predicted service life of the same casting in 40-mph service.

Track maintenance costs for the crossing diamond were developed using industry average data. The data available was not broken down by actual track speed. Therefore, TTCI used the same relationship between service life and speed to account for the speed effect in maintenance effort.

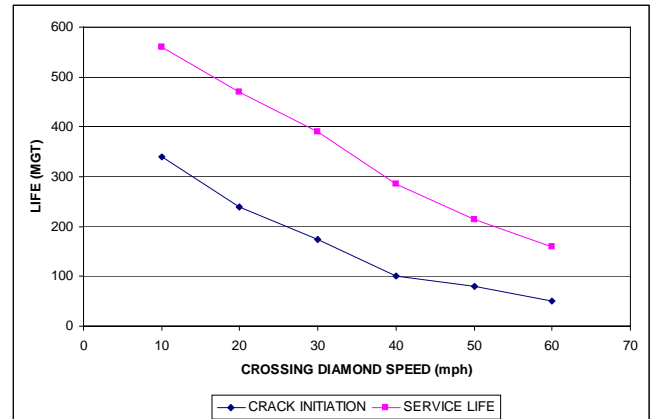


Figure 8. Effect of Speed on Predicted Frog Service Life

The crossing-diamond analysis tools described above provide the railroad planner with the capabilities to develop engineering based policies for allowable speed on crossing diamonds. This capability allows evaluation of operating and engineering concerns within the same framework.

REFERENCE

1. Drish, W. and D. Davis. August 1997. "Effects of Train Delay on Crossing Economics." *Technology Digest* TD97-019. Association of American Railroads, Transportation Technology Center, Inc., Pueblo, CO.



Figure 7. Flangeway Effective Gap Gage

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