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Evaluation of the Effects of Speed and Rail Conditions on the Performance of Yard Switches

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Summary

The Transportation Technology Center, Inc. (TTCI) has completed an initial study of allowable train speeds through turnouts. Current speed limits are based on ride quality studies and are not sensitive to switch entry conditions. TTCI has conducted a NUCARS®* modeling effort to better understand the conditions of yard switches, and the effect those conditions have on the forces generated by passing vehicles.

TTCI measured and modeled two switches, one located on site at the Facility for Accelerated Service Testing, and the other located off site at the Union Pacific Yard in Pueblo, Colorado. NUCARS allowed a large parametric study to be completed for both of the switches. Variables included wheel profile, vehicle type, vehicle loading, and track quality (measured profiles, gage, and cross level). Both AREMA No. 10 switches were in good to fair condition for wear and overall track quality. A 2-millimeter hollow-worn wheel was used for the worn wheel condition. In all cases, 4 to 7 vehicle types were modeled in the empty and loaded conditions. The focus of this study was on the switch points and closure curve, so the frog and associated guardrails were not modeled.

NUCARS outputs were reduced and then analyzed using Chapter XI criteria of the Association of American Railroads' (AAR) *Manual of Standards and Recommended Practices*. In addition to Chapter XI limits, Nadal values were calculated for cases where exceedances occurred. Both switch locations showed similar results. A summary of the analysis is as follows:

- The Chapter XI criterion for the maximum L/V ratio for a single wheel was exceeded at 5 mph by an empty hopper with worn wheels for the yard switch, but the Nadal limit was not exceeded under the same conditions.
- Under new wheel/new rail conditions, no Chapter XI criteria were exceeded for typical operating speeds. The results suggest that new and minimally worn yard switches can be operated safely at, or even above, the customary allowed speeds of 15-20 mph.
- Loaded cars have little wheel climb risk at typical operating speeds. The loaded grain hopper and the 5-unit well car exceeded minimum vertical load criteria at 40 mph for the switch at FAST and at 35 mph by an empty hopper car at the switch in Pueblo.
- Worn wheel profiles did not significantly affect the forces on the worn switch profiles.

*NUCARS® is a registered trademark of the Transportation Technology Center, Inc.

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Transportation Technology Center, Inc.

INTRODUCTION AND BACKGROUND

TTCI has completed an initial investigation into allowable train speeds through turnouts. The work was completed under the guidance of the Association of American Railroads' Strategic Research Initiatives Program.

Federal Railroad Administration (FRA) track speed limits that typically govern switches are based on allowable cant deficiency in the diverging side "curved" portion of a turnout.1 This criterion is based on ride quality and may not accurately reflect the risk of accident for switches under heavy axle load (HAL) freight operations. Railroads typically limit speeds in turnouts to 1.5 to 2 times the frog number.

Since the economics of maintenance usually limit turnout speeds below the allowable maximums on main lines, the potential problems are mostly relevant for smaller-sized yard switches.

Smaller-sized switches under HAL traffic have been known to experience problems at lower speed than specified in the FRA criteria. Problems are most likely occurring because of the combination of track quality, track geometry, and wheel/rail contact geometry, but little research has been completed to determine the causes and effects in smaller-sized turnouts.

In order to gain a better understanding of the problems associated with current FRA criteria in smaller-sized switches, TTCI has conducted a study to investigate the effects of track quality, track geometry, and wheel/rail contact geometry on allowable speeds through the turnouts.

NUCARS MODELING

The NUCARS wheel/rail penetration contact model was used to evaluate the effects of various track parameters on the allowable speed through switches. The benefits of the penetration model include:

- Up to five overlapping contact points per wheel
- Permitting profile variations along the track
- The ability to use measured or theoretical track geometry
- The capability to model guard rails and frogs
- The output of animated wheel/rail interactions

Two switches and one base case were modeled in this study. The first switch is located in the High Tonnage Loop at FAST. The second switch is located at the Union Pacific (UP) Yard in Pueblo, CO. The base case is a new rail/new wheel scenario. All switches are AREMA No. 10 straight point switches. Both switches had undercut stock rails with corresponding "5100 detail" switch points. The rail in each switch was 6-inch base RE sections. The switch at FAST uses 136-pound rail, while the UP switch uses 133-pound rail.

The NUCARS penetration contact model output was used to evaluate the forces generated over No. 10 switches under various car types, load conditions, switch rail conditions, and wheel conditions at speeds ranging from 5 to 70 mph. The models do not include the frog portion of the turnouts. Table 1 summarizes the parameters varied for each of the models. Figure 1 displays the rail condition for both switches.

Table 1. Parametric Study Summary

	Model		
	Base	FAST	Yard
Rail Condition	New	Good	Fair
Track Input	None	None	Gage and Cross-Level
Wheel Profile	New	New and Worn	New and Worn
Speed Range	5-70	5-70	5-70
Number of Car Types	4	7	7

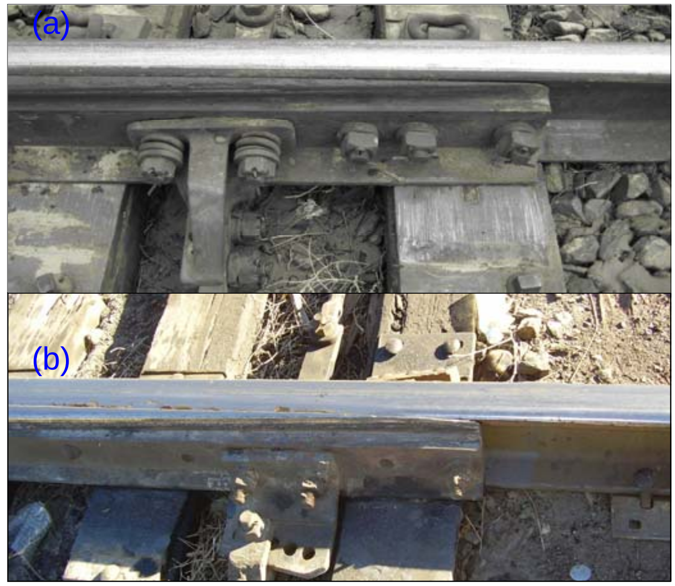

Figure 1. Rail Condition for FAST (a) and UP (b) Switches

Car types included various hopper cars, tank cars, and 5-unit well cars in the loaded and empty conditions. The worn wheel profile was a 2-millimeter hollow AAR-1B wheel. Figure 2 shows the difference between a new AAR-1B profile and the 2-millimeter worn profile.

The UP switch is slightly more worn than the switch at FAST, but both switches were in fair to good condition.

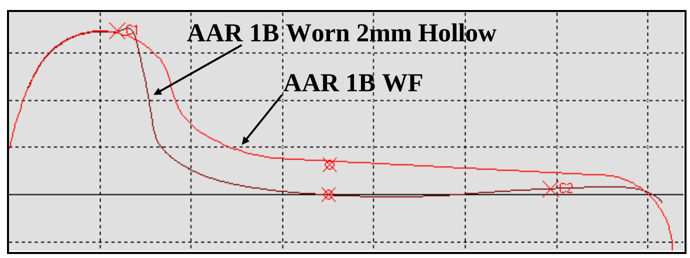

Figure 2. Wheel Profiles for New AAR-1B and Worn AAR-1B

PERFORMANCE EVALUATING CRITERIA

Over 750 simulations were completed using NUCARS to span the entire range of variables for the parametric study. An embedded data visualization software support package for NUCARS was used for data analysis once the simulations were complete. Data from both turnouts and one base case (new wheel/new rail) was compared to AAR's Chapter XI criteria[2] for assessing the requirements for field service. Although there is not a specific reference to turnouts in the Chapter XI specification, the limiting values were chosen for the spiral regime, to account for the transient response due to track geometry conditions. The spiral regime limiting value for the maximum wheel L/V must not exceed 1.0 for more than 50 milliseconds or for a distance greater than 3 feet for any instance. The spiral regime is more conservative than the constant curving regime (limiting value of 0.8) and therefore a better measure for turnouts. Table 2 shows the criterion selected for the turnout analysis.

Table 2. Criteria used for Model Analysis

Simulation Output	Derailment Mechanism	Chapter XI Criteria
Minimum Vertical Wheel Load	Wheel Unloading	Must not fall below 10% of static
Maximum Wheel L/V	Flange Climb	Must not exceed 1.0

Flange climb derailments in switches occur because as friction increases and wheel/rail contact angle decreases, the maximum L/V ratio required for flange climb decreases. In addition, flange climb commonly occurs when vertical wheel loads decrease as other forces push a wheelset laterally into flange contact causing higher L/V ratios. A summary of some parameters that affect flange climb is listed below with a pictorial representation following in Figure 3.

- Vertical and lateral wheel climb forces
- Instantaneous ratio of lateral to vertical wheel/rail forces (L/V ratio)
- Coefficient of friction (μ) between wheel flange and rail gage face
- Contact angle between wheel flange and rail gage face
- Angle of attack between wheelset and rails

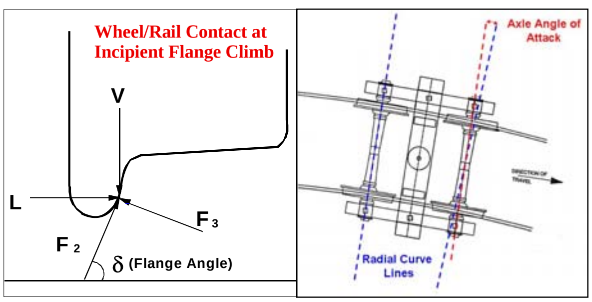

Figure 3. Flange Climb Derailment Parameters

The vertical wheel load and single wheel L/V ratio were chosen as a result of the data from the base case. Other criteria, such as net axle L/V ratio, maximum lateral force, and truck side L/V, were also reviewed to determine the limiting factors for vehicles through turnouts.

BASE CASE AND FAST SWITCH RESULTS

Comparison of the NUCARS predictions and the Chapter XI criteria for the base case and switch at FAST showed that minimum vertical load is the limiting value. In both cases, the 100-ton loaded grain hopper car and the loaded 5-unit well car exceeded Chapter XI criteria for minimum vertical load at 40 mph. All other vehicles exceeded the criteria at 45 mph and above. Figures 4 and 5 show the results for the base and FAST cases for all runs, respectively. The results suggest that new and minimally worn yard switches can be operated safely at, or even above, the customary allowed speeds of 15-20 mph.

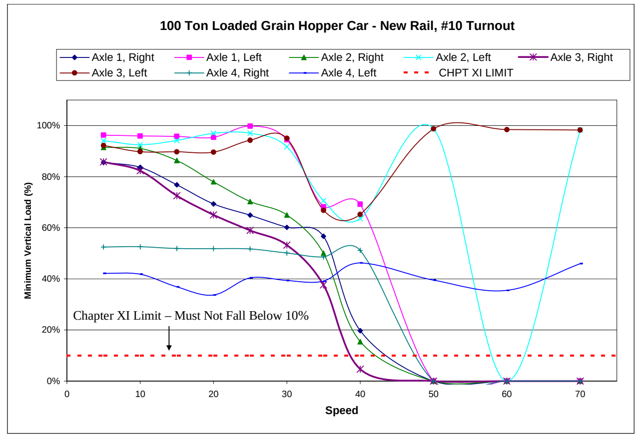

Figure 4. Minimum Vertical Wheel Load Data for Base Case with new AAR-1B Wheel Profile

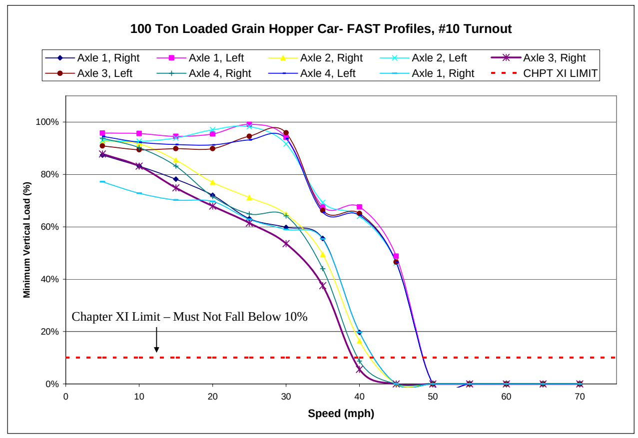

Figure 5. Minimum Vertical Wheel Load Data for FAST Switch with new AAR-1B Wheel Profile

The worn-wheel profile and loading condition had a negligible effect on the results for either case. Figure 6 shows the minimum vertical load data for the switch at FAST with the worn-wheel profile. Comparing this to Figure 5, minimal changes are observed.

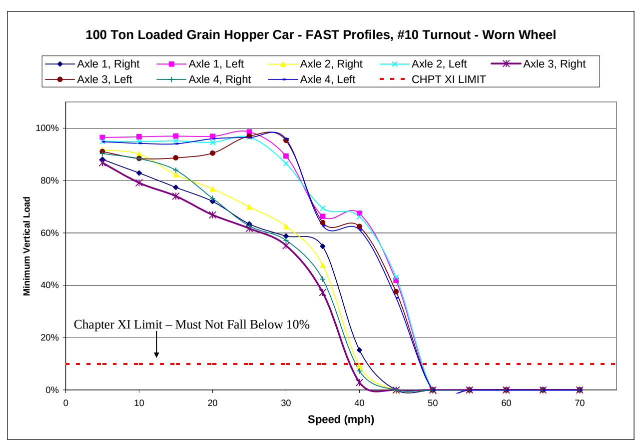

Figure 6. Minimum Vertical Wheel Load for FAST Switch with 2-mm Hollow-Worn Wheel Profile

In addition to the minimum vertical load exceedances, the carbody roll angle exceeded the Chapter XI criterion for both cases at 40 mph, and the single wheel L/V ratio criterion exceeded criteria at 45 mph and above.

YARD SWITCH RESULTS

As with the previous two switches, the same parametric study was completed for the yard switch. When compared, the minimum vertical wheel load data from both the yard switch and the FAST switch is similar. For the FAST and yard switches, the grain hopper and 5-unit well car exceeded minimum vertical wheel load criteria at 40 mph. In addition, the yard switch produced a minimum vertical wheel load exceedance at 35 mph for the generic empty hopper, as Figure 7 shows.

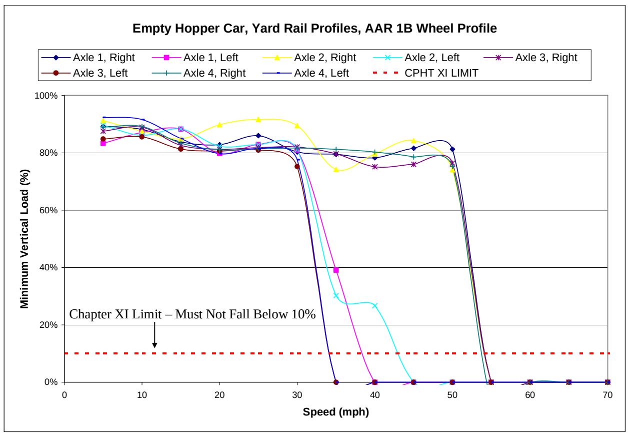

Figure 7. Minimum Vertical Wheel Load for Yard Switch with new AAR-1B Profile

The largest variance between the two switches was in the single wheel L/V ratio for the empty hopper with the 2-millimeter hollow-worn wheel profile. For the yard switch, the empty hopper had higher L/V ratios (over 0.85 at speeds as low as 5 mph) than the same case for the FAST switch where the L/V values averaged about 0.42 at 5 mph. Figure 8 shows the L/V values for the lead axle, the Chapter XI limit, and the calculated Nadal value for the specific wheel/rail geometry condition.

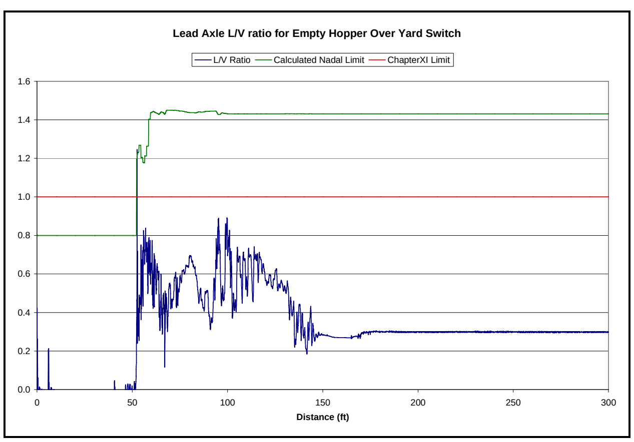

Figure 8. Lead Axle L/V ratio for Yard Switch

For this particular case, the Nadal limits were calculated to compare to the L/V ratio and Chapter XI limits. The Nadal value in Figure 8 was calculated using the following formula:

$$\frac{Tan(\delta)-0.5}{(1+0.5Tan(\delta))}$$

Where δ is the maximum wheel/rail contact angle at the specific location in the switch, not the actual contact angle.

Figure 8 shows that the L/V values for the empty hopper with the worn wheel profile are well below the limits for both Chapter XI and Nadal, with exceedances occurring at speeds above 50 mph using the Chapter XI limit. Although, the L/V ratio did not exceed the specified limits, they are still approximately 2 times greater under conditions in the yard than at FAST.

CONCLUSION

Results from the parametric study of three switch conditions showed similar results. The expected results of large differences between the switches were not observed because the switch conditions at FAST and in the UP yard were too similar. Results show that many yard-switch related problems can be attributed to the flange climb mechanism. Worn wheel profiles did not have a significant effect on the FAST switch which is in good condition, but did have a more noticeable effect on the slightly more worn yard switch. What will vary from location to location will be the specific switch point wear pattern. Safe operating speeds over yard switches are not recommended in this initial study because the sample size of measured switches is not adequate.

FUTURE WORK

TTCI suggests that several more yard switches in various stages of degradation be modeled. Excessively worn switches need to be measured and modeled to access accurately the effect of switch degradation on vehicle forces at various speeds. Additionally, it would be of value to determine the effect of the frog and guardrail on the switch performance. Once all extremes have been accounted for and understood, speed recommendations can be provided.

Acknowledgement

Special recognition is given to Jeremy Montoya, TTCI summer engineering intern, for his dedication to the data reduction necessary for this analysis.

REFERENCES

1. U.S. Department of Transportation, January 1999, Federal Railroad Administration – Office of Safety; Track Safety Standards Part 213, Subpart A to F Class of Track 1-5, Washington, D.C.
2. Association of American Railroads. 2007. *Manual of Standards and Recommended Practices,* M-1001, Chapter XI, "Service Worthiness Tests and Analyses for New Freight Cars." Washington, D.C.