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Railroad Switch Design and Failure Mode Analysis

David D. Davis, Vincent R. Terrill* and Daniel B. Mesnick**

Summary

A literature review, a performance survey, and a failure mode analysis of North American freight railroad mainline and yard switches were conducted. The study identified the most common switch designs used, the significant switch failure modes seen, and potential research opportunities.

While some switch designs have unique failure modes, a lot of commonality of failure modes exists among the split switch designs used by North American railroads. Typical failure scenarios were identified and analyzed.

Switch failure modes most mentioned include:

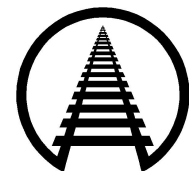
- Point chipping or breakout is the most prevalent problem. Stock rail metal flow, relative movement between point and stock rail, switch geometry, switch point design and lack of timely grinding maintenance are potential contributing factors.
- Vertical support problems can be significant (esp. for yard switches). Many older switch and frog heel designs are inadequate for long-term durability under HAL traffic. The most serious consequence of vertical support problems is a split switch derailment due to differential movement of the point and stock rail under load. Additionally, poor timber condition can contribute to poor alignment, heel failures, and accidents. The current designs make timber tie installation and maintenance difficult.
- Longitudinal movement problems (e.g., rods binding on tie) can contribute to switch point chipping and switch operation failures.

A trend in the industry today is standardization. As railroads attempt to avail themselves of the benefits of consolidation into larger systems, the trend toward standardization in special track-work designs is strong. Cost and logistics benefits are expected after a very long payback period.

TTCI sponsored the study under the Association of American Railroads' Strategic Research Initiatives Program to improve the performance of special track work.

* Terrill Track Consultants

**TransTech Management



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INTRODUCTION

The Association of American Railroads’ (AAR) special track work research program is intended to improve the performance of turnouts and crossing diamonds in mainline service. While switch performance has improved since the 1970’s and the rate of switch related accidents has gone down, they are still routinely in the top five track causes in the Federal Railroad Administration’s (FRA) accident database. Some switch related accidents will be difficult to eliminate by better switch design. These include switch operation caused accidents (i.e., human error) and dragging equipment or “one wheel off” accidents where the train has already derailed, but “piles up” at the switch. However, this still leaves a considerable number of accidents that are related to failure of the switch hardware to operate as designed. The leading categories of switch related accidents are switch point worn or broken, switch damaged or out of adjustment, and switch point gapped (FRA database cause codes T314, T311, and T319, respectively).

Special track work is also a major source of over the road train delay due to maintenance and slow orders for operations on the diverging route. More reliable switches would reduce the frequency of maintenance and the need for slow orders.

TTCI sponsored the study under the AAR’s Strategic Research Initiative (SRI) Program to improve the performance of special track work. The study identified the most common switch designs used, the significant switch failure modes seen, and potential research opportunities.

METHODOLOGY

Track engineers from Terrill Track Consultants conducted a literature review, railroad expert survey, and failure mode analysis for TTCI.¹ Survey questionnaires were developed from literature review and the combined experience of Terrill Track Consultants and TPCI staff. Surveys were developed for mainline switches and yard switches. The surveys attempted to gather basic information on switch designs used and the typical failure modes seen with each design. A list of failure scenarios was developed along with some example failure modes to assist those surveyed in developing their responses. Additional information on design changes already

made and being contemplated by each railroad were solicited.

Special track work experts from the AAR Engineering Research Committee’s Technical Advisory Group for Special Track Work research were sought to assist in this study. AMTK, BNSF, CN-IC, CP, CSX, NS, and UP were member railroads represented. Survey responses were analyzed to determine how railroads are dealing with switch failures in their design, maintenance, and future purchasing decisions.

RESULTS

The smaller size turnouts are the most common in yards and mainline track. Table 1 shows the top 4-6 switches each railroad plans to purchase, grouped by AREMA plan and turnout number.* Most railroads use switch designs that are similar to AREMA plans. Each railroad has changed the AREMA design to suit its own needs. The industry, with the exception of BNSF, has standardized on uniform risers. UP and CN-IC have varied most from AREMA plans. In some significant areas, like use of gage plates and switch point rollers, there is considerable variation. For the same nominal No. 20 switch plan, the number of gage plates used varies from 2 to 11. The number of rollers varies from 0 to 5.

Table 1. Mainline Switch Designs for New or Planned Orders Ranked by Railroad

AREMA Plan	Nominal Switch Number	Switch Point Length	AMTK	BN	CN	CSX	NS	UP	AVG Rank
111-00	7-10	16’6”	2			1	1	1	1
112-00	7-10	16’6”		3					
181-00	7-10	16’6”					5	3	
	10	31’6”			3				
123-00	9-12	19’6”							
124-00	9-12	19’6”		2					4
	12	36’7”			1				
115-00	11-14	22’0”					6		5
116-00	11-14	22’0”							
181-00	14	24’0”						4	
125-00	14-16	26’0”	4			2	2		3
126-00	14-16	26’0”		4					
	16	38’9”			4				
117-00	15-20	30’0”					4		
118-00	15-20	30’0”							
127-00	18-20	39’0”	3			3	3	2	2
128-00	18-24	39’0”		1					
	20	58’10”			2				
	30	82’0”							
No. 20 & 32.75 H.S.	20, 32.75	Tan. Geom.	1						

* The most popular switch is the 16’6” switch point, AREMA Plan 111 used in yard and siding turnouts. The next most frequently purchased switch is the 39’ switch point, AREMA plan 127 used in No. 20 turnouts.



In the important area of switch point vertical slope design, all railroads use a two-slope or “two cut” design. While design details vary somewhat, they all are intended to lower the switch point tip below the top of the stock rail. However, none lowers the point tip as much as one inch, which would help to avoid the potential risk of flange climb accidents. The first cut is generally 3/4 inch deep and varying in length with the switch. Second cuts are 3/16-1/4 inch deep and 12 inches in length.

The point slope used should be related to the entry angle of the switch and its thickness versus elevation of the stock rail. Since most railroads use the same point slopes for all switches, this suggests that the slope used is designed for the larger switches. Yet, larger switches have switch point chipping failures.

SWITCH FAILURE MODES ANALYSIS

Failure modes, effects, and criticality analysis (FMECA) are methods of accurately assessing the highest risk events that are most likely to occur in the field and affect operations. In this context, the *consequence* of an event is the product of the incident *severity* and *frequency*. A frequent event of lower severity may be determined to have the *same* negative impact on operations as an event of lower frequency but higher consequence when it does happen.

The FMECA method relies first on developing an accurate scenario with a set of heuristics best describing actual behaviors in the field and those *branches* along the decision tree. In this case, we developed the scenarios that we felt lead to service failure on turnouts and asked the railroaders we contacted to use a list of possible turnout failure modes to create scenarios from the subset of those given or add their own inputs.

The process was open-ended, and, in a number of cases, the experts provided us additional input on how to best establish the failure scenarios themselves. We used a detailed survey instrument to “extract” these scenarios from the minds of experts appointed by each railroad— most of who are members of the AAR’s Technical Advisory Group (TAG) on turnouts.

The challenge is how to best reduce the risk of catastrophic events *preventively*, using a combination of knowledge and experience.

Sixteen mainline and 10 yard switch failure scenarios were developed and analyzed. They have been further consolidated into the following summary points:

- Point chipping or breakout is the most prevalent problem. Stock rail metal flow, relative movement between point and stock rail, switch geometry, switch point design and lack of timely grinding maintenance are potential contributing factors. Point chipping shortens switch life and can increase the risk of derailments.
- Vertical support problems are significant (esp. for yard switches). Many older switch and frog heel designs are inadequate for long-term durability under HAL traffic. The most serious consequence of vertical support problems is a split switch derailment due to differential movement of the point and stock rail under load.
- Additionally, timber failures contribute to poor alignment, heel failures, and accidents. The current designs make timber installation and maintenance difficult. These support problems result in poor surface, ballast degradation, and slow orders.
- Longitudinal movement problems (e.g., rods binding on tie) are common. They contribute to switch point chipping and switch operation failures. The switch rods are attached to the switch points; whereas, the ties are attached to the stock rails. As the points move longitudinally relative to the stock rails, the rods and timbers can interfere, affecting switch operation.
- Debris buildup from snow, ice, or sand can affect switch performance and result in bent or damaged components, split or gapped switch points, and wheel climb derailments.
- Switch geometries, with relatively large entry angles, can generate large lateral forces. These forces can cause running surface flow, plate wear, and fastener breakage. Designs that lower dynamic train forces would be useful.



- Switch throw failures due to switch rod bending. Vertical support and longitudinal movement problems can result in bent switch rods. With vertical settlement, the ends of the rods can interfere with the stock rails, preventing proper switch operation.

Standardization

North American railroads are currently benchmarking their track standards to develop best practices for design. Special track work is also a part of this exercise. Two large western US railroads are developing common standards for purchasing special track work in 2003. The benefits from standardization include:

- Analysis of constituent railroad designs with selection of the best for current standard design.
- Reduction of parts inventory, purchasing support, logistics, etc.
- Potential economic benefits—product becomes a commodity common to several railroads rather than a custom made item.

FUTURE WORK

This study has identified switch research and development needs. These items will be considered in the future AAR SRI program. Table 2 lists switch performance problems and potential research to address these issues.

TTCI is actively working on several of these issues under the Special Track Work and Heavy Axle Load Research Initiatives.

REFERENCES

1. Mesnick, D.B. and V.R. Terrill, “Railroad Switch Design and Failure Modes Analysis;” Report to TTCI, April 2002.

Note: Contact David Davis at (719) 584-0754 with questions or comments about this document. E-mail: david_davis@ttci.aar.com Visit TTCI’s website at <http://www.ttci.aar.com>

Table 2. Switch Performance Issues and Proposed Research

Switch Problem	Failure Mode	Priority	Proposed Research	Status
Running surface-wheel/rail contact effective wheel transfer from stock rail to switch point.	Switch point chipping.	1	1) Switch point cross section design. 2) Switch running surface design.	In current AAR research program; prototype in test. In current AAR research plan.
Longitudinal restraint of switch rails.	Switch operation failure misalignment.	2	Develop methods to accommodate differential point-stock rail movement.	Not in current AAR research program.
Switch throw mechanism obstructs surfacing equipment.	Surface ad alignment problems.	3	Develop tampable switch that is economic and reliable in all weather conditions.	Current AAR work is focused of reducing number of switch rods.
Track stiffness transitions.	Surface and alignment problems.	4	Develop methods of smoothing transitions mitigate the effects of dynamic loads on foundation.	FRA project on reduced impact track will address issue.
Fastener failures.	Gage widening or excessive vertical movement.	5	Quantify HAL service environment so that suppliers can design fasteners for loading and deflections seen.	Not in current AAR research program.
Tie/surface failures.	Surface problems, esp. at joints.	6	Develop improved ties and plate work to support dynamic loads.	Not in current AAR research program.
Material wear.	Running surface flow and wear.	7	Develop stronger, tougher steels.	Recent AAR work on bainitic steels is being applied in prototype switch points.
Running surface discontinuities.	Joint batter, frog batter, stock rail batter.	8	Develop improved joining processes for dissimilar materials (e.g., rail and frog steels).	AAR work on bainitic steel welds is ongoing.

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