On the Derailment of Rail Vehicles Through Turnouts; A Review of Derailment Causes and Mechanisms

by
Dr. Allan M. Zarembski, P .E.[1]
Mr. Donald Holfeld, P. Eng.[2]
Mr. Joseph Palese, P.E.[3]

ABSTRACT

This paper presents a review of causes and mechanisms associated with the derailment of rail vehicles in turnouts. The paper makes use of several recent studies of derailment causes in both transit and freight rail environments and addresses those factors that contributed to the derailments. This specific area of focus is that of track caused derailments for the several classes of rail vehicles together with remedial actions that can be taken to prevent future occurrences.

INTRODUCTION

Turnouts and other special trackwork represent a design "discontinuity" in the railroad track structure necessitated by the physical requirements associated with a rail vehicle moving from one track to another. Due to their very nature as a discontinuity, representing a change not only in track geometry but in the stiffness of the track structure as well, high levels of force are generated as a vehicle negotiates the turnout. If the turnout is not properly designed for the type of traffic and operating conditions it must support, or if the turnout is not properly maintained, these discontinuities can cause derailments. Such derailments can be due to either failure of a component (under the increased level of loading) or to improper geometry and/or clearances which can result in the development of excessive force levels (both lateral and vertical) and associated wheel climb or "walk off' of the vehicle. Such derailments have been found to occur across the entire spectrum of railway activity including freight railroad, inter-urban passenger railways, commuter railroads, and transit systems.

While most such derailments occur in yards and non-main tracks, they also occur on main line tracks. In the case of freight operations, these main line derailments can be quite expensive not only in terms of the damage caused to the equipment, but also due to interference with normal operation of the main lines. In the case of passenger carrying rail systems, such as transit systems, this class of derailments has resulted in injuries to passengers which is an unacceptable condition on any passenger carrying entity. However they occur, derailments are undesirable and as such have been the focus of much attention aimed at monitoring, controlling, and reducing their occurrence.

[1] President, ZETA-TECH Associates, Inc., Cherry Hill, NJ
[2] Director Training and Field Engineering, ZETA-TECH Associates, Inc., Cherry Hill, NJ
[3] Manager Engineering Analysis, ZETA-TECH Associates, Inc., Cherry Hill, NJ

This paper will review the results of several studies which have examined the occurrence of derailments in turnouts, particularly track caused derailments, and which have identified several key classes of causal mechanisms as well as potential techniques and devices for the control and/or reduction of these derailments.

TURNOUT DERAILMENT DATA

Derailment data for railroads, primarily freight and inter-urban railroads, is collected by the U.S. Department of Transportation, Federal Railroad Administration for U.S. operating rail systems [1,2]. While derailment data for transit systems is not normally collected in a comparable manner, a recent study of turnout derailments for transit systems [3] provided for a comprehensive set of transit related derailment information.

Of the FRA reported railroad derailments, there were 328 derailments attributed to turnout related causes in 1994. Of these, 62% (202) were track caused and 38%(126) were attributed to operating causes (such as operator error). Derailments in 1993 represented a similar distribution, with 67% of the 356 reported derailments being attributed to track causes and 33% to operating causes. Note; no derailments were attributed to mechanical causes due to the nature of the reporting categories.

Analysis of the transit reported derailments showed a somewhat different distribution, which is presented in Table 1. It. can be seen from this table that 38% of the reported derailments are due to track related causes, with 4% relating to design and the remaining 34% relating to maintenance. Vehicle related derailments comprised 0% of the total reported derailments, while 54% are due to operator error. Note that an additional 109 derailments were attributed to a combination of several of these specific factors, including contributions from both the track and the equipment. (This was observed to be the case for at least one major derailment category, wheel climb derailments).

Table 1

Derailments by Category [3]

Track	Number	Percentage
Track – Maintenance	31*	34.1%
Track – Design	4*	4.4%
Mechanical/Vehicle	0*	0.0%
Operator	49	53.8%
Miscellaneous	7	7.7%
Total	91*	100.0%

* An additional 109 derailments were reported to have been caused by a combination of worn wheels, improper (tight) track gauge, out of tolerance back to back wheel gauge and poor design (incompatible design). Because of the large number of these derailments, and the combination of causes, these derailments are not included in the percentage distributions presented in this table.

TRACK RELATED DERAILMENT CAUSES

Analysis of the railroad related derailments divided the track causes into the following categories:

- Wear/Failure of Stock Rail
- Failure of the Switch Mechanism
- Improper Adjustment of Switch
- Wear/Failure of Frog Wear/Failure of the Switch Point
- Gap Between Switch Point and Stock Rail

Figure 1 shows the relative distribution of these categories for freight railroads by number of derailments. As can be seen from this Figure, degradation of the switch point (wear, chipping, etc.) represents the largest single category of derailment causes, with over 90 derailments attributed to this one category alone in 1994 (for a total cost of over $2 Million). Examination of the cost per derailment (Figure 2) shows that while degradation of the switch point is the most common class of derailments, it is not the most expensive (per derailment) with degradation (wear, breaks, etc.) of the stock rail and frog representing a more expensive (per derailment) class of derailments.

Analysis of the transit data also suggests that there are four major areas within the turnout that are most susceptible to derailments. These areas are defined in Table 2.

Table 2

Derailment Prone Areas in a Turnout

Location	Closure, Stock, or Point Rail	Comment
Switch Point, about 20” from toe of point rail	Point	First L/V transient spike[4] for facing point move
Stock Rail, about 20” ahead of point	Stock	Where truck "de-swivels"[5] upon leaving curving mode
Curved Closure Rail, near heel of switch point	Closure	Change in curvature[6]
Curved Closure Rail, near toe of frog	Closure	Change in curvature[7] (also near where guard rail ends in trailing point move)

As can be seen from this Table, the data shows that transits have a high number of derailments at the switch point, similar to the railroad experience. While the railroads experience a significant number of their derailments due to broken components, because of their high axle loads and high tonnage densities, transits experience a larger number of wheel climb type derailments. This can be observed from the failure locations in Table 2 where the four defined areas are most likely to generate high lateral force levels and correspondingly high L/V ratios which are associated with wheel climb derailments.

[4] Transient spike is the short duration peak load that occurs during entry.
[5] Truck is trying to return to its tangent position, in a trailing point move.
[6] Curvature is becoming more severe.
[7] Curvature is becoming more severe.

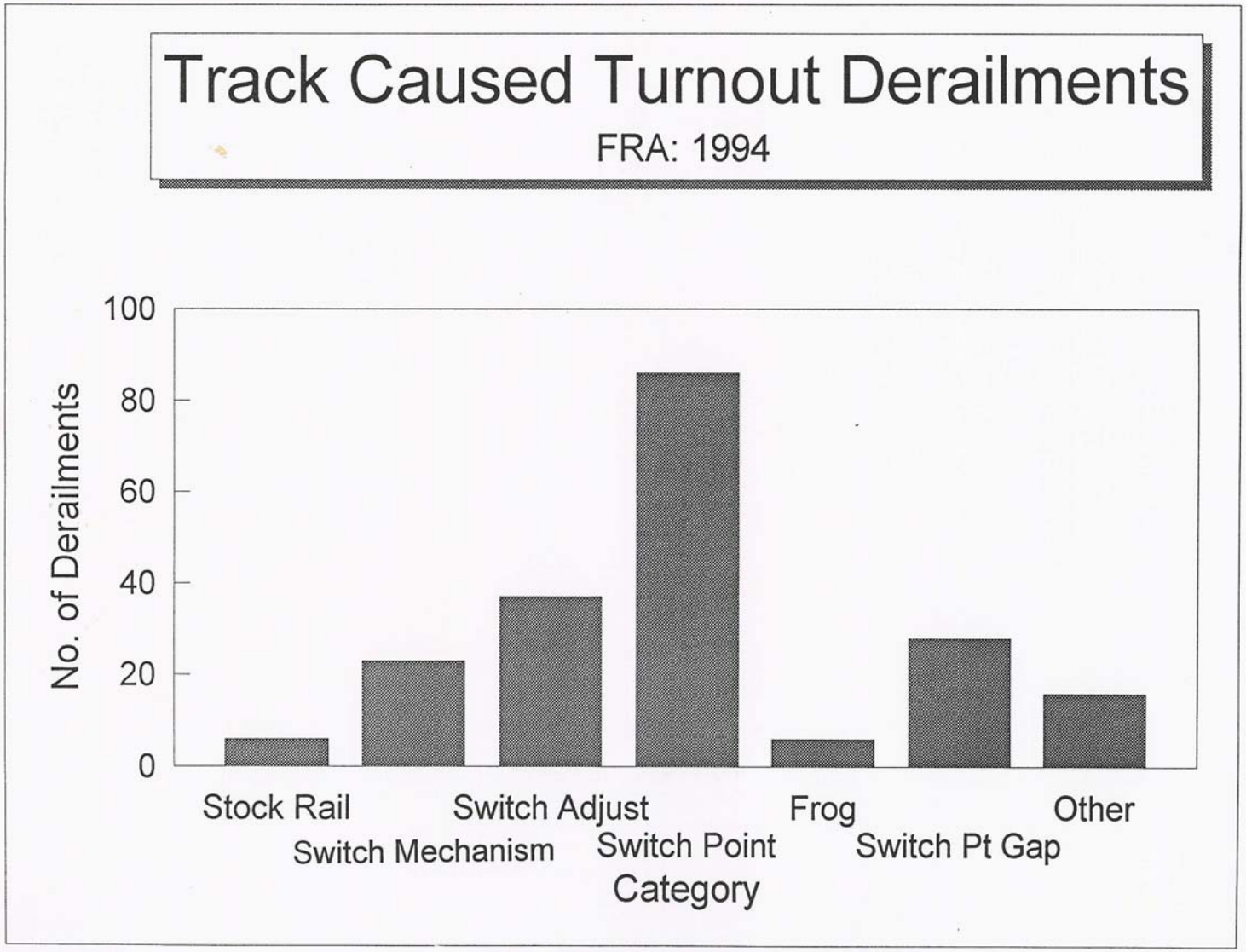


Figure 1: Track Caused Turnout Derailments

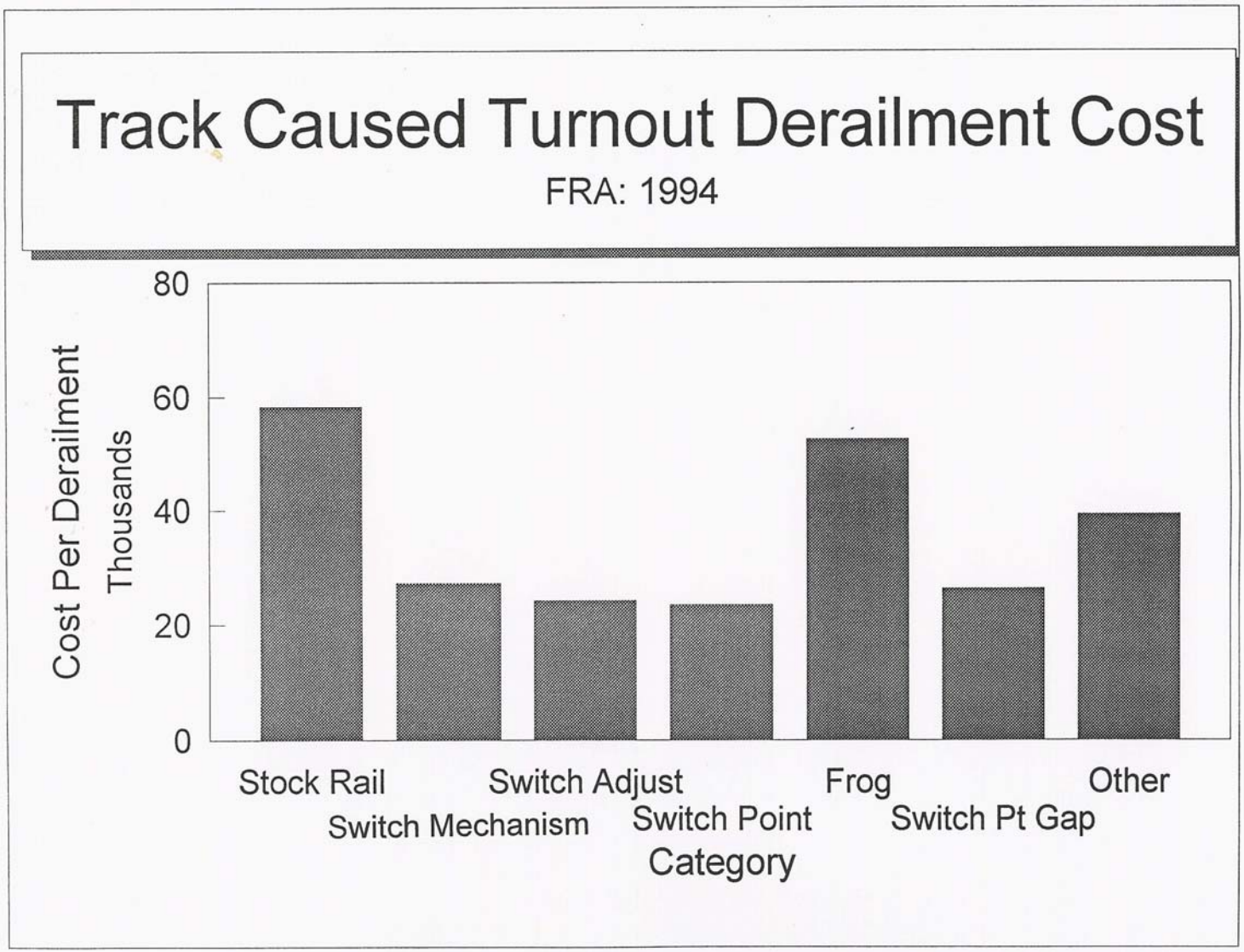


Figure 2: Track Caused Turnout Derailment Cost

This class of derailments (wheel climb derailments) has been identified [3] as the largest single category of turnout derailments for lighter axle load transit vehicles. (This appears to be due not only to the (relatively) high lateral forces generated in the turnout transition points but also to the relatively low vertical forces due to the lighter vehicle weight. These two factors combine to generate the high L/V ratios which are necessary for wheel climb.)

IDENTIFICATION OF CONTRIBUTORY FACTORS

As part of the transit derailment study, an attempt was made to examine, quantify and prioritize those factors that contribute to derailments in turnouts. This focus was not only on the direct contributory mechanism, but also on the potential for improvement of turnout design to prevent the relevant" classes of derailments. In the approach used, each derailment contributory factor was assigned a numerical rating in each of four areas:

- Contribution to Derailment
- Potential for Improvement
- Need for Improved Design or Practice
- Derailment History

The *Contribution to Derailment* was based directly on that factor's contribution to an existing derailment, based on experience with past derailments:

The *Potential for Improvement* category provided a rating for each factor based on that factor's anticipated potential for improvement in relation to practical and economical concerns.

The *Need for Improved Design or Practice* category identified and prioritized requirements for improved design and/or practice as indicated by the derailment data evaluated.

Derailment History was a direct count of the number of derailments identified with that causal factor during the study years.

Each factor in each of the four categories was evaluated as to its relative importance. By assigning an index to the level of importance for each of the four categories, a composite rating index was developed) thus allowing for a prioritization of the factors.

Each of the first three categories for each factor was assigned an index as follows:

High: A significant level of importance or observed relationship

Medium: A moderate level of importance and some observed relationship.
Low: Very little importance or observed relationship.

In order to prioritize the list of factors, a numerical value was assigned to each of the three indexes as follows:

High = 3
Medium =
Low = 1

In the case of the Derailment History category a numerical weighting was assigned as follows:

If a large number of derailments (defined to be greater than 3) were reported for that factor, then a weight of 2 was assigned, If 3 or fewer derailments were reported, then a weight of 1 was assigned.

In this manner, a composite index was determined as the sum of each of the values for each of the four categories. The higher the composite index; the more important the factor.

The initia1 list of factors (which is presented in Appendix A) was composed of 54 specific causal factors. Assigning the corresponding numerical value to each of the factors, as presented in Table 3, allowed for an unbiased weighting of the factors and development of a ranking of these factors. The result was a primary listing of 15 factors, of which eight were assigned a very high ranking. Of these eight highly ranked factors, three were operating factors and the remaining were track related factors.

The highest ranked track design and/or maintenance factors were:

- Transition into switch point (Design)
- Transition from switch to stock rail (Design)
- Wear standards (Maintenance)
- Lack of adequate lubrication (Maintenance)
- Out of adjustment (Maintenance)

Table 3. High Priority Factors

Design, Maintenance, Operator, Vehicle	Factor	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Composite Weighting Factor	Reported Derailments Index
D	Transition into Switch Point	high	high	high	3	3	3	9	2
D	Transition From Switch to Stock Rail	high	high	high	3	3	3	9	2
M	Wear Standards	high	high	high	3	3	3	9	2
M	Lubrication Practices (lack of)	high	high	high	3	3	3	9	2
M	Out of Adjustment	high	high	high	3	3	3	9	2
O	Non Reported Run Through	high	high	high	3	3	3	9	2
O	Operating Speed	high	high	high	3	3	3	9	2
O	Train Handling: Acceleration	high	high	high	3	3	3	9	2
D	Approach Angle (Angle of Attack)	high	high	high	3	3	3	9	1
M	Fit with Stock Rail	high	high	high	3	3	3	9	1
M	Inspection Practices (lack of)	high	high	high	3	3	3	9	1
M	Trackwork Maintenance Intervals	high	high	high	3	3	3	9	1
V	Wheel Profiles	high	high	high	3	3	3	9	1
V	Vehicle Maintenance Intervals	high	high	high	3	3	3	9	1
V	Wheel Flange/Tread Standards and Tolerances	high	high	high	3	3	3	9	1

METHODS OF DERAILMENT PREVENTION

Noting the high ranking derailment causal factors, it is possible to define the methods of derailment control that best match these factors. The following is a listing of techniques for reducing derailments based primarily on the wheel/rail dynamic class of derailments identified in the transit derailment study [3]. Analysis of freight derailments suggests that these methods likewise would be effective in preventing freight railroad derailments. However, in the heavy axle load freight environment, these would have to be supplemented with the use of high quality components such as premium or high integrity material to reduce the incidence of component failure that occurs in that environment. Table 4 provides a summary of what are considered to be effective techniques that may be used to address several of the major classes of derailments and associated causal factors.

Table 4

Methods of Derailment Mitigation

- Improved Entry Geometry
- Improved Guarding of Turnouts
  - Extended Guard Rail Turnout
  - Fully Guarded Crossover
  - House Top Point Protectors
- Development and Implementation of Maintenance and Inspection Standards
- Standards for Gage Face Wear Angle for Switch and Closure Rails
- Lubrication
- Switch Point Protectors
- Elimination of Mismatch Between Wheel and Rail
- Premium Components

These techniques are described individually as follows:

Improved Entry Geometry

Traditional straight switch points have a large switch entry angle (also referred to as the switch angle) which can generate large dynamic forces, particularly lateral forces, as the vehicle enters into and negotiates the switch. Use of improved geometry designs, such as curved switch points, tangential geometry turnouts, etc. can result in a reduction in the entry angle. This can be accomplished in some designs (curved switch points), while keeping the length of the switch constant. In others (tangential geometry turnouts) the length of the switch is increased. In all of these cases, the radius incorporated into the new design switch point allows for a more gradual rate of change in curvature as the vehicle enters into the switch and traverses the switch point (going into the body of the turnout). This, in turn, results in a reduction in the lateral wheel/rail forces through the entry and transition zones in the turnout with a corresponding reduction in both L/V ratio and derailment risk [4].

It should be noted that improved entry geometry designs are generally more expensive than straight AREA switch points, and in some cases, must be custom designed to allow for retrofit-into an existing turnout design.

Improved Guarding of Turnouts

In sharp turnouts (such as number 8 or lower turnouts) and short crossovers, powered vehicles, such as transit cars, have a potential to climb the outside rail in the curved portion of the turnout when a combination of curve worn rail, high speed and/or sudden power application occurs. Under certain conditions the ratio of lateral. (L) force to the vertical force (V), usually referred to as the L/V ratio, exceeds the threshold for potential wheel climb (the Nadal Limit, $L/V > 0.8$), which can result in the wheel climbing over the outside rail [4].

In order to reduce or eliminate these derailments, guard rails are used, particularly at locations where the risk of this type of wheel climb derailment is greatest. By modifying guard rail design or extending guard rail length, the risk of derailments at these locations can be further reduced.

In general, there are four classes of guarded turnouts commonly found in special trackwork. These are as follows:

1) Standard (AREA) Turnout
2) Extended Guard Rail Turnout
3) Fully Guarded Turnout/Crossover (without house top)
4) Fully Guarded Turnout/Crossover with house top point protection[8]

[8] Note: A house top is a point guard (i.e. a guarding device located at the switch point, usually on the curved side of a turnout) to control flanging of the wheel set through the switch point and stock rail. House top protectors can be used independent. of any other guard or protection

The standard turnout provides guard protection in the area of the frog only, while the extended guard rail turnout (Figure 3) provides protection from the point of the switch through the frog. The fully guarded turnout or crossover (Figure 4) provides protection from point to point through the entire device. The extended guard rail (and also the fully guarded turnout) restrains the angle of attack of the lead wheel and, as wear takes place, equalizes the forces on the gauge side of the outside rail and the guarding face of the guard rail. These guarded turnouts and crossovers have significantly reduced, if not fully eliminated, wheel climb derailments within the guard rail area, unless other contributing car or track conditions exist. The house top protection at the point (Figure 5) can be added to either an extended guard rail turnout or a fully guarded turnout/crossover, or used independently.

Note that extended guard turnouts, fully guarded turnouts and house tops have been used primarily on transit systems because of their relatively high cost and additional maintenance requirements.

Development and Implementation of Maintenance and Inspection Standards

Examination of the factors that contributed to derailments, as well as the reported derailments themselves, showed that a significant number of derailments were associated with worn wheels, worn rails, inadequate guard rail spacing or other issues associated with inadequate or improper maintenance or replacement of turnout components. This included a large number of reported derailments due to components that were' approaching the limits of wear (or which had exceeded the limits but had not been so identified by the rail system) [3].

Adoption and or implementation of effective track and vehicle standards has been shown to be effective in the mitigation of this class of derailments.

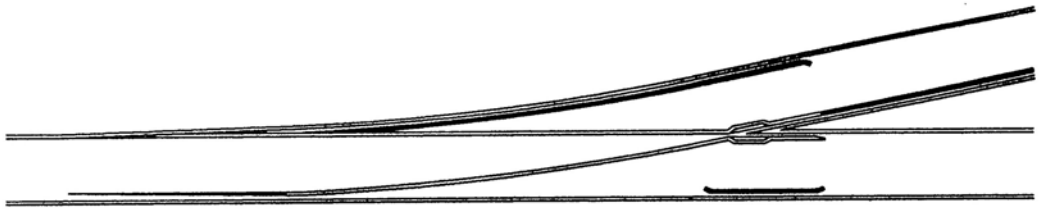
Use of improved maintenance and inspection standards, or rigorous enforcement of existing standards, has been shown to be a cost-effective way to reduce turnout derailments [3].

Standards for Gauge Face Wear Angle for Switch and Closure Rails

Recent research has related the risk of wheel climb not only to the L/V ratio but also to the angle of contact between the wheel and the rail. The angle of contact, in turn, is directly related to the gauge face wear angle of the rail, which increases as the rail experiences gauge face wear. The higher the gauge face wear angle, the lower the L/V ratio required for wheel climb to occur [5], and thus the greater the risk of derailment. This behavior has been reported to be the apparent cause of several derailments [3,5]. These derailments can occur on curves as well as within turnouts, wherever high levels of lateral load and L/V are generated.

In order to reduce the risk of this class of derailments, several properties have instituted standards for maximum allowable gauge face wear angle (angle Φ in Figure 6).

Figure 3: Extended Guard Rail Turnout.



= TURNOUT RUNNING RAIL

= GUARD RAIL

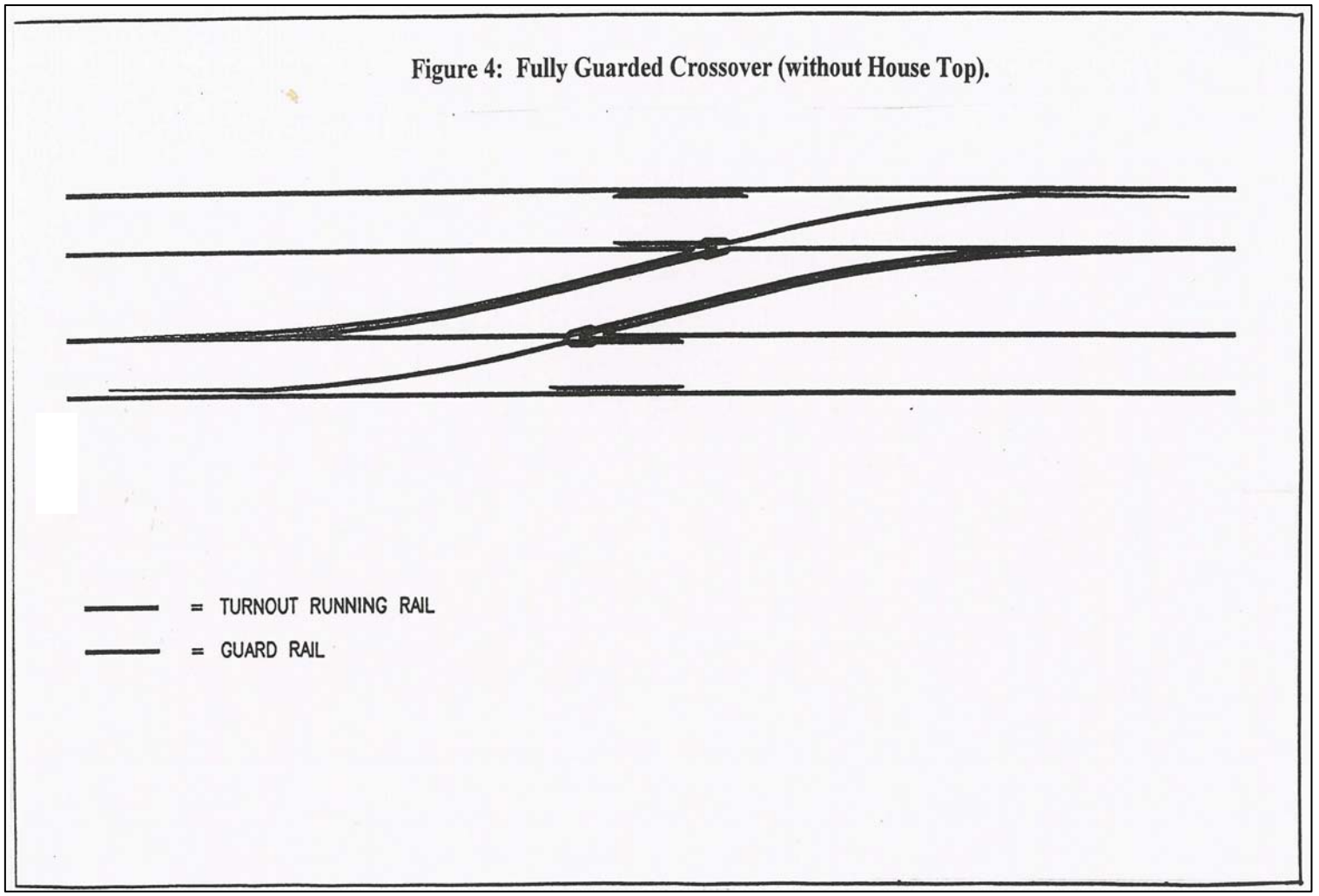
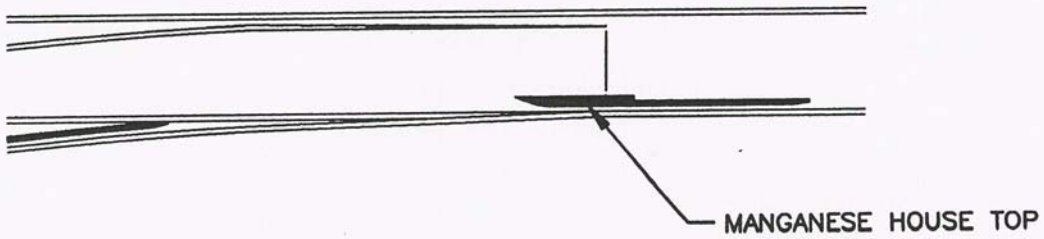


Figure 4: Fully Guarded Crossover (without House Top).
= TURNOUT RUNNING RAIL
= GUARD RAIL

Figure 5: House Top Protection Switch.



= TURNOUT RUNNING RAIL

= GUARD RAIL

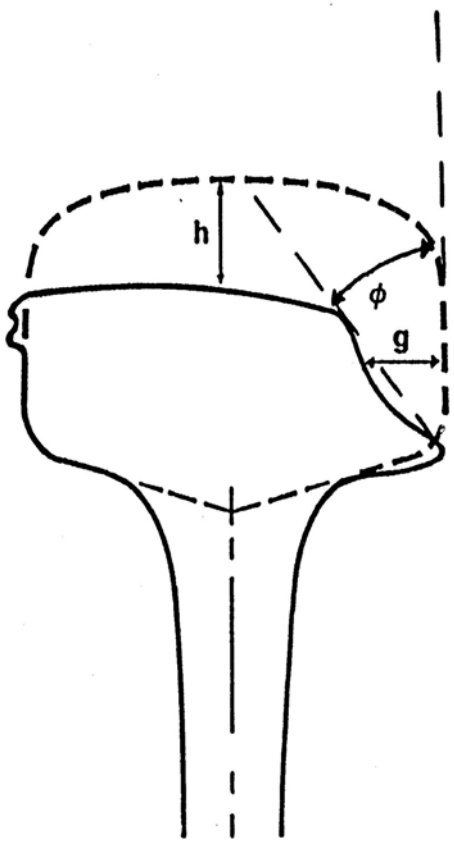


Figure 6: Rail Wear Criterion.

In the case of turnouts, these limits are generally applied through the diverging switch point, curved closure rail, and straight stock rail just ahead of the diverging point.

Use of Lubrication

In a manner analogous to that discussed previously for gauge face wear angle, the coefficient of friction between the wheel and the rail also directly affects the risk of wheel climb derailments, both on sharp curves and within a turnout (or wherever large lateral forces and LN ratios are generated). A high coefficient of friction (dry rail) generates an increased risk of wheel climb by lowering the LN ratio threshold [5]. Here too, derailments in turnouts on both transits and freight railroads have been associated with dry or very dry rail conditions [3]. As a result, the use of lubrication is a cost effective method to reduce the risk of derailment. However, it must be strongly cautioned that lubrication should be used with great care to prevent the lubricant from migrating to the top of the rail head and causing problems in braking or accelerating through the turnout (or onto the adjacent track).

Use of Switch Point Protectors

As a vehicle enters a turnout in a facing move, there is a likelihood of the wheel impacting the front of the switch point, particularly if the point is not properly fitted against the rail (if there is a gap between the point and the stock rail): If such impacts occur, they can result in damage to the point and possible widening of the gap between the switch point and the stock rail. This in turn can lead to derailments either due to the wheel "splitting" the switch (with the wheel flange going between the switch point and the stock rail) or due to the wheel climbing a badly worn/chipped switch point.

One technique for protecting the switch point from this type of damage, and correspondingly reducing the risk of these types of derailments, is to provide an external protector for the switch point that deflects the wheel slightly so as to prevent impact. (Another approach is to undercut the stock rail so that the switch point fits tightly against the stock rail, thus av9iding exposure of the tip. In this case, maintenance and inspection is very important to ensure that the point is always tight against the stock rail.)

Switch point protectors can take several forms:

- an external bolt-on protector placed ahead of the switch point to deflect the wheel away from the point
  - one configuration bolted to the rail
  - one configuration bolted to the switch point (and cantilevered forward ahead of the point)
- a weld bead placed ahead of the point to deflect the wheel away from the point
- a geometric perturbation ("knuckle") placed in the rail ahead of the switch point to protect the point from the wheel

- a switch point guard (such as the house top already discussed)
- an undercut stock rail/switch point configuration (such as the AREA Samson switch)
- a switch point guard placed ahead of the point to guide the flange of the opposite wheel (used in high speed operations)
- a switch point guard placed outside of and higher than the running rail that guides the outer face of the wheel (used in low speed operations)

Both railroad and transit properties make use of switch point protectors (or point guards) which represent a relatively low cost method for addressing several classes of turnout derailments, including the category of split switch (a frequent cause category for freight railroads, particularly in low density lines).

Elimination of Mismatch Between Wheel and Rail

As has already been noted, there is significant dynamic interaction between the vehicle and the track as the vehicle negotiates a turnout. This interaction is: sensitive to the design parameters of both the vehicle system and the turnout. Wheel and axle relationships must be defined so that tread width, flange depth and thickness, back to back dimensions and tolerances properly match the track and special trackwork configurations (including allowable tolerances for both wheels and rails). Furthermore, wheel profiles and associated switch geometry must not be allowed to degrade to the point where proper wheel movement through the switch is affected. For example, where a "false flange" on a wheel can fall between the switch point and stock rail causing rail rollover or otherwise preventing proper movement of the wheel through the switch.

Another situation, found primarily on transit systems, is that where non-AAR wheel profiles are operated on AREA specification track. This has occurred particularly on light rail systems, which often use smaller wheel tread and flange sizes. Thus, for example, significant problems have been reported when equipment with European wheel profiles (such as the DB II profile which has an effective wheel flange of 19.5 mm (0.77 inches)) is run on special trackwork built to AREA specifications (which are based on 1" wheel flanges).

Use of Premium Components

Component failure, i.e. cracking or breaking, under traffic is a significant mode of failure for -freight railroads, both in the frog and the switch areas of the turnout. This mode of failure, which is most frequently found on heavy axle load, high tonnage lines, has been addressed through the development and use of "premium" components, i.e. components with increased strength, hardness, fracture toughness, and with reduced

internal "flaws". These premium components have been found to reduce maintenance requirements and decrease risk of component failure [7]. Thus, for example, the use of high integrity frog castings, which have a reduced probability of internal flaws, can reduce the derailment potential that occurs as a result of a fracture of the frog under traffic. In general, however, premium components are more expensive than conventional components.

Summary and Ranking

The derailment mitigation (prevention) techniques defined above directly relate to the causal factors and mechanisms defined for both freight railroads and transit systems. Table 5 presents a summary and ranking of these methods for derailment mitigation. This summary addresses and provides an overall ranking (High, Moderate or Low) of effectiveness, cost and potential for improvement for each method.

These techniques have been identified as offering potential for an improvement in the control of turnout derailments, particularly derailments that have been attributed to track or track related causes. This includes not only direct failure of components, ca major cause mechanism for freight railroads, but also wheel climb related derailments, which can be a function of track, mechanical and/or operating factors. Even in those cases where the primary derailment cause is not track related, use of the above devices or techniques can reduce or eliminate the probability of derailment. For example, the use of a switch protector can reduce split switch derailments, even in the presence of thin flanges.

Table 5

Ranking of Methods of Derailment Mitigation

	Effectiveness	**Cost**	**Potential for Improvement**	**Overall Ranking**
Improved Entry Geometry	Moderate	Moderate to High	High	Moderate
Improved Guarding of Turnouts	High	Moderate to High	Moderate	High
Development and Implementation of Maintenance and Inspection Standards	High	Low	High	High
Standards for Gage Face Wear Angle for Switch and Closure Rails	High	Low	High	High
Lubrication	Moderate	Moderate to High	High	Moderate
Switch Point Protectors	Moderate to High	Moderate	Moderate	Moderate
Elimination of Mismatch Between Wheel and Rail	Moderate to High	Moderate to High	High	Moderate
Use of Premium Components	Moderate to High	Moderate to High	Moderate	Moderate

By properly understanding the relation between derailment mechanism, cause, and protection device, it is possible to best define and identify those approaches that can be used to control turnout derailments associated with a given set of operations and conditions. However, it should be noted that cost and effectiveness are strongly dependent on the operation itself. Thus, derailment prevention techniques that can be very effective in a heavy axle load freight environment (e.g. use of premium components to reduce failures) may not be cost effective in a different environment (such as the lighter axle load transit environment where component failure does not frequently occur). It is therefore necessary to match derailment prevention techniques to the type of operation and to the value of the benefit that can be accrued.

REFERENCES

1. "Accident/Incident Bulletin No. 163, Calendar Year 1994", U.S. Department of Transportation, Federal Railroad Administration, August 1995.

2. "Accident/Incident Bulletin No. 162, Calendar Year 1993", U.S. Department of Transportation, Federal Railroad Administration, June 1994.

3. ZETA-TECH Associates, Inc., "Derailment of Transit Vehicles in Special Trackwork", Final Report Transit Cooperative Research Program Project D-2, July 1996.

4. Zarembski, A. M., "Reducing Wheel Rail Forces in Turnouts", **Tracking R&D: Research & Development,** Simmons-Boardman Publishing Corp., CT. (1992) pp 199-200.

5. Blader F., "A Review of Literature and Methodologies in the Study of Derailments caused by Excessive Forces at the Wheel/Rail Interface", **Association of American Railroads Report R- 717,** December 1990.

6. Zarembski, A. M., "Development of Gage Face Angle Standards to Prevent Wheel, Climb Derailments" Bulletin of the American Railway Engineering Association, Bulletin 756, Volume 97, May 1996.

7. Zarembski, A.M., "Improved Performance From Premium Turnouts", **Tracking R&D: Research & Development,** Simmons-Boardman Publishing Corp., CT., (1992) pp 199-200.

APPENDIX A

LISTING OF ALL 54 TURNOUT CAUSAL FACTORS

APPENDIX A. LIST OF WEIGHTED FACTORS

Factor	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Composite Weighting Factor
Trackwork Design Factors:							
Switch Point Configuration	high	med	med	3	2	2	7
Radius of Closure Rail	low	low	low	1	1	1	3
Switch Point Protection	low	high	med	1	3	2	6
Switch Geometry (including approach angle), curved vs straight points	med	med	med	2	2	2	6
Approach Angle (Angle of Attack)	high	high	high	3	3	3	9
Transition into Switch Point	high	high	high	3	3	3	9
Transition From Switch to Stock Rail	high	high	high	3	3	3	9
Transition From Stock Rail to Frog	low	low	low	1	1	1	3
Transition Off of Frog	low	low	low	1	1	1	3
Frog Geometry	low	med	med	1	2	2	5

APPENDIX A. LIST OF WEIGHTED FACTORS (CONTINUED)

Factor	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Composite Weighting Factor
Overall Geometry	med	high	high	2	3	3	8
System Tolerances	med	med	high	2	2	3	7
Switch Area Guards	low	high	high	1	3	3	7
Frog Guards	med	high	med	2	3	2	7
Extended Frog Guards	low	high	high	1	3	3	7
Frog Design/Construction							
Frog Gap Design	med	high	med	2	3	2	7
Frog Point Design	low	low	low	1	1	1	3
Manganese Casting	low	low	low	1	1	1	3
Rail Bound	low	low	low	1	1	1	3
Self-Guarded	low	med	med	1	2	2	5
Track Strength							

APPENDIX A. LIST OF WEIGHTED FACTORS (CONTINUED)

Factor	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Composite Weighting Factor
Longitudinal	low	high	med	1	3	2	6
Lateral	high	high	med	3	3	2	8
Vertical	med	med	high	2	2	3	7
Trackwork Maintenance Factors:							
Fit with Stock rail	high	high	high	3	3	3	9
Out of Adjustment	high	high	high	3	3	3	9
Rail Expansion	low	low	low	1	1	1	3
Poor Subgrade/Support (Under Heel)	med	med	med	2	2	2	6
Poor Subgrade/Support (Under Point)	med	med	med	2	2	2	6
Wear Standards	high	high	high	3	3	3	9
Standards for Chipping and/or Flow	med	high	high	2	3	3	8
Clearance Standards	low	low	high	1	1	3	5

APPENDIX A. LIST OF WEIGHTED FACTORS (CONTINUED)

Factor	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Composite Weighting Factor
Lubrication Practices (lack of)	high	high	high	3	3	3	9
Grinding Practices	med	med	high	2	2	3	7
Surface Condition Standards	med	med	high	2	2	3	7
Inspection Practices (lack of)	high	high	high	3	3	3	9
Component vs Panel Change-Out	med	high	high	2	3	3	8
Track Strength							
Longitudinal	low	high	med	1	3	2	6
Lateral	high	high	med	3	3	2	8
Vertical	med	med	high	2	2	3	7
Standardization (lack of)	med	high	high	2	3	3	8
Trackwork Maintenance Intervals	high	high	high	3	3	3	9
Operating Factors:							

APPENDIX A. LIST OF WEIGHTED FACTORS (CONTINUED)

Factor	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Composite Weighting Factor
Non Reported Run Through	high	high	high	3	3	3	9
Operating Speed	high	high	high	3	3	3	9
Operating Restrictions	med	med	med	2	2	2	6
Direction of Traffic	med	med	med	2	2	2	6
Future Expansion	low	med	low	1	2	1	4
Train Handling							
Acceleration	high	high	high	3	3	3	9
Braking	med	med	med	2	2	2	6
Vehicle Factors:							
Wheel Profiles	high	high	high	3	3	3	9
Wheel Flange/Tread Standards and Tolerances	high	high	high	3	3	3	9
Vehicle Maintenance Intervals	high	high	high	3	3	3	9

APPENDIX A. LIST OF WEIGHTED FACTORS (CONTINUED)

Factor	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Contribution to Derailment	Potential for Improvement	Need for Improved Design or Practice	Composite Weighting Factor
Economic Factors:							
First Cost (Installation Cost)	med	med	low	2	2	1	5
Estimated Maintenance Cost (Annual)	med	med	low	2	2	1	5
Life Cycle Cost	low	low	low	1	1	1	3