

FINAL REPORT

Evaluation of Single Crew Risks

Comparative Risk Assessment

ICF #142985

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Report to:

Association of American Railroads
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1. Introduction

At the request of the Association of American Railroads (AAR), ICF Incorporated (ICF) conducted a comparative risk analysis for select accident causes under present day mainline operations with traditional two-person crews versus future mainline operations on Class I railroad lines when a positive train control (PTC) system complying with Federal Railroad Administration (FRA) regulations is fully implemented—for both one- and two-person crews. The focus was on determining the frequency of accidents that might be impacted by crew size, and was limited to that fraction of Class I railroads' operations that are subject to PTC requirements. **Thus, it does not consider all causes of accidents and is not a full comparison of accident frequencies with and without PTC.**

PTC systems can warn the crew of the need to take certain types of action, and are able to stop trains to avoid train-to-train collisions, overspeed derailments, incursions into established work zones, or passage through improperly positioned mainline switches. This allows the PTC systems to enhance safety, but also essentially minimizes the benefit of the second member of the crew in the locomotive. Single crew operations are not without precedent within the rail industry and within other industries. Most commuter and intercity passenger trains in the US are operated with one person in the cab, and many international rail systems and a few smaller railroads on the US also safely and effectively operate freight trains with a single crew member. Other industries have also reduced their staffing of critical operations as technology has developed to the point where fewer people are needed for the same activities. This can be seen in situations from control rooms to vessel navigation to manufacturing facilities.

2. Approach

This analysis looks at various scenarios that would be impacted by the implementation of a one-person crew and compares the risks for those specific scenarios for the present base case and both the one- and two-person crew alternatives under PTC operations. The intent of the analysis is to understand what could go wrong, what the consequences would be, and the chance of something actually occurring. Safety performance was measured primarily by the predicted occurrence of FRA-reportable train accidents.

Given some of the issues that have been encountered in achieving full implementation of PTC systems, this analysis does not use a specific future date—rather it assumes full implementation of PTC where it will be required and feasible. For traditional two-person crews, the time period used for data collection depended on the specific type of data, but typically was for 2013 or 2011-2013. It should be noted that the only data used in this analysis is for the Class I railroads as a whole. The intent of the analysis is to compare the nationwide difference for the select scenarios between the present and future operations cases, not to identify differences across individual railroads.

2.1 Accident Scenarios

ICF previously worked with a Risk Analysis Working Group (RAWG) assembled by the AAR, and comprising representatives of member railroads, AAR staff, and consultants to identify accident scenarios that were expected to be impacted by crew size. The RAWG

reported through the Interoperable Operations and Train Control Working Committee to the Safety and Operations Management Committee of the AAR (SOMC), which is composed of the chief operating officers of member railroads. The prior collaboration with the RAWG informed the present analysis.

The earlier work identified all the activities presently performed by today's two-person crews. If the train crew is reduced to one crew member, the primary and secondary activities performed by second crew member would have to be reallocated, modified, or eliminated. The potential ways of addressing the second crew member responsibilities are:

- Reallocate them to the remaining crew member (the operator), where this is judged to be safe and operationally feasible.
- Use technology (in this case the PTC system) to modify the activity so that it can be carried out by the remaining crew member without reducing safety and operational performance.
- Transfer responsibility for the activity to a mobile worker who comes to the train when required.
- Change operating practices to eliminate the activity when trains are operated by a single crew member (or if they are required, do not operate that train with a single crew member).

A fault tree analysis was used to develop and display the different ways in which certain types of accidents or injuries arise today and how these might change under both future scenarios. To develop the fault trees, each train crew function was examined in turn to describe how the function is performed today with two-person crews and how it would be performed under PTC. For example, if a function of the train crew is to operate the train in compliance with speed limits and signal indications, then the accident scenario is a collision or derailment caused by a failure to comply with the limits and indications. Functions where there is no material change between one- and two-person crew operations, or where the nature of the new operations simply eliminates a function, were not considered further. Thus, the risk analysis considered only that subset of accident scenarios that would be expected to change (positively or negatively) under the crew size assumptions.

Four basic sets of accident scenarios were considered for changes under crew-size assumptions:







- **Accidents Due to Violations:** The accidents of concern for the comparative risk analyses are those that are driven by crew member actions, namely authority, overspeed, and signal decertifications. The fault trees also reflect the fact that there is the potential for a PTC system to display a warning to the operator to enable them to take a timely and appropriate action and to actually enforce the underlying requirements if appropriate. [Fault Trees 1 and 2]
- **Route Integrity Failures:** Accidents of interest that are attributable to route integrity failures are those that can be caused by visible problems with the track or route where the crew members have time to react but fail to do so, or that may be caused

by certain problems with the track where PTC and other systems would have a chance of detecting the problem. [Fault Trees 3, 4A, and 4B]

- Rollaway Accidents:** Two particular accident scenarios were identified that would be different for traditional operations today versus under the future cases. These involved instances in which: 1) the train was intentionally stopped to either move a hand operated switch or 2) to inspect the train after an emergency brake or detector stop. Regardless of why the train was stopped, the concern is if the train starts to roll away and the engineer in the cab must stop the train before an accident occurs. In general this will only happen if the train has not been properly secured and the slope is sufficient for the train to start to roll. In the future one-person crew case, there is no engineer in the cab, so the operator on the ground must get back into the cab to stop the train or the onboard system must stop the train. [Fault Trees 5 and 6]
- Failure to Sound Horn:** Crew members influence the chance of an accident at a grade crossing because if they need to sound a horn and fail to do so, there is an increased chance of a grade crossing collision occurring. In the future case with a PTC system, the automatic activation of the horn also has to be considered. [Fault Trees 7 and 8]

2.2 Fault Tree Analysis

To construct a fault tree, one states the undesired event and then repeatedly asks how that might come about, until the basic causes or the lowest practical level of detail is achieved. The construction of the fault tree is the most critical step in fault tree analysis and involves elements of both art and science. A standard set of logic and event symbols facilitates construction. The logic operators indicate whether just one event is needed or if the full set of events shown is required for the event to progress. The symbols are depicted and described below to serve as guides for interpreting the fault trees that appear in Attachment A. The data for each event in the fault trees is given in Attachment B.

	AND gate - all of the contributing events must occur to cause the identified intermediate or top event; inputs are multiplied
	OR gate - one of the contributing events must occur in order to cause the identified intermediate or top event; inputs are added
	Initiating event
	Contributing event - rate of occurrence per demand; conditional on prior initiating and contributing events
	Intermediate level event - caused by more primary events developed below
	Multiplier - accounts for number of similar components or systems such as the number of vehicles

The use of fault trees not only shows the combinations of events and failures that can lead to an accident, but also supports the quantification of the likelihood of occurrence of accidents under the different cases. The quantification considers historical data derived from analysis of the FRA accident database and data collection efforts by Class I railroads as described later in this memorandum, human error rates from other data sources, and professional judgments based on the collective experience gathered during the 2006 analysis from the working group for that study.

2.3 Data Sources

AAR played a key role in gathering data from the Class I railroads as well as in extracting data from the FRA's safety databases to assist in the analysis. Specific data was obtained from:

- **FRA.** The FRA makes available on its website (safetydata.fra.dot.gov) numerous safety databases, many going back to 1975. AAR selected data for the Class I freight railroads only generally for both 2013 and for the five-year period 2009 through 2013, inclusively. Use of these FRA databases greatly simplified and standardized the estimates of accident and incident rates and risks as compared to obtaining and using data from individual railroads.

AAR extracted the following parameters from the FRA Train Accident database:

- FRA-reportable train accidents attributed to :
 - Signal violations
 - Authority violations
 - Speeding violations
- FRA-reportable train accidents attributed via cause codes or accident type codes to obstructions or track defects. A small proportion of such defects might have been detected in time by a second crewman.

From the FRA Highway Rail Accident/Incident (grade crossing) database, AAR extracted grade crossing collisions (a small proportion of which might have been preventable by the presence of a second crewman) out on the line of road.

From the FRA Grade Crossing Inventory database, AAR extracted a partial measure of grade crossing collision exposure, i.e., the number of grade crossings, both the total and just those protected by active warning devices.

And from the FRA Operational Data database, AAR extracted train miles as another exposure measure.

- **Class I Railroads.** Six individual Class I freight railroads participated in the study and submitted several types of data covering calendar years 2011-2013 from their internal databases. The railroads were CSX, NS, BNSF, UP, CN, and KCS.

Parameters on which these railroads provided data included:

- Road crew starts and road crew starts in PTC territory

- Signal, speed, and authority violations
- **ARINC Engineering Services.** In late 2012, ARINC conducted a reliability, availability, and maintainability study for various PTC system segments, providing an indication of the availability and failure rates for the wayside, locomotive, base station, and back office components. They noted that the software systems (back office) will improve in some ways as the systems are tested and enhanced, but that the hardware reliability is not expected to change much.

3. Results and Conclusions

Using the data from the fault trees in Attachment A, the following results were obtained for the comparison cases, expressed as results per million crew starts.

Table 1: Fault Tree Results per Million Crew Starts

Scenario	Results Today	One-Person Crew with PTC	Two-Person Crew with PTC
1. Train Accidents due to Violations	3.4	0.027	0.027
2. Train Accidents Due to Selected Route Integrity Failures	4.1	0.79	0.78
3. Train Accidents due to Rollaways	0.97	0.096	0.97
4. Grade Crossing Collisions due to Failure to Sound the Horn	0.7	0.07	0.07

These results suggest the following observations:

- The number of accidents due to violations decreases significantly (by more than a factor of 100) in the future case where there is a PTC system.
- Accidents due to the analyzed route integrity failures decline significantly, but not as much as those due to violations.
- Train accidents due to rollaways decrease by a factor of 10 with the removal of a second person from the cab due to fewer potential situations and additional care taken when the sole operator leaves the cab. [This scenario is not impacted by the addition of the PTC system, just the change in crew size.]
- Grade-crossing collisions attributable to the failure to sound the horn decrease by roughly a factor of 10 in the future case.
- The two future cases have very similar results, regardless of crew size.

Each of the major categories of events as shown in Table 1 represents an outcome that can also be expressed as an annual number of accidents, as shown in Table 2. The figures given in Table 2 are based on the crew starts in PTC territory for the seven major Class I railroads in the United States, an average of about 3.1 million crew starts for 2011-2013.

As such, these accidents represent only a fraction of the overall accidents—another 560,000 crew starts (based on 2011-2013 averages) would likely see the same rates as

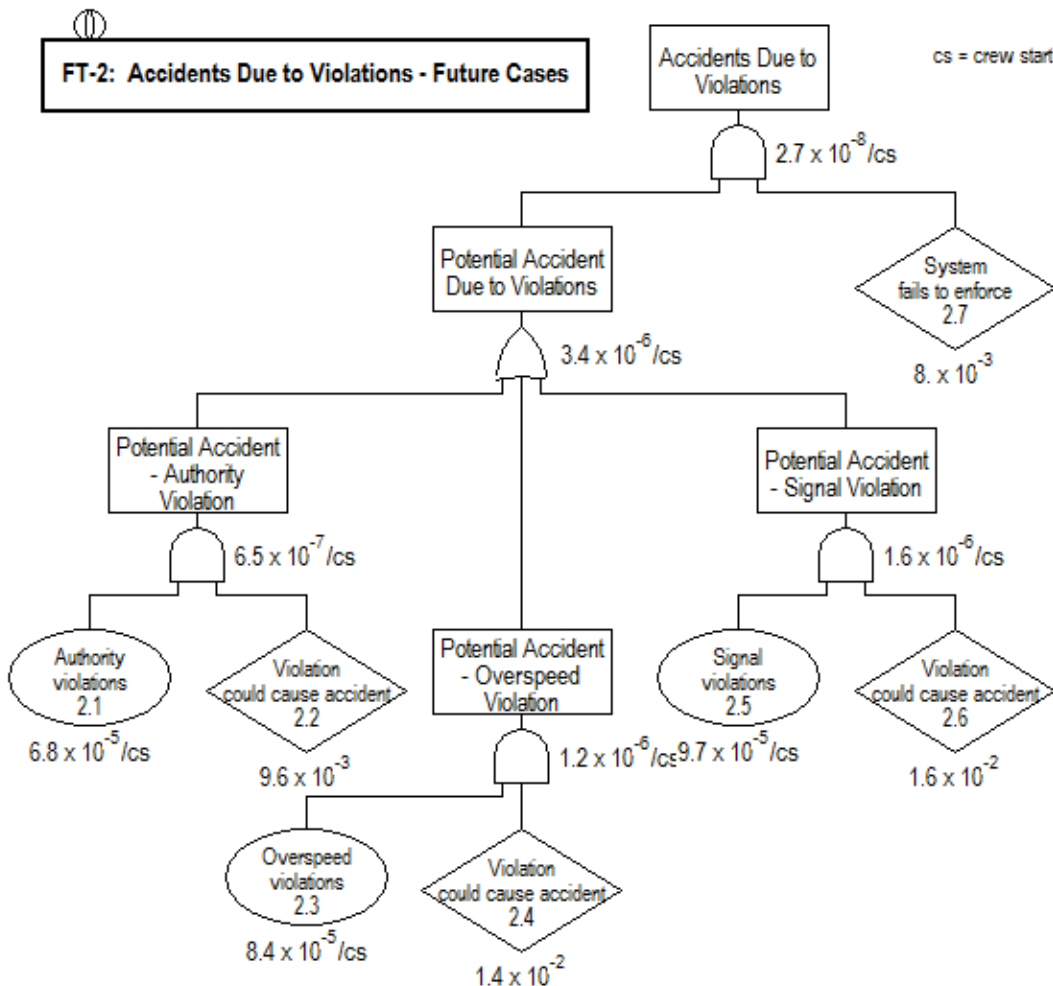
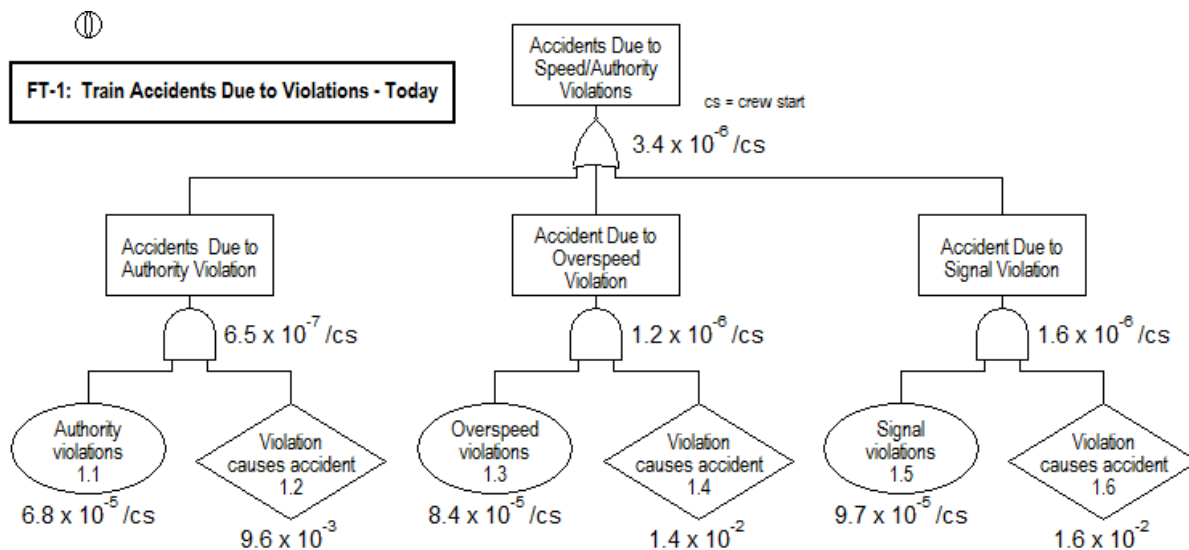
today and there are many other causes of accidents that were not the subject of this evaluation.

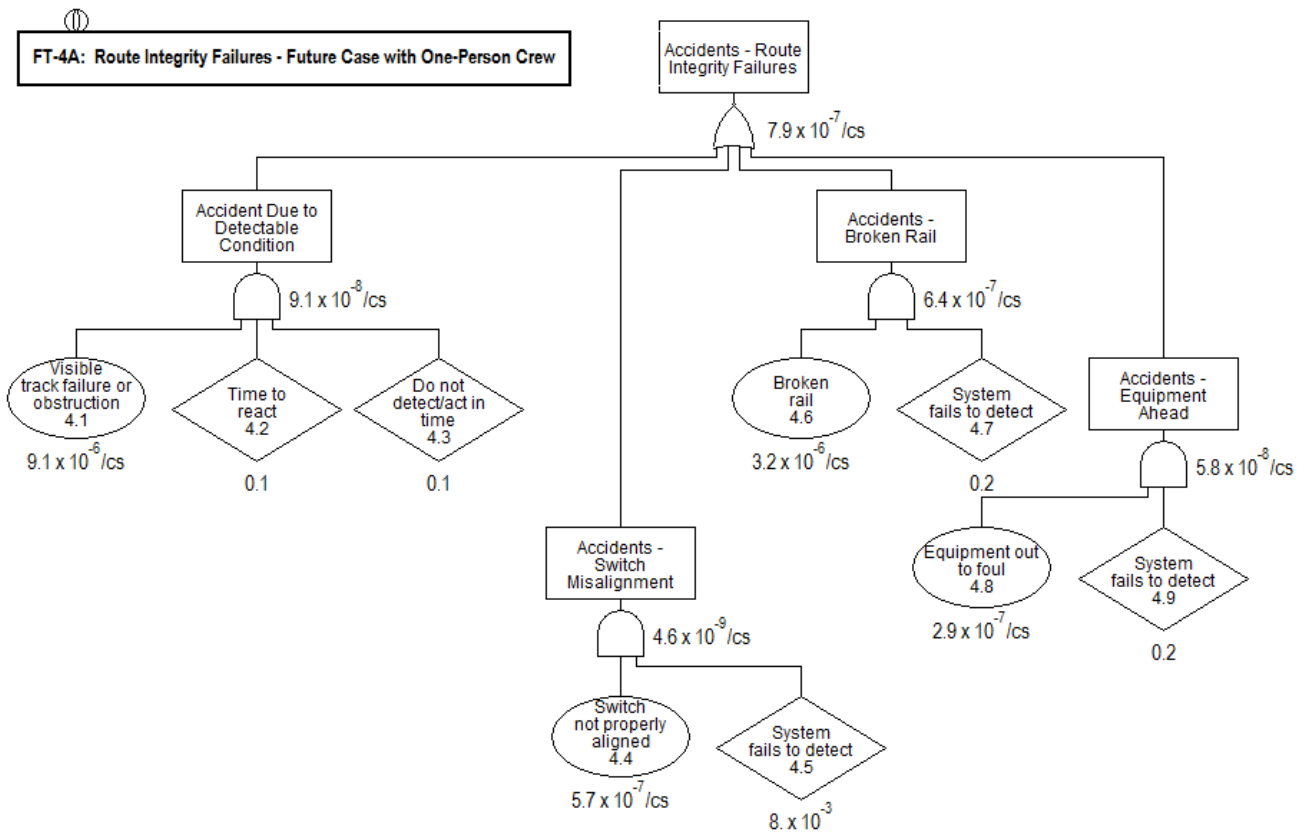
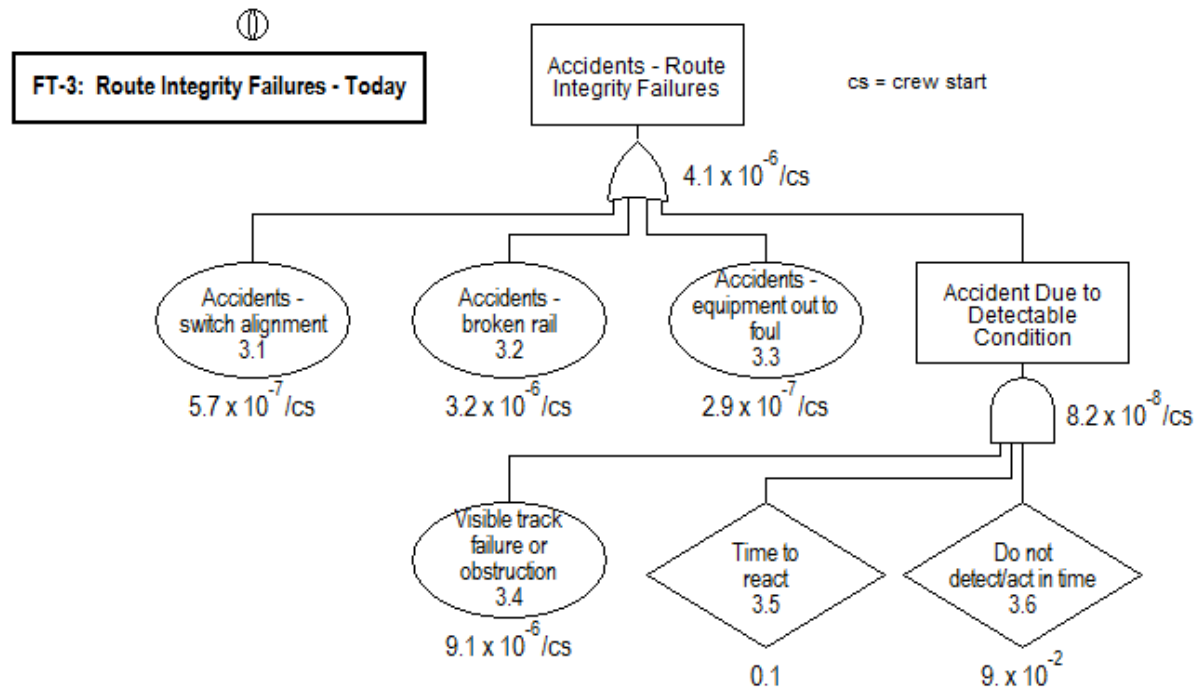
Table 2: Fault Tree Results Expressed in Accidents per Year in PTC Territory

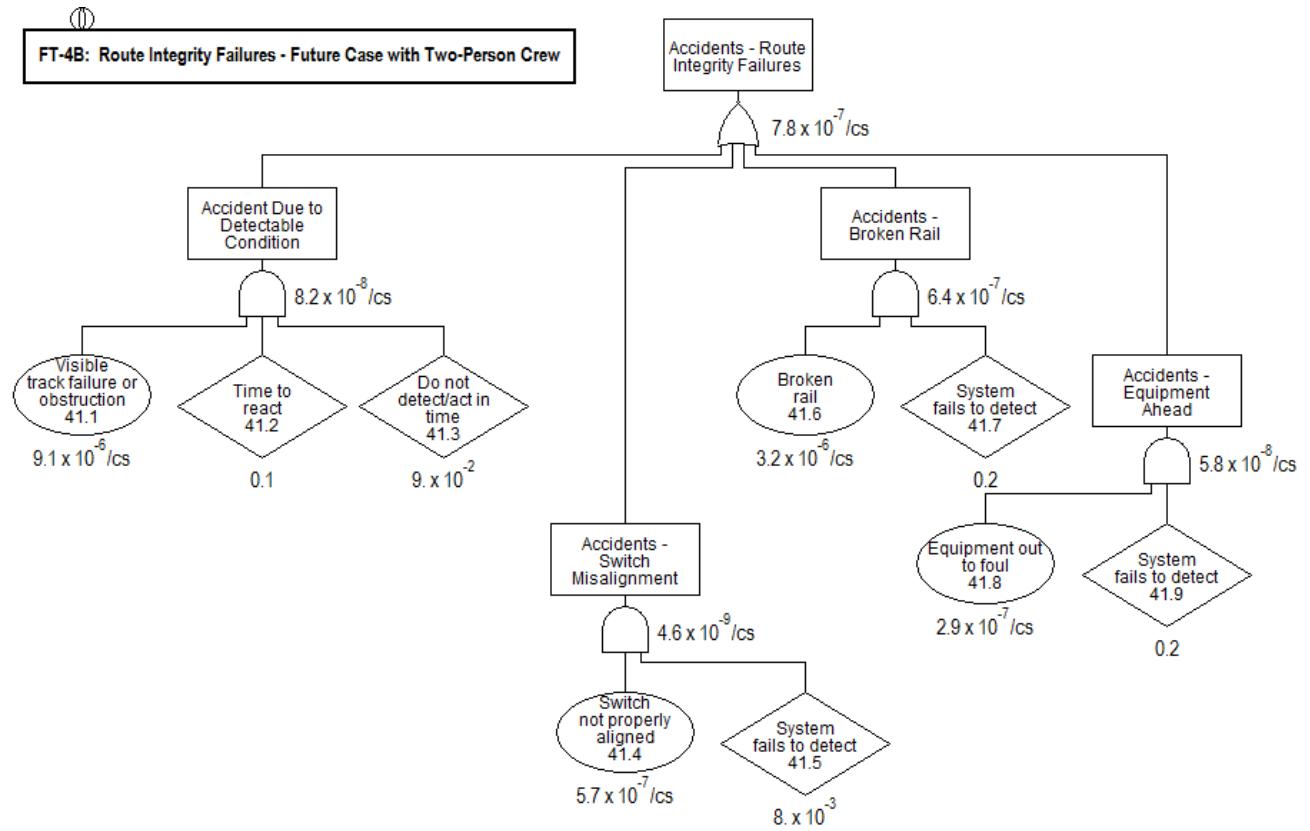
Scenario	Results Today	One-Person Crew with PTC	Two-Person Crew with PTC
1. Train Accidents due to Violations	11	0.1	0.1
2. Train Accidents Due to Selected Route Integrity Failures	13	2.5	2.4
3. Train Accidents due to Rollaways	3	0.3	3.0
4. Grade Crossing Collisions due to Failure to Sound the Horn	2	0.2	0.2
Accident Totals	29	3.1	5.7

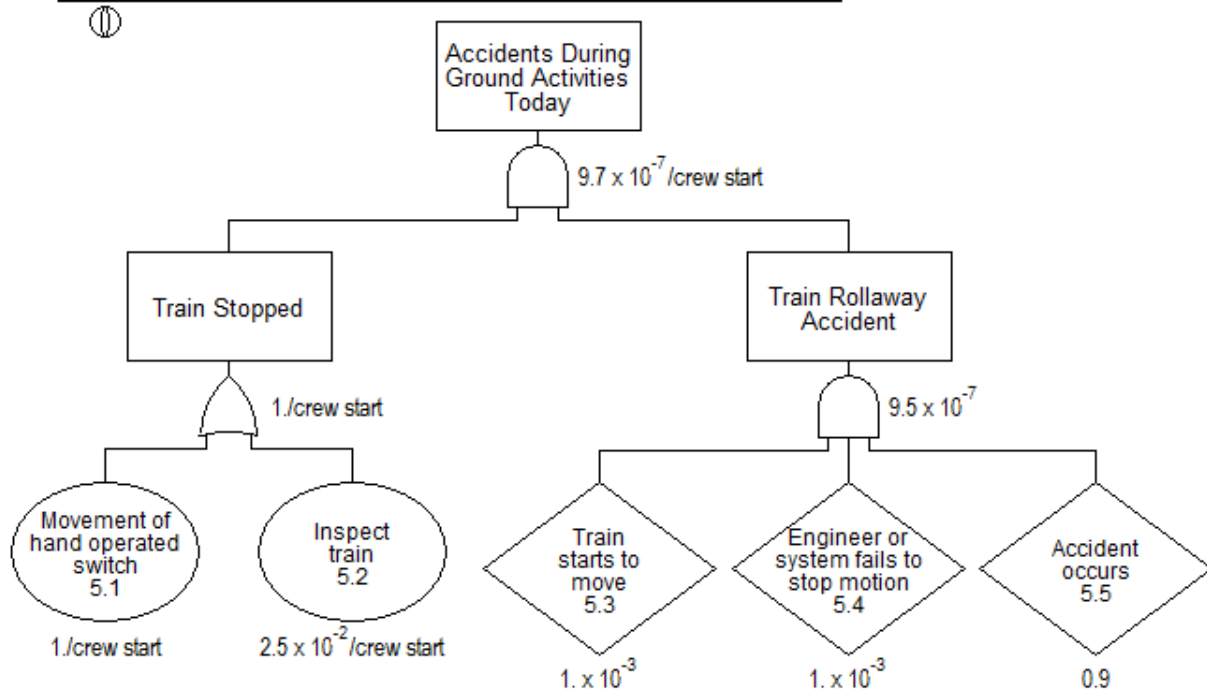
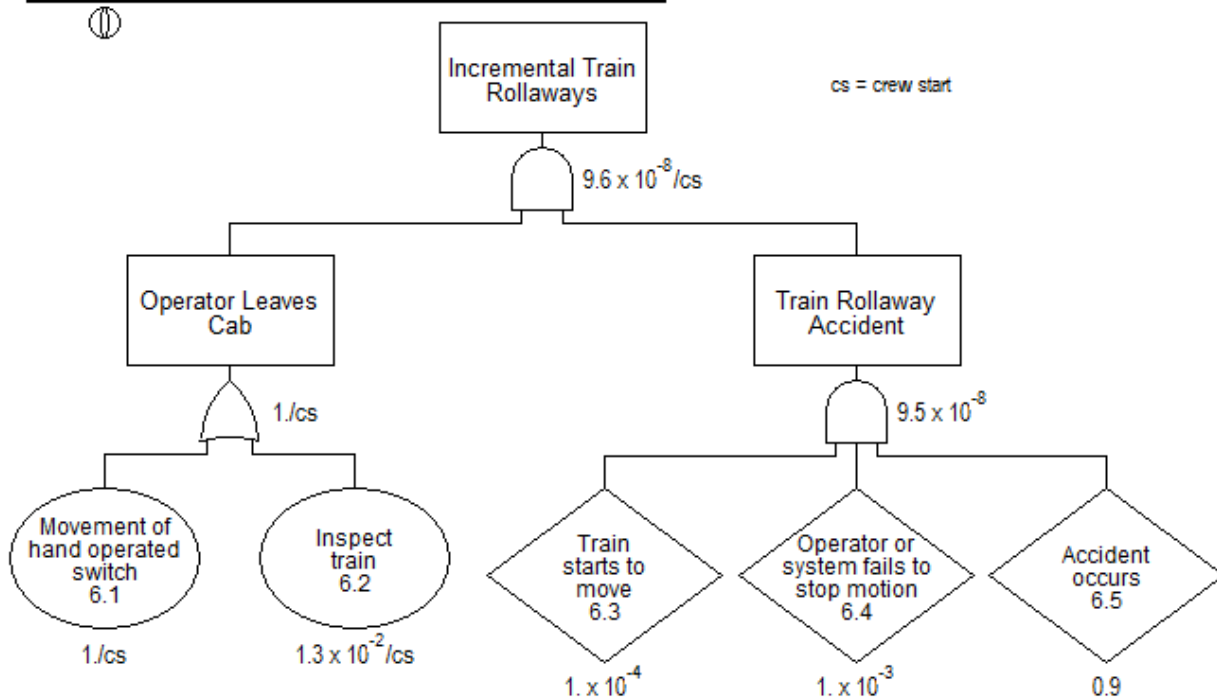
Taken as a whole, future operations for the analyzed scenarios have fewer predicted accidents, limited from further reductions only by the current ability of today's systems to identify a number of broken rail and equipment-out-to-foul failures as depicted on Fault Trees 3, 4A, and 4B. The differences between one- and two-person crews in the future cases are small, and both cases have appreciably fewer predicted accidents for the analyzed scenarios.

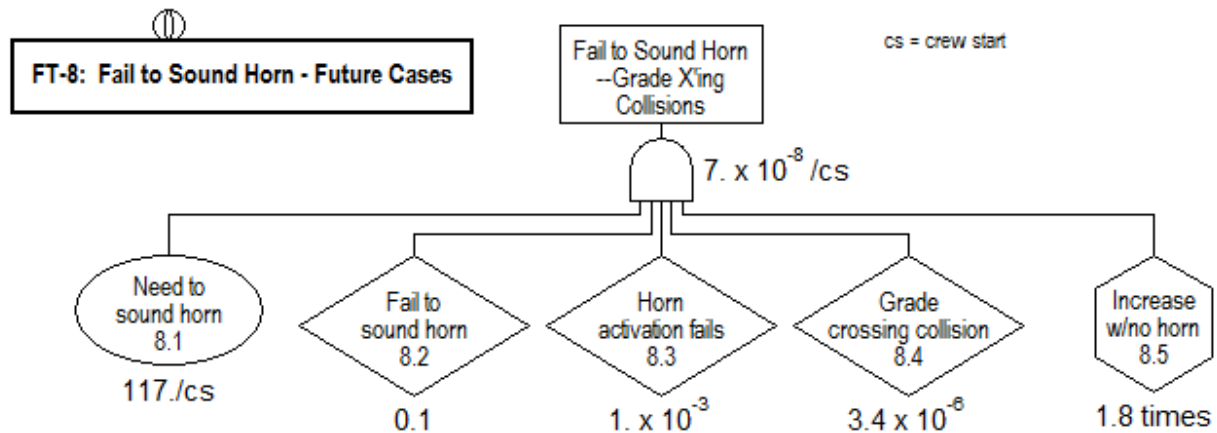
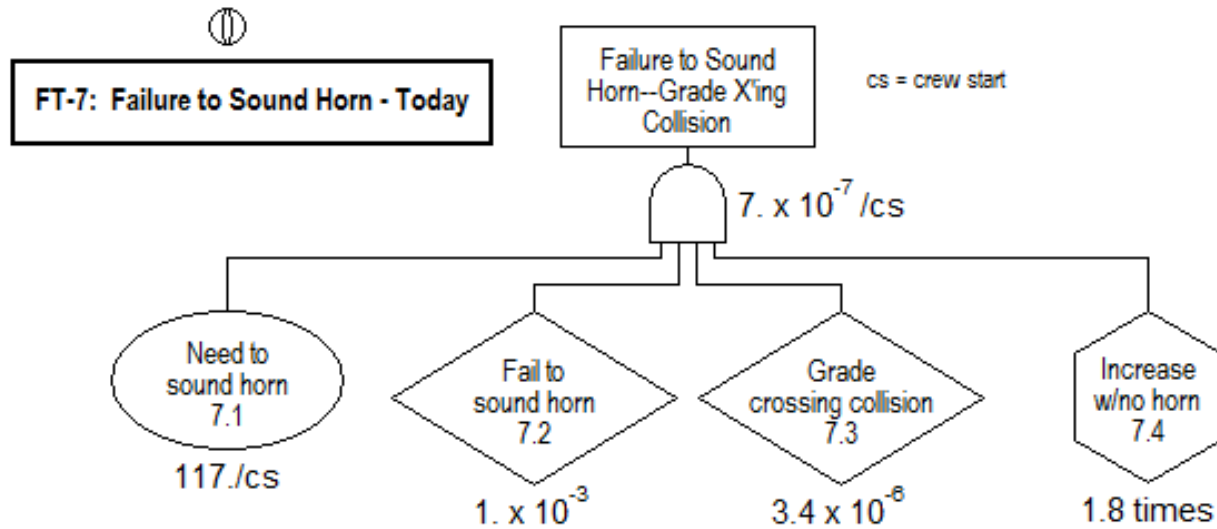
Attachment A: Fault Trees







FT-5: Rollaway Accidents - Today and Future Case with Two-Person Crew

FT-6: Train Rollaways - Future Case with One-Person Crew




Attachment B: Explanation of Data Used in the Fault Trees

The specific data value used for each event indicated in the fault trees is summarized below. Each event has a unique identifying number that correlates to its entry in the table.

Data Used in Fault Trees

Event	Value	Discussion
Fault Tree 1: Train Accidents Due to Violations – Today		
1.1 Authority violations	6.8×10^{-5} /crew start	Based on violations of authorities resulting in decertifications as reported for 2011-2013 for six Class I railroads.
1.2 Violation causes accident	9.6×10^{-3}	Actual ratio of average annual authority violation accidents to decertifications.
1.3 Overspeed violations	8.4×10^{-5} /crew start	Based on overspeed violations resulting in decertifications as reported by six Class I railroads.
1.4 Violation causes accident	1.4×10^{-2}	Actual ratio of average annual speed violation accidents to decertifications.
1.5 Signal violations	9.7×10^{-5} /crew start	Based on signal violations resulting in decertifications as reported by six Class I railroads.
1.6 Violation causes accident	1.6×10^{-2}	Actual ratio of average annual signal and other violation accidents to decertifications.
Fault Tree 2: Train Accidents Due to Violations – Future Cases		
2.1 Authority violations	6.8×10^{-5} /crew start	Assumed same as today's case. See Event 1.1.
2.2 Violation causes accident	9.6×10^{-3}	Assumed same as today's case. See Event 1.2.
2.3 Overspeed violations	8.4×10^{-5} /crew start	Assumed same as today's case. See Event 1.3.
2.4 Violation causes accident	1.4×10^{-2}	Assumed same as today's case. See Event 1.4.
2.5 Signal violations	9.7×10^{-5} /crew start	Assumed same as today's case. See Event 1.5.
2.6 Violation causes accident	1.6×10^{-2}	Assumed same as today's case. See Event 1.6.
2.7 System fails to enforce	8×10^{-3}	Based on data in ARINC study on likely overall PTC system availability.
Fault Tree 3: Train Accidents Due to Route Integrity Failures – Today		
3.1 Accidents – switch alignment (dark territory)	5.7×10^{-7} /crew start	Involving road freight trains on main track at higher speeds, not during switching. Based on AAR analysis of FRA train accident data,

Event	Value	Discussion
only)		2009-2014 for seven Class I railroads.
3.2 Accidents – visible broken rail, freight trains in dark territory only	3.2×10^{-6} /crew start	Based on AAR analysis of FRA train accident data, 2009-2014, this gives 6.4×10^{-6} /crew start. Since many broken rail accidents occur far back in the train, suggesting the break occurred under the train, only 50% of the broken rails are assumed to be visible.
3.3 Accidents – equipment out to foul	2.9×10^{-7} /crew start	Based on AAR analysis of FRA train accident data, 2009-2014 for seven Class I railroads.
3.4 Visible track failure or obstruction	9.1×10^{-6} /crew start	Road bed defects, obstructions, and track buckling. Based on AAR analysis of FRA train accident data, 2009-2014 for seven Class I railroads, this gives 1.8×10^{-5} /crew start. Only 50% of the obstructions or track failures are assumed to be visible to the crew.
3.5 Time to react	0.1	Estimate of the fraction of the time that the crew will have time to react based on judgment.
3.6 Do not detect/act in time	9×10^{-2}	It has been estimated that the engineer will fail to see the problem in 10% of the occurrences and that the second crew member will have a 90% failure rate as he/she will be focusing on something else or that there will not be adequate time to take action.
Fault Tree 4A: Train Accidents Due to Route Integrity Failures – Future Case with One-Person Crew		
4A.1 Visible track failure or obstruction	9.1×10^{-6} /crew start	Assumed same as today. See Event 3.4.
4A.2 Time to react	0.1	Assumed same as today. See Event 3.5.
4A.3 Do not detect/act in time	0.1	It has been estimated that the single operator will fail to see the problem in 10% of the cases.
4A.4 Switch not properly aligned (dark territory only)	5.7×10^{-7} /crew start	Assumed same as today. See Event 3.1.
4A.5 System fails to detect	8.0×10^{-3}	Estimate of likely PTC performance. See Event 2.7.
4A.6 Broken rail (freight trains in dark territory only)	3.2×10^{-6} /crew start	Assumed same as today. See Event 3.2.
4A.7 System fails to detect	0.2	Estimate of likely system performance.
4A.8 Equipment out to foul	2.9×10^{-7} /crew start	(primarily on-track equipment out to foul) Assumed same as today. See Event 3.3.
4A.9 System fails to detect	0.2	Estimate of likely system performance.

Event	Value	Discussion
Fault Tree 4B: Train Accidents Due to Route Integrity Failures – Future Case with Two-Person Crew		
41.1 Visible track failure or obstruction	9.1×10^{-6} /crew start	Assumed same as today. See Event 3.4.
41.2 Time to react	0.1	Assumed same as today. See Event 3.5.
41.3 Do not detect/act in time	9×10^{-2}	Assumed same as today. See Event 3.6.
41.4 Switch not properly aligned (dark territory only)	5.7×10^{-7} /crew start	Assumed same as today. See Event 3.1.
41.5 System fails to detect	8.0×10^{-3}	Estimate of likely PTC performance. See Event 2.7.
41.6 Broken rail (freight trains in dark territory only)	3.2×10^{-6} /crew start	Assumed same as today. See Event 3.2.
41.7 System fails to detect	0.2	Estimate of likely system performance.
41.8 Equipment out to foul	2.9×10^{-7} /crew start	(primarily on-track equipment out to foul) Assumed same as today. See Event 3.3.
41.9 System fails to detect	0.2	Estimate of likely system performance.
Fault Tree 5: Train Accidents due to Rollaways – Today and Future Case with Two-Person Crew		
5.1 Movement of hand operated switch	1/crew start	Value based on statistics provided by two Class I freight railroads for the prior study.
5.2 Inspect train	2.5×10^{-2} /crew start	By rule, emergency brake and detector stops are assumed always to require inspections by the conductor. Railroad data suggests this number of inspections required per crew start.
5.3 Train starts to move	1×10^{-3}	A basic human error in securing the train coupled with being on a slope.
5.4 Engineer or system fails to stop motion	1×10^{-3}	Expert opinion was that the engineer in today's operation would stop train motion in almost all cases. Furthermore, the current alerter systems installed on most if not all road locomotives would stop any train from a rollaway accident once engaged if the engineer failed to take control. Probability reflects small fraction of locomotives without a functioning system.
5.5 Accident occurs	0.9	This will typically happen once the train is out of control, but a small fraction (10%) may not actually have an accident.
Fault Tree 6: Train Accidents due to Rollaways – Future Case with One-Person Crew		

Event	Value	Discussion
6.1 Movement of hand operated switch	1/crew start	Same as Event 5.1 above.
6.2 Inspect train	1.3×10^{-2} /crew start	One-half of emergency brake and detector stops are assumed to require inspections by the single operator. The other half are assumed to require a mobile worker to perform the inspection.
6.3 Train starts to move	1×10^{-4}	A basic human error in securing the train coupled with being on a slope, but the train is more likely to be secured than today (see Event 5.3) as the single operator will not have anyone in the cab to rely on if the train starts to move.
6.4 Operator or system fails to stop motion	1×10^{-3}	Operator will generally be in proximity to the train, but will not have the same ease of access as an engineer in the cab (see Event 5.4). However, the alerter systems would stop any train from a rollaway accident once engaged if the operator failed to take control. Probability reflects small fraction of locomotives without a functioning system.
6.5 Accident occurs	0.9	Same as Event 5.5 above.
Fault Tree 7: Grade Crossing Collisions Due to Failure to Sound Horn – Today		
7.1 Need to sound horn	117 crossings / crew start	Based on AAR analysis of FRA grade crossing inventory database, grade crossings per route mile times miles per crew start gives crossings per crew start.
7.2 Fail to sound horn	1×10^{-3}	The human error for the first crew member is assumed to be 10^{-2} based on a typical error rate for a critical task and the second crew member has a higher chance of error (0.1), both due to the reliance on the first person taking action and on having less time to take action.
7.3 Grade crossing collision	3.4×10^{-6} / train crossings	Based on AAR analysis of the grade crossing collisions per million train crossings on the Class I railroads—10-year average for conservatism.
7.4 Increase in accident rate without horn	1.75	"Use of Locomotive Horns at Highway-Rail Grade Crossings; Interim Final Rule," <u>Federal Register</u> , Thursday, December 18, 2003, p. 70603.
Fault Tree 8: Grade Crossing Collisions Due to Failure to Sound Horn – PTC Case		
8.1 Need to sound horn	117 crossings / crew start	Same as today. See Event 7.1 above.

Event	Value	Discussion
8.2 Fail to sound horn	0.1	With the activation by the PTC system, it is assumed that the operator(s) will be less vigilant as there is an automated system that will be expected to come on.
8.3 Horn activation fails	1×10^{-3}	Estimate of likely failure of automatic horn activation, given possible problems like database errors.
8.4 Grade crossing collision	3.4×10^{-6} / train crossings	Same as today. See Event 7.3 above.
8.5 Increase in accident rate without horn	1.75	Same as today. See Event 7.4 above.



Evaluation of Single Crew Risks

Comparative Risk Assessment

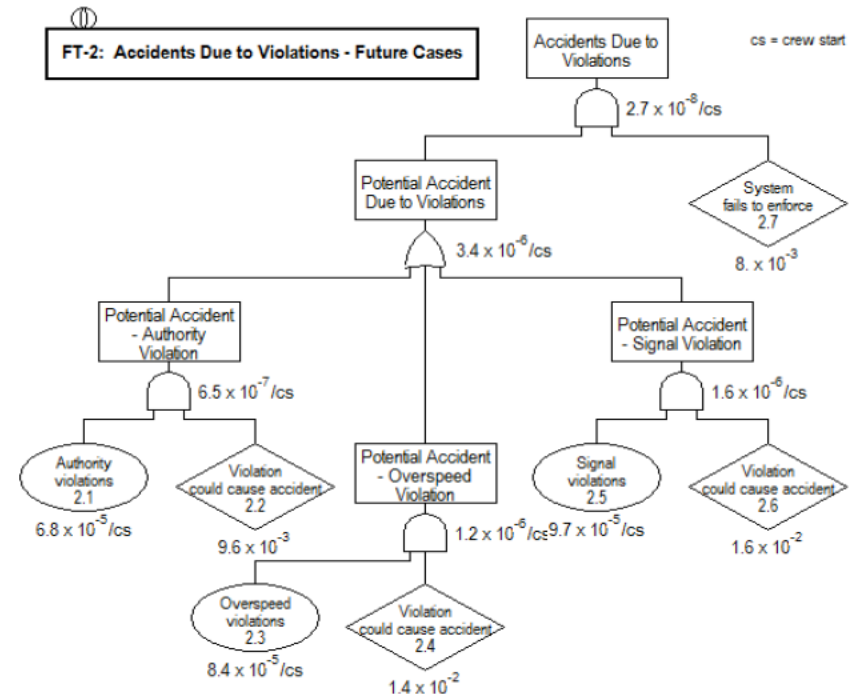
February 12, 2015

Overview

- Study complements Oliver Wyman evaluation—predictive analysis rather than historic review
- Comparative safety performance measured by predicted occurrence of train accidents for select accident causes for
 - Present Class I mainline operations with traditional two-person crews
 - Future Class I mainline operations with PTC and one-person crews
 - Future Class I mainline operations with PTC and two-person crews
- Focused on accidents that might be impacted by crew size
- Limited to Class I railroad operations subject to PTC requirements

Approach

- Worked with railroad members, AAR staff, and consultants to identify accident scenarios which could be impacted by crew size
- Applied fault tree analysis (FTA) to develop and display different ways in which those accidents arise today and how they might change under both future cases
- FTA is a logical presentation of sequences or combinations of failures needed to have an adverse event occur
- Applied in aerospace, nuclear, chemical, and other industries to analyze impacts of natural hazards, manmade failures, human errors, and multiple layers of safety
- Can use for what-if analysis



AND gate - all of the contributing events must occur to cause the identified intermediate or top event; inputs are multiplied



OR gate - one of the contributing events must occur in order to cause the identified intermediate or top event; inputs are added

Data

- Used data derived from FRA accident database, data provided by Class I railroads, human error rates, and professional judgments based on the collective experience of working group
- For current case, data was generally for 2013 or 2011-2013
- Future cases based on full implementation of PTC where required, not a specific date
- Data addressed
 - Adverse events: numbers of accidents or violations of various types
 - Exposure: number of train miles, number of grade crossings, road crew starts
 - Estimated equipment reliability: for parts of PTC systems

Results

Fault Tree Results Expressed in Accidents per Year in PTC Territory

Scenario	Results Today	One-Person Crew with PTC	Two-Person Crew with PTC
1. Train Accidents due to Violations	11	0.1	0.1
2. Train Accidents Due to Selected Route Integrity Failures	13	2.5	2.4
3. Train Accidents due to Rollaways	3	0.3	3.0
4. Grade Crossing Collisions due to Failure to Sound the Horn	2	0.2	0.2
Accident Totals	29	3.1	5.7

The two future cases have very similar results, regardless of crew size

Results

- Accidents due to violations decrease by more than a factor of 100 in the future cases where there is a PTC system
- Accidents due to analyzed route integrity failures decline significantly, but not as much as those due to violations
- Rollaways decrease by a factor of 10 with the removal of a second crew member due to fewer potential situations and additional care taken when the sole operator leaves the cab
 - Scenario not impacted by addition of PTC, just change in crew size
- Grade-crossing collisions attributable to failure to sound horn decrease by roughly a factor of 10 in future cases

Conclusions

- Future operations for the analyzed scenarios have significantly fewer predicted accidents
- Differences between one- and two-person crews in the future cases are very small
- Predicted frequencies are more significant on a comparative basis than for absolute values