Semi-quantitative risk assessment of adjacent track accidents on shared-use rail corridors

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ABSTRACT: Adjacent track accidents (ATA) primarily refer to train accident scenarios in which derailed railroad equipment intrudes upon ("fouls") adjacent tracks and is potentially struck by another train on an adjacent track. ATA has been identified as one of the most important safety issues on shared passenger and freight railroad corridors. Various infrastructure, equipment and operational factors affect the probability and consequence of an ATA. The research described in this paper presents a comprehensive approach to identifying and evaluating various factors affecting the probability and consequence of ATAs. ATAs are divided into three sequential events: initial derailment, intrusion, and train presence on adjacent tracks. Each event is associated with a probability component. Factors affecting each probability component and consequence are identified and their effects are discussed. This research intends to depict a high-level overview of ATA risk and provides a basis for future quantitative risk analyses and risk mitigation measures.

1 INTRODUCTION

Adjacent track accidents (ATA) primarily refer to train accident scenarios in which derailed railroad equipment intrudes upon ("fouls") adjacent tracks and is struck by, or strikes another train on the adjacent track (Lin et al. 2016). Figure 1 depicts a typical sequence of events for an ATA. Under normal operation, the "equipment loading gauge" which defines the allowable height, width, and loads of rolling stock (referred to as the "clearance plate" in North America) of a train stays entirely within the clearance envelope (the clearance limits of civil infrastructure) of the track (Figure 1a). If a train derails, derailed equipment will generally exceed the clearance envelope of its own track (Figure 1b) and if the derailed equipment intrudes upon the adjacent track's clearance envelope, it results in an "intrusion" (Figure 1c). When an intrusion occurs, another train on the adjacent track may be on, or approaching, the location of the intrusion location and potentially collide with the derailed equipment (Figure 1d).

A derailment without an intrusion may cause equipment and infrastructure damage, casualties, and operational disruption, while an intrusion may lead to more severe consequences due to the potential risk of subsequent collision. ATAs have been an emerging topic of railroad safety, especially due to actual or proposed growth in passenger rail services in the United States (Saat & Barkan 2013). As new passenger train services are introduced, overall train frequency will increase. Consequently, the probability of the presence of other trains on adjacent tracks increases. Furthermore, many existing or planned passenger train services involve shared-use of railroad tracks and/or right-of-way (ROW). A passenger train may derail, foul an adjacent track and then be struck by a freight train, or vice versa. Another concern is transportation of hazardous materials on a shared-use rail corridor because of the potential hazard if there is a release due to ATAs that may affect the safety of passengers in another train.

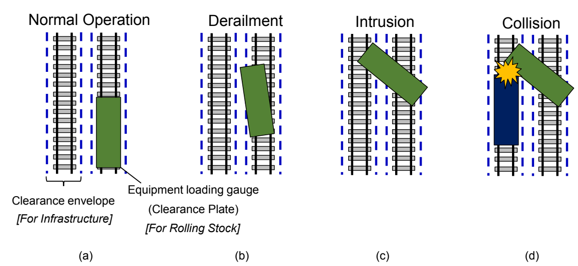

Figure 1. A Typical ATA Event Sequence (Lin et al., 2016)

The research described in this paper presents a comprehensive approach to identifying and evaluating various factors affecting the probability and consequence of ATAs. ATAs are divided into three sequential events: initial derailment, intrusion and train presence on adjacent tracks. Each event has an asso-

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ciated set of probability components. Factors affecting each of these components and consequences are identified and their effects are discussed.

2 SEMI-QUANTITATIVE RISK ASSESSMENT

2.1 *Risk Model Development*

A common definition of risk is the multiplication of the probability or frequency of an event and the consequence of the event. It is commonly expressed as follows:

$$R = P \times C \qquad (1)$$

where:
R: Risk
P: Probability
C: Consequence

The probability, P, is divided into three components corresponding to the three stages described above. ATA risk is thus defined as:

$$R = P(D) \times P(I|D) \times P(T|I|D) \times C \qquad (2)$$

where:
R: The risk index for an ATA
P(D): The probability of an initial derailment on a multiple track section
P(I|D): Conditional probability of intrusion (CPI) given an initial derailment
P(T|I|D): Conditional probability of the presence of a train on adjacent track given an intrusion
C: The consequence of an ATA

There are three probability components and one consequence component in the model intended to calculate and compare the relative ATA risks on different track segments. A rating system was developed and each model component has five levels with corresponding values from 1 (the lowest) to 5 (the highest). To assess the risk for each track segment, infrastructure, rolling stock, train operating characteristics and any other relevant factors that affect the model components are evaluated to determine the probability and consequence levels. The overall ATA risk of a track segment can then be calculated using equation (2). In the following subsections, factors affecting each model component are introduced and discussed.

2.2 *Probability of Initial Derailment, P(D)*

The probability of an initial derailment can be estimated by analyzing previous train accident data. The United States Department of Transportation (U.S. DOT) Federal Railroad Administration (FRA) Rail Equipment Accident/Incident database contains train accident data as well as annual railroad traffic volume data in the United States (FRA 2011). Five factors affecting the probability of initial derailment are identified and discussed below: method of operation, track quality, traffic density, type of equipment, and rolling stock defect detection technology.

Method of operation

Method of operation indicates the presence of a wayside signal or automatic train control system. Previous research suggested that accident rate on signaled track segments is lower than non-signaled track segments (Liu et al 2017). In this study, track segments are classified as either signaled or non-signaled based on Liu et als' results (2017).

Track quality

The FRA classifies track quality into nine classes based on their construction and maintenance standards. Previous research has found an inverse relationship between track class and train derailment rate (Anderson & Barkan 2004, Liu et al. 2015). In this research, track classes are categorized into five groups. This categorization is based on their differences in train derailment rates (Liu et al. 2017). Track classes 6 and higher are grouped together because in general they are only used on lines that are primarily for passenger train operations. We are not aware of any quantitative analyses of derailment rates for these track classes but based on the research cited above, we presume that they are at least as low, and probably lower, than Class 5.

Traffic density

Traffic density is measured in annual gross tonnage in millions of gross tons (MGT) and is the total weight of all locomotives, rolling stock and lading operating on a particular segment of track. Higher traffic densities are correlated with lower derailment rates (Liu et al. 2017). The exact mechanism for this is not known but it may result from more frequent inspection, maintenance and frequency of wayside defect detection systems on high density rail lines. Dedicated passenger lines usually have lower derailment rates due to higher track maintenance standards and inspection frequency. In addition, the lighter axle loads of passenger equipment inflicts relatively less damage to the track structure, reducing the potential for accidents due to track defects. Thus, it is assumed that, *ceteris paribus*, dedicated passenger lines will have lower derailment rates.

Type of equipment

Failures of wheels, axles and other rolling stock components can cause derailments. Different component designs may have differing failure rates. However, there is generally little quantitative data on how these may affect derailment rates. Further research is needed to address these potential effects. For the purposes of this research we identify it as an important factor but do not attempt to assign quantitative values.

Defect detectors and track inspections

Wayside defect detection technology is used to identify incipient flaws in various rolling stock components before they fail, thereby reducing the likelihood of a derailment. For example, Wheel Impact Load Detectors (WILD) are used to identify wheel defects that could lead to a mechanical failure (Van Dyk et al. 2013, Hajibabai et al. 2012). Similarly, various types of track inspections and technologies are used to identify incipient defects before they develop into a failure such as a broken rail, thereby reducing the likelihood of infrastructure-related derailments (Dick et al. 2003, Barkan et al. 2003, Liu et al. 2012, 2013a, 2013b, 2013c, 2014). Although it is well-accepted that these technologies and practices are effective at preventing derailments, the quantitative relationship between the use of a particular technology and its preventive effect has not be measured, so as is the case with type of equipment type above, we do not attempt to assign a quantitative value.

Levels of initial derailment probability are developed based on the aforementioned factors, except type of equipment, defect detectors and track inspections for the reasons discussed above. An Accident Factor Score (AFS) is assigned to each factor for a specific track segment (Table 1). The AFS ranges from 1 to 2 for each factor where the base value is 1. The higher the AFS, the higher the increase in initial derailment rate from that factor. For a track segment, all AFS are summed and based on the total AFS, a level of initial derailment probability is assigned to the track segment.

The effects of different factors on the initial derailment rate may vary. For instance, the effect of FRA track class on initial derailment rate may be different from the effect of traffic density. The effects of different levels within a factor may also differ. Take FRA track class as an example, the difference in train derailment rate between class 4 track and class 5 track is likely to differ from the difference of train derailment rate between class 5 track and class 6 track. Some of these relationships are addressed by quantitative analyses, while others are not fully understood. In our research, a linear approach is implemented for each affecting factor in which each factor has equal effect on the initial derailment rate, and each level within a factor also has equal impact on the initial derailment rate. For the purpose of consistency and simplicity, there are some underlying assumptions for the AFS: the effect of each factor is weighted equally, AFS for each factor is equally divided by the number of categories for the factor and the total AFS is equally divided into 5 levels.

Table 1. AFS and initial derailment probability

Initial Derailment Factors	**Criteria**	**AFS**
FRA Track Class	6 or above	1.00
	5	1.25
	4	1.50
	2, 3	1.75
	X, 1	2.00
Traffic Density	*Freight-Train only or Freight and Passenger Shared Lines*	
	More than 60 MGT	1.00
	40 - 60 MGT	1.33
	20 - 40 MGT	1.67
	Less than 20 MGT	2.00
	Passenger-Train only Lines	
	Passenger Line	1.00
Method of Operation	Signaled	1.00
	Non-Signaled	2.00
The highest score possible		**6.00**
The lowest score possible		**3.00**

Total AFS	**Level of initial derailment probability**
AFS ≤ 3.6	1
3.6 < AFS ≤ 4.2	2
4.2 < AFS ≤ 4.8	3
4.8 < AFS ≤ 5.4	4
AFS > 5.4	5

2.3 *Conditional Probability of Intrusion, P(I|D)*

Several factors affect intrusion probability including distance between track centers, track alignment and geometry, elevation differential, adjacent structures, containment, train speed, and point of derailment. In order to account for these factors in the model, an Intrusion Factor Score (IFS) is assigned to each factor for a track segment. The rationale and qualitative effect of each factor are discussed in the following sections.

Distance between track centers

Research by English et al. (2007) found an inverse relationship between the distance between track centers and probability of intrusion. Both developed the distribution of maximum lateral distance traveled by derailed rolling stock in accidents (Figure 2). In the model described in this paper, IFS for distance between track centers is assigned based on the 25th, 50th, 60th and 80th percentile from the cumulative probability distribution of lateral displacement.

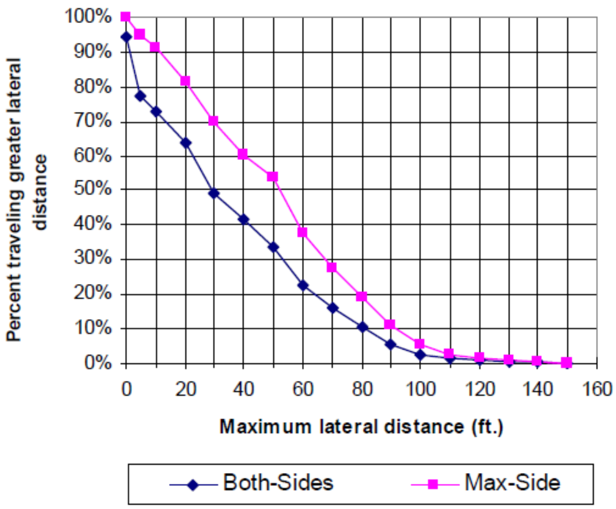

Figure 2. Distribution of maximum lateral displacement by derailed rolling stock (English et al. 2007)

Track alignment and geometry

Track alignment and geometry indicates whether a track segment is tangent, curved, level or on a grade. A level, tangent track segment is considered the base case scenario. If a derailment occurs on a curved track segment, additional lateral forces may be introduced that increase the intrusion probability. A derailment on a grade may affect longitudinal forces (draft or buff, respectively depending on whether the train is traveling up or down the grade at the time of the derailment) that indirectly affect intrusion probability. These longitudinal, in-train forces do not directly cause lateral movement of equipment; however, they may affect the extent that derailed rolling stock impacts other equipment in the train. These impacts may cause equipment to be moved laterally or rotate causing an intrusion on an adjacent track.

Elevation differential between adjacent tracks

If there is an elevational difference between two adjacent tracks then derailments occurring on the two tracks may have different intrusion rates. Specifically, derailments on the high track are more likely to intrude upon the lower track due to derailed equipment falling down the embankment (Figure 3a). Conversely, derailed equipment on the lower track, is less likely to intrude upon the higher adjacent track because of the constraining effects of the embankment (Figure 3b).

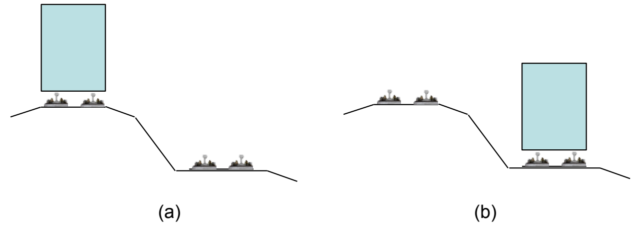

Figure 3. Effect of elevation differential

Adjacent structures

Adjacent structures refers to structure along the railroad segment that may have a "rebound" effect (Figure 4). If a structure is close enough to the railroad tracks and strong enough to potentially redirect the movement of derailed equipment from outside track back onto adjacent tracks opposite the track where the train derails, then its presence could affect intrusion probability. Adjacent structures, depending on their shape and density, are classified into single, discrete and continuous structures. A single structure is an independent, self-supported structure such as a bridge abutment or pier. Discontinuous structures could be multiple buildings located close to each other along a track segment, such as a group of grain elevators or silos. Examples of a continuous structure are noise barriers located alongside the track or residential buildings along the track in an urban area.

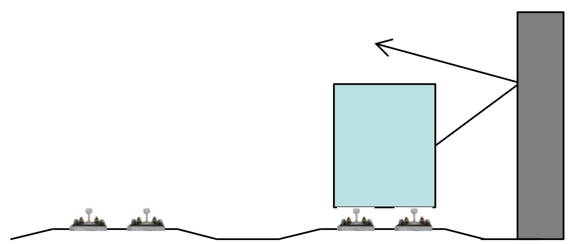

Figure 4 Effect of adjacent structure

Containment

Containment is located between adjacent tracks and its purpose is to prevent intrusions. Containment may also reduce the consequences by absorbing the energy from derailed equipment (further discussed in the Consequence subsection of this paper). Three types of containment are currently used in high-speed rail systems in Europe and Asia: guard rails, parapets, and physical barriers (Hadden et al. 1992, Moyer et al. 1994, Ullman and Bing, 1995, Rulens, 2008).

Guard rails or check rails are used for various related but distinct purposes. They are widely used in railroad turnouts and other special trackwork to ensure safe passage of rolling stock and minimize damage to track components. They are used in sharp curves to help keep equipment on the track. In the context of this study, guard rails are also used in trackage on, or leading up to, bridges and certain other special situations. In this case their purpose is to contain derailed equipment within or close to the clearance envelope in order to prevent it from damaging the structural members of the bridge or adjacent tracks in case of a derailment (Figure 5). The latter type of guard rail is expected to reduce the intrusion rate.

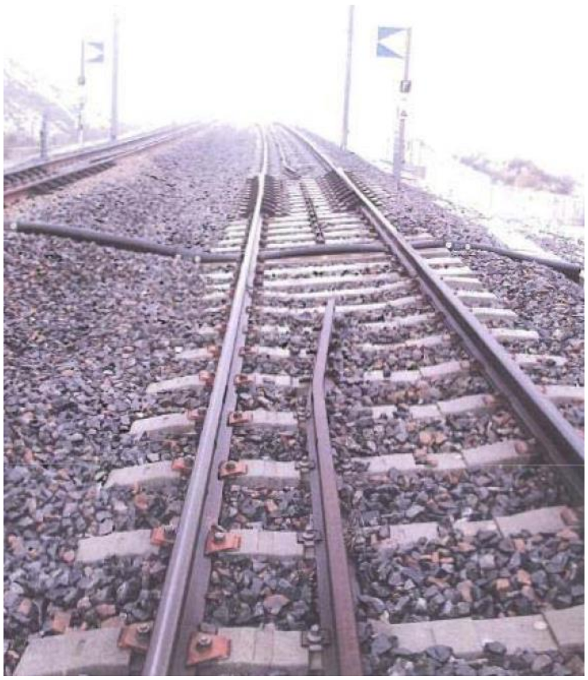

Figure 5. An example of guard rail (Rulens 2008)

Parapets are reinforced railings mounted adjacent to the track (Figure 6) and physical barriers can be earth berms or concrete walls (Figure 7). Both are installed to absorb the impact of derailed equipment and prevent it from intruding upon adjacent tracks.

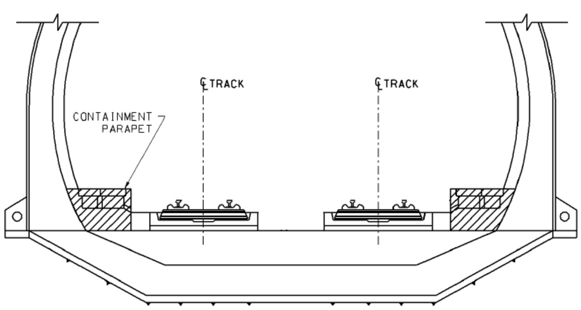

Figure 6. Example of a parapet (Rulens 2008)

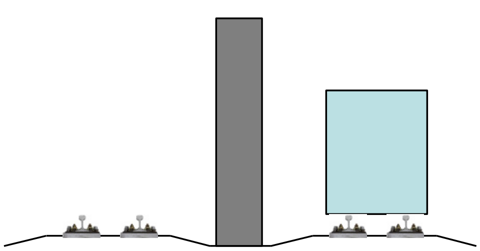

Figure 7. Presence of containment can potentially reduce the intrusion probability

Train speed

Speed of train may affect intrusion rate because the higher the speed, the more energy involved when a train derails, resulting in more opportunity for derailed equipment to move farther and foul adjacent tracks.

Train speed is assigned high, medium, or low to a track segment, based on the average speed on the segment. The average speed is affected by various factors, including type of traffic (bulk freight, intermodal, passenger, etc.), track alignment, track class, and so on. Two speeds are selected for categorization: 50 mph for key trains and 79 mph for maximum authorized speed of passenger trains on most U.S. passenger rail corridors. Key trains transport hazardous materials cars and their maximum authorized speed is 50 mph (AAR 2013).

Point of derailment

Point of derailment (POD) refers to the position-in-train of the first car derailed (Anderson, 2005; Liu et al., 2013a). The position of the first derailed car may affect intrusion rate due to reaction forces at the coupler. Also, because the first and the last car are only coupled at one end, they are less restrained with regard to lateral movement and might have more chance to rotate and foul adjacent tracks in a derailment. On the other hand, cars in the middle of the train consist are coupled at both ends, providing more restraining forces to the cars. However, the most common situation is when a single car in the middle of a train derails and causes other cars to derail, resulting in a larger derailment and intrusion.

Similar to AFS, IFS is assigned for each intrusion factor. The higher the IFS, the higher the increase in intrusion rate. Each factor has an IFS ranging from 1 to 2 where the base value is 1. For a track segment, IFS from all intrusion factors are summed. Based on the total IFS, a level of intrusion probability (from 1 to 5) is assigned to the specific track segment. The intrusion probability has the same assumption as the probability of initial derailment. Table 2 summarizes aforementioned intrusion factors except POD and associated IFS and the relationship between total IFS and corresponding levels of P(I|D). The higher the level, the more likely the occurrence of intrusion given an initial derailment.

Table 2. IFS and intrusion probability

Intrusion Factor	Criteria	IFS
Distance Between Track Centers, X, in feet (meters)	X > 75 (22.9)	1.00
	52 (15.8) < X ≤ 75 (22.9)	1.25
	40 (12.2) < X ≤ 52 (16.7)	1.50
	20 (6.1) < X ≤ 40 (12.2)	1.75
	X ≤ 20 (6.4)	2.00
Track Alignment	Tangent and level	1.00
	Tangent and on gradient when traveling upward	1.13

	Tangent and on gradient when traveling downward	1.25
	Curved on outside track and level	1.38
	Curved on inside track and level	1.50
	Curved on inside track and on gradient when traveling upward	1.63
	Curved on outside track and on gradient when traveling upward	1.75
	Curved on outside track and on gradient when traveling downward	1.88
	Curved on inside track and on gradient when traveling downward	2.00
Elevation Differential	The track where a train derail is 10 ft. lower than adjacent track	1.00
	The track where a train derail is level with adjacent track	1.50
	The track where a train derail is 10 ft. higher than adjacent track	2.00
Adjacent Structure	No adjacent structure	1.00
	Single structure	1.33
	Discrete structure	1.67
	Continuous structure	2.00
Containment	All containments installed	1.00
	Physical barrier and guard rail or parapet installed	1.20
	Physical barrier installed only	1.40
	Parapet and guard rail installed	1.60
	Parapet or guard rail installed only	1.80
	No containment installed	2.00
Train Speed	Low (less than 40 mph)	1.00
	Medium (40 mph to 70 mph)	1.50
	High (more than 70 mph)	2.00
The highest score possible		**12.00**
The lowest score possible		**6.00**

Total IFS	Level of intrusion probability
IFS ≤ 7.2	1
7.2 < IFS ≤ 8.4	2
8.4 < IFS ≤ 9.6	3
9.6 < IFS ≤ 10.8	4
IFS > 10.8	5

2.4 *Conditional probability of train presence on adjacent tracks, P(T|I|D)*

The third probability component of the ATA risk model is the presence of trains on adjacent tracks given an intrusion. There are two variants for the presence of train. One is that when an intrusion occurs, there is a train adjacent to the derailing equipment, and the other is that the train on the adjacent track is approaching the intrusion location. Factors affecting this probability include intrusion detection and warning systems, traffic density, method of operation, train speed, and shunting.

Intrusion detection and warning system (IDW)

The IDW system detects intruding rail equipment when it derails and breaks the fences installed with detectors between tracks, and changes the signal on either side of the adjacent track to stop (Hadden et al. 1992, Ullman & Bing 1995, Saat & Barkan 2013). Trains on adjacent tracks beyond the next block would have enough time to stop before striking the intruding equipment. However, IDW may not work if the train is already in the block where the intrusion occurs unless there are cab signals or other advanced train control system that transmits the information directly to the train and may allow it to stop before it encounters the intruding equipment.

Traffic density

The higher the traffic density, the more likely the presence of a train at the time of intrusion occurs. The traffic density of a track segment is measured using the gross tonnage of the track segment. The traffic density for dedicated passenger lines is assigned the highest level.

Method of operation

Different train control systems have different accuracy of train location as well as the ability to communicate the information between engineers (train drivers) and dispatchers. For example, the traditional track circuit system can only identify a train's location by "block" but does not provide the exact position of the train, whereas more advanced train control systems may be capable of identifying the trains' location more precisely. Representative systems include the European Rail Traffic Management System (ERTMS) in European countries and Advanced Train Administration & Communications System (ATACS) in Japan. Also, advanced train control systems communicate information more efficiently than traditional communication methods between dispatchers and engineers. IDW can also be integrated with advanced train control systems so that the intrusion warnings can be efficiently and instantly delivered to other trains in the proximity (Hadden et al. 1992, Ullman & Bing 1995).

In the model described in this study, train control systems are divided into three categories: advanced train control system, typical train control system and dark territory. Advanced train control systems refer to the track segment with these train control systems. Typical train control systems refer to track segments protected by track circuits. Dark territory refers to non-signaled track segments.

Train speed

If a train on an adjacent track is already in the block where initial accident and intrusion occur, typical train control systems may not be able to protect the train from striking the derailed equipment. If train speed is high or the distance is short, it may not be able to stop in time and will result in a collision. Train speed is assigned high, medium, or low to a track segment based on the average train speed of the adjacent track.

Based on engineering judgments, Train Presence Score (TPS) is assigned to train presence factors and are summarized in Table 3. Similar to the initial derailment probability and intrusion probability, each train presence factor has a TPS ranging from 1 to 2 where the base value is 1. The total TPS in a specific track segment is calculated by summing the TPS from all train presence factors. Total TPS is then converted into levels of train presence. The higher the level, the more likely the presence of a train given an intrusion. Although not all the combinations are considered, the selected factor combinations are assumed to be representative to account for most of the circumstances. TPS probability holds the same assumption as AFS and IFS.

Table 3. TPS and train presence probability

Train Presence Factors	Criteria	TPS
IDW	Presence	1.00
	Absence	2.00
Traffic Density	*Freight or Freight and Passenger Shared Lines*	
	Less than 20 MGT	1.00
	20 - 40 MGT	1.33
	40 - 60 MGT	1.67
	More than 60 MGT	2.00
	Passenger Lines	
	Dedicated Passenger Line	2.00
Method of Operation	Advanced train control	1.00
	Typical train control system	1.50
	Dark territory	2.00
Average Train Speed	Low (less than 50 mph)	1.00
	Medium (50 mph to 79 mph)	1.50
	High (more than 79 mph)	2.00
The highest score possible		**8.00**
The lowest score possible		**4.00**

Total TPS	Level of train presence probability
TPS ≤ 4.8	1
4.8 < TPS ≤ 5.6	2
5.6 < TPS ≤ 6.4	3
6.4 < TPS ≤ 7.2	4
TPS > 7.2	5

2.5 *Overall Probability, P*

The three probability levels are multiplied into a single score to represent the overall probability:

$$P=P(D)\times P(I|D)\times P(T|I|D) \quad (3)$$

Based on the values of P, a level of overall probability will be assigned. Table 4 shows the relation between the value of P and the level of overall probability.

Table 4. Overall probability level

Multiplication of P(D), P(I|D), and P(T|I|D)	Overall Probability Level, P
1 < P ≤ 10	1
10 < P ≤ 20	2
20 < P ≤ 30	3
30 < P ≤ 50	4
P > 50	5

2.6 *Consequence, C*

Consequence is the impacts from an ATA. The major concern is the consequence resulting from the collision between derailed equipment and trains on adjacent tracks. Previous research showed that the average casualties for passenger train collisions are higher than for passenger train derailments (Lin et al. 2013). The consequences of ATAs include multiple types of impact as follows:

- Casualties (injuries and fatalities)
- Equipment damage
- Infrastructure damage
- Non-railroad property damage
- System disturbance and delay
- Environmental impact
- Economic loss

Casualties refer to passenger and non-passenger fatalities or injuries from accident impact, and/or casualties due to exposure to hazardous materials release in an ATA involving a freight train transporting hazardous materials. Equipment damage is the cost required to repair rail cars. Infrastructure damage is the cost required to replace damaged track structure. Non-railroad property damage includes the non-railroad structure damaged by the impact of derailed equipment or explosion. System disturbance and delay resulted from the derailment is measured by system shutdown time and the number of trains affected. Environmental impact refers to environmental damage due to the release of fuel or hazardous materials. Economic loss refers to the damage or release of the lading being carried by freight cars. Several factors are identified to affect the severity of ATA accidents: speed of train, equipment strength, containment, and product being transported. These factors are discussed in the following subsections.

Equipment strength

Equipment strength is a key factor for reducing the potential casualties on board from the derailment and/or collision impact. Crashworthiness analyses have been conducted for higher-speed passenger trains (Tier I standard) (Carolan et al. 2011) to understand how reinforced equipment can withstand larger collision impact and thus result in lower consequences. Rolling stock is classified into two categories: reinforced equipment and traditional equipment. Reinforced equipment refers to passenger rail cars that meet the FRA Tier I or higher crashworthiness regulations, or tanks that are equipped with top fitting protection, jacket, and couplers that prevent them from overriding other rail cars. Traditional equipment refers to railcars that do not meet the aforementioned standards.

Train speed

With higher train speed, more energy will be involved when a derailment or collision occurs. Research shows that train speed may affect the consequence of an accident (Liu et al., 2011). Therefore, more severe consequence are expected if the train speed is higher.

Containment

The presence of containment reduces not only the conditional probability of intrusion but also the consequence by absorbing the impact from the derailing equipment (Hadden et al., 1992; Moyer et al., 1994; Ullman and Bing, 1995).

Product Being Transported (Freight Train)

If the collision involves freight trains carrying hazardous material (or dangerous goods), it may release the hazardous material and result in more severe consequences.

Similar to the way probability components of ATA are calculated, the Consequence Factor Score (CFS) is assigned to different situations for each consequence factor (Table 5). The total CFS is calculated by summing the CFS from individual consequence factor together. The total CFS is then related to the level of consequences.

Table 5. CFS and consequence level

Consequence Factor	**Criteria**	**Consequence Factor Score (CFS)**
Equipment Strength	Reinforced equipment	1.00
	Traditional equipment	2.00
Train Speed	Low (less than 40 mph)	1.00
	Medium (40 mph to 70 mph)	1.50
	High (more than 70 mph)	2.00
Containment	Containment Present	1.00
	No Containment	2.00
Product being transported	No Hazardous material	1.00
	Hazardous material	2.00
The highest score possible		**8.00**
The lowest score possible		**4.00**

Total CFS	**Level of Consequence**
CFS ≤ 4	1
4 < CFS ≤ 5	2
5 < CFS ≤ 6	3
6 < CFS ≤ 7	4
CFS > 7	5

3 CONCLUSION

The research described in this paper presents a comprehensive approach to evaluating the ATA risk and identifying factors affecting the probability and consequence of ATA. Levels of probability and consequences are defined. Various factors affecting the initial accident, the intrusion, the presence of trains on adjacent tracks as well as the consequences are identified and investigated. This research intends to depict a high-level overview of ATA, and provides a basis for future quantitative risk analyses and risk mitigation implementations.

4 ACKNOWLEDGMENTS

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