Analysis of Factors Affecting Train Derailments at Highway-Rail Grade Crossings

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ABSTRACT

Implementation of highway-rail grade crossing warning systems, educational programs and research on crossings have all contributed to a steady reduction in the risk to highway users of grade crossings over the past several decades. Much less attention has been given to understanding the effect of grade crossings on train safety and risk. Collisions at highway-rail grade crossings can have serious consequences for the public and the railroads alike, especially in the form of train derailments. The goal of this research is to identify and understand the factors leading to these derailments. This paper focuses on three factors affecting train derailments at highway-rail grade crossings. An examination of the effect of highway vehicle type on derailment occurrence showed that large highway vehicles, such as tractor-semitrailers, cause a disproportionate number of derailments but that vehicle size does not affect derailment severity. Examinations of highway vehicle collision speed and train collision speed showed that derailments are more likely to occur at higher vehicle speeds and lower train speeds.

INTRODUCTION

Considerable research has been conducted to understand the impact of highway-rail grade crossings on highway users. This has led to improved grade crossing warning systems, integration of grade crossing operations with highway traffic signaling, public education programs such as Operation Lifesaver, and numerous other improvements. These technologies and programs aim to reduce the number of casualties due to train-highway vehicle collisions, and the result has been a steady decline in the number of incidents and casualties over the past several decades (*1*).

However, much less research has focused on understanding the risk that highway users pose to trains at highway-rail grade crossings. We used two databases maintained by the Federal Railroad Administration (FRA) in order to better understand the effect that highway users have on trains, especially on train derailment rates. Some highway-rail grade crossing collisions result in derailment of the train, whereas others do not; the challenge is to identify the critical factors affecting the former. This paper focuses on 1) type of highway vehicle involved in the collision, 2) speed at collision of highway user, and 3) speed at collision of train. This paper seeks to answer the following questions:

- Are trucks more likely than cars to cause a derailment and if so how much?
- Does vehicle size affect derailment severity?
- Does impact velocity (of the highway vehicle and/or the train) affect derailment rate and severity?
- How does vehicle size affect the speed distribution of a vehicle striking a train?

In this paper, a grade crossing incident is defined as any collision between a rail consist and a highway user at a grade crossing[2]. A grade crossing derailment is defined as any grade crossing incident where one or more cars or locomotives were derailed as a result of the incident.

DATA SOURCES

The FRA maintains two databases that are of great interest to this study. The Rail Equipment Accident (REA) database collects data on any damage sustained by a train consist that exceeds a reporting threshold set by the FRA. This threshold periodically changes to account for inflation and other adjustments; as of 2011 it was set at $9,400. This data is reported to the FRA through the use of form FRA F 6180.54, which is filed by railroads that experienced an incident meeting this criterion. It provides useful information about incidents, such as the number of cars or locomotives derailed, the length of consist, the type of track involved, and a number of other variables of interest.

The Highway Rail Accident (HRA) database collects data concerning "any impact, regardless of severity, between a railroad on-track equipment consist and any user of a public or private crossing site" (FRA 2011). All grade crossing collisions are reported to the FRA regardless of the monetary value of damage caused. The data is reported using form FRA F 6180.57. The database contains a variety of information including data about the highway user

[2] The FRA defines a grade crossing accident as "any collision, derailment, fire, explosion, act of God, or other event involving operation of railroad on-track equipment (standing or moving) that results in damages greater than the current reporting threshold to railroad on-track equipment, signals, track, track structures, and roadbed." A grade crossing incident is defined as "any event involving the movement of on-track equipment that results in a reportable casualty but does not cause reportable damage above the current threshold established for train accidents" (*2*).

involved, the speed of the train at collision, and environmental factors such as time of day and weather conditions.

METHODOLOGY

Data for all U.S. railroads during the period 1991 through 2010 were used. Each of the two databases described above provides useful data for this study. The HRA database contains the largest amount of pertinent information; however, further analysis required identification of incidents that resulted in derailment, and the HRA database does not provide any information about the number of cars or locomotives derailed in the incident. On the other hand, the REA database does provide the derailment information but not the detailed data needed regarding grade crossing incidents.

The solution was to merge the two databases in order to create a dataset consisting of incidents that had been reported using both forms. A unique identification code was created for each incident in the HRA and REA databases. The code concatenated the date, time, and crossing identification number to provide a field that could be cross-referenced between the two databases.

This methodology resulted in a consolidated dataset consisting only of incidents that occurred at grade crossings and were also REA-reportable (i.e. exceeded the REA damage value threshold). This consolidated dataset contained what were likely the most severe grade crossing incidents. Mainline grade crossing incidents were the focus of this study because they accounted for approximately 88% of all incidents. A Venn diagram was prepared showing the relationship among the datasets used (Figure 1).

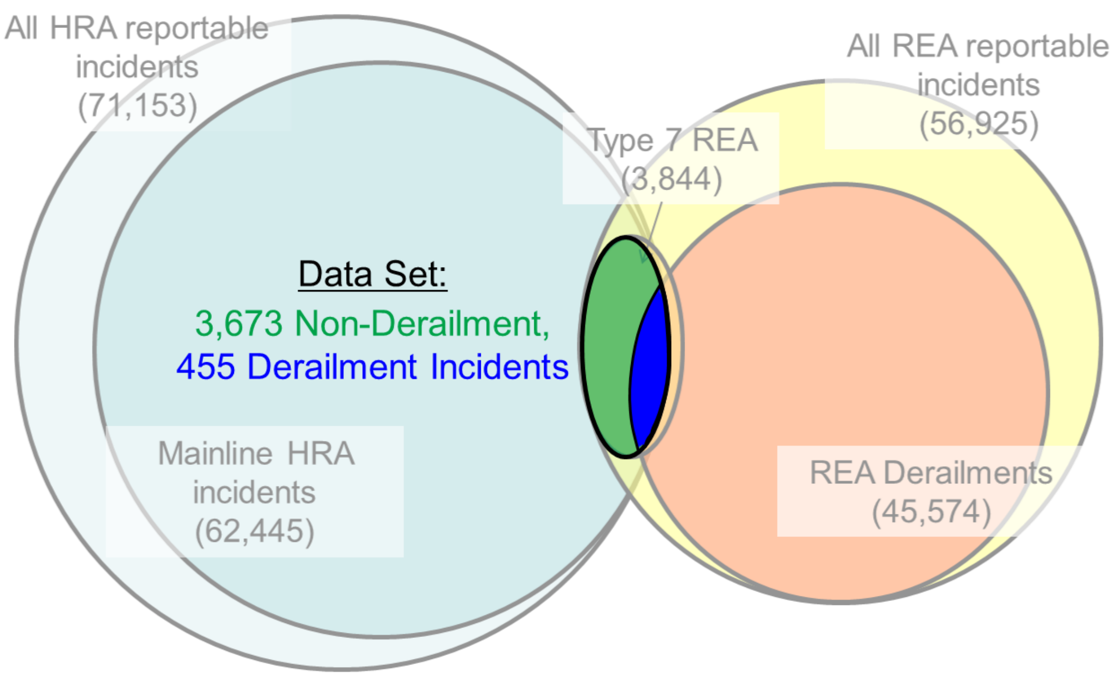


Figure 1 Venn diagram representing data set.

RESULTS

The frequency distribution of incident severity as measured by the number of cars or locomotives derailed in individual grade crossing incidents was plotted (Figure 2). The modal value was for incidents in which one car or locomotive derailed with declining frequency up to a maximum of 35 derailed cars and locomotives in one incident.

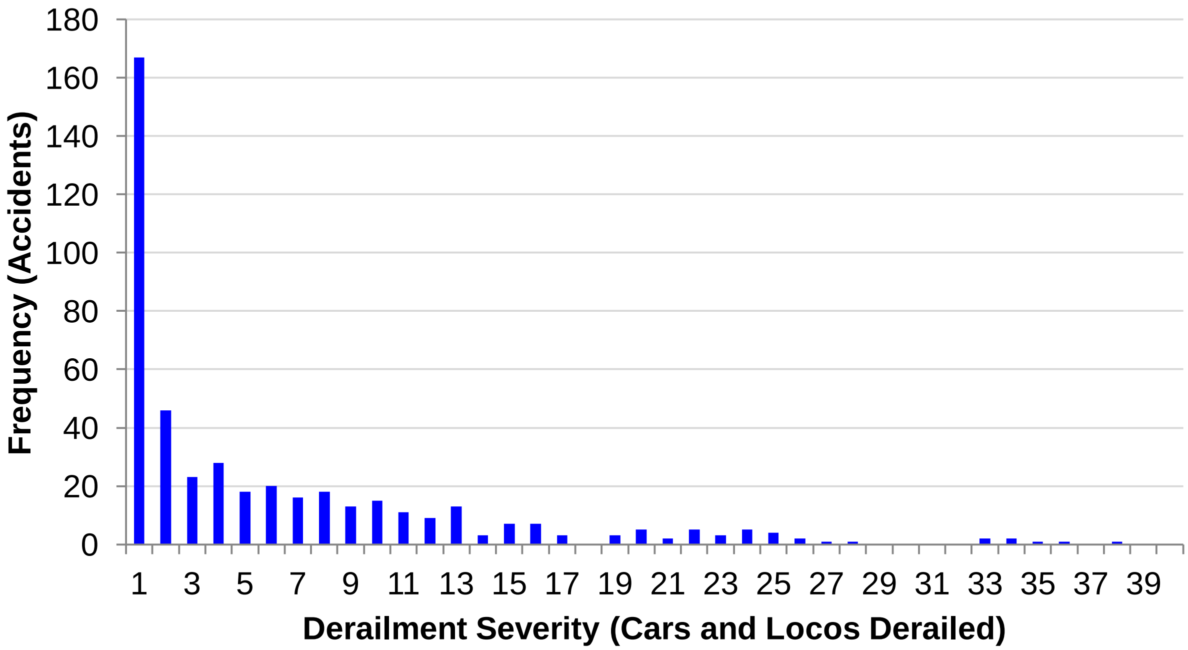


Figure 2 Number of rail cars derailed per incident at grade crossings given that a derailment occurred.

Large Highway Vehicle Involvement

The larger mass of trucks suggests that train collisions with them may be more likely to result in a derailment. An analysis was conducted to test this hypothesis and quantify the relative difference between larger and smaller motor vehicles. The percentage of large highway vehicle traffic at a given highway-rail grade crossing may have a corresponding risk of causing a derailment. The HRA database contains a field that identifies the type of highway vehicle involved in the incident. Types “B” (straight truck) and “C” (tractor-semitrailer) were believed to generally be the heaviest vehicles and these were compared to all other types[3]. For the study period, the total number of REA-reportable, mainline grade crossing derailments involving large vehicles were compared with those involving other vehicles (Figure 3).

[3] It is possible that buses (type “F”) should also be included in the large vehicle category; however, analysis showed that their exclusion did not affect the results for the twenty-year period being studied because no derailments exceeding the REA reporting threshold involving buses occurred.

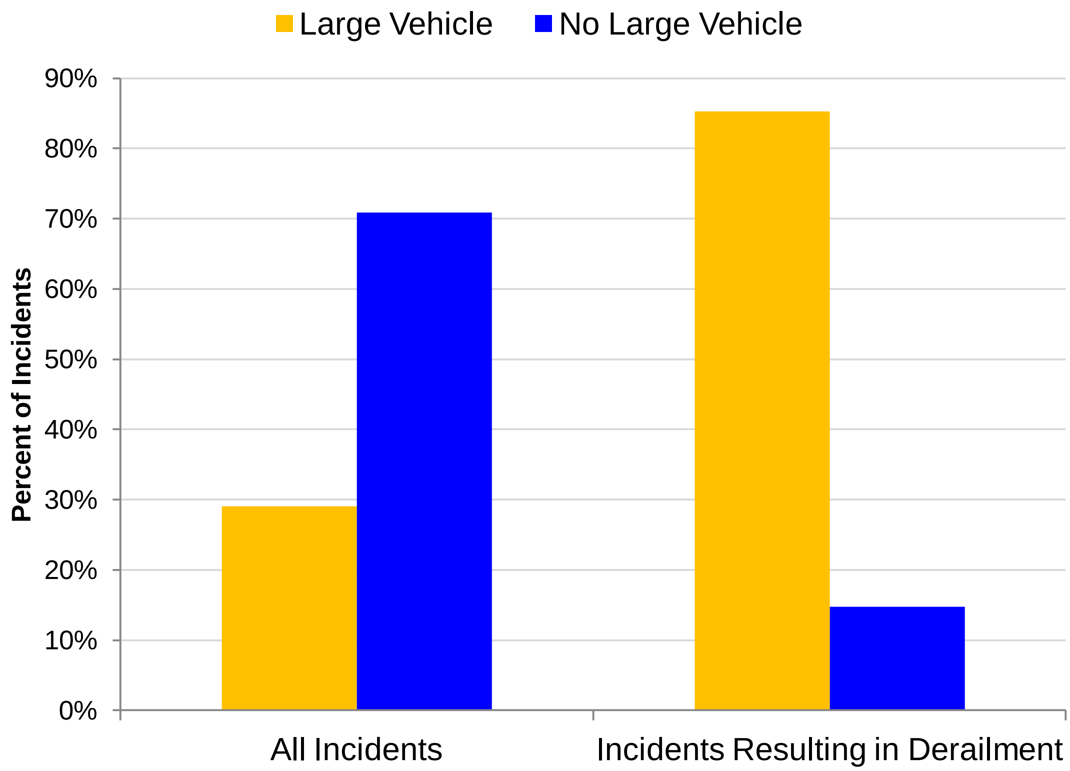


Figure 3 Incidents occurring at grade crossings on mainline track from 1991 to 2010 involving large highway vehicles versus all other vehicles.

The data shows that large highway vehicles were involved in 29% of all mainline grade crossing incidents and 85% of mainline REA-reportable grade crossing derailments and thus were four times more likely to cause a derailment. The other 15% of grade crossing derailments involved automobiles, pick-up trucks, other motor vehicles, and vans.

The greater tendency for large vehicles to cause derailments led to the question about whether they might also tend to cause more severe derailments than smaller vehicles. To investigate this hypothesis, the distribution of total cars and locomotives derailed in incidents was compared for incidents that did and did not involve large vehicles (Figure 4). Statistical testing of the data using the Wilcoxon Rank Sum test with $\alpha = 0.05$ showed that there was no significant difference between the severity of derailment incidents involving large vehicles, and the severity of derailment incidents not involving large vehicles. In other words, once a motor vehicle has caused a derailment, the severity of that derailment is little affected by the size of the vehicle that caused it.

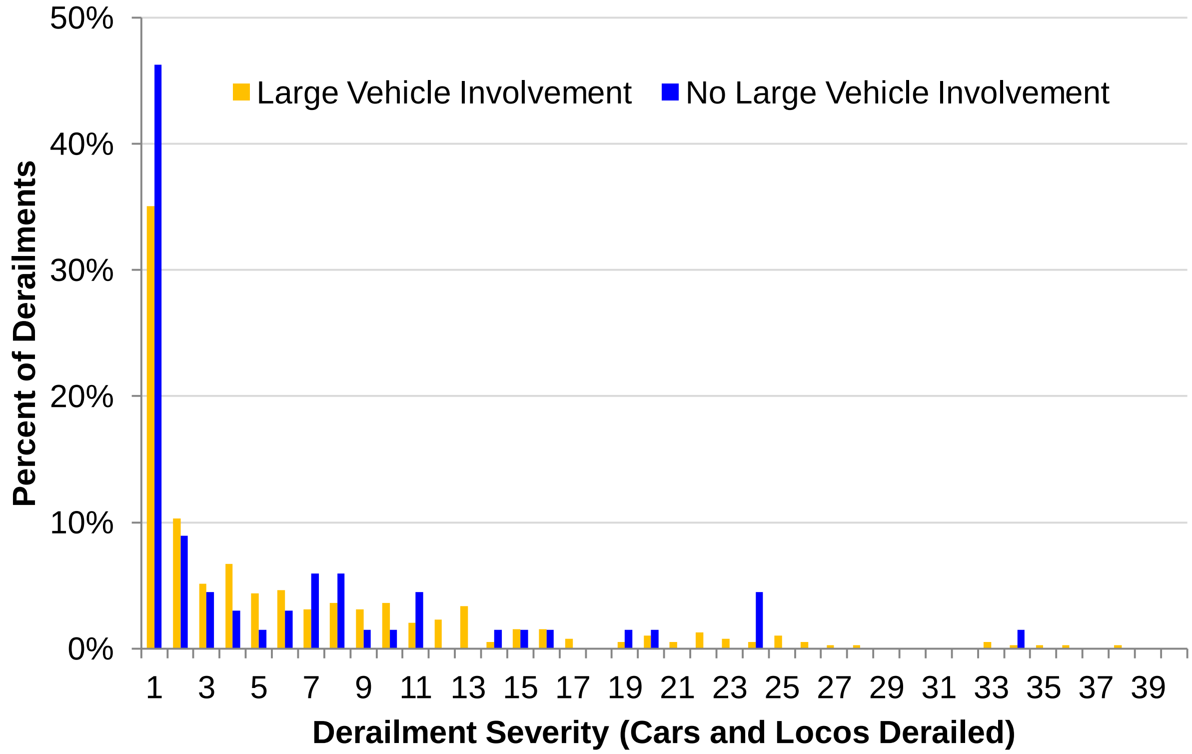


Figure 4 Number of cars and locomotives derailed in grade crossing incidents by vehicle type. Frequencies are given as a percentage of all incidents of each type.

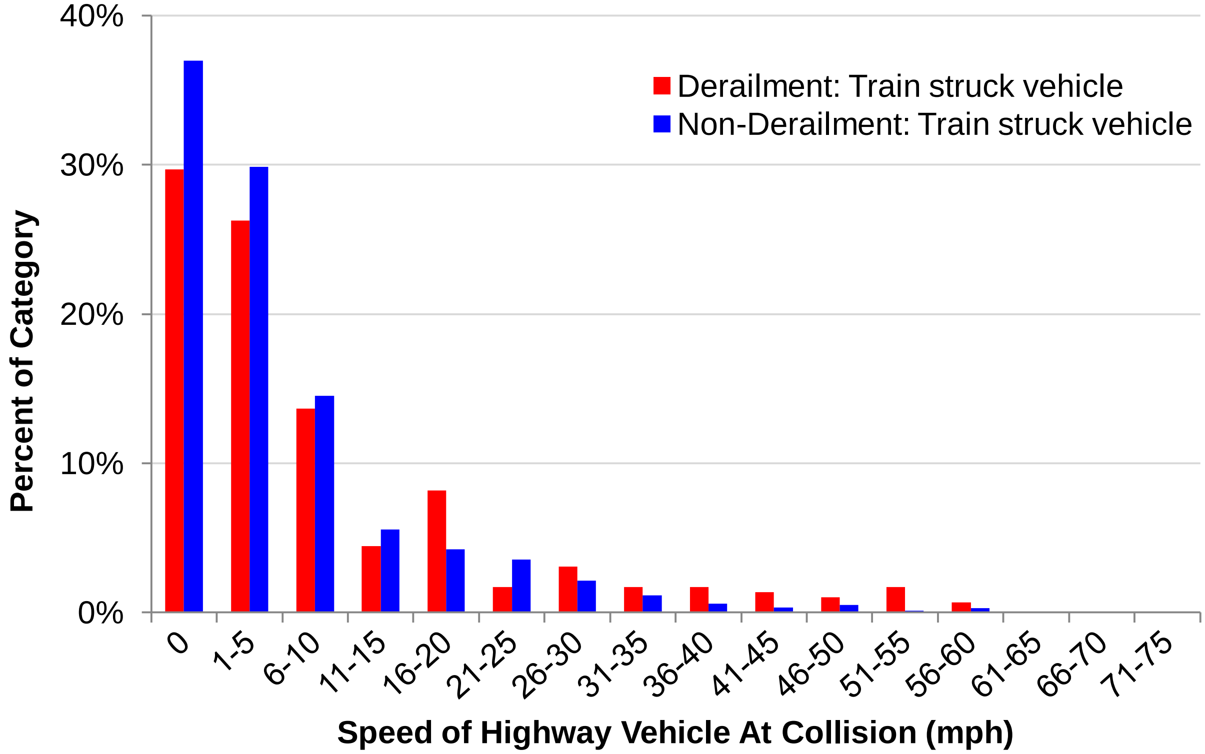
Speed of Highway Vehicle at Collision

Another factor of interest in terms of assessing the hazard that grade crossings pose to train safety is velocity and whether the motor vehicle struck the train or the train struck the motor vehicle. The speeds of both the highway vehicle and train might affect this so both were investigated.

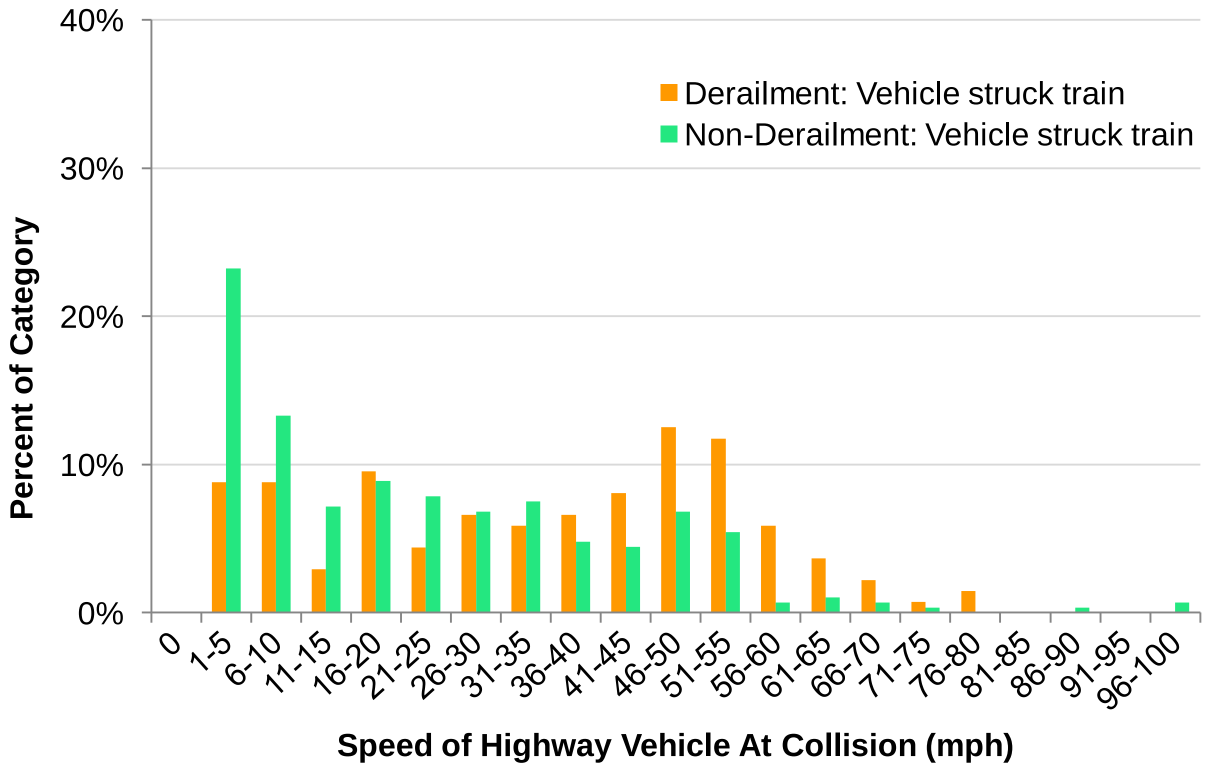
The FRA records data about the speed at collision of the highway vehicle involved in grade crossing incidents. It should be noted that these data are estimated by observers at the incident scene.

The data were divided into two categories according to whether the train struck the highway vehicle or the highway vehicle struck the train. This was done because the physical mechanism involved in these two types of collisions is likely very different and may have to be accounted for differently in the final statistical model.

For each category, we further divided the data according to derailments and non-derailments. We then performed pair-wise comparisons within the categories. This is shown in Figures 5a and 5b.


Derailment: Train struck vehicle
Non-Derailment: Train struck vehicle
Percent of Category
40%
30%
20%
10%
0%
0
1-5
6-10
11-15
16-20
21-25
26-30
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
Speed of Highway Vehicle At Collision (mph)

(a)


Derailment: Vehicle struck train
Non-Derailment: Vehicle struck train
Percent of Category
40%
30%
20%
10%
0%
0
1-5
6-10
11-15
16-20
21-25
26-30
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
86-90
91-95
96-100
Speed of Highway Vehicle At Collision (mph)

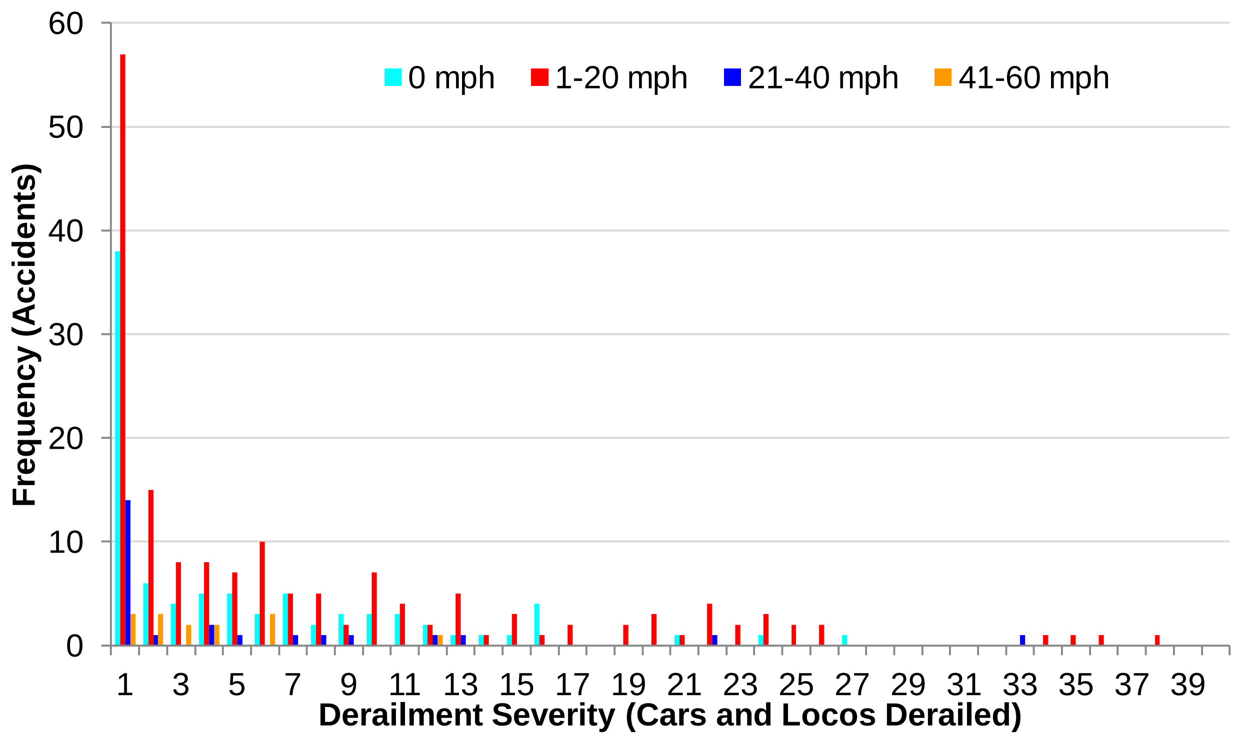
(b)

Figure 5 Speed at collision of vehicles involved in grade crossing incidents, 1991-2010 for (a) train striking highway vehicle scenario and (b) highway vehicle striking train scenario.

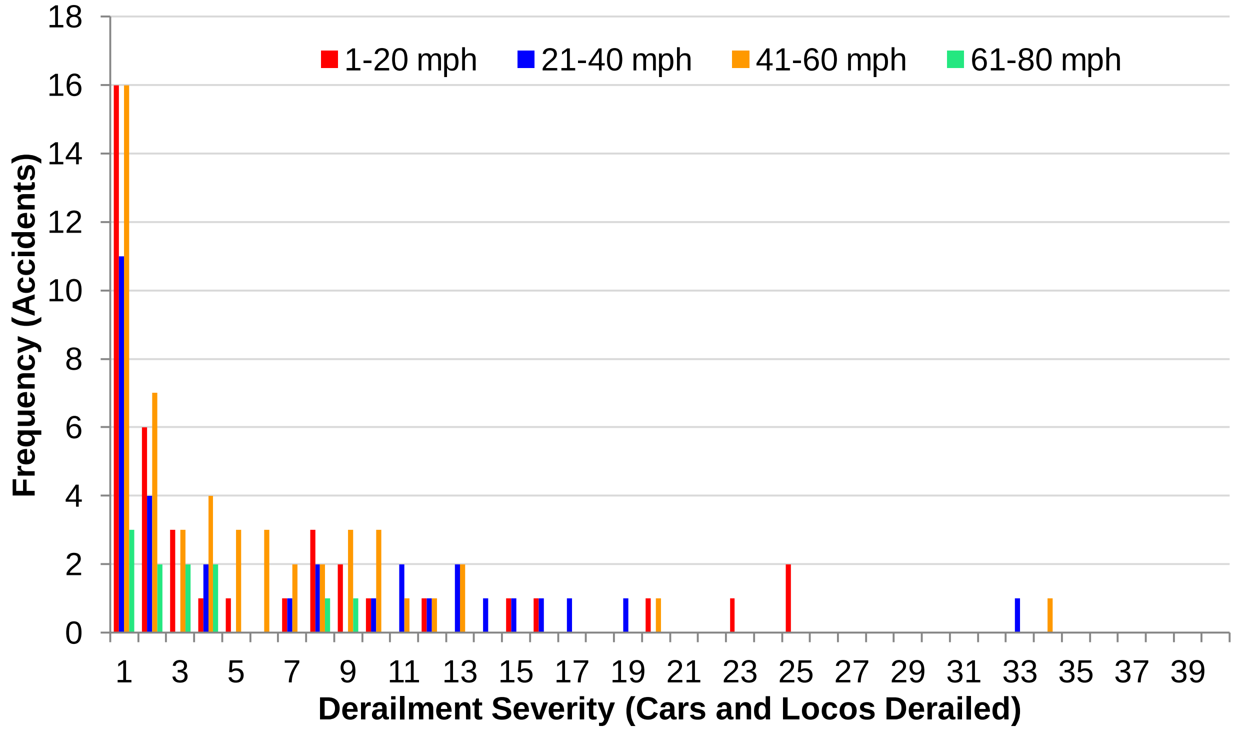
The majority of "train striking vehicle" incidents occurred at highway vehicle speeds less than 5 mph. A large number of incidents occurred in which the highway vehicle stopped or became stranded on the tracks. A survey of the narrative fields provided with each incident record indicates that this is a common problem, with about 40% of all "train striking vehicle" incidents involving a highway user stopped on the tracks. Speeds for the "vehicle striking train" incidents were generally higher, mostly concentrated in the 40 to 60 mph speed range.

Statistical testing was performed on the data to determine if there was a difference in speed between derailment and non-derailment incidents. Testing using the Wilcoxon Rank Sum test with $\alpha = 0.05$ showed that in both the "train striking vehicle" and "vehicle striking train" scenarios derailments are more likely to occur at higher vehicle speeds.

The effect of vehicle speed on derailment severity was also studied (Figures 6a and 6b). The distributions of the total number of cars and locomotives derailed do not suggest any strong relationship between highway vehicle speed at collision and derailment severity.



(a)



(b)

Figure 6 Distribution of total cars and locomotives derailed in incidents, by vehicle speed category, where (a) train struck motor vehicle and (b) motor vehicle struck train.

As discussed above, large highway vehicles were involved in a disproportionately large percentage of grade crossing derailments, so the motor-vehicle-speed analysis was repeated using only large highway vehicles (Figure 7). The results followed the same trends exhibited by the all-vehicle analysis.

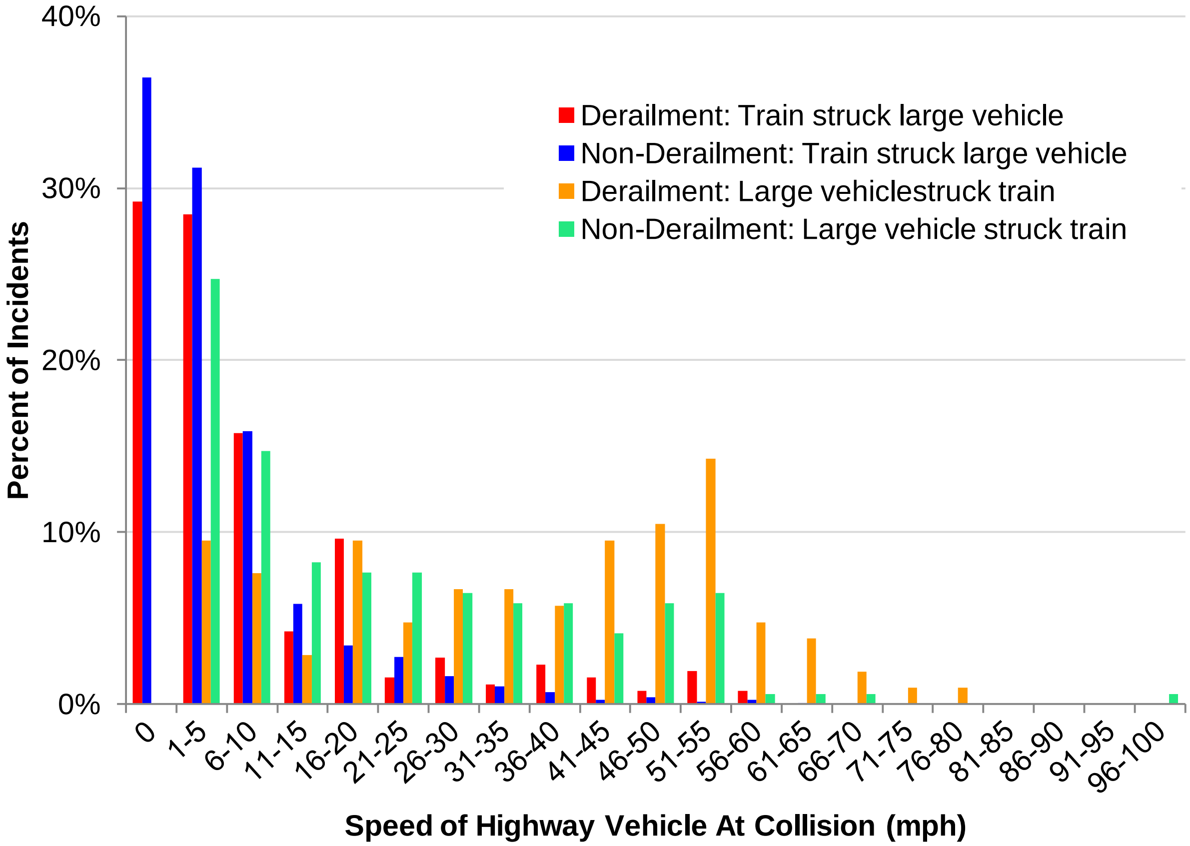


Figure 7 Speed at collision of large vehicles involved in grade crossing incidents.

Speed of Train at Collision

A complementary analysis was conducted to investigate the effect of train speed on derailment occurrence and severity. The FRA also records information about the speed of trains involved in grade crossing incidents, and these data may be either exact or estimated. The data were grouped into the same four categories described above. The percentage of each type of incident that occurred at a given train speed was plotted (Figure 8).

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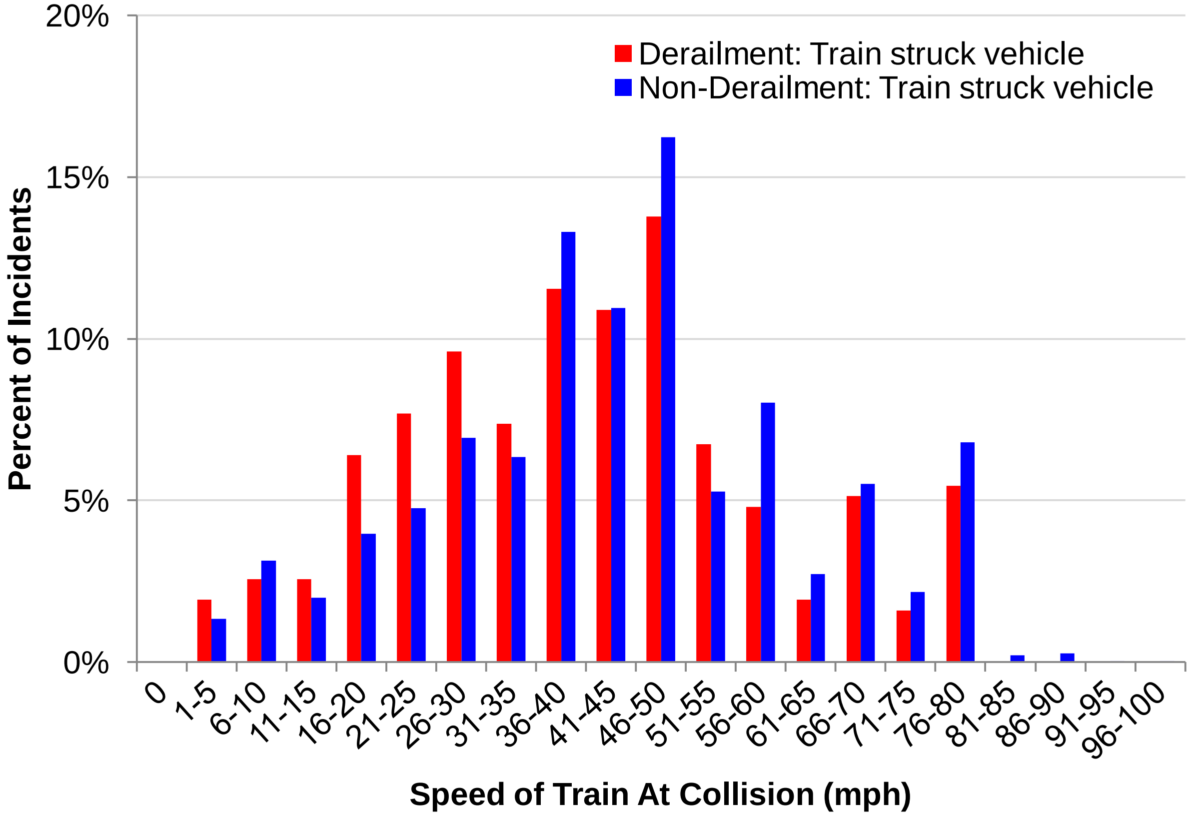
212



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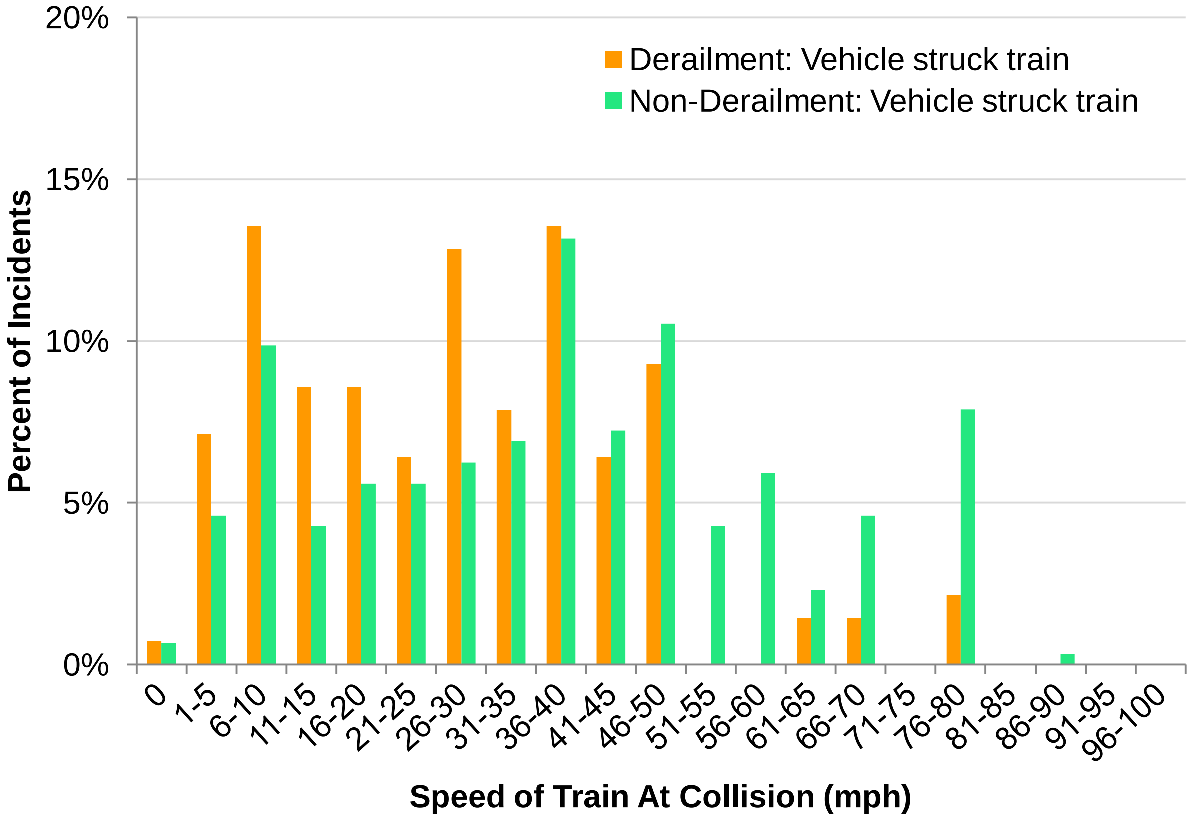
214 (a)



(b)

Figure 8 Speed at collision of trains involved in grade crossing incidents for (a) train striking vehicle and (b) vehicle striking train scenarios.

The distributions for all four scenarios were roughly the same, with the majority of collisions occurring in the 35 to 55 mph range most likely because this represents the typical range of mainline speeds. Statistical testing of the data using the Wilcoxon Rank Sum test with $\alpha = 0.05$ showed that derailments were more likely to occur at lower train speeds for both scenarios. The effect of train speed on derailment severity was also studied for all vehicles and for large motor vehicles alone, but no obvious relationship was evident for any of these scenarios.

DISCUSSION

Throughout this paper, each of the questions posed in the introduction have been considered. First, large vehicles such as trucks appear to be about four times more likely to cause a grade crossing derailment than small vehicles. Figure 3 shows that large vehicles are involved in a disproportionately greater number of derailments than the number of incidents in which they are involved, and by a considerable margin. This result is not surprising; in cases where a train hits a large, heavy vehicle its mass may make it more likely to dislodge the train from the tracks, and it is also capable of absorbing more of the train's momentum causing a sudden stop and possible jack-knifing of the train. A smaller, lighter vehicle is more likely to be pushed down the tracks allowing the train to lose speed more gradually.

Somewhat surprisingly, vehicle size did not seem to have much effect on derailment severity. While the most severe incidents – those resulting in the derailment of more than 25 cars and locomotives – were generally caused by trucks, this accounted for only 3% of all incidents. Setting aside this 3%, the distribution of severity for the “large vehicle” and “no large vehicle” cases was very similar (Figure 4).

Impact velocity of both the highway vehicle and the train were found to have an effect on derailment rate. It was shown that derailments tended to occur at higher vehicle speeds and lower train speeds. That higher vehicle speeds result in more derailments is not surprising given that the energy involved in high vehicle speed collisions is greater than other collisions, making the vehicle more likely to dislodge the train from the traicks. It was more surprising to find that derailments were more likely to occur at lower train speeds. One proposed reason for this is that a train traveling at higher speeds is more likely to knock the vehicle out of the way in a collision, whereas a slower train will not impart enough force to do so.

Additionally, some interesting patterns were evident in the velocity study. For the “train striking vehicle” category, about 40% of these incidents occurred between a train and a vehicle that was stationary on the tracks (with a speed of 0 mph). 30% of all derailments for this category occurred with a stationary vehicle. Examination of these incidents found that at least 40% were caused by a truck being stuck on a crossing and unable to move in time. This suggests that further efforts to modify crossing geometry so that trucks are less likely to get stuck would yield benefits. Alternatively, frequent crossing inspection combined with careful route planning could prevent trucks from becoming stuck by sending them on routes that are more appropriate given their under-truck clearance.

It is difficult to tell if impact velocity has an effect on derailment severity, because the small data set available did not provide a very clear distribution. However, it seems that speed alone may not have sufficient explanatory power. Momentum, as opposed to speed, seems to be a more important factor affecting train derailment severity. Speed may be more important if it is correlated with vehicle size and train length.

Vehicle size appeared to have little relationship with the speed distribution of vehicles striking the train. Although the data were not all presented due to space constraints, the distributions for all motor vehicles and for large vehicles were similar.

FUTURE WORK

Future research will be expanded to include detailed data about the intersecting highways, perhaps using data from the Federal Highway Administration, which maintains travel monitoring throughout the U.S. Additionally, the latitude and longitude information given for each grade crossing in the Highway-Rail Crossing Inventory could allow for integration with current GIS data, which could expand the scope and power of the analysis. Other factors pertaining to grade crossing incidents and derailments are also being explored, with the ultimate goal of developing a model to predict derailment rate at an individual grade crossing or along a rail line with a combination of different grade crossing vehicular traffic and warning systems.

Additional analysis will also consider passenger and freight trains separately, to better understand the different effect that grade crossing collisions have on these two train types.

CONCLUSIONS

This paper analyzed three factors in grade crossing incidents and their effect on derailment rate and severity. The purpose was to identify which factors have an effect on these metrics, with the longer range goal of developing a model to predict derailment risk at a given grade crossing. The results show that vehicle size has a strong effect on derailment rate, but little effect on derailment severity. Vehicle and train speed at collision also have an effect on derailment rate but little effect on severity. Current research considered only mainline, REA-reportable incidents from the years 1991 to 2010, which represents an expanded data set which was developed to obtain a more robust sample size and greater statistical power.

ACKNOWLEDGEMENTS

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