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NJ Transit Grade Crossing Safety
FINAL REPORT

November 2022

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16. Abstract

Grade crossings pose one of the most significant safety challenges for railroads and transit agencies across the United States (U.S.) and encompass 34% of railroad incidents in the past ten years. The elimination of grade crossings to reduce risk can improve public safety, decrease financial burdens, and improve service to the public. To improve grade crossing safety in New Jersey, this research provided the New Jersey Transit (NJT) with a list of 20 grade crossings prioritized for closure from an initial list of 100 grade crossings provided by NJT.

Through this research effort, the team surveyed the latest literature on grade crossing closure and prioritization. Based on the state of practice methodologies used by other States, a list of twenty critical data fields was created and verified with New Jersey Transit for each one hundred grade crossings. These data fields were crash history, average annual daily traffic, roadway speed, roadway lanes, length of the crossing's street, weekday train traffic, train speed category, number of tracks, access to train platforms, intersection angle, distance to alternate crossings, distance to emergency and municipal buildings, whether emergency and municipal buildings are on the same street, and date of last or future planned signal and surface upgrades.

This data was used to rank the crossings through an analytical hierarchical process (AHP) where they were filtered, normalized, and ranked. Three lists were generated: 1) a list of the top twenty grade crossings prioritized for closure, 2) a rank list of all crossings on the North Jersey Coast Line, and 3) a ranked list of the omitted state and county route crossings.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

Grade crossings pose one of the most significant safety challenges for railroads and transit agencies across the United States (U.S.) and encompass 34% of railroad incidents in the past ten years. The elimination of grade crossings to reduce risk can improve public safety, decrease financial burdens, and improve service to the public. To improve grade crossing safety in New Jersey, this research provided the New Jersey Transit (NJT) with a list of 20 grade crossings prioritized for closure from an initial list of 100 grade crossings provided by NJT.

Through this research effort, the team surveyed the latest literature on grade crossing closure and prioritization. Based on the state of practice methodologies used by other States, a list of twenty critical data fields was created and verified with New Jersey Transit for each 100 grade crossings. These data fields included: crash history, average annual daily traffic, roadway speed, roadway lanes, length of the crossing's street, weekday train traffic, train speed category, number of tracks, access to train platforms, intersection angle, distance to alternate crossings, distance to emergency and municipal buildings, whether emergency and municipal buildings are on the same street, and date of last or future planned signal and surface upgrades. These data then underwent screening and ranking through an analytical hierarchical process to generate a list of 20 grade crossings for closure.

The methodology consisted of four steps, filtering, ranking, adjacent crossing removal and list generation. Firstly, crossings with no alternate path or on state or county routes were removed from the final list due to the impracticability of closing the selected crossing. Secondly, an Analytical Hierarchy Process (AHP) was utilized to rank the crossings. In this process a total score was aggregated by multiplying the normalized value of each data field by the variable's corresponding weight. Normalized values were created by calculating the variables normalized value in a range of 0-1. This was based on its relative distance from the maximum and minimum of this value across all 100 crossings.

The crossings were ranked in descending order of total score and priority. Adjacent crossings in the list were removed in descending order to accommodate the anticipated overflow of traffic from closing the higher priority crossings. Lastly, three lists were generated: 1) a list of the top 20 grade crossings prioritized for closure, 2) a rank list of all crossings on the North Jersey Coast Line, and 3) a ranked list of the omitted state and county route crossings.

1.0 INTRODUCTION

Grade crossings pose one of the most significant safety challenges for railroads and transit agencies across the United States (U.S.) and encompass 34% of railroad incidents in the past ten years. The elimination of grade crossings with the intention of reducing risk can improve public safety, decrease financial burdens, and improve service to the public. To improve grade crossing safety in New Jersey, this research aims to provide New Jersey Transit (NJT) with a decision-making process to select grade crossings for closure. A listing of 100 crossings and associated features provided by NJT can be found in appendix E. The result of this research has the potential to guide NJT and NJDOT in maximizing the benefits to the communities of New Jersey.

2.0 BACKGROUND

The removal or modification of grade crossings with the intention of reducing risk can improve public safety, decrease financial burdens, and improve service to the public. A summary of the national trend for highway-rail grade crossing injuries and fatalities in the U.S. is shown in Figure 1. The data trend in 2020 is anomalous, likely due to the decrease in highway traffic due to the Covid-19 pandemic [1].

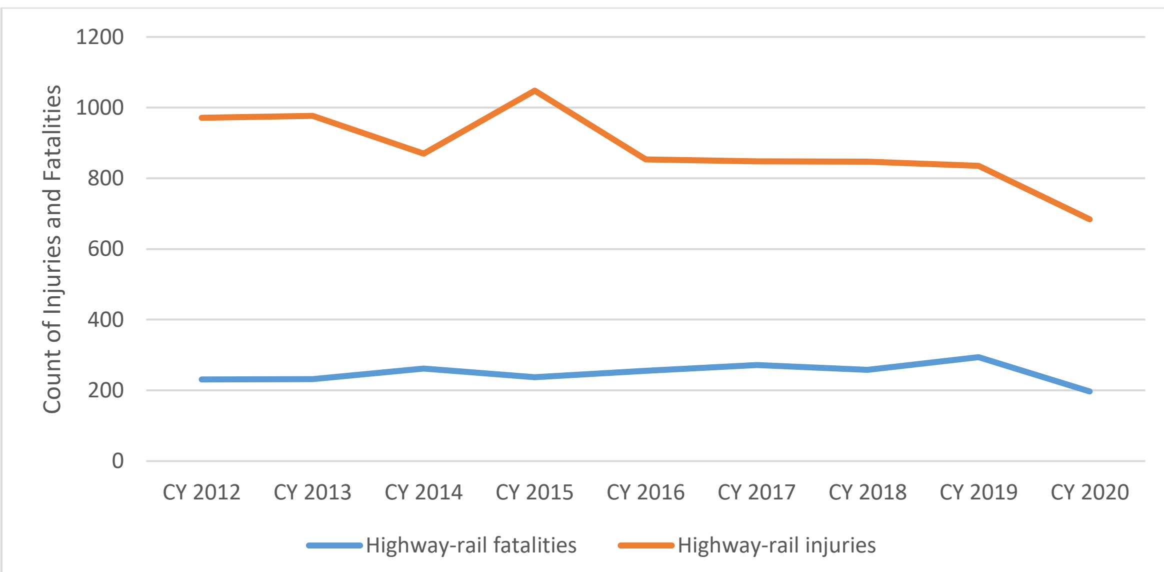

Figure 1. U.S. Highway Rail Grade Crossing Trends from 2012 – 2020 [2]

To improve grade crossing safety in New Jersey, this research provided the New Jersey Transit (NJT) with a list of 20 crossings for closure from an NJT supplied list of 100 crossings. This methodology can be reapplied to larger lists of crossings to prioritize crossings for closure in the future. The results of this research will support NJT and NJDOT in the efficient spending of limited funds to maximize the benefit for the communities of New Jersey.

3.0 OBJECTIVES

The objective of this research is to narrow the NJT-provided list of 100 grade crossings to 20 through a developed selection method that can be utilized on a larger inventory in the future. This methodology will prioritize the provided grade crossings for closure by formulating a ranking model with selection criteria and evaluation factors, such as traffic and train volumes, speed, community impacts, and warning devices.

4.0 SUMMARY OF THE LITERATURE REVIEW

This document presents a summary of the findings of a literature review on grade crossing elimination, hazard identification and prioritization. This effort ensured that the state-of-practice and state-of-the-art approaches were understood, enabling the selection of the best approach for prioritizing grade crossings for closure in New Jersey. A full copy of the literature review is included in Appendix F.

The primary focus of this research is grade crossing closure. A review of New Jersey's current practices, federal guidance, key factors, and case studies are presented. This review also summarizes past efforts in grade crossing prioritization. According to the Highway-Rail Grade Crossing Handbook, the first recommended alternative when considering modifying a grade crossing is elimination [3]. This is reinforced by 23 CFR 646.214(c) where "all crossings of railroads and highways at grade shall be eliminated where there is full control of access on the highway (a freeway) regardless of the volume of railroad or highway traffic" [3].

Elimination comes in three main varieties, grade separation, permanently closing the crossing to highway traffic, and permanently closing the crossing to railroad traffic. Grade separation usually involves installing a structure to carry highway traffic over or under the railway. While this change provides the greatest level of protection with the least roadway traffic impacts, it is often accompanied by the highest cost of all alternatives.

Grade crossing elimination has several benefits, including increased safety, reduced delays, and decreased maintenance costs. When a crossing is eliminated, the interaction between highway traffic and trains is removed, and the delays associated with stopped trains, crossing activations, and the required stopping of special vehicles (e.g., hazardous material vehicles, school buses) are also removed. Additionally, trains would no longer have to sound their horn when approaching the crossing, thus eliminating a nuisance to the surrounding community. Finally, the reduced maintenance of active signal treatments and the roadway/railway interface of the crossing is eliminated.

Eliminations can significantly improve safety, service, and reduce maintenance costs. Despite these improvements, elimination faces several challenges, including "negative community feedback," funding, and the lack of forceful State laws authorizing closure or the reluctant utilization of State laws that permit closure" [3]. Additionally, grade separations may require right-of-way acquisition for the construction of a grade-separated crossing, which poses a further barrier to elimination.

4.1 Elimination Key Factors

Eliminating a highway-rail grade crossing requires a review of key factors. These factors are a combination of financial and engineering details focused on increasing the safety of motorists, pedestrians, and passengers. In New Jersey, grade crossing closure initiation falls into three categories: engineering review, net-zero development, and consolidation.

4.1.1 Engineering Review

Maintaining authorities, like NJDOT, systematically review their inventory of grade crossings for closure candidates. These reviews consist of engineering studies of critical factors to determine if they are eligible for closure. A summary of some of the factors considered in New Jersey can be seen in Table 1. Recommendations from engineering reviews can include but are not limited to closure, separation, upgrades, or no action.

Table 1 - Grade Crossing Elimination Key Factors in New Jersey

Factor	Closure Criteria	Separation Criteria	Source
Accident and Near-Miss History	Many Events		FRA Safety Database
Traffic	< 2000 AADT	>2000 AADT	FRA Safety Database
Emergency Vehicle Usage	Low Usage	High Usage	Township Data & Interviews
Distance to Schools, Municipal Buildings, Hospitals, etc.	Far Distance	Nearby	Maps and GIS Dataset
Distance to Alt. Crossings	Nearby	Far Distance	Maps and GIS Dataset
Access to Train Platforms	No	Yes	Maps and GIS Dataset
Geometry and Layout	Poor sight distance, vertical curves, nearby traffic lights, etc.		Maps and Engineering Drawings

Crash history is a prime motivator for grade crossing closures. In some cases, crashes will initiate engineering studies to eliminate crossings. Traffic volume is another prime consideration when deciding to close a crossing. If traffic volume is sufficiently low, this may indicate that the crossing is eligible for closing to highway traffic. However, if the traffic volume is high but other factors indicate that it must be eliminated, grade separation may be considered.

Emergency vehicle usage of the crossing is another prime consideration. The distance from the crossing to fire stations, hospitals and police should be evaluated. Similarly, utilization by school buses or adjacent municipal complexes should be considered.

In some locations, there are many crossings in a small area. On corridors like NJT's Coast Line, crossings can be 300-400 feet apart (i.e., Asbury Park). This increases further with a high density of stations, such as the 2.5-mile corridor between Allenhurst, Asbury Park, and Bradley Beach stations. If one of these crossings were to be closed, the routed traffic would have sufficient alternate routes to cross the tracks. When multiple crossings are considered for elimination and upgrade as a group, they are called a grade crossing consolidation project.

Additionally, crossings near or within train stations should be considered for elimination. Crossings that provide pedestrian access to station platforms are good elimination candidates due to the reduced commuter exposure when accessing a station. Finally, the geometry of the crossing should be considered. Traffic speeds, skew, and vertical curves are examples of features that can cause the vehicle to slow or become stopped on the tracks. If the engineering study reveals that geometry may contribute to increased risk exposure, then elimination should be considered.

4.1.2 Net Zero Development

Grade crossing elimination projects are also initiated when a grade crossing is added to a corridor by land development projects. When this occurs, a grade crossing engineering review is started to remove an equivalent number of crossings within the same municipality.

4.1.3 Corridor Projects (Consolidation)

Finally, the third category of grade crossing elimination initiation is corridor projects, also called consolidation. An effective way to eliminate crossings is to develop a "program of treatments to eliminate significant numbers of crossings within a segment of rail line while improving those that are to remain at grade" [4]. This type of treatment is called a grade crossing consolidation program. These programs, which are supported by the FRA and the American Association of State Highway and Transportation Officials (AASHTO) propose a set of high-level steps to determine crossings for elimination.

According to federal guidance and research on grade crossing consolidation, firstly, corridors of rail lines are selected, and crossings are selected and filtered based on jurisdictional criteria (public vs. private crossings). After the areas and crossing lists are selected, it is recommended that a diagnostic team studies the number of road lanes, the number of tracks, average daily traffic, crash history, and proximity and access to other crossings. Once the consolidation factors are established, funding can be sought through several federal programs, including Section 148 of the Safe, Accountable, Flexible, Efficient Transportation Equity Act, which sets aside $220 million annually for grade crossing safety improvements or the Section 1103(f) of SAFETEA-LU which allows federal monies to be used for hazard elimination along designated high-speed rail corridors [4].

In 2018, Codjoe et al. [5] evaluated the incentive programs for grade crossing consolidation and closure through a survey circulated to state transportation agencies.

The results showed that 16 states had no incentive programs, and those same states had the least proportion of highway-rail crossing closures. “The study revealed that cash incentives, while popular, are not effective because although the Federal Government contributes to a state’s effort in offering cash incentives for closure of public grade crossings, the amount is not substantial enough to be considered a significant incentive by most local governments.” However, crime rate reduction incentives, greenness improvement programs, and the development of a grade crossing consolidation model were proposed as effective consolidation methods.

4.2 Federal Grade Crossing Elimination Guidance

According to the Grade Crossing Handbook, 3rd Edition, “locations with more than four crossings per railroad route-mile with fewer than 2,000 vehicles per day and more than two trains per day are prime candidates for closure” [3]. The access of emergency vehicles and the increased risk at other crossings due to diverting highway traffic should also be considered. An elimination at one crossing may have the adverse effect of increasing risk at other crossings, and therefore eliminations often coincide with upgrades at nearby crossings.

4.3 Alternative Ranking Tools

In 2019 the Transportation Research Board published report 901 Prioritization Procedure for Proposed Road-Rail Grade Separation Projects Along Specific Rail Corridors [6]. This report provides “the Rail Crossing Assessment Tool (RCAT) was developed based on previous research, transportation agency input, professional guidelines and reports, and practical experience, which is described in detail in the NCHRP Project 25-50 Final Report” [6]. The tool automatically imports crossings and ranks them based on safety data, economic data, environmental factors and community/livability features.

The methodology presented in this report differs in two main areas, accident data and GIS analysis. Firstly, both methods consider accident data, but this approach includes NJDHTS data in addition to FRA reported accidents. Secondly, this research considers a detailed GIS analysis of the crossing, considering alternative routing distance.

5.0 SUMMARY OF THE WORK PERFORMED

The work was performed in two primary tasks, data collection, and grade crossing ranking. During the data collection task, 20 fields of data related to the grade crossing were generated from varying databases and analyses. Following the data collection, the crossings were ranked based on an analytical hierarchical process (AHP) where different values were normalized, weighted, and sorted by cumulative scores.

AHP was selected as the ranking process for this tool because of its unique advantages in aggregating data with different ranges and incorporating intuitive judgements of industry experts. According to Palcic et al, AHP “aims at quantifying relative priorities for a given set of alternatives on a ratio scale, based on the judgment of the decision-maker, and stresses the importance of the intuitive judgments of a decision-maker as well as the consistency of the comparison of alternatives in the decision-making process". [7]

AHP functions in several distinct steps as described by Placic et al. Firstly, a criteria hierarchy is established, determining if one or multiple levels of filters are required. In this research project there are three levels of hierarchy for ranking the alternatives. The first is a pass that considers the roadway type and alternate route availability. The second is a weighted ranking of normalized variables. The third is an adjacent crossing removal filter. [7]

The second step in an AHP process is the allocation of weights to chosen criteria. This was accomplished directly in this research where individual weights capturing the decision makers judgement and best practices were incorporated. The third step is to assign numerical values of equivalent scale to each criterion. This was accomplished by normalizing each value as a ratio relative to the maximum and minimum values across all 100 crossings. In the case of categorical values like true vs. false, perpendicular vs. skewed, binary values of 1 and 0 were assigned. The final step in the process is to apply the weights to the normalized values and aggregate the final ranking scores within the aforementioned hierarchy. The final output will be a prioritized list of all possible alternatives. [7]

5.1 Data Collection

5.1.1 Data Collection Overview

Twenty different data fields were collected and generated to prioritize the selected list of 100 crossings for closure. These data fields were crash history, average annual daily traffic, roadway speed, roadway lanes, length of the crossing's street, weekday train traffic, train speed category, number of tracks, access to train platforms, intersection angle, distance to alternate crossings, distance to emergency and municipal buildings, whether emergency and municipal buildings are on the same street, and date of last or future planned signal and surface upgrades.

5.1.2 Crash History

In this project, the crash history for the 100 grade crossings was obtained from two databases, including the Federal Highway Administration (FRA) and the New Jersey Division of Highway Traffic Safety (NJDHTS) Crash Analysis Tool.

5.1.2.1 FRA Database

The first crash dataset was obtained from crossing inventory data provided by the FRA Office Of Safety with the goal of offering different data users and policymakers high-quality information. This dataset is open to the public. By searching the grade crossing ID, a user can access the crash history of the grade crossing. In this project, 11 years of crash data (from 2010 to 2020) was obtained for the 100 grade crossings using the FRA database (see Table 2). According to this table, a total of 65 crashes occurred at 40 out of the 100 grade crossings during the study period. Moreover, grade crossing ID 263164S had the highest number of crashes among other grade crossings, with 11 crashes occurring at this location.

Table 2 - Crash history from FRA database from 2010 to 2020

Grade Crossing ID	# of Crashes	Grade Crossing ID	# of Crashes	Grade Crossing ID	# of Crashes	Grade Crossing ID	# of Crashes
263164S	11	856918S	2	263193C	1	856895M	1
263186S	4	856958P	2	263416R	1	856923N	1
263413V	3	263028S	1	263418E	1	856935H	1
856945N	3	263029Y	1	266877K	1	856941L	1
263044B	2	263030T	1	266880T	1	856942T	1
263050E	2	263047W	1	266882G	1	856943A	1
263082K	2	263049K	1	266883N	1	856946V	1
263165Y	2	263051L	1	586073E	1	856956B	1
263412N	2	263052T	1	586075T	1	856963L	1
856917K	2	263185K	1	586077G	1	856972K	1
Total				**65 Crashes in 40 of the 100 Grade Crossings Provided by NJ Transit**			

5.1.2.1 NJDHTS Crash Analysis Tool

The second crash dataset was obtained from the NJDHTS Crash Analysis Tool with the goal of empowering the local agencies and states to save more lives on the roadways. This dataset is not open to the public. The variable “Intersection Related: At or near Railroad Crossing” was used to extract the crashes from this database. Then the extracted crashes were plotted using their GPS coordinates. For this study, only the crashes that occurred near the 100 grade crossings were considered. It is notable to mention that some of the crash records in this database did not have any coordinates. Other information such as crash location, cities/municipalities, and county were utilized to identify the approximate location of these crashes.

In this project, 7 years’ worth of crash data (from 2010 to 2016) was obtained for the 100 grade crossings. The data after the 2016 was not available for the “At or near Railroad Crossing” crashes in this database. As the final step, the extracted crashes from the Crash Analysis Tool were compared with the crashes obtained from the FRA database. By doing so, a total of 11 duplicates were identified and removed from the final crashes in this database. Table 3 tabulates the obtained crashes from the Crash Analysis Tool database. As shown in this table, a total of 131 crashes occurred at 56 grade crossings during the study period. Moreover, grade crossing ID 266877K had the highest number of crashes among other grade crossings, with 10 crashes occurring at this location.

Table 3 - Crash history from Numetric database from 2010 to 2016

Grade Crossing ID	# of Crashes	Grade Crossing ID	# of Crashes	Grade Crossing ID	# of Crashes	Grade Crossing ID	# of Crashes
266877K	10	263228B	3	856952Y	2	586075T	1
263164S	8	263415J	3	856959W	2	586080P	1
263412N	7	856947C	3	856973S	2	856897B	1
263050E	6	856961X	3	916134G	2	856923N	1
263165Y	4	856963L	3	263047W	1	856925C	1
263193C	4	263027K	2	263190G	1	856926J	1
263413V	4	263032G	2	263232R	1	856931F	1
856894F	4	263046P	2	263242W	1	856935H	1
856956B	4	263053A	2	263414C	1	856938D	1
263043U	3	263082K	2	263418E	1	856939K	1
263044B	3	263185K	2	266876D	1	856942T	1
263051L	3	856895M	2	266882G	1	856957H	1
263186S	3	856917K	2	266883N	1	856958P	1
263227U	3	856918S	2	266890Y	1	856971D	1
Total				**131 Crashes in 56 Grade Crossings**			

Table 4 presents the combined crashes from both databases for the grade crossings of interest in this study. As shown in this table, a total of 196 crashes were recorded in 70 grade crossings. It should be noted that the crashes provided in Tables 2, 3, and 4 are unique crashes. The duplicate crashes from both FRA and the NJDHTS databases were removed as part of the data collection.

Table 4 - Combined Crash History from FRA and Numetric from 2010 to 2020

Grade Crossing ID	# of Crashes	Grade Crossing ID	# of Crashes	Grade Crossing ID	# of Crashes	Grade Crossing ID	# of Crashes
263164S	19	263043U	3	263418E	2	586080P	1
266877K	11	263415J	3	856923N	2	266876D	1
263412N	9	263228B	3	856935H	2	263414C	1
263050E	8	263227U	3	856942T	2	263028S	1
263413V	7	856895M	3	263047W	2	263029Y	1
263186S	7	263185K	3	263027K	2	263030T	1
263165Y	6	856958P	3	856971D	1	263049K	1
856956B	5	856945N	3	856938D	1	263052T	1
263193C	5	263032G	2	856926J	1	263416R	1
263044B	5	856959W	2	266890Y	1	266880T	1
856894F	4	856952Y	2	263232R	1	586073E	1
263082K	4	856973S	2	263242W	1	586077G	1
263051L	4	263046P	2	856897B	1	856941L	1
856963L	4	916134G	2	263190G	1	856943A	1
856918S	4	263053A	2	856957H	1	856946V	1
856917K	4	586075T	2	856925C	1	856972K	1
856947C	3	266882G	2	856931F	1		
856961X	3	266883N	2	856939K	1		
Total			**196 Crashes in 70 Grade Crossings**				

5.1.3 Road Characteristics

In prioritizing crossings closure, it is important to investigate the road characteristics on which the crossings are located. These characteristics indicate the importance of a road in terms of traffic volume. To this end, in this study, the data elements of the Annual Average Daily Traffic (AADT), posted speed limit, and the number of lanes for each roadway of the study's crossings were aggregated.

This data was primarily obtained from the Federal Railroad Administration (FRA). Regarding the AADT, the data showed noticeable variations where the lowest AADT was recorded as 25, while the highest was 24,874. In terms of the roadway speed, the values ranged 25 miles/hour for 90 of the crossings, 30 miles/hour at 6 crossings, 35 miles/hour at 3 crossings, and 40 miles/hour for one crossing.

By the means of the roadway lanes, it ranged from one-lane roadways to five-lane roadways. However, the majority of the crossings' roadways had two lanes, except nine crossings where two had a one-lane roadway, three crossings had three-lane roadways, another three crossings had four-lane roadways, and only one crossing was classified as a five-lane roadway.

5.1.4 Train Characteristics

Characteristics of the train at each crossing were captured as well. This included the weekday train traffic; train speed; and the number of tracks. The weekday train traffic dataset explains the number of trains passing the crossing each weekday. This data was obtained from the trains' basic schedules provided by NJ Transit, where a timetable is displayed for each train from which the train traffic data was aggregated. Weekend train traffic was available but not included due to the determination that weekday traffic was sufficient to differentiate the volume of train traffic at each crossing. Weekdays were also chosen for comparison because they have more traffic activity when compared to weekends.

Train traffic at each crossing during the weekdays ranged from 24 trains per day at the crossing with the lowest activity to 93 at the highest. Regarding the train speed data, it was derived from the General Order Rule Book, prepared by NJ Transit, which indicates the speed at which each should travel. The provided speeds were categorized into three categories (i.e., low, medium, and high) and assigned for their relative crossings. Low speed was anything less than 40 miles per hour (mph), the medium was 41-60 mph, and the high was 61-80 mph.

The aggregated data recorded 3 crossings where the trains ran at high speed, 44 crossings at low speed, and 48 at medium speed. Lastly, the number of tracks at each crossing was obtained from the crossing's dataset provided by NJ Transit. The number of tracks ranged from one to three tracks, where 3 crossings had three tracks, 72 crossings had two tracks, and 24 had one track.

5.1.5 Access to Train Platforms

The access to train platforms dataset investigates the crossings' proximity to train stations. The dataset includes a true value if a crossing is located within 1000 feet of a train station. The data was obtained by inspecting maps of the 100 crossings and measuring the distance using built-in tools. The data showed that 27 crossings were near train platforms.

5.1.6 Grade Crossing Intersection Angle

This data element investigates the sharpness of a crossing's intersection angle. This data was derived from the Federal Railroad Administration safety database, where the data was provided as a category for each crossing named "smallest crossing angle" and ranged from 0° to 90°. For the studied crossings, the data were reclassified into two categories "Perpendicular" and "Skewed", where the skewed values indicate the angles which are less than 90°. The finalized data was evenly distributed, 46 crossings were classified as "Perpendicular", and 54 recorded "Skewed" angles.

5.1.7 Distance to Alternate Crossings

Distance to the alternate crossing is a data element that indicates the length of the alternative route a pedestrian or vehicle needs to complete when closing a crossing. This data was obtained by utilizing the ArcGIS Pro software, where the crossings dataset and roads networks were incorporated. The proximity analysis tool "Nearest Road Distance" supported by ArcGIS Pro was performed to calculate the shortest alternative route measured by the unit mile/s, where the start and end points were assigned at the first intersection before and after each crossing.

The difference between the original distance from a start point to an end point through the crossing and the shortest alternative distance was calculated and assigned as a continuous variable for each crossing named "out of distance". Higher values indicate further alternative routes. In the dataset, five crossings did not have any alternative routes and were excluded from the final list of crossings. For the crossing where an alternative route was available, the out-of-distance values ranged from 0.1 miles to 0.72 miles.

5.1.8 Distance to Critical Public Facilities (e.g., Schools, Municipal Buildings)

In the process of closing a crossing, it is important to investigate the users of this crossing and how its closure would affect critical pillars such as safety and accessibility. To investigate this aspect in this study, the location of critical public facilities (i.e., acute care centers, fire stations, police stations, and schools) were analyzed. The nearest route distance between these services and each studied crossing was calculated, restricted within a 5-mile range.

To perform this analysis, the “Nearest Road Distance'' tool supported by ArcGIS was utilized, and the spatial data for each of the targeted critical public facilities were incorporated along with the crossing’s dataset. The facility location was obtained from several public sources in a shapefile format. Acute care centers and Schools locations were obtained from the New Jersey Geographic Information Network (NJGIS) open data portal, while the Police and Fire stations were located using the Homeland Infrastructure Foundation-Level Data (HIFLD). This data was represented by assigning a variable for each examined service that represents the nearest distance to the service from the related crossing.

Additionally, for critical public facilities located within one mile of a crossing, a variable was included if the amenity is located on the same street as the crossing or not. The same street variable was assigned as a True or False value, where True indicated the same street location and False indicated the opposite. Table 5 represents a summary of the data values related to the closest amenities data element.

Table 5 - A Summary of the Closest Amenities Data

Service	Acute care centers	Fire stations	Police stations	Schools
Range of nearest distance mile(s)	0.6 – 2.5	0.04 – 0.8	0.16 – 0.9	0.23 – 1.85
Number of crossings with no amenities within 5-mile distance	29	0	0	0
Number of amenities within 1-mile distance	28	100	100	71
Number of same street locations	0	1	1	6
Number of different street locations	28	99	99	65

5.1.10 Signal and Surface Upgrades

Upgrading a crossing and its related infrastructure requires considerable budget and planning efforts. This study incorporated the latest past and future upgrade data for each crossing. The latest upgrade for a crossing's signals or surface was obtained directly from NJ Transit. The data indicate the latest year when the upgrade was implemented. The surface upgrade data ranged from 1985 to 2021, while signal upgrades ranged from 2005 to 2022. It is worth mentioning that within the last 10 years, 45 of the studied crossings had surface upgrades, and 9 of them had signal upgrades.

5.1.11 Length of Crossing's Street

In addition to the AADT, the length of a street is an indicator of the traffic volume and importance of that road. In this study, the length of the street at which each crossing is located was obtained and given weight within the prioritization process. This data was acquired using the ArcGIS Pro tool "Calculate Geometry" which was incorporated into the roads dataset which was obtained from the Census Bureau TIGER/Line Shapefiles data. The lengths of the crossings' streets were measured by the unit mile/s, and the values ranged from 0.02 – 3.3 mile/s.

5.2 Grade Crossing Ranking

The grade crossings were ranked for closure in four primary steps, filtering out locations where closing is not possible, ranking the crossings based on AHP, removing adjacent crossing closure recommendations in sequence, and generating three final lists. The following section describes the overall methodology, variable directions, weights, feedback session changes, and comparisons to other studies.

5.2.1 Methodology

The first step in this methodology filtered out locations that could not be closed. This included any crossing on a County or State route. Additionally, crossings with no alternate paths, determined through GIS analysis of alternate routing, were filtered out. In the list of 100 crossings 19 County routes, 3 State routes, and 5 crossings with no alternate paths were filtered out of the final list for closure.

Next, the remaining crossings were ranked by an AHP. Within this process, each variable was given a direction and a weight which was used to calculate each crossing total score. The individual variable directions and weights are described in detail in the following sections. The variable direction describes whether a higher or lower variable value will indicate that the crossing should be closed. The weight indicates the variables relative importance in deciding which crossing should be prioritized for closure.

Thirdly, adjacent crossings identified for closure were removed from the prioritization list in sequence. An adjacent crossing is defined as a grade crossing that is next along tracks without any other crossings or bridges/tunnels in between. When calculating alternate routes, often adjacent crossings are expected to bear the additional traffic generated by closing the crossing in question. Therefore, a script was developed to check if each crossing had a neighbor that had a higher priority for closure and if true the crossing would be removed from the final list.

Lastly, three files were generated: a top 20 crossings identified for closure, a ranked list of all crossings on the North Jersey Coast Line, and a ranked list of the 27 crossings removed in the initial filter (e.g., state routes, county routes)

5.2.2 Variable Direction

Each variable had a corresponding direction which indicates that a selected crossing should be prioritized for closure. A full listing can be seen in Table 6.

In this research, the higher the crash data, the more likely the crossing would be indicated for closure. The lower the roadway's importance in the local community, the more likely the crossing would be indicated for closure. This was represented by the average annual daily traffic, roadway speed, number of roadway lanes, and total length of the crossing's street.

Conversely, the higher the importance to the railway network, the more likely the crossing would be recommended for closure. This was represented by weekday train traffic, train speed category and the number of tracks. Additionally, if a station was not adjacent to the crossing, representing that it is not utilized directly by station pedestrian traffic, the more likely it would be recommended for closure. The more skewed the angle of the crossing, the more likely it would be prioritized for closure. This variable approximates the visibility of the crossing from a safety perspective.

The further away critical public facilities are, and if the locations are not on the same street, the more likely the crossing is recommended to be closed. This value approximates the utilization of the crossing by emergency and municipal vehicles. Lastly, the longer ago signal surface upgrades occurred at the crossing, the more likely the crossing is recommended to be closed.

Table 6 - Closure Methodology Variable Directions

Category	**More likely to be a Candidate for Closure**
Crashes	Higher
AADT	Lower
Roadway Speed	Lower
Roadway Lanes	Lower
Length of the Crossings Street	Shorter
Crossing Angle	Skewed
Weekday Train Traffic	Higher
Train Speed Category	Higher
Number of Tracks	Higher
Station Adjacent	No
Alternate Route Distance (mi)	Shorter
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	Further Away
Is a Fire Station on the Same Street	No
Nearest Distance to Fire Station	Further Away
Is a Police Station on the Same Street	No
Nearest Distance Police Station	Further Away
Is a School on the Same Street	No
Distance to Nearest School	Further Away
Signal and Surface Upgrades	Longer Ago

5.2.3 Weights

Each variable had an associated weight indicating its importance in the overall study. The values range from 0.1, least impactful, to 2, most impactful. The values in Table 7 were generated based on iterative testing of the prioritization process, a review of past literature, and discussions with NJT.

AADT was given a weight of 0.5, while other roadway features (speed, lanes, street length, and crossing angle) were each given a weight of 0.25. Railroad features (weekday train traffic, train speed category, number of tracks) were given a weight of 0.5. These values represent medium importance to the overall ranking. Crash data was given a weight of 0.75, indicating that crash history is an important variable in the overall recommendation. This is the third highest weight given to a variable in this methodology.

Station adjacency and the presence of critical public facilities on the same street were given a weight of 1, indicating that these values were very important to the ranking process. These are the second highest values in the process. Conversely, the distance to the nearest municipal or emergency service location was given a ranking of 0.1, indicating they are not as impactful in the ranking process.

The highest weight of 2 was given to the alternate route distance, which directly represents the longest distance a driver or pedestrian must travel to reach the opposite side of the crossing if it were closed. This variable also indirectly represents the number of crossings in a mile, and some locations within the 100 crossings have many in a short distance (North Jersey Coast Line). Federal guidance suggests that crossings should be reduced to a maximum of 4 per mile, which motivated the selection of this as the highest weighted variable.

Table 7 - Closure Methodology Variable Weights

Category	**Weights**
Crashes	0.75
AADT	0.5
Roadway Speed	0.25
Roadway Lanes	0.25
Length of the Crossings Street	0.25
Crossing Angle	0.25
Weekday Train Traffic	0.5
Train Speed Category	0.5
Number of Tracks	0.5
Station Adjacent	1
Alternate Route Distance (mi)	2
Is the Hospital on the Same Street?	1
Distance to Nearest Hospital	0.1
Is a Fire Station on the Same Street	1
Nearest Distance to Fire Station	0.1
Is a Police Station on the Same Street	1
Nearest Distance Police Station	0.1
Is a School on the Same Street	1
Distance to Nearest School	0.1
Signal and Surface Upgrades	0.1

5.3.4 Feedback Session and Changes

Several feedback sessions were held throughout the course of this project, and several changes and suggestions were made to improve the ranking process. New data such as planned upgrades, past upgrades, and the length of the crossing's street were suggested and incorporated into the analysis. Refinements such as restricting the analysis of municipal facilities on the same street to one mile and accommodating municipal facilities which had alternative driveways on the crossing's street were also incorporated.

Several recommendations were made but not included in this study. Firstly summer vs. fall AADT changes were suggested for incorporation into this analysis due to the significant change in recreation traffic during the summer. This was not implemented due to a lack of different summer and fall traffic data at all 100 crossings. This refinement can be considered for a subsequent study where the final 20 crossings for closure are studied in greater depth.

Additionally, the adjacency to switching yards was suggested as a variable. This variable was not included in the current analysis because only one crossing was found to be adjacent to a switching yard. If this system were applied to a larger dataset where multiple crossings would have this criterion, it might be considered to include this variable.

Lastly, it was requested to analyze the final list of 20 crossings to determine if the federal guidance of 4 crossings in one mile was achieved. However, it was found that with the inclusion of the adjacent crossing removal restriction, this goal could not be reached on the North Jersey Coast Line. As an alternative, a ranked list of the supplied crossings on the North Jersey Coast Line is provided in Appendix C.

5.3 Comparison to Other Analyses

5.3.1 FR Harris Study [8]

Fredrich R. Harris Inc conducted a study in 1994 to propose crossings for closure or consolidation. Approximately 300 at-grade railroad crossings are present on NJ TRANSIT property. FR. Harris Inc. established a complete inventory of characteristics of each crossing based on multiple sources. These sources include the FRA database, communications with NJ TRANSIT regarding train traffic volumes, 11-year crash database from 1983 to 1993 provided by NJ TRANSIT, field inspections performed by Frederic R. Harris team, surveys of local government and county engineers, existing traffic reports, and engineering evaluation of the Frederic R. Harris team.

The Frederic R. Harris team utilized this complete inventory that covers over 300 crossings of NJ TRANSIT to apply U.S. DOT Accident Prediction Equations. With this accident prediction equation as a component, a crossing ranking system was established. This formed a basic means of qualifying candidate crossings for closure. Some common features were crossings activated by a train stopped at a nearby station, field notes, crossings with high traffic volumes and high a-rank, pedestrian incident sites in the vicinity of schools or stations, future-scenario accident predictions, and numbers of accidents/injuries/fatalities. All 300 crossings are ranked according to this ranking system, and the top 100 are presented with 30 crossings identified for selection. In the result, Frederic R. Harris team identified the top 30 private and low-use crossings for closure of the top 100 crossing by manually reviewing and revision of top 100 crossing list and dividing the list into closures and separations.

Following this study, two of the thirty crossings were closed, and one was separated. Augusta Street in South Amboy was closed after 2006 and Summerfield Ave, was closed to vehicle and pedestrian traffic after 2014. New County Road in Secaucus was separated before 2006.

Compared to our proposed method and result, the research team of Frederic R. Harris manually reviewed over 300 at-grade railroad crossings on the passenger lines of NJ TRANSIT and selected the top 30 crossings for elimination. Items considered were project complexity, approximate costs, institutional issues, and benefits associated with each site. In our research, we ranked 100 crossings across the state crossing and selected the top 20 crossings for closure based on accident history, traffic, distance to schools and municipal buildings, distance to alternate crossings, access to train platforms, geometry, and train density and speed.

Specifically, we both focus on the impact of traffic volumes, crash record, distance to schools and municipal buildings, and distance to alternate crossings.

Our method relies on the ranking system that weights each characteristic of at-grade crossings and selects the top 20 of 100 crossings for closure by one ranking process. In contrast, the Frederic R. Harris's study requires three stages manual selection and filtering to select the top 30 of 300 crossings for closure.

5.3.2 Stantec Study [9]

A study was conducted by Stantec in 2009 to propose crossings for consolidation in Asbury Park NJ. NJ TRANSIT planned to close 6 crossings in the project area, which consists of 12 at-grade crossings between Memorial Drive and Main Street in Asbury Park NJ, from Lake Avenue to 6th Avenue. Stantec established data collection program in the summer and fall that focus on existing traffic, land use data, and determines the seasonality of traffic conditions. Specifically, automatic traffic recorders, turning movement counts, pedestrian counts, accident data, observations of land use, and community features are included. According to collected data, Stantec set up a range scoring system to rank the crossing for closure leveraged on these seven characteristics: peak hour traffic volume, hours above 200 VPH, peak hour pedestrian volumes, crash rate per million entering vehicles, injury ration, importance to street grid, land use or frontage (between Main Street and Memorial Drive) and importance to future redevelopment.

With the help of the scoring system, 6 of 12 crossings were selected for closure recommendation, and the research team stated the remaining locations could be sufficient to maintain traffic operations without significantly influencing the surrounding conditions and result in a slight change to the existing travel patterns based on the professional opinion of the engineers performing the study. One crossing, Summerfield Ave, was closed to vehicle and pedestrian traffic after 2014.

Compared to our proposed method and result, the research team of Stantec utilized a scoring system that can rank 12 crossings down the shore based on seven factors mentioned above, while we rank over 100 crossings across the state crossing based on accident history, traffic, distance to schools and municipal buildings, distance to alternate crossings, access to train platforms, geometry, and train density and speed.

Specifically, we both focus on the impact of traffic variables, accident history, distance to schools and municipal buildings, and distance to alternate crossings. Stantec ranks crossing leverage on peak hour traffic volume, hours above 200 vehicles per hour, peak hour pedestrian volumes, the crash rate per million entering vehicles, injury ration and importance to the street grid.

Additionally, our method also considers accessibility to train platforms, geometry, and train density and speed, while Stantec's study concentrates on the land use and importance to future redevelopment that is not in our scope.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Top 20 Crossings for Closure

According to the proposed methodology, the 20 recommended crossings for closure are listed in Table 8, which includes the rank, crossing id, line name, roadway name, and town and county of selected crossings. More details on each of the selected crossings can be found in Appendix B. A breakdown of the selected crossing by New Jersey County can be seen in Figure 2. The crossings are in Monmouth County (60%), Bergen (25%), and Essex (15%).

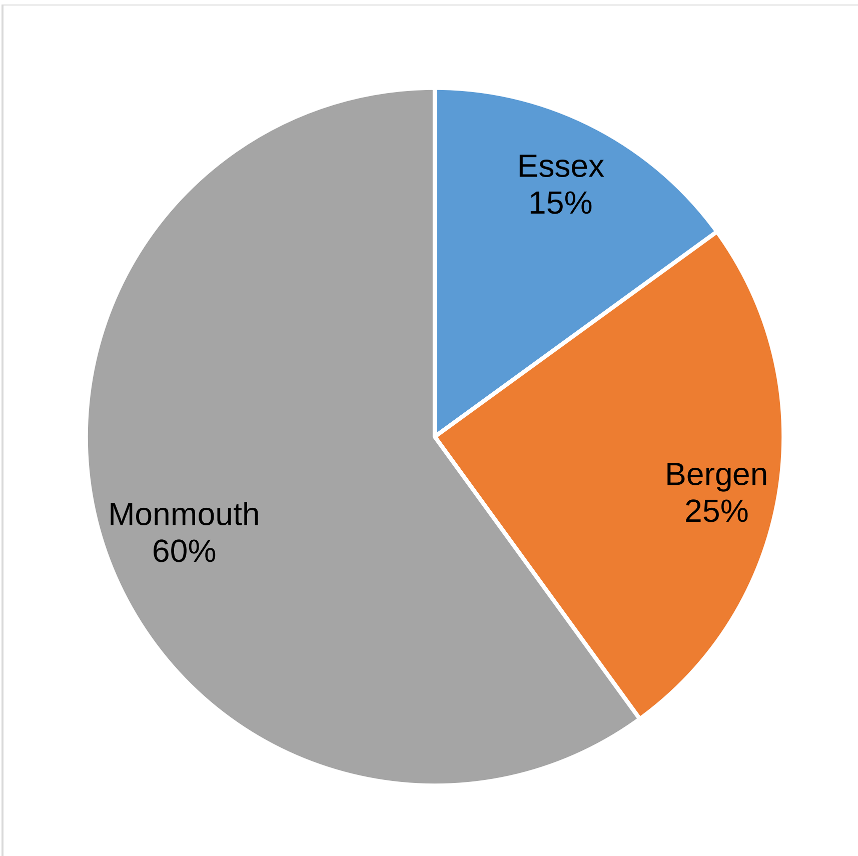

Figure 2. County Breakdown of Final Top 20

A breakdown of the selected crossings by NJT line can be seen in Figure 3. The crossings operate on the North Jersey Coast Line (60%), Pascack Valley Line (20%), Montclair Line (15%), and Bergen County Line (5%).

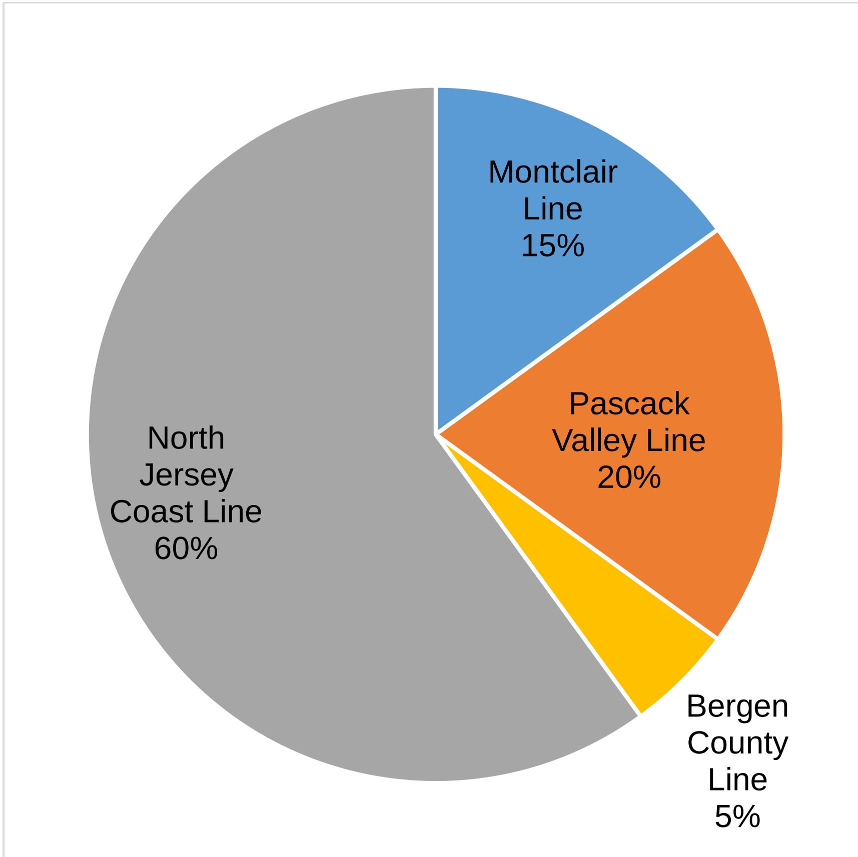

Figure 3. NJT Line Breakdown of Final Top 20

Table 8 - Top 20 Crossings for Closure

Rank	Crossing ID	Line Name	Roadway Name	Town	County
1	263229H	Montclair Line	Walnut St	Montclair	Essex
2	263025W*	Pascack Valley Line	Orchard St	Hillsdale	Bergen
3	263418E	Bergen County Line	Hobart Place	Garfield	Bergen
4	856967N*	North Jersey Coast Line	Church St	Spring Lake	Monmouth
5	263046P	Pascack Valley Line	Euclid Ave	Hackensack	Bergen
6	856936P*	North Jersey Coast Line	Fifth Ave	Asbury Park	Monmouth
7	856934B	North Jersey Coast Line	Sixth Ave	Asbury Park	Monmouth
8	856962E*	North Jersey Coast Line	Thirteenth Ave	Belmar	Monmouth
9	856956B	North Jersey Coast Line	Evergreen Ave	Bradley Beach	Monmouth
10	856941L	North Jersey Coast Line	First Ave	Asbury Park	Monmouth
11	266882G	Montclair Line	Jerome Place	Montclair	Essex
12	856969C	North Jersey Coast Line	St. Clair Ave	Spring Lake	Monmouth
13	263029Y	Pascack Valley Line	Irvington St	Westwood	Bergen

* Meets all three federal criteria of more than four crossings per railroad route-mile, fewer than 2000 vehicles per day, and more than two trains per day

Rank	Crossing ID	Line Name	Roadway Name	Town	County
14	856897B	North Jersey Coast Line	Chestnut St	Red Bank	Monmouth
15	263028S	Pascack Valley Line	Industrial Rd	Westwood	Bergen
16	856964T*	North Jersey Coast Line	Seventeenth Ave	Belmar	Monmouth
17	263227U	Montclair Line	Claremont Ave	Montclair	Essex
18	856923N	North Jersey Coast Line	Roosevelt Ave	Deal	Monmouth
19	856975F*	North Jersey Coast Line	Shore Rd	Spring Lake	Monmouth
20	856957H*	North Jersey Coast Line	Seventh Ave	Belmar	Monmouth

* Meets all three federal criteria of more than four crossings per railroad route-mile, fewer than 2000 vehicles per day, and more than two trains per day

7.0 FUTURE STUDIES

This methodology is intended to filter many crossings and narrow a selected list down to twenty. This is the first step in selecting and investigating crossings with greater detail to determine if the closure is possible and correct. The following is a preliminary list of actions that could be undertaken to further study and prepare evidence for grade crossing closure. This list is preliminary and not exhaustive.

- Detailed traffic study to show different classes (pedestrian, truck, car, etc.)
- Traffic networking study to determine if alternate routes can accommodate new traffic flow.
- ADA study to determine if alternate crossings need to be upgraded to accommodate disabled persons.
- Trespassing and grade crossing violation study to understand how many near misses and violations are occurring.

Ongoing efforts continue to capture updated data for each of the subject crossings identified by this study. For example, detailed traffic information was collected for Shore Road on August 17, 2022, seen below.

- 542 motor vehicles
- 104 bicycles
- 60 pedestrians

Additionally, detailed traffic information was collected for Seventh Avenue on July 27th, 2022, seen below

- 1372 motor vehicles
- 123 bicycles
- 216 pedestrians

8.0 BIBLIOGRAPHY

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APPENDIX A LIST OF TOP 20 CROSSINGS FOR CLOSURE

Table 9 - Appendix Top 20 Crossings for Closure

Rank	Crossing ID	Line Name	Roadway Name	Town	County
1	263229H	Montclair Line	Walnut St	Montclair	Essex
2	263025W*	Pascack Valley Line	Orchard St	Hillsdale	Bergen
3	263418E	Bergen County Line	Hobart Place	Garfield	Bergen
4	856967N*	North Jersey Coast Line	Church St	Spring Lake	Monmouth
5	263046P	Pascack Valley Line	Euclid Ave	Hackensack	Bergen
6	856936P*	North Jersey Coast Line	Fifth Ave	Asbury Park	Monmouth
7	856934B	North Jersey Coast Line	Sixth Ave	Asbury Park	Monmouth
8	856962E*	North Jersey Coast Line	Thirteenth Ave	Belmar	Monmouth
9	856956B	North Jersey Coast Line	Evergreen Ave	Bradley Beach	Monmouth
10	856941L	North Jersey Coast Line	First Ave	Asbury Park	Monmouth
11	266882G	Montclair Line	Jerome Place	Montclair	Essex
12	856969C	North Jersey Coast Line	St. Clair Ave	Spring Lake	Monmouth

* Meets all three federal criteria of more than four crossings per railroad route-mile, fewer than 2000 vehicles per day, and more than two trains per day

Rank	Crossing ID	Line Name	Roadway Name	Town	County
13	263029Y	Pascack Valley Line	Irvington St	Westwood	Bergen
14	856897B	North Jersey Coast Line	Chestnut St	Red Bank	Monmouth
15	263028S	Pascack Valley Line	Industrial Rd	Westwood	Bergen
16	856964T*	North Jersey Coast Line	Seventeenth Ave	Belmar	Monmouth
17	263227U	Montclair Line	Claremont Ave	Montclair	Essex
18	856923N	North Jersey Coast Line	Roosevelt Ave	Deal	Monmouth
19	856975F*	North Jersey Coast Line	Shore Rd	Spring Lake	Monmouth
20	856957H*	North Jersey Coast Line	Seventh Ave	Belmar	Monmouth

* Meets all three federal criteria of more than four crossings per railroad route-mile, fewer than 2000 vehicles per day, and more than two trains per day

APPENDIX B DETAILED INFORMATION FOR TOP 20 CROSSINGS

As stated in the Method section, we collected the required variables of candidate crossings and rank crossings based on AHP. Below are the characteristics of the top 20 crossings and corresponding maps to the crossings.

Rank 1: 263229H Walnut Street, Montclair

Table 10 - Characteristics of Crossing 263229H Walnut Street, Montclair

Variable	Value
Crashes	0
AADT	8976
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	65
Train Speed Category	M
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Skewed
Alternate Route Distance (mi)	0.04 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	0.45 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.76 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.84 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.46 Miles
Signal and Surface Upgrades	2011
Length of the Crossings Street	0.99 Miles

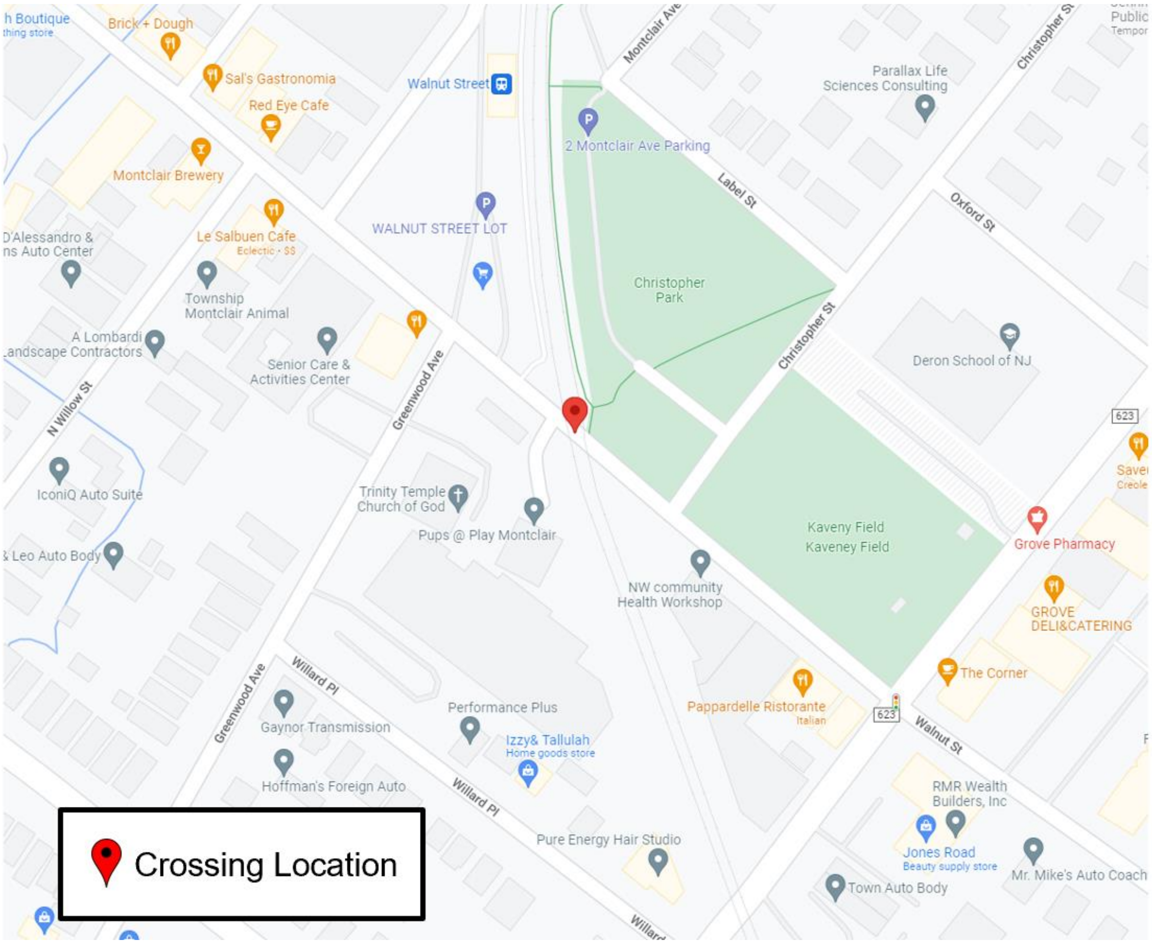

Figure 4. Maps of Crossing 263229H Walnut Street, Montclair

Rank 2: 263025W Orchard Street, Hillsdale

Table 11 - Characteristics of Crossing 263025W Orchard Street, Hillsdale

Variable	Value
Crashes	0
AADT	1802
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	41
Train Speed Category	M
Number of Tracks	1
Station Adjacent	No
Crossing Angle	Skewed
Alternate Route Distance (mi)	0.1 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	2.46 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.27 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.26 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.49 Miles
Signal and Surface Upgrades	2019
Length of the Crossings Street	0.21 Miles

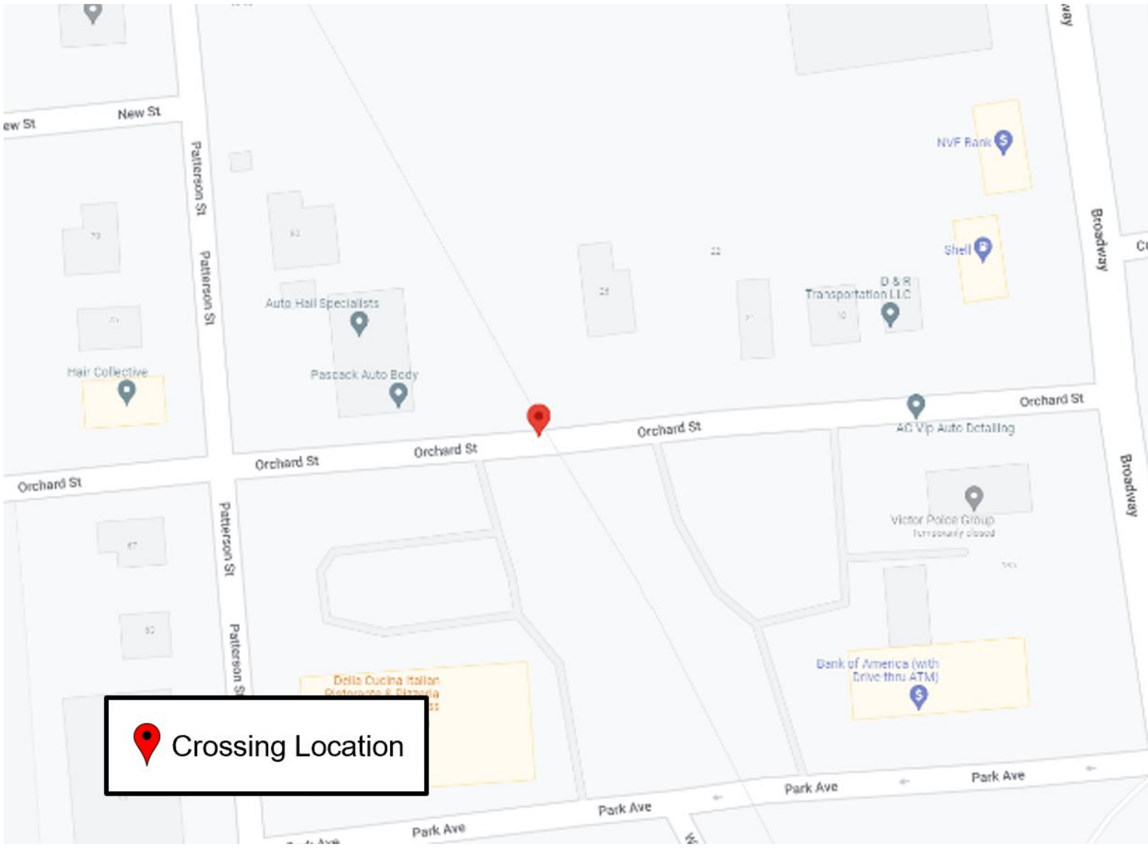

Figure 5. Maps of Crossing 263025W Orchard Street, Hillsdale

Rank 3: 263418E Hobart Place, Garfield

Table 12 - Characteristics of Crossing 263418E Hobart Place, Garfield

Variable	Value
Crashes	2
AADT	2628
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	46
Train Speed Category	M
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Skewed
Alternate Route Distance (mi)	0.25 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	2.20 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.39 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	1.06 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.22 Miles
Signal and Surface Upgrades	2014
Length of the Crossings Street	0.2 Miles

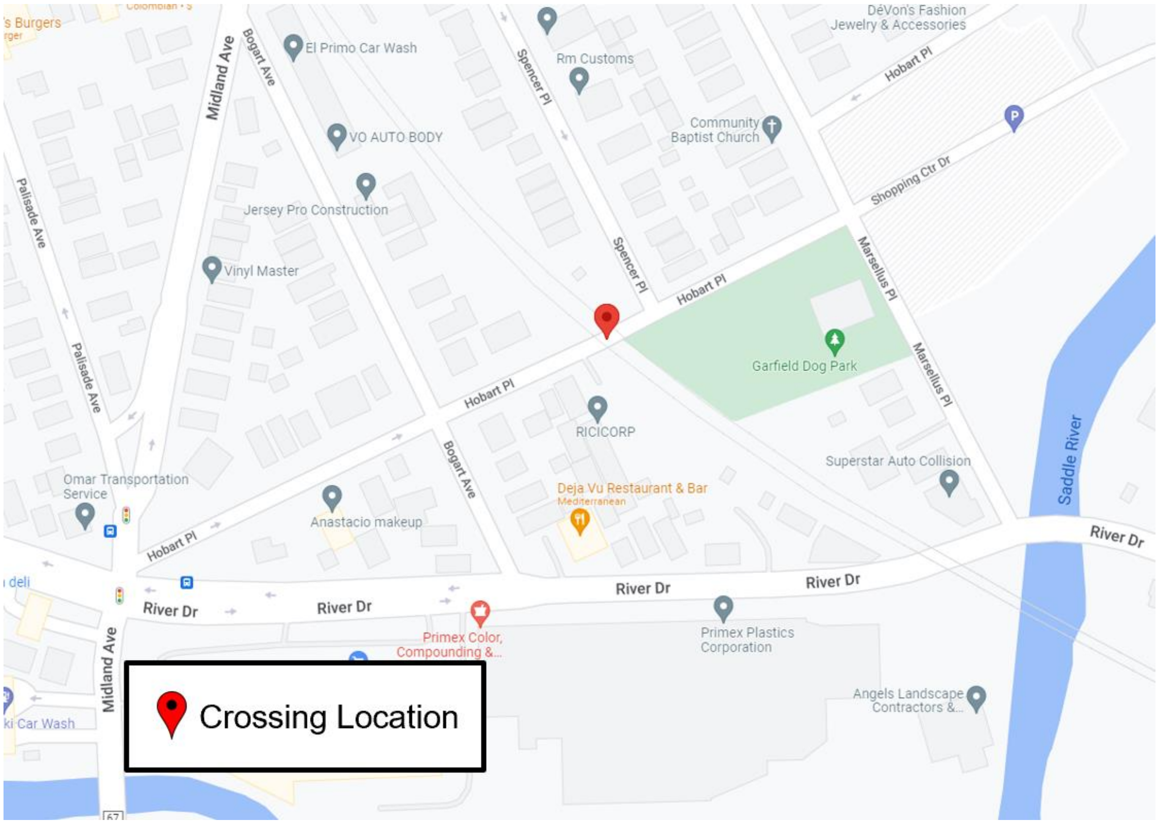

Figure 6. Maps of Crossing 263418E Hobart Place, Garfield

Rank 4: 856967N Church Street, Spring Lake

Table 13 - Characteristics of Crossing 856967N Church Street, Spring Lake

Variable	Value
Crashes	0
AADT	1472
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	36
Train Speed Category	M
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Skewed
Alternate Route Distance (mi)	0.25 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	4.27 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.58 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.54 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.36 Miles
Signal and Surface Upgrades	1999
Length of the Crossings Street	0.36 Miles

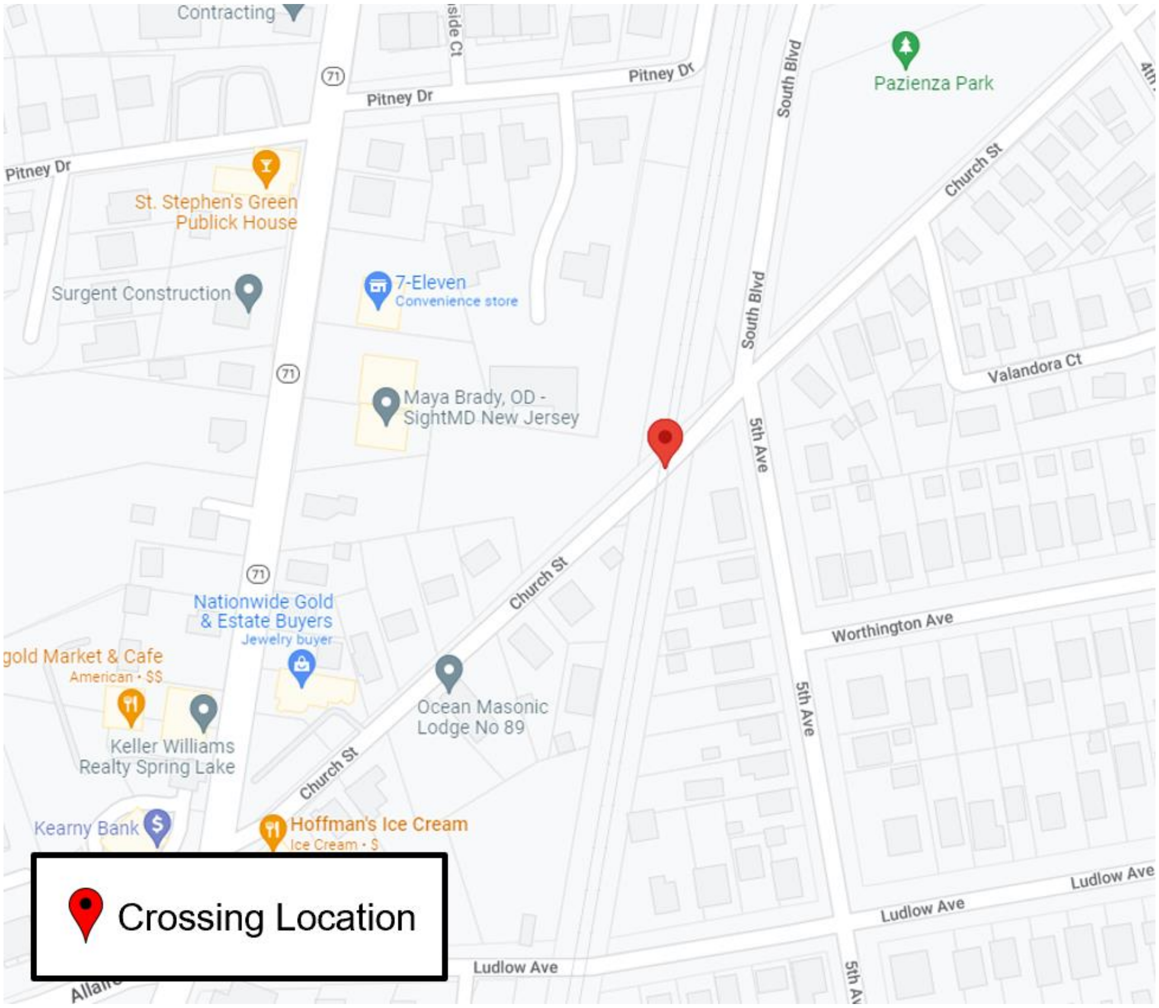

Figure 7. Maps of Crossing 856967N Church Street, Spring Lake

Rank 5: 263046P Euclid Ave, Hackensack

Table 14 - Characteristics of Crossing 263046P Euclid Ave, Hackensack

Variable	Value
Crashes	2
AADT	4080
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	41
Train Speed Category	L
Number of Tracks	1
Station Adjacent	No
Crossing Angle	Skewed
Alternate Route Distance (mi)	0.14 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	2.26 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.57 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.83 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.31 Miles
Signal and Surface Upgrades	NA
Length of the Crossings Street	0.75 Miles

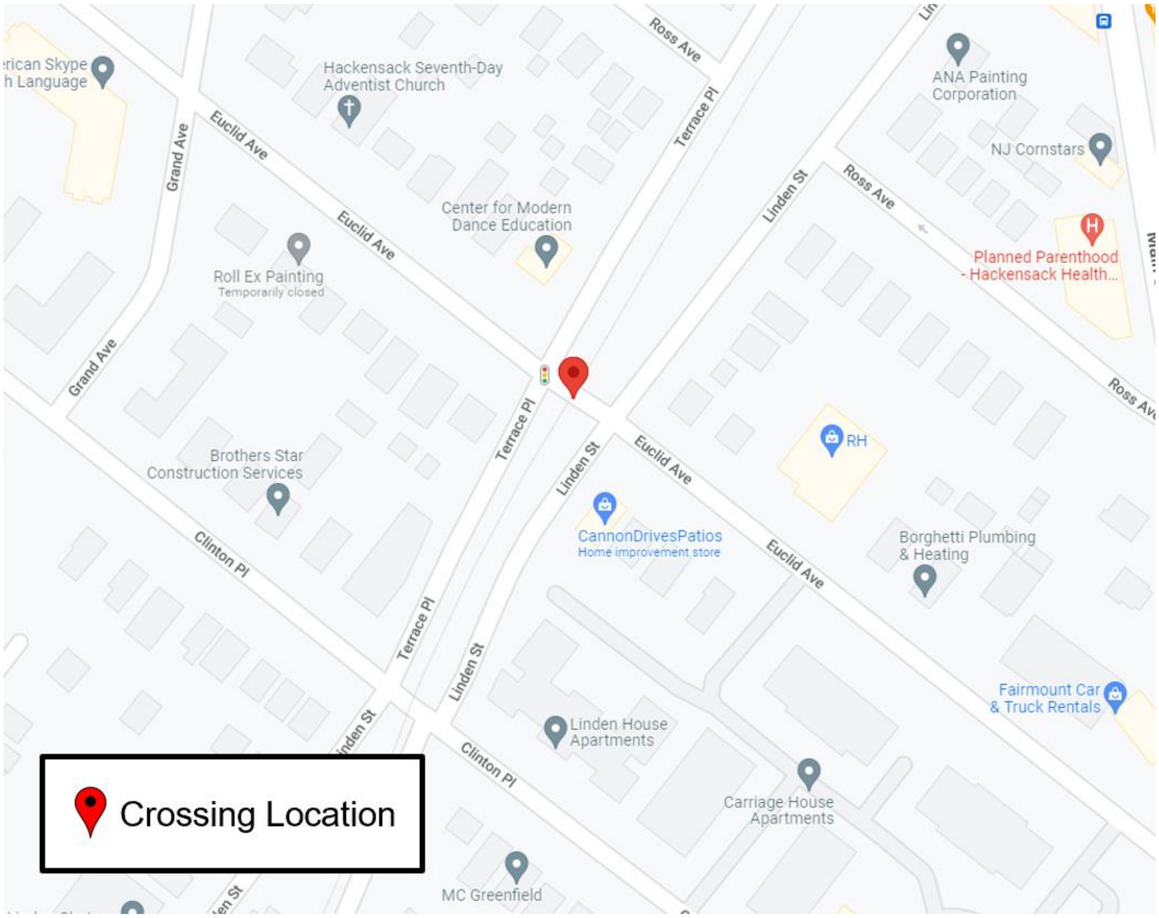

Figure 8. Maps of Crossing 263046P Euclid Ave, Hackensack

Rank 6: 856936P Fifth Ave, Asbury Park

Table 15 - Characteristics of Crossing 856936P Fifth Ave, Asbury Park

Variable	Value
Crashes	0
AADT	1376
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	36
Train Speed Category	L
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Perpendicular
Alternate Route Distance (mi)	0.15 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	2.61 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.45 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.66 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.23 Miles
Signal and Surface Upgrades	2002
Length of the Crossings Street	1.12 Miles

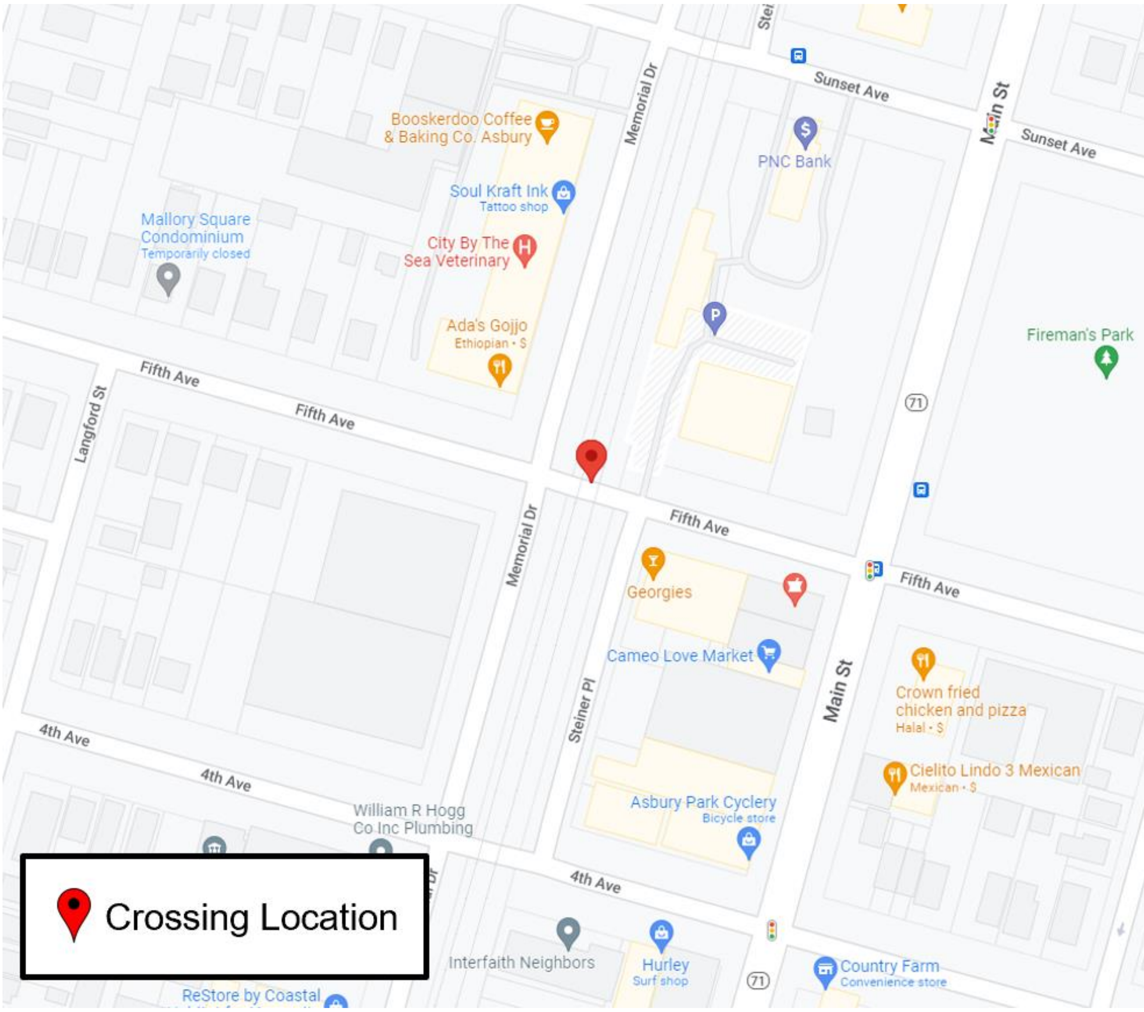

Figure 9. Maps of Crossing 856936P Fifth Ave, Asbury Park

Rank 7: 856934B Sixth Ave, Asbury Park

Table 16 - Characteristics of Crossing 856934B Sixth Ave, Asbury Park

Variable	Value
Crashes	0
AADT	2144
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	36
Train Speed Category	L
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Perpendicular
Alternate Route Distance (mi)	0.15 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	2.78 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.52 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.50 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.19 Miles
Signal and Surface Upgrades	2013
Length of the Crossings Street	0.58 Miles

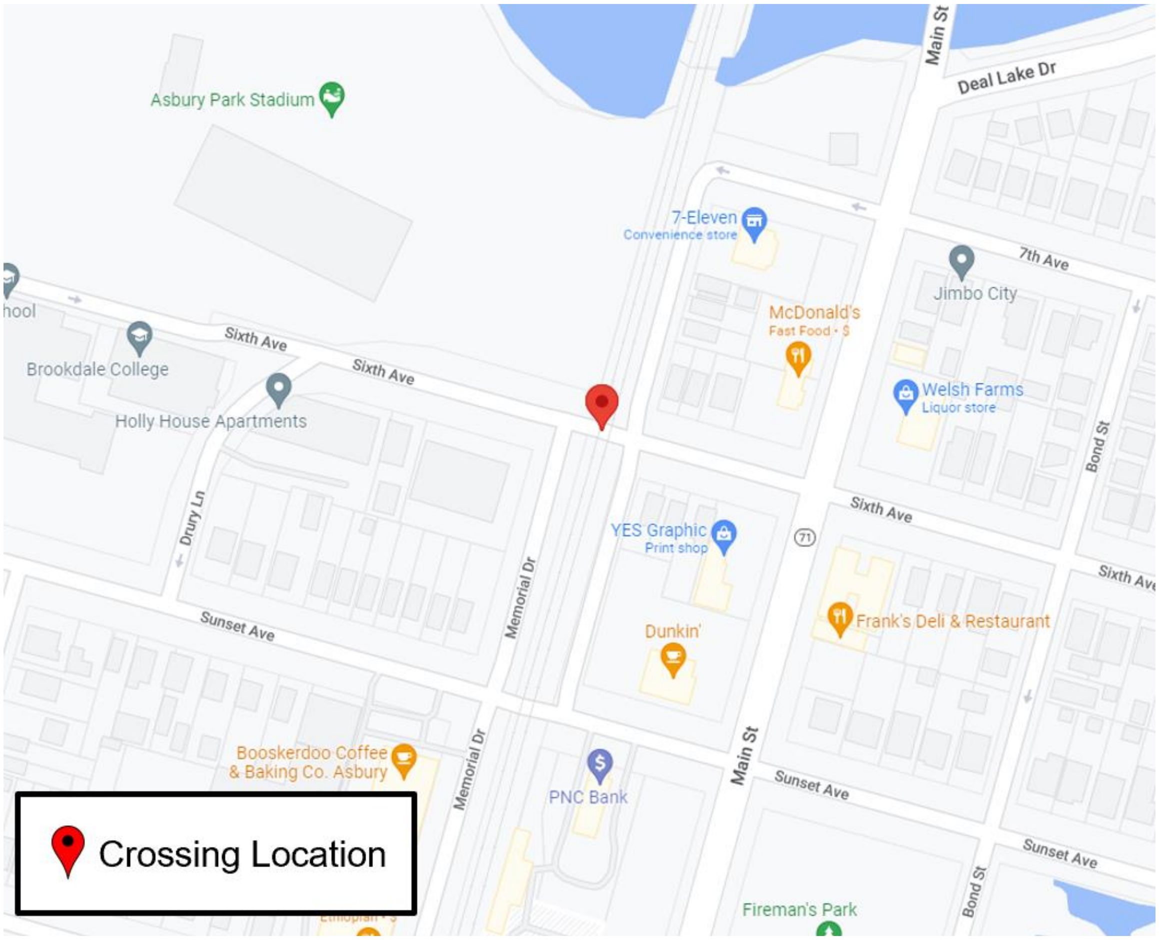

Figure 10. Maps of Crossing 856934B Sixth Ave, Asbury Park

Rank 8: 856962E Thirteenth Ave, Belmar

Table 17 - Characteristics of Crossing 856962E Thirteenth Ave, Belmar

Variable	Value
Crashes	0
AADT	1936
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	36
Train Speed Category	M
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Perpendicular
Alternate Route Distance (mi)	0.24 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	2.98 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.29 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.45 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.18 Miles
Signal and Surface Upgrades	1997
Length of the Crossings Street	1.07 Miles

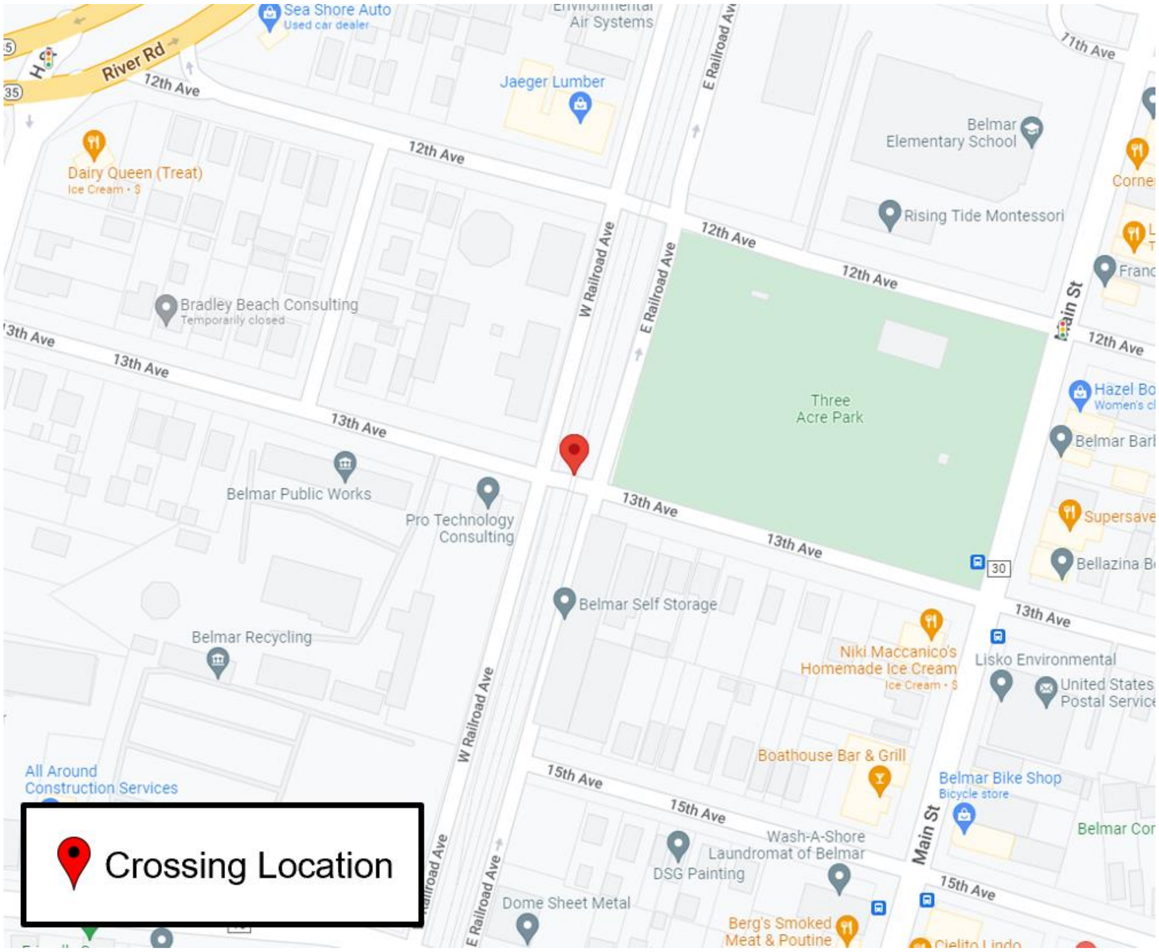

Figure 11. Maps of Crossing 856962E Thirteenth Ave, Belmar

Rank 9: 856956B Evergreen Ave, Bradley Beach

Table 18 - Characteristics of Crossing 856956B Evergreen Ave, Bradley Beach

Variable	Value
Crashes	5
AADT	4682
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	36
Train Speed Category	L
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Skewed
Alternate Route Distance (mi)	0.3 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	1.63 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.58 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.42 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.48 Miles
Signal and Surface Upgrades	2014, 2017
Length of the Crossings Street	0.96 Miles

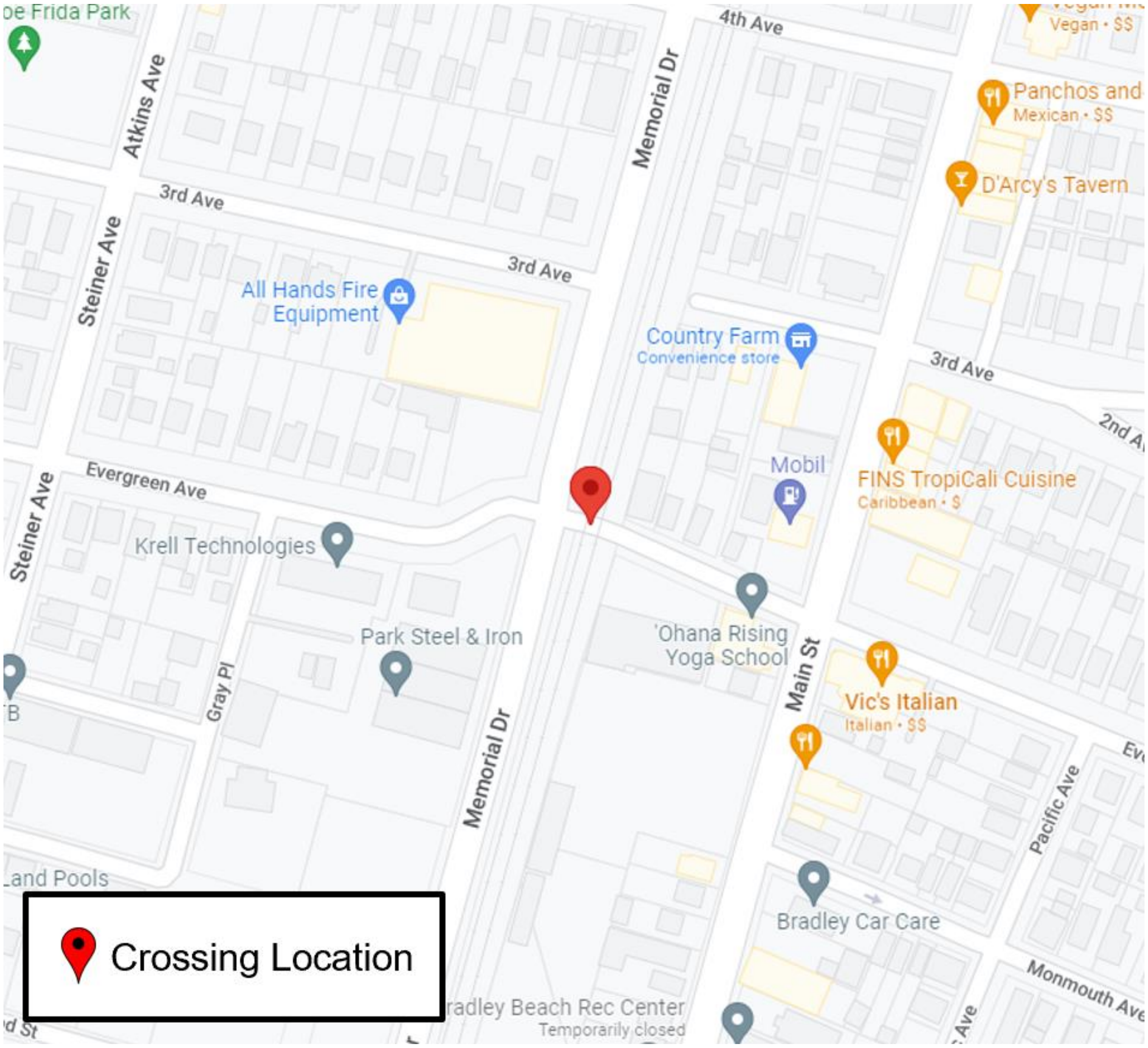

Figure 12. Maps of Crossing 856956B Evergreen Ave, Bradley Beach

Rank 10: 856941L First Ave, Asbury Park

Table 19 - Characteristics of Crossing 856941L First Ave, Asbury Park

Variable	Value
Crashes	1
AADT	2015
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	36
Train Speed Category	L
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Perpendicular
Alternate Route Distance (mi)	0.22 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	2.20 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.15 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.44 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.33 Miles
Signal and Surface Upgrades	1985
Length of the Crossings Street	0.92 Miles

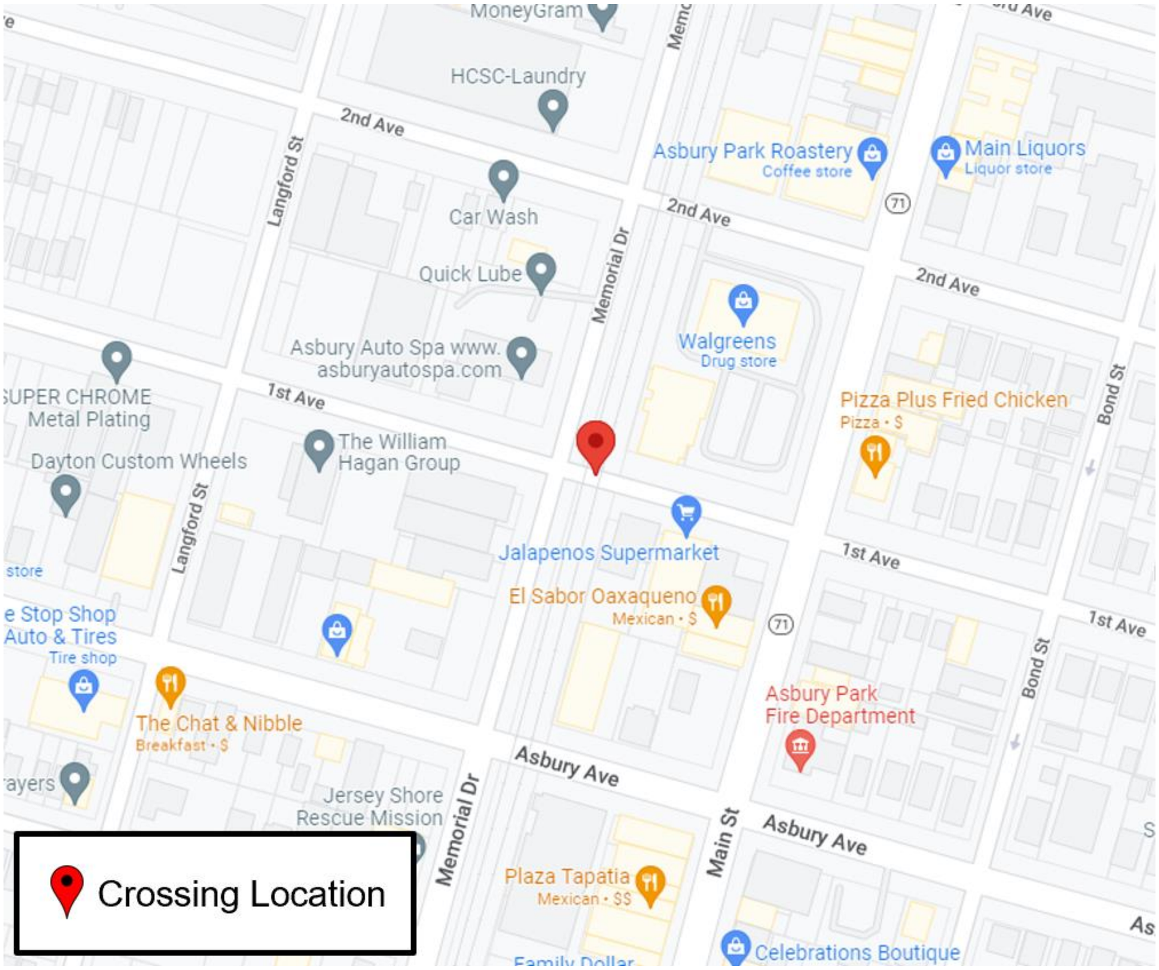

Figure 13. Maps of Crossing 856941L First Ave, Asbury Park

Rank 11: 266882G Jerome Place, Montclair

Table 20 - Characteristics of Crossing 266882G Jerome Place, Montclair

Variable	Value
Crashes	2
AADT	2496
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	65
Train Speed Category	L
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Perpendicular
Alternate Route Distance (mi)	0.34 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	2.97 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.38 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	1.39 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.53 Miles
Signal and Surface Upgrades	2020
Length of the Crossings Street	0.14 Miles

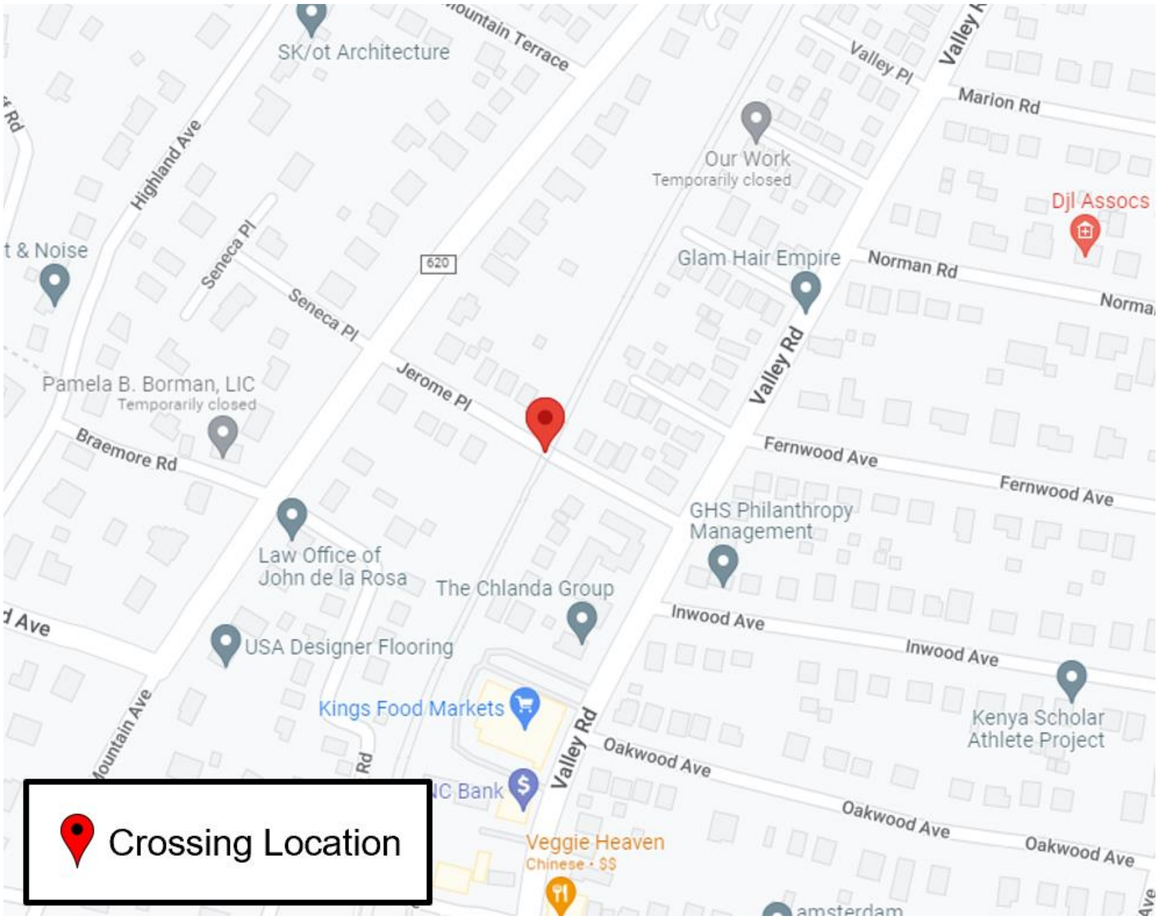

Figure 14. Maps of Crossing 266882G Jerome Place, Montclair

Rank 12: 856969C St. Claire Ave, Spring Lake

Table 21 - Characteristics of Crossing 856969C St. Claire Ave, Spring Lake

Variable	Value
Crashes	0
AADT	3846
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	36
Train Speed Category	M
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Skewed
Alternate Route Distance (mi)	0.39 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	4.50 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.39 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.18 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.26 Miles
Signal and Surface Upgrades	1999
Length of the Crossings Street	0.85 Miles

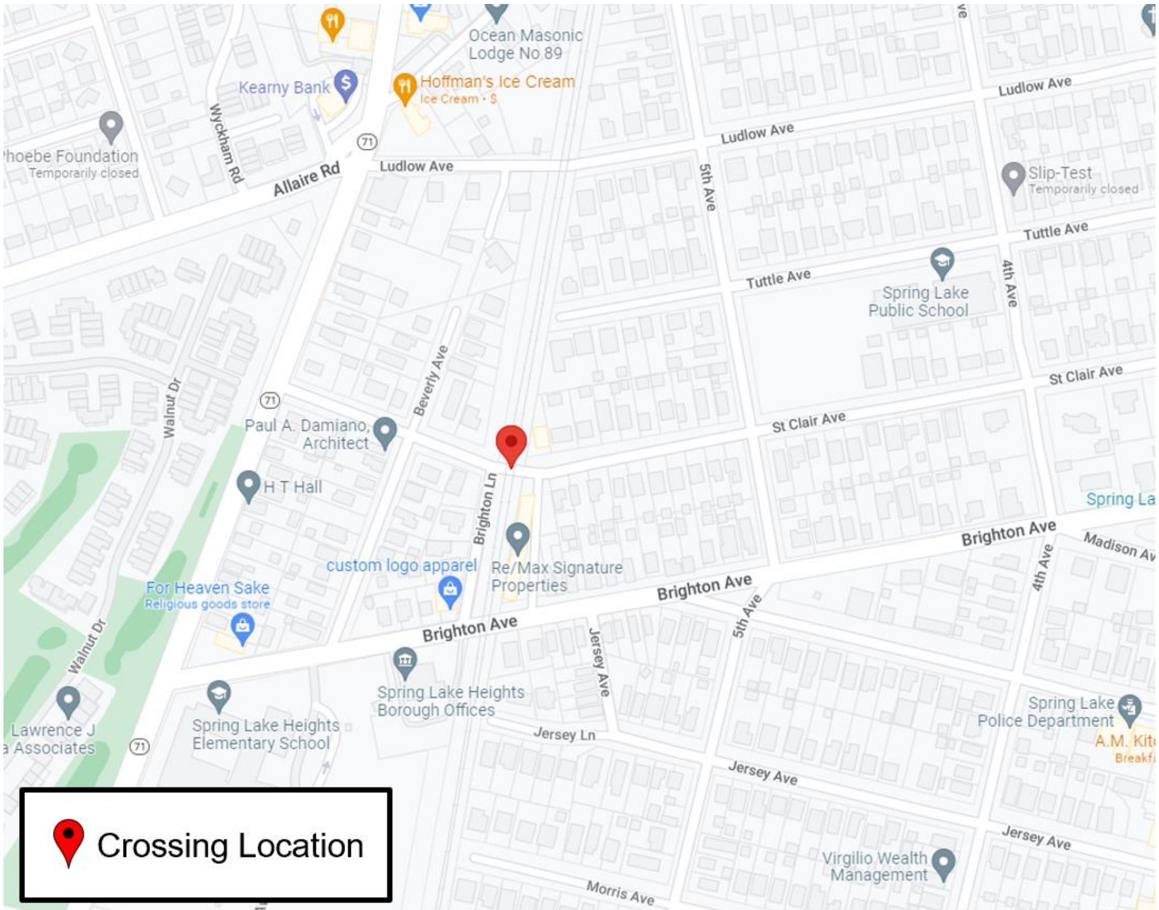

Figure 15. Maps of Crossing 856969C St. Claire Ave, Spring Lake

Rank 13: 263029Y Irvington Street, Westwood

Table 22 - Characteristics of Crossing 263029Y Irvington Street, Westwood

Variable	Value
Crashes	1
AADT	7032
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	41
Train Speed Category	M
Number of Tracks	1
Station Adjacent	No
Crossing Angle	Perpendicular
Alternate Route Distance (mi)	0.26 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	1.55 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.39 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.22 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.61 Miles
Signal and Surface Upgrades	2013
Length of the Crossings Street	0.34 Miles

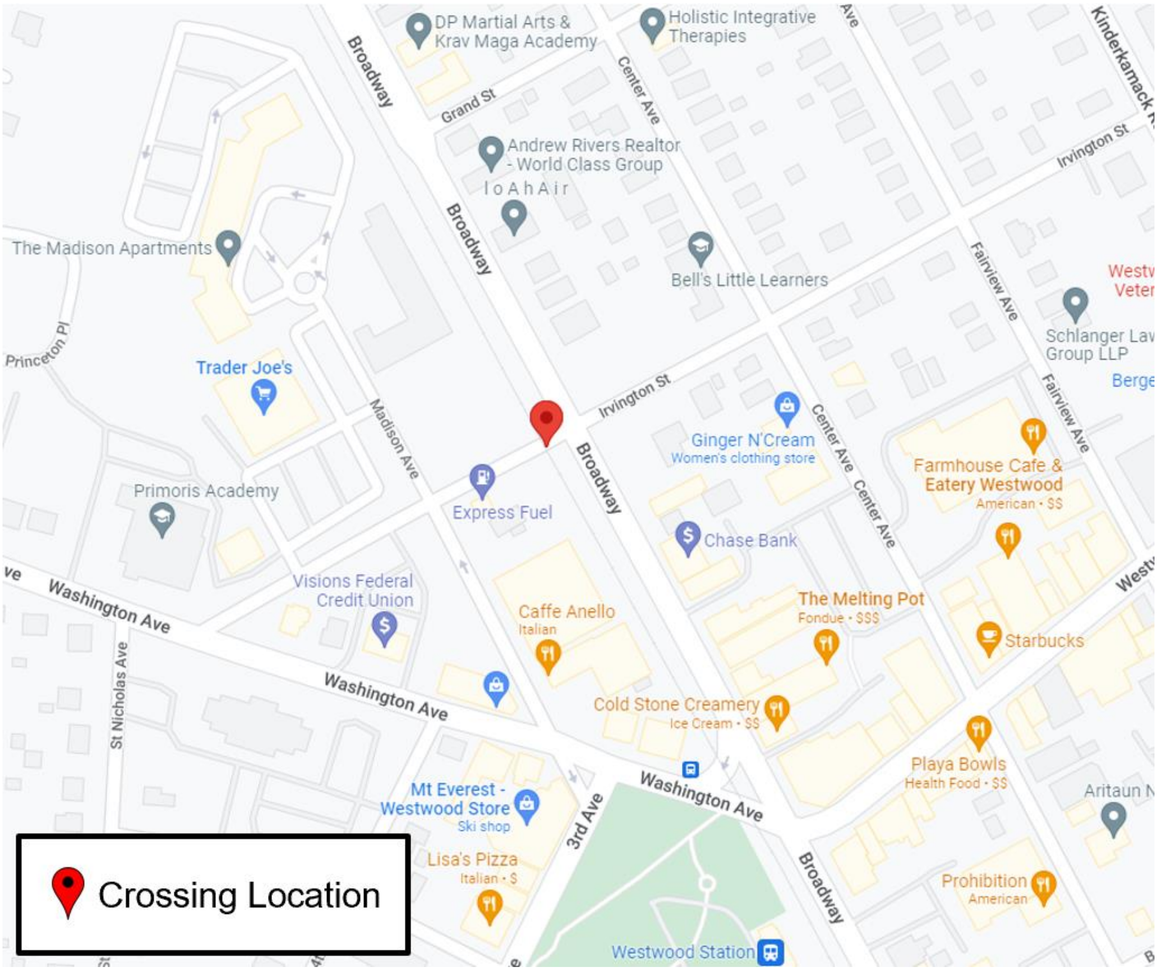

Figure 16. Maps of Crossing 263029Y Irvington Street, Westwood

Rank 14: 856897B Chestnut Street, Red Bank

Table 23 - Characteristics of Crossing 856897B Chestnut Street, Red Bank

Variable	Value
Crashes	1
AADT	7486
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	36
Train Speed Category	M
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Skewed
Alternate Route Distance (mi)	0.45 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	1 Mile
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.26 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.34 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.16 Miles
Signal and Surface Upgrades	2020
Length of the Crossings Street	0.40 Miles

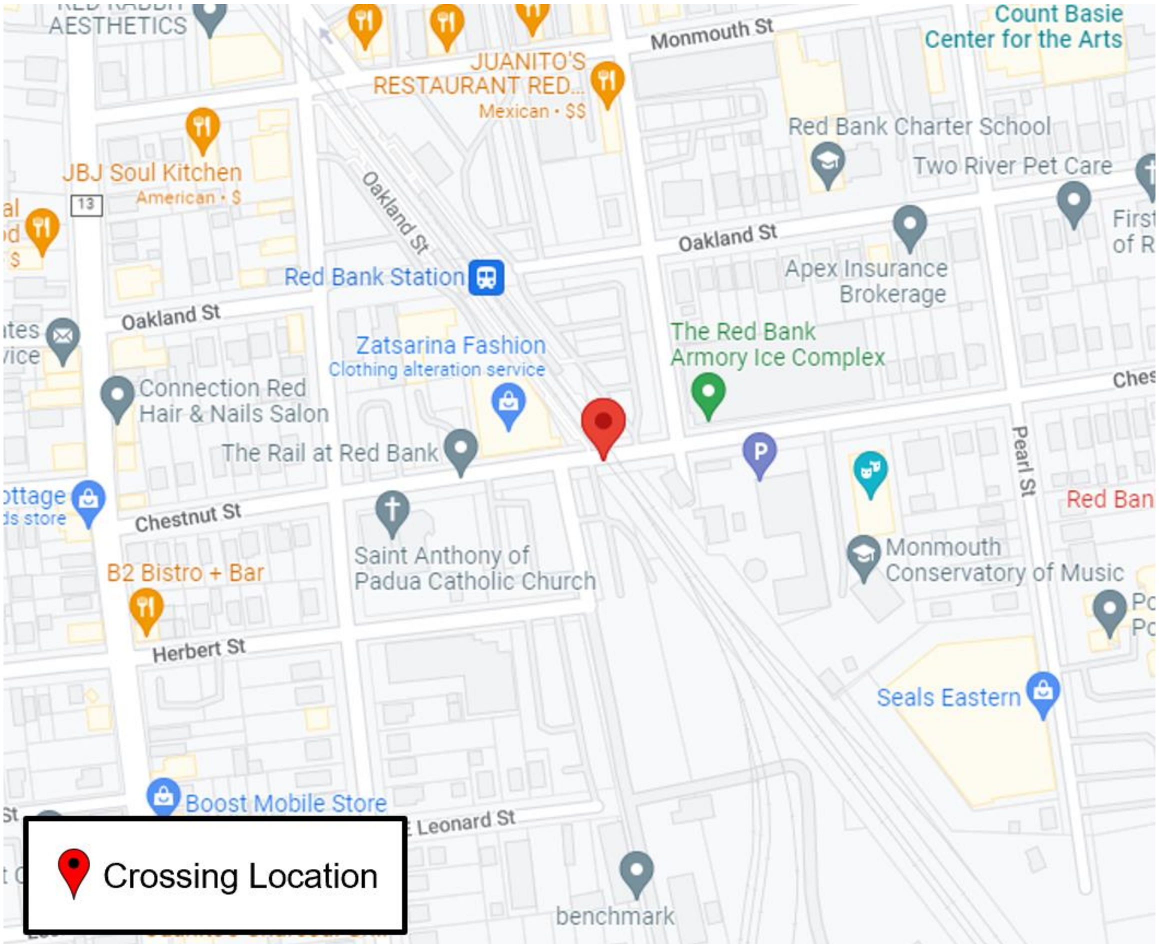

Figure 17. Maps of Crossing 856897B Chestnut Street, Red Bank

Rank 15: 263028S Industrial Road, Westwood

Table 24 - Characteristics of Crossing 263028S Industrial Road, Westwood

Variable	Value
Crashes	1
AADT	3624
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	41
Train Speed Category	M
Number of Tracks	1
Station Adjacent	No
Crossing Angle	Perpendicular
Alternate Route Distance (mi)	0.46 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	1.97 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.41 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.45 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.55 Miles
Signal and Surface Upgrades	NA
Length of the Crossings Street	0.02 Miles

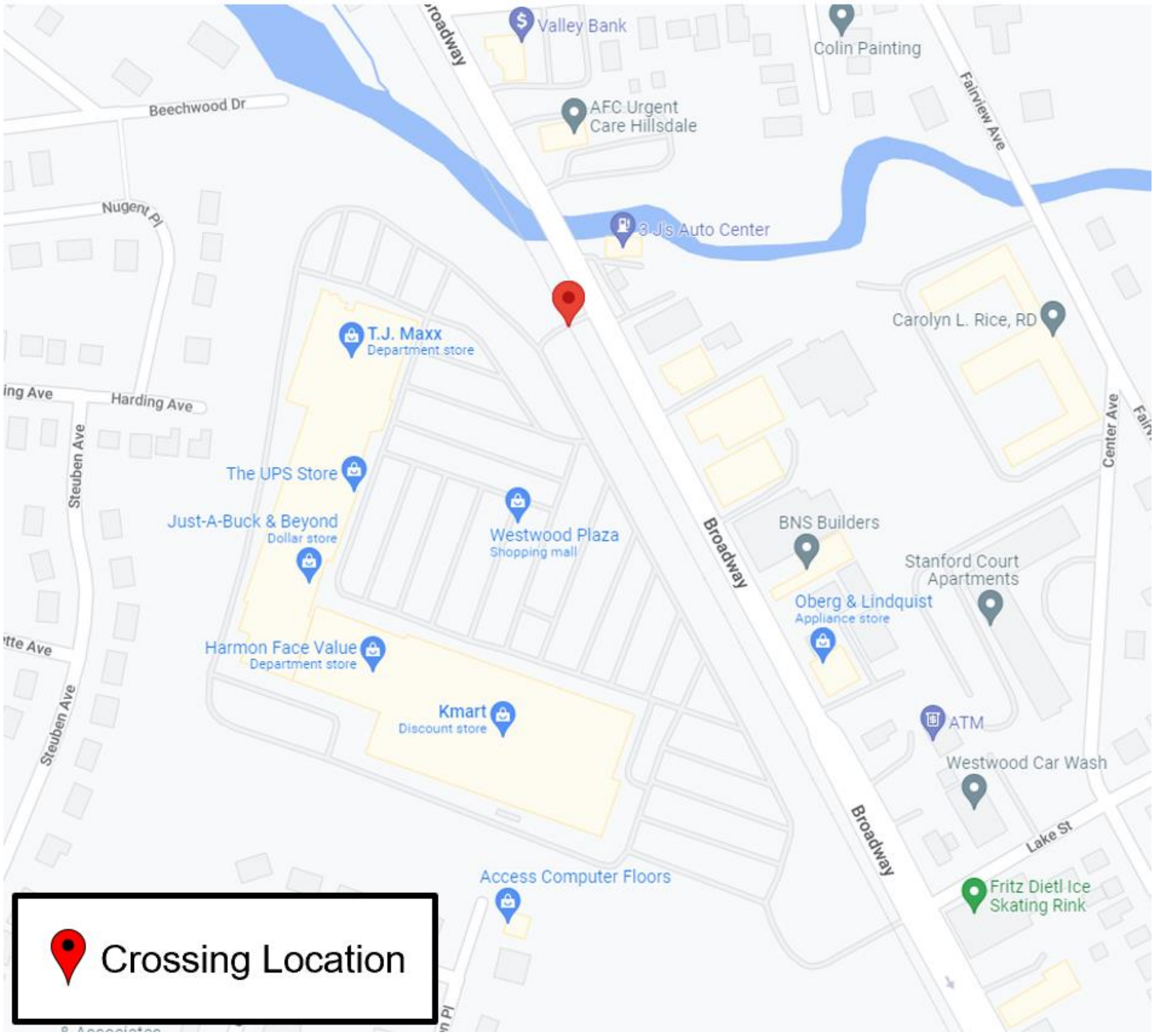

Figure 18. Maps of Crossing 263028S Industrial Road, Westwood

Rank 16: 856964T Seventeenth Ave, Belmar

Table 25 - Characteristics of Crossing 856964T Seventeenth Ave, Belmar

Variable	Value
Crashes	NA
AADT	1456
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	36
Train Speed Category	M
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Skewed
Alternate Route Distance (mi)	0.55 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	3.39 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.27 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.27 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.27 Miles
Signal and Surface Upgrades	2000
Length of the Crossings Street	1.61 Miles

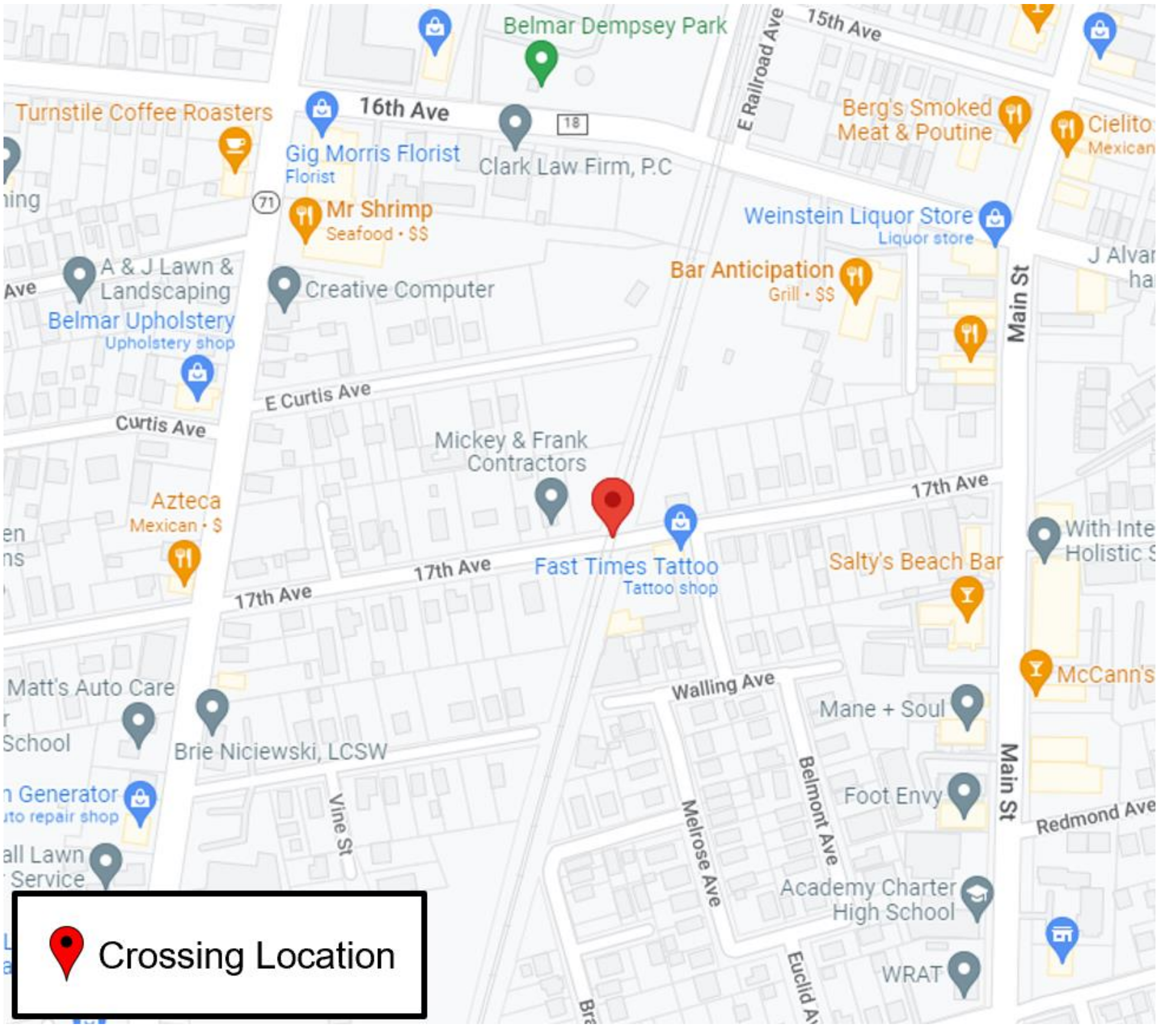

Figure 19. Maps of Crossing 856964T Seventeenth Ave, Belmar

Rank 17: 263227U Claremont Ave, Montclair

Table 26 - Characteristics of Crossing 263227U Claremont Ave, Montclair

Variable	Value
Crashes	3
AADT	14304
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	65
Train Speed Category	L
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Skewed
Alternate Route Distance (mi)	0.48 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	0.25 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.44 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.90 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.49 Miles
Signal and Surface Upgrades	2018
Length of the Crossings Street	1.50 Miles

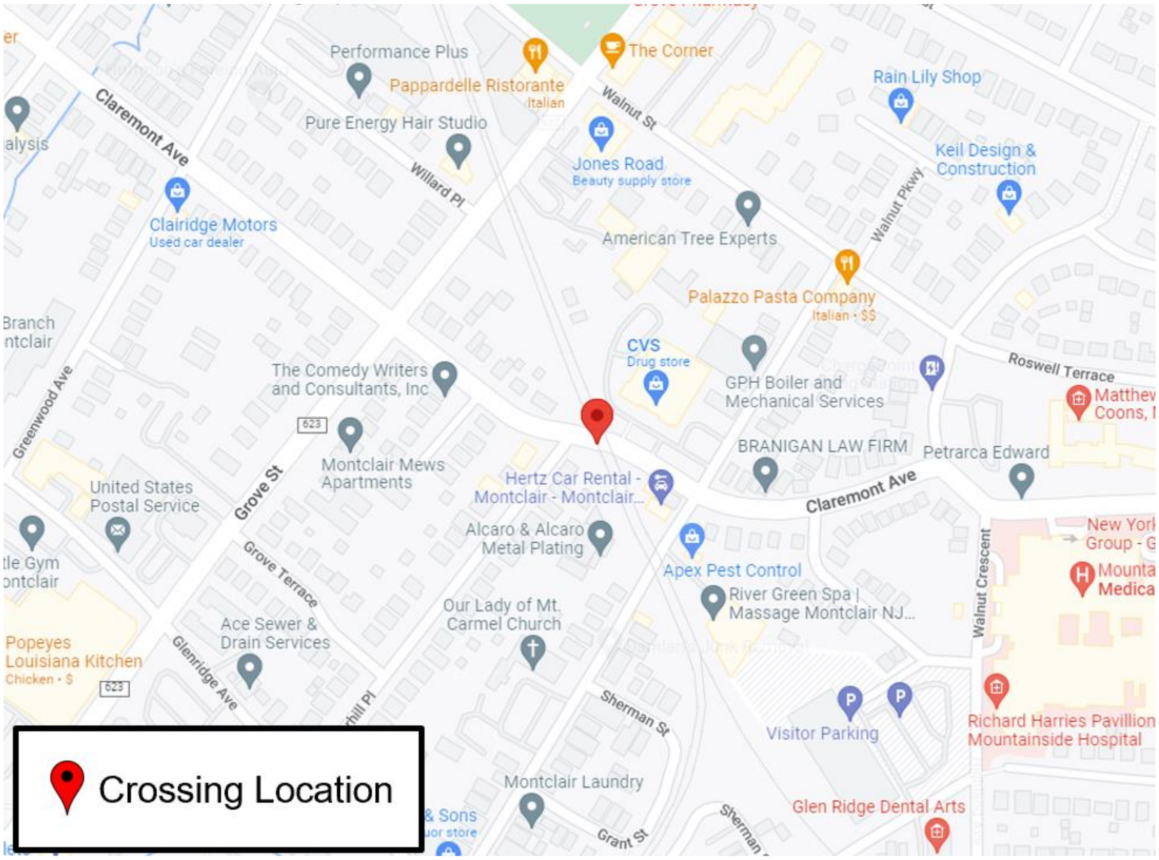

Figure 20. Maps of Crossing 263227U Claremont Ave, Montclair

Rank 18: 856923N Roosevelt Ave, Deal

Table 27 - Characteristics of Crossing 856923N Roosevelt Ave, Deal

Variable	Value
Crashes	2
AADT	5360
Roadway Speed	35
Roadway Lanes	2
Weekday Train Traffic	36
Train Speed Category	L
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Skewed
Alternate Route Distance (mi)	0.54 Miles
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	3.34 Miles
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.61 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	1.03 Miles
Is a School on the Same Street?	No
Distance to Nearest School	1.10 Miles
Signal and Surface Upgrades	2001
Length of the Crossings Street	1.58 Miles

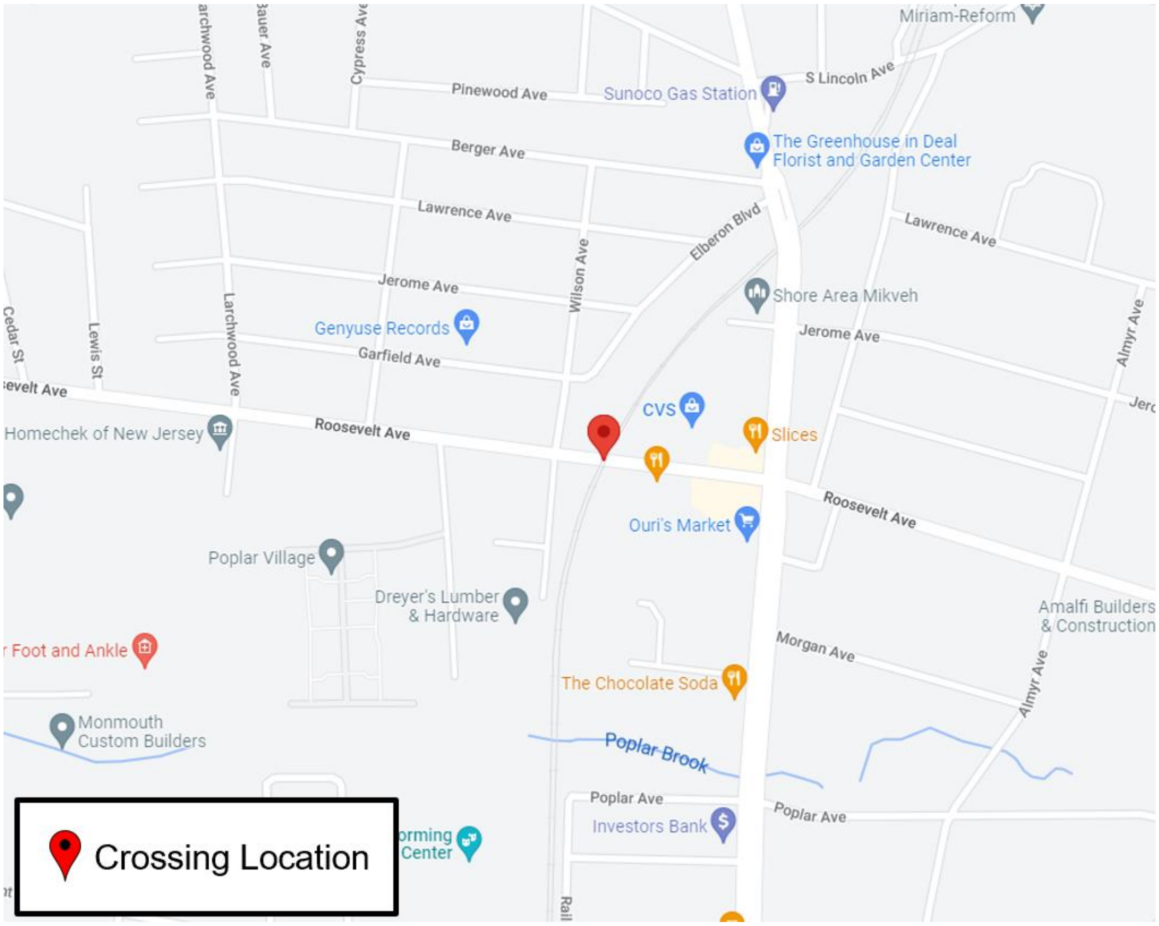

Figure 21. Maps of Crossing 856923N Roosevelt Ave, Deal

Rank 19: 856975F Shore Road, Spring Lake

Table 28 - Characteristics of Crossing 856975F Shore Road, Spring Lake

Variable	Value
Crashes	0
AADT	542
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	36
Train Speed Category	M
Number of Tracks	2
Station Adjacent	No
Crossing Angle	Skewed
Alternate Route Distance (mi)	0.36 Miles
Is the Hospital on the Same Street?	NA
Distance to Nearest Hospital	NA
Is a Fire Station on the Same Street?	No
Nearest Distance to Fire Station	0.92 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	1.04 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.87 Miles
Signal and Surface Upgrades	2001
Length of the Crossings Street	0.47 Miles

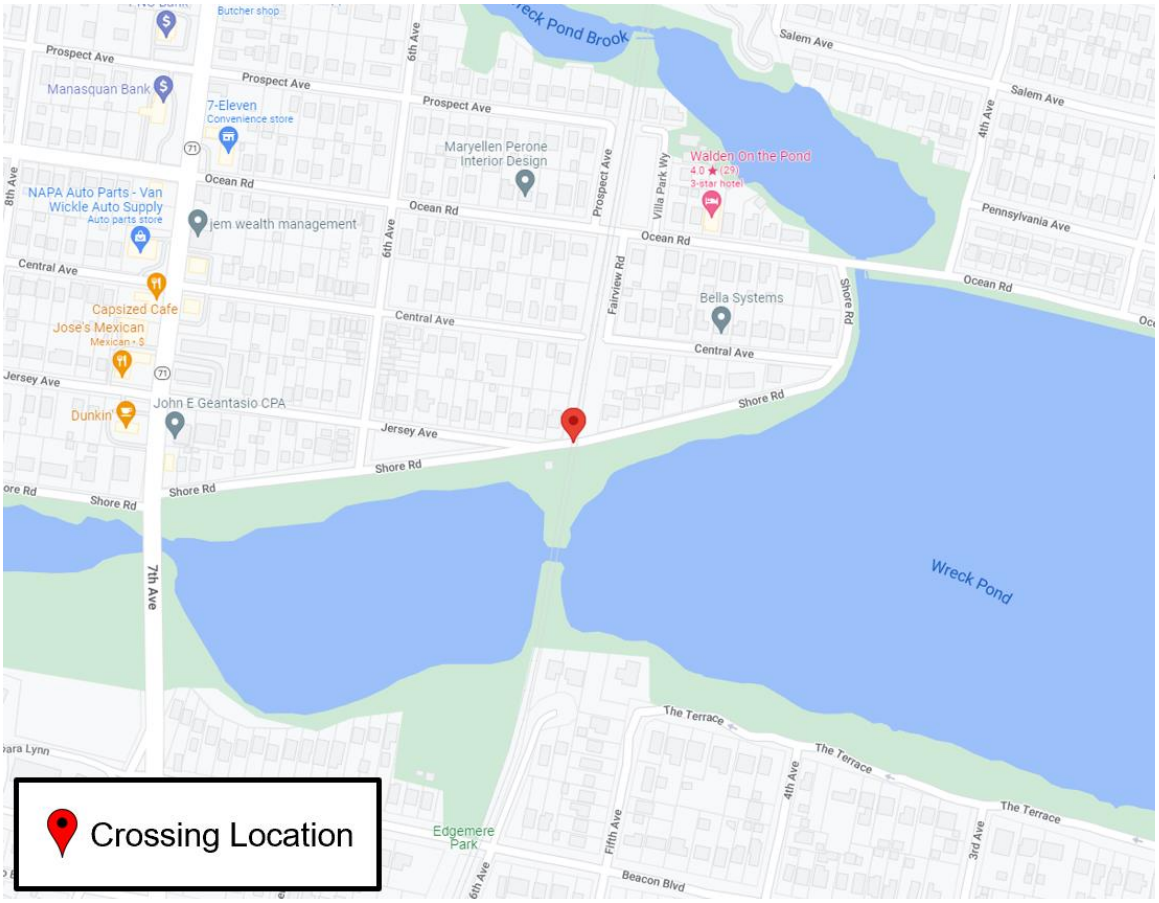

Figure 22. Maps of Crossing 856975F Shore Road, Spring Lake

Rank 20: 856957H Seventh Ave, Belmar

Table 29 - Characteristics of Crossing 856957H Seventh Ave, Belmar

Variable	Value
Crashes	1
AADT	1372
Roadway Speed	25
Roadway Lanes	2
Weekday Train Traffic	36
Train Speed Category	M
Number of Tracks	2
Station Adjacent	FALSE
Crossing Angle	Perpendicular
Alternate Route Distance (mi)	0.22
Is the Hospital on the Same Street?	No
Distance to Nearest Hospital	2.65 Miles
Is a Fire Station on the Same Street?	Yes
Nearest Distance to Fire Station	0.18 Miles
Is a Police Station on the Same Street?	No
Nearest Distance to Police Station	0.14 Miles
Is a School on the Same Street?	No
Distance to Nearest School	0.49 Miles
Signal and Surface Upgrades	2020
Length of the Crossings Street	0.4 Miles

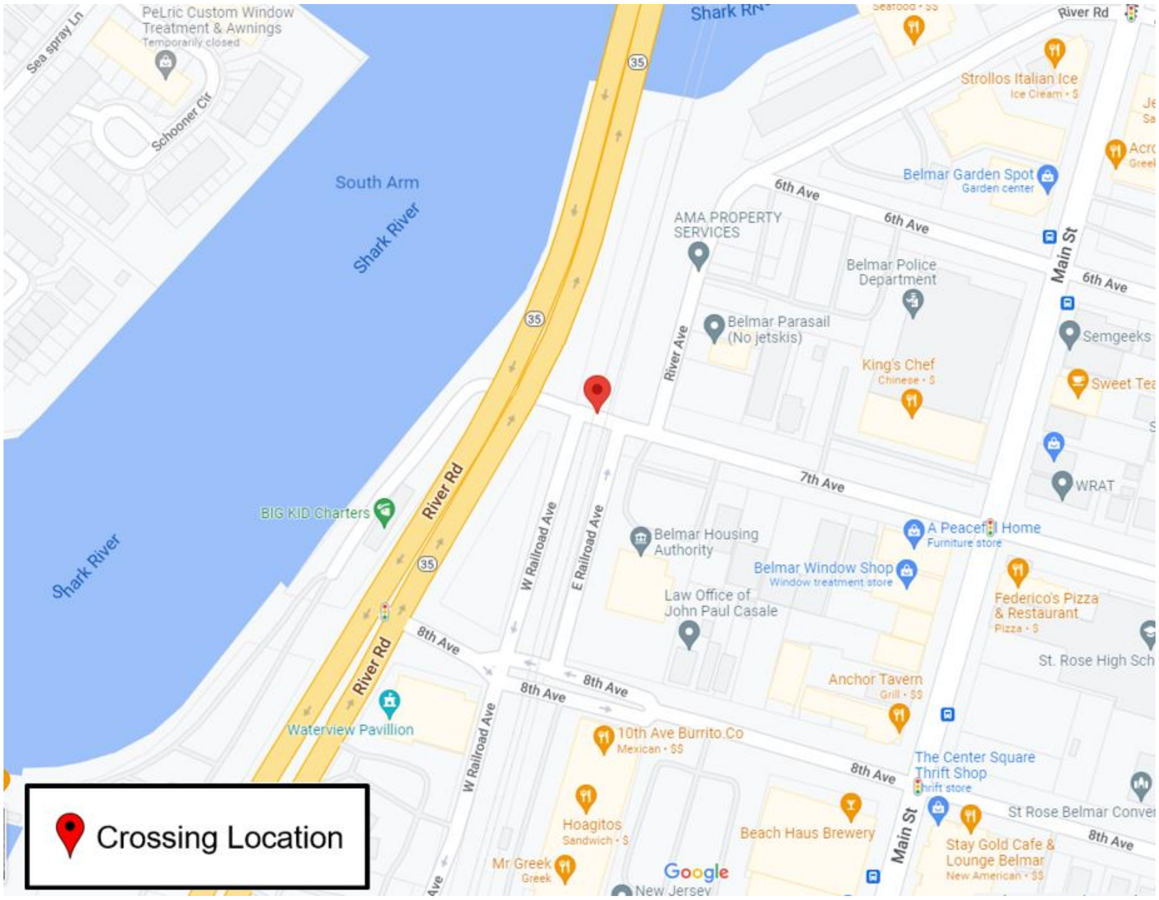

Figure 23. Maps of Crossing 856957H Seventh Ave, Belmar

APPENDIX C NORTH JERSEY COAST LINE RANKINGS

The results of North Jersey Coast Line rankings are shown in the Table 30, show the Coast Line rank, grade crossing ID, line name, milepost, number of tracks, roadway name, roadway type, roadway lanes, town, and county.

Table 30 - Coast Line Rankings

#	Grade Crossing ID	MP	Number of Tracks	Roadway Name	Roadway Type	Lanes	AADT	Town	County
1	856967N	32.1	2	Church St	Local Road	2	1472	Spring Lake	Monmouth
2	856968V	32.3	2	Ludlow Ave	Local Road	2	4368	Spring Lake	Monmouth
3	856936P	27.4	2	Fifth Ave	Local Road	2	1376	Asbury Park	Monmouth
4	856934B	27.3	2	Sixth Ave	Local Road	2	2144	Asbury Park	Monmouth
5	856962E	31.0	2	Thirteenth Ave	Local Road	2	1936	Belmar	Monmouth
6	856937W	27.5	2	Fourth Ave	Local Road	2	3584	Asbury Park	Monmouth
7	856956B	29.3	2	Evergreen Ave	Local Road	2	4682	Bradley Beach	Monmouth
8	856941L	27.7	2	First Ave	Local Road	2	2015	Asbury Park	Monmouth
9	856969C	32.4	2	St. Clair Ave	Local Road	2	3846	Spring Lake	Monmouth
10	856939K	27.6 27.7	2	Second Ave	Local Road	2	1744	Asbury Park	Monmouth
11	856897B	16.6	2	Chestnut St	Local Road	2	7486	Red Bank	Monmouth
12	856961X	30.9	2	Twelfth Ave	Local Road	2	1616	Belmar	Monmouth
13	856963L	31.0	2	Sixteenth Ave	Local Road	2	4288	Belmar	Monmouth
14	856964T	31.2	2	Seventeenth Ave	Local Road	2	1456	Belmar	Monmouth

#	Grade Crossing ID	MP	Number of Tracks	Roadway Name	Roadway Type	Lanes	AADT	Town	County
15	856954M	29.2	2	Fourth Ave	Local Road	2	4680	Bradley Beach	Monmouth
16	856923N	25.1	2	Roosevelt Ave	Local Road	2	5360	Deal	Monmouth
17	856975F	33.4	2	Shore Rd	Local Road	2	542	Spring Lake	Monmouth
18	856948J	28.7	2	Eleventh Ave	Local Road	2	3576	Neptune	Monmouth
19	856917K	23.2	2	Brighton Ave	Local Road	2	3904	Long Branch	Monmouth
20	856930Y	26.6	2	Spier Ave	Local Road	2	888	Allenhurst	Monmouth
21	856957H	30.5	2	Seventh Ave	Local Road	2	1372	Belmar	Monmouth
22	856916D	23.1	2	West End Ave	Local Road	2	1248	Long Branch	Monmouth
23	856959W	30.7	2	Tenth Ave	Local Road	2	3030	Belmar	Monmouth
24	856945N	28.0	2	Bangs Ave	Local Road	2	5586	Asbury Park	Monmouth
25	856935H	27.3	2	Sunset Ave	Local Road	2	6752	Asbury Park	Monmouth
26	916144M	24.6	2	Elberon Station Pedestrian Xing	Ped Xing	0	NA	Long Branch	Monmouth
27	856938D	27.6	2	Third Ave	Local Road	2	4880	Asbury Park	Monmouth
28	856943A	27.9	2	Monroe Ave	Local Road	2	12050	Asbury Park	Monmouth
29	856965A	31.4	2	Eighteenth Ave	County Road	2	5616	Belmar	Monmouth
30	856942T	27.8	2	Asbury Ave	County Road	2	7120	Asbury Park	Monmouth
31	856958P	30.6	2	Eighth Ave	State Highway	2	10440	Belmar	Monmouth
32	856927R	26.0	2	Drummond Ave	Local Road	2	1136	Deal	Monmouth

#	Grade Crossing ID	MP	Number of Tracks	Roadway Name	Roadway Type	Lanes	AADT	Town	County
33	856894F	16.3	2	Shrewsbury Ave	County Road	2	21255	Red Bank	Monmouth
34	856966G	31.9	2	Wall Rd	Local Road	2	1878	Spring Lake	Monmouth
35	856946V	28.2	2	Springwood Lake Ave	Local Road	2	8280	Asbury Park	Monmouth
36	856924V	25.4	2	Grant Ave	Local Road	2	2896	Deal	Monmouth
37	856926J	25.9	2	Roseld Ave	Local Road	2	4396	Deal	Monmouth
38	856895M	16.4	2	Monmouth St / Bridge St	Local Road	4	19420	Red Bank	Monmouth
39	856947C	28.5	2	Corlies Ave	State Highway	4	24874	Neptune	Monmouth
40	856970W	32.5	2	Brighton Ave	Local Road	2	1792	Spring Lake	Monmouth
41	856972K	33.0	2	Monmouth Ave	Local Road	2	1696	Spring Lake	Monmouth
42	856952Y	29.0	2	Lareine Ave	Local Road	2	3576	Bradley Beach	Monmouth
43	856973S	33.3	2	Ocean Rd	Local Road	2	3432	Spring Lake	Monmouth
44	856953F	29.1	2	Brinley Ave	County Road	2	6816	Bradley Beach	Monmouth
45	856931F	26.6	2	Corlies Ave	Local Road	2	5124	Allenhurst	Monmouth
46	856925C	25.5	2	Sherman Ave	Local Road	2	5424	Deal	Monmouth
47	856971D	32.7	2	Warren Ave	Local Road	2	4752	Spring Lake	Monmouth
48	856933U	27.0	2	Grassmere Ave	County Road	2	12512	Interlaken	Monmouth
49	856918S	23.4	2	Cedar Ave	County Road	2	14464	Long Branch	Monmouth

APPENDIX D STATE, COUNTY AND OTHER ROUTE RANKINGS

As shown in the Table 31, the rankings of state, county and other route, grade crossing ID, line name, milepost, number of tracks, roadway name, roadway type, roadway lanes, town, and county are stated.

Table 31 - State, County and Other Route Rankings

#	ID	Line	MP	Tracks	Roadway Name	Roadway Type	Lanes	Town	County
1	263050E	Pascack Valley Line	13.6	1	Passaic St	County Road	2	Hackensack	Bergen
2	263082K	Main Line	22.5	2	Hollywood Ave	Local Road	2	Ho Ho Kus	Bergen
3	263165Y	Bergen County Line	13.6	2	Market St	County Road	4	Elmwood Park	Bergen
4	266877K	Morristown Line	38.2	2	South Morris St	County Road	2	Dover	Morris
5	586073E	Atlantic City Line	30.4	1	Bellevue Ave	State Highway	2	Hammonton	Atlantic
6	263030T	Pascack Valley Line	20.6	1	Westwood Ave	County Road	5	Westwood	Bergen
7	856965A	North Jersey Coast Line	31.4	2	Eighteenth Ave	County Road	2	Belmar	Monmouth
8	263228B	Montclair Line	11.9	2	Grove St	County Road	2	Montclair	Essex
9	856942T	North Jersey Coast Line	27.8	2	Asbury Ave	County Road	2	Asbury Park	Monmouth
10	263044B	Pascack Valley Line	14.1	1	Main St	County Road	2	Hackensack	Bergen
11	856958P	North Jersey Coast Line	30.6	2	Eighth Ave	State Highway	2	Belmar	Monmouth
12	856894F	North Jersey Coast Line	16.3	2	Shrewsbury Ave	County Road	2	Red Bank	Monmouth
13	263413V	Bergen County Line	12.7	2	Outwater Lane	County Road	2	Garfield	Bergen
14	263027K	Pascack Valley Line	21.5	1	Hillsdale Ave	County Road	2	Hillsdale	Bergen
15	856947C	North Jersey Coast Line	28.5	2	Corlies Ave	State Highway	4	Neptune	Monmouth

#	ID	Line	MP	Tracks	Roadway Name	Roadway Type	Lanes	Town	County
16	856953F	North Jersey Coast Line	29.1	2	Brinley Ave	County Road	2	Bradley Beach	Monmouth
17	586086F	Atlantic City Line	31.0	1	Park Ave	Local Road	2	Hammonton	Atlantic
18	263051L	Pascack Valley Line	13.2	1	Central Ave	County Road	2	Hackensack	Bergen
19	263186S	Main Line	26.6	2	Main St	County Road	2	Ramsey	Bergen
20	263416R	Bergen County Line	11.5	2	Somerset St	Local Road	1	Garfield	Bergen
21	266890Y	Montclair Line	14.9	2	Normal Ave	County Road	2	Montclair	Essex
22	856933U	North Jersey Coast Line	27.0	2	Grassmere Ave	County Road	2	Interlaken	Monmouth
23	856918S	North Jersey Coast Line	23.4	2	Cedar Ave	County Road	2	Long Branch	Monmouth

APPENDIX E ORIGINAL LIST OF GRADE CROSSINGS

Table 32 - Original List of Grade Crossings

ID	Line	MP	Number of Tracks	Roadway Name	Roadway Type	Lanes	Town	County
263025W	Pascack Valley Line	21.7	1	Orchard St	Local Road	2	Hillsdale	Bergen
263026D	Pascack Valley Line	21.6	1	Park Ave	Local Road	1	Hillsdale	Bergen
263027K	Pascack Valley Line	21.5	1	Hillsdale Ave	County Road	2	Hillsdale	Bergen
916139R	Pascack Valley Line	21.4	1	Washington St Ave	Local Road	3	Hillsdale	Bergen
263028S	Pascack Valley Line	21.2	1	Industrial Rd	Local Road	2	Westwood	Bergen
916135N	Pascack Valley Line	21.0	1	Lake St	Local Road	3	Westwood	Bergen
263029Y	Pascack Valley Line	20.8	1	Irvington St	Local Road	2	Westwood	Bergen
263030T	Pascack Valley Line	20.6	1	Westwood Ave	County Road	5	Westwood	Bergen
263031A	Pascack Valley Line	20.5	1	First Ave	Local Road	3	Westwood	Bergen
263043U	Pascack Valley Line	14.2	1	Temple Ave	Local Road	2	Hackensack	Bergen
263044B	Pascack Valley Line	14.1	1	Main St	County Road	2	Hackensack	Bergen
263046P	Pascack Valley Line	13.9	1	Euclid Ave	Local Road	2	Hackensack	Bergen
263047W	Pascack Valley Line	13.8	1	Clinton Place	Local Road	2	Hackensack	Bergen
263049K	Pascack Valley Line	13.7	1	Anderson St	Local Road	2	Hackensack	Bergen
263050E	Pascack Valley Line	13.6	1	Passaic St	County Road	2	Hackensack	Bergen
916134G	Pascack Valley Line	13.4	1	Berry St	Local Road	2	Hackensack	Bergen
263051L	Pascack Valley Line	13.2	1	Central Ave	County Road	2	Hackensack	Bergen

ID	Line	MP	Number of Tracks	Roadway Name	Roadway Type	Lanes	Town	County
263052T	Pascack Valley Line	13.0	1	Beech St	Ped Xing	0	Hackensack	Bergen
263053A	Pascack Valley Line	12.9	1	Atlantic St	Local Road	2	Hackensack	Bergen
586071R	Atlantic City Line	30.3	1	Orchard St	Local Road	2	Hammonton	Atlantic
586073E	Atlantic City Line	30.4	1	Bellevue Ave	State Highway	2	Hammonton	Atlantic
586075T	Atlantic City Line	30.5	1	Passmore Ave	Local Road	2	Hammonton	Atlantic
586077G	Atlantic City Line	30.6	1	Line St	Local Road	2	Hammonton	Atlantic
586080P	Atlantic City Line	30.8	1	11th St	Local Road	2	Hammonton	Atlantic
586086F	Atlantic City Line	31.0	1	Park Ave	Local Road	2	Hammonton	Atlantic
856975F	North Jersey Coast Line	33.4	2	Shore Rd	Local Road	2	Spring Lake	Monmouth
856973S	North Jersey Coast Line	33.3	2	Ocean Rd	Local Road	2	Spring Lake	Monmouth
856972K	North Jersey Coast Line	33.0	2	Monmouth Ave	Local Road	2	Spring Lake	Monmouth
856971D	North Jersey Coast Line	32.7	2	Warren Ave	Local Road	2	Spring Lake	Monmouth
856970W	North Jersey Coast Line	32.5	2	Brighton Ave	Local Road	2	Spring Lake	Monmouth
856969C	North Jersey Coast Line	32.4	2	St. Clair Ave	Local Road	2	Spring Lake	Monmouth
856968V	North Jersey Coast Line	32.3	2	Ludlow Ave	Local Road	2	Spring Lake	Monmouth
856967N	North Jersey Coast Line	32.1	2	Church St	Local Road	2	Spring Lake	Monmouth
856966G	North Jersey Coast Line	31.9	2	Wall Rd	Local Road	2	Spring Lake	Monmouth
856965A	North Jersey Coast Line	31.4	2	Eighteenth Ave	County Road	2	Belmar	Monmouth

ID	Line	MP	Number of Tracks	Roadway Name	Roadway Type	Lanes	Town	County
856964T	North Jersey Coast Line	31.2	2	Seventeenth Ave	Local Road	2	Belmar	Monmouth
856963L	North Jersey Coast Line	31.0	2	Sixteenth Ave	Local Road	2	Belmar	Monmouth
856962E	North Jersey Coast Line	31.0	2	Thirteenth Ave	Local Road	2	Belmar	Monmouth
856961X	North Jersey Coast Line	30.9	2	Twelfth Ave	Local Road	2	Belmar	Monmouth
856959W	North Jersey Coast Line	30.7	2	Tenth Ave	Local Road	2	Belmar	Monmouth
856958P	North Jersey Coast Line	30.6	2	Eighth Ave	State Highway	2	Belmar	Monmouth
856957H	North Jersey Coast Line	30.5	2	Seventh Ave	Local Road	2	Belmar	Monmouth
856956B	North Jersey Coast Line	29.3	2	Evergreen Ave	Local Road	2	Bradley Beach	Monmouth
856954M	North Jersey Coast Line	29.2	2	Fourth Ave	Local Road	2	Bradley Beach	Monmouth
856953F	North Jersey Coast Line	29.1	2	Brinley Ave	County Road	2	Bradley Beach	Monmouth
856952Y	North Jersey Coast Line	29.0	2	Lareine Ave	Local Road	2	Bradley Beach	Monmouth
856948J	North Jersey Coast Line	28.7	2	Eleventh Ave	Local Road	2	Neptune	Monmouth
856947C	North Jersey Coast Line	28.5	2	Corlies Ave	State Highway	4	Neptune	Monmouth
856946V	North Jersey Coast Line	28.2	2	Springwood ~~Lake~~ Ave	Local Road	2	Asbury Park	Monmouth
856945N	North Jersey Coast Line	28.0	2	Bangs Ave	Local Road	2	Asbury Park	Monmouth
856943A	North Jersey Coast Line	27.9	2	Monroe Ave	Local Road	2	Asbury Park	Monmouth
856942T	North Jersey Coast Line	27.8	2	Asbury Ave	County Road	2	Asbury Park	Monmouth
856941L	North Jersey Coast Line	27.7	2	First Ave	Local Road	2	Asbury Park	Monmouth

ID	Line	MP	Number of Tracks	Roadway Name	Roadway Type	Lanes	Town	County
856939K	North Jersey Coast Line	27.6 27.7	2	Second Ave	Local Road	2	Asbury Park	Monmouth
856938D	North Jersey Coast Line	27.6	2	Third Ave	Local Road	2	Asbury Park	Monmouth
856937W	North Jersey Coast Line	27.5	2	Fourth Ave	Local Road	2	Asbury Park	Monmouth
856936P	North Jersey Coast Line	27.4	2	Fifth Ave	Local Road	2	Asbury Park	Monmouth
856935H	North Jersey Coast Line	27.3	2	Sunset Ave	Local Road	2	Asbury Park	Monmouth
856934B	North Jersey Coast Line	27.3	2	Sixth Ave	Local Road	2	Asbury Park	Monmouth
856933U	North Jersey Coast Line	27.0	2	Grassmere Ave	County Road	2	Interlaken	Monmouth
856931F	North Jersey Coast Line	26.6	2	Corlies Ave	Local Road	2	Allenhurst	Monmouth
856930Y	North Jersey Coast Line	26.6	2	Spier Ave	Local Road	2	Allenhurst	Monmouth
856927R	North Jersey Coast Line	26.0	2	Drummond Ave	Local Road	2	Deal	Monmouth
856926J	North Jersey Coast Line	25.9	2	Roseld Ave	Local Road	2	Deal	Monmouth
856925C	North Jersey Coast Line	25.5	2	Sherman Ave	Local Road	2	Deal	Monmouth
856924V	North Jersey Coast Line	25.4	2	Grant Ave	Local Road	2	Deal	Monmouth
856923N	North Jersey Coast Line	25.1	2	Roosevelt Ave	Local Road	2	Deal	Monmouth
916144M	North Jersey Coast Line	24.6	2	Elberon Station Pedestrian Xing	Ped Xing	0	Long Branch	Monmouth
856918S	North Jersey Coast Line	23.4	2	Cedar Ave	County Road	2	Long Branch	Monmouth
856917K	North Jersey Coast Line	23.2	2	Brighton Ave	Local Road	2	Long Branch	Monmouth
856916D	North Jersey Coast Line	23.1	2	West End Ave	Local Road	2	Long Branch	Monmouth

ID	Line	MP	Number of Tracks	Roadway Name	Roadway Type	Lanes	Town	County
266890Y	Montclair Line	14.9	2	Normal Ave	County Road	2	Montclair	Essex
266889E	Montclair Line	14.7	2	Mt. Hebron Rd	Local Road	2	Montclair	Essex
266886J	Montclair Line	14.3	2	Laurel Place	Local Road	2	Montclair	Essex
266882G	Montclair Line	14.0	2	Jerome Place	Local Road	2	Montclair	Essex
266883N	Montclair Line	13.8	2	Lorraine Ave	Local Road	2	Montclair	Essex
266880T	Montclair Line	13.7	2	Bellevue Ave	Local Road	2	Montclair	Essex
263232R	Montclair Line	12.7	2	N. Fullerton Ave	Local Road	2	Montclair	Essex
263229H	Montclair Line	12.1	2	Walnut St	Local Road	2	Montclair	Essex
263228B	Montclair Line	11.9	2	Grove St	County Road	2	Montclair	Essex
263227U	Montclair Line	11.8	2	Claremont Ave	Local Road	2	Montclair	Essex
263242W	Montclair Line	11.7	2	Pine St	Local Road	2	Montclair	Essex
263164S	Bergen County Line	13.8	2	Midland Ave	Local Road	2	Elmwood Park	Bergen
263165Y	Bergen County Line	13.6	2	Market St	County Road	4	Elmwood Park	Bergen
263412N	Bergen County Line	12.9	2	Midland Ave	Local Road	2	Garfield	Bergen
263413V	Bergen County Line	12.7	2	Outwater Lane	County Road	2	Garfield	Bergen
263414C	Bergen County Line	12.0	2	Van Winkle Ave	Local Road	2	Garfield	Bergen
263415J	Bergen County Line	11.7	2	Monroe St	Local Road	2	Garfield	Bergen
263416R	Bergen County Line	11.5	2	Somerset St	Local Road	1	Garfield	Bergen

ID	Line	MP	Number of Tracks	Roadway Name	Roadway Type	Lanes	Town	County
263418E	Bergen County Line	11.3	2	Hobart Place	Local Road	2	Garfield	Bergen
266876D	Morristown Line	38.3	2	Orchard St	Local Road	2	Dover	Morris
266877K	Morristown Line	38.2	2	South Morris St	County Road	2	Dover	Morris
856897B	North Jersey Coast Line	16.6	2	Chestnut St	Local Road	2	Red Bank	Monmouth
856895M	North Jersey Coast Line	16.4	2	Monmouth St / Bridge St	Local Road	4	Red Bank	Monmouth
856894F	North Jersey Coast Line	16.3	2	Shrewsbury Ave	County Road	2	Red Bank	Monmouth
263185K	Main Line	26.9	2	Geertzen Plaza	Local Road	2	Ramsey	Bergen
263186S	Main Line	26.6	2	Main St	County Road	2	Ramsey	Bergen
263190G	Main Line	24.4 24	2	Chestnut St	Local Road	2	Allendale	Bergen
263082K	Main Line	22.5	2	Hollywood Ave	Local Road	2	Ho Ho Kus	Bergen
263193C	Main Line	22.2	2	Warren Rd	Local Road	2	Ho Ho Kus	Bergen

APPENDIX F LITERATURE REVIEW

BUREAU OF RESEARCH

TECHNICAL MEMORANDUM

PROJECT:	New Jersey Transit Grade Crossing Safety
DATE:	September 20th, 2021
SUBMITTED BY:	Dr. Xiang Liu, Dr. Mohammad Jalayer, Geoffrey Hubbs
CUSTOMER:	Susan O'Donnell
RPM:	Stefanie Potapa
SUBJECT:	Task 1 Literature Review

Grade crossings pose one of the most significant safety challenges for railroads and transit agencies across the United States (U.S.) and encompass 34% of railroad incidents in the past ten years. The elimination of grade crossings with the intention of reducing risk can improve public safety, decrease financial burdens, and improve service to the public. To improve grade crossing safety in New Jersey, this research aims to provide New Jersey Department of Transportation (NJDOT) and New Jersey Transit (NJT) with a decision-making tool to select grade crossings for closure. A listing of 100 crossings and associated features provided by NJT can be found in appendix A. The result of this research has the potential to guide NJT and NJDOT in maximizing the benefits to the communities of New Jersey.

As part of this research effort, this document presents the findings of a literature review on grade crossing elimination, hazard identification and prioritization. This effort ensures that the state-of-practice and state-of-the-art approaches are understood, enabling the selection of the best approach for prioritization in New Jersey.

The primary focus of this research is grade crossing closure. A review of New Jersey's current practices, federal guidance, key factors, and case studies are presented. The key factors are summarized and will guide future data gathering efforts in subsequent phases of this research. At minimum, accident history, highway traffic volumes, emergency vehicle usage, distance to nearby critical civil infrastructure, distance to alternate crossings, adjacency to train station platforms, and crossing geometry will be used to evaluate and rank the crossings in New Jersey for closure. However, a detailed review of the available data and crossing inventory will guide the selection of a prioritization approach.

This review also summarizes past efforts in grade crossing prioritization. A summary of the five preeminent grade crossing accident prediction models (Coleman -Stewart, Iowa Accident Prediction Formula, Jaqua Formula, National Cooperative Highway Research Program (NCHRP) Report 50 Accident Prediction Formula, Peabody-Dimmick and USDOT Accident Prediction Formula) and 15 hazard index models are included in appendix B. A summary of the key factors can be found in appendix C.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Acronyms

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADT	Average Daily Traffic
ALTDIST	Alternative Distance Traveled
APTA	American Public Transit Association
CFR	Code of Federal Regulations
DOT	Department of Transportation
EMSDIST	Emergency Services Proximity
FHWA	Federal Highway Administration
FRA	Federal Railroad Administration
GIS	Geographic Information System
HRGC	Highway-Rail Grade Crossing
HRX	Highway-Rail Grade Crossing
HTBR	Hierarchical Tree-Based Regression
ILCS	Illinois Compiled Statutes
INDOT	Indiana Department of Transportation
LADOTD	Louisiana Department of Transportation and Development
NCHRP	National Cooperative Highway Research Program
NJDOT	New Jersey Department of Transportation
NJT	New Jersey Transit
NHS	National Highway System
PennDOT	Pennsylvania Department of Transportation
RDSYS	Farm-To-Market Or Primary Road System Status
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users
SCHDIST	School Proximity
SCHFRQ	School Location Count in A Radius Around The Crossing
TRB	Transportation Research Board
TWG	Technical Working Group
USDOT	United States Department of Transportation
XGboost	Extreme Gradient Boosting
ZINDOT	Zero-Inflated Negative Binomial Model with variables from the USDOT Accident Prediction Formula

INTRODUCTION

Goal and Scope

Grade crossings pose one of the most significant safety challenges for railroads and transit agencies across the U.S.[1], comprising 34% of railroad incidents in the past 10 years. The removal or modification of grade crossings with the intention of reducing risk can improve public safety, decrease financial burdens, and improve service to the public. A summary of the national trend for highway rail grade crossing injuries and fatalities in the U.S. can be seen in Figure 1. The data trend in 2020 is anomalous, likely due to the decrease in highway traffic due to the Covid-19 pandemic.[2]

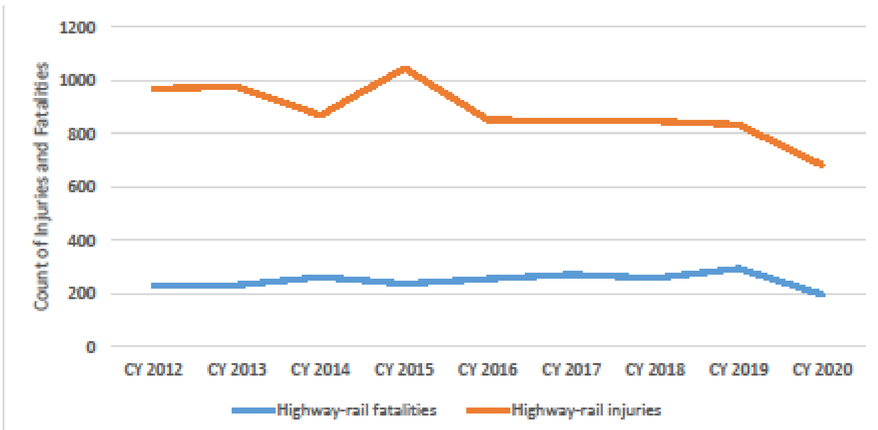

Figure 1 U.S. Highway Rail Grade Crossing Trends from 2012 - 2020[1]

To improve grade crossing safety in New Jersey, this research aims to provide New Jersey Department of Transportation (NJDOT) and New Jersey Transit (NJT) with a decision-making tool to select grade crossings for closure. To do so, a comprehensive literature review on grade crossing hazard identification, prioritization, and closure was conducted. This effort ensures that the state-of-practice and state-of-the-art approaches are understood, enabling the selection of the best approach for prioritization in New Jersey. The results of this research will support NJT and NJDOT in the efficient spending of limited funds to maximize benefit for the communities of New Jersey.

Search Methodology

The research team explored three main areas of interest to understand the current practice of grade crossing prioritization and closure. Firstly, the research team reviewed summary studies that describe grade crossing closure and prioritization approaches in the U.S. Secondly, these summaries prompted the review of individual State closure and prioritization efforts and case studies. Lastly, recent developments in state-of-the-art approaches, like logistic regression and machine learning, were explored.
This literature review is organized as follows. Firstly, we discuss grade crossing

elimination, covering criteria for closure and several case studies. Secondly, we present an overview of grade crossing prioritization in the U.S. Lastly, we present our conclusions and recommendations.

Table 1 Grade Crossing Elimination Key Factors in New Jersey

Factor	Closure Criteria	Separation Criteria	Source
Accident and Near-Miss History	Many Events		FRA Safety Database
Traffic	< 2000 AADT	>2000 AADT	FRA Safety Database
Emergency Vehicle Usage	Low Usage	High Usage	Township Data & Interviews
Distance to Schools, Municipal Buildings, Hospitals, etc.	Far Distance	Nearby	Maps and GIS Dataset
Distance to Alt. Crossings	Nearby	Far Distance	Maps and GIS Dataset
Access to Train Platforms	No	Yes	Maps and GIS Dataset
Geometry and Layout	Poor sight distance, vertical curves, nearby traffic lights etc.		Maps and Engineering Drawings

Accident history is a prime motivator for grade crossing closures. In some cases, accidents will initiate engineering studies to eliminate crossings. Traffic is another prime consideration when deciding to close a crossing. If traffic is sufficiently low this may indicate that the crossing is eligible for closing to highway traffic. However, if the traffic is high, but other factors indicate that it must be eliminated, grade separation may be considered.

Emergency vehicle usage of the crossing is another prime consideration. The distance from the crossing to fire stations, hospitals and police should be evaluated. Similarly, utilization by school busses or adjacent municipal complexes should be considered.

In some locations there are many crossings in a relatively small area. On corridors like NJT's Coast Line, crossings can be 300-400 feet apart (i.e., Asbury Park). This increases further with a high density of stations such as the 2.5-mile corridor between Allenhurst, Asbury Park and Bradley Beach stations. If one of these crossings were to be closed, the routed traffic would have sufficient alternate routes to cross the tracks. When multiple crossings are considered for elimination and upgrade as a group, they are called a grade crossing consolidation project.

Additionally, crossings near or within train stations should be considered for elimination. Crossings that provide pedestrian access to station platforms are good elimination candidates due to the reduced commuter exposure when accessing a station. Finally, the geometry of the crossing should be considered. Traffic speeds, skew, and vertical curves are examples of features which can cause vehicle to slow or become stopped on the tracks. If the engineering study reveals that geometry may contribute to increased risk exposure, then elimination should be considered.

Net Zero Development

Grade crossing elimination projects are also initiated when a grade crossing is added to a corridor by land development projects. When this occurs, a grade crossing engineering review is started to remove an equivalent number of crossings within the same municipality.

Corridor Projects (Consolidation)

Finally, the third category of grade crossing elimination initiation is corridor projects, also called consolidation. An effective way to eliminate crossings is to develop a "program of treatments to eliminate significant numbers of crossings within a segment of rail line while improving those that are to remain at grade."[4] This type of treatment is called a grade crossing consolidation program. These programs, which are supported by the FRA and American Association of State Highway and Transportation Officials (AASHTO) propose a set of high-level steps to determine crossings for elimination.

According to federal guidance and research on grade crossing consolidation, firstly corridors of rail lines are selected, and crossings are selected and filtered based on jurisdictional criteria (public vs. private crossings). After the areas and crossing lists are selected it is recommended that a diagnostic team studies the number of road lanes, the number of tracks, average daily traffic, accident history, and proximity and access to other crossings. Once the consolidation factors are established, funding can be sought through several federal programs including the Section 148 of the Safe, Accountable, Flexible, Efficient Transportation Equity Act which sets aside $220 million annually for grade crossing safety improvements or the Section 1103(f) of SAFETEA-LU which allows federal monies to be used for hazard elimination along designated high-speed rail corridors.[4]

In 2018, Codjoe et al[5], evaluated the incentive programs for grade crossing consolidation and closure through a survey circulated to state transportation agencies. The results showed that 16 states had no incentive programs, and those same states had the least proportion of highway-rail crossing closures. "The study revealed that cash incentives, while popular are not effective because although the Federal Government contributes to a state's effort in offering cash incentives for closure of public grade crossings, the amount is not substantial enough to be considered a significant incentive by most local governments." However, crime rate reduction incentives, greenness improvement programs, and the development of a grade crossing consolidation model were proposed as effective consolidation methods.

Federal Grade Crossing Elimination Guidance

According to the Grade Crossing Handbook, 3rd Edition "locations with more than four crossings per railroad route-mile with fewer than 2,000 vehicles per day and more than two trains per day are prime candidates for closure" [3]. The access of emergency vehicles and the increases risk at other crossings due to the diversion of highway traffic should also be considered. An elimination at one crossing may have the adverse effect of increasing risk at other crossings, and therefore eliminations are often coincided with upgrades at nearby crossings.

The USDOT established a Technical Working Group (TWG) after the 1995 Fox River Grove, IL Metra commuter train and school bus collision. This TWG was tasked with developing "best practices" guidance on a selection of crossing treatments.[3] A portion of this TWG's recommendations included criteria for grade crossing separation. If one or more of the following conditions exist, a grade separation should be considered.

- The posted highway speed equals or exceeds 55 mph
- Average Annual Daily Traffic (AADT) exceeds 30,000 in urban areas or 20,000 in rural areas
- Maximum authorized train speed exceeds 79 mph
- An average of 30 or more trains per day
- An average of 75 or more passenger trains per day in urban areas or 30 or more passenger trains per day in rural areas
- An average of 150 or more transit trains per day in urban areas or 60 or more passenger trains per day in rural areas
- Freight Train Crossing Exposure (the product of the number of trains per day and AADT) exceeds 900,000 in urban areas or 600,000 in rural areas
- Passenger Train Crossing Exposure (the product of the number of passenger trains per day and AADT) exceeds 2,250,000 in urban areas or 600,000 in rural areas
- Transit Train Crossing Exposure (the product of the number of transit trains per day and AADT) exceeds 4,500,000 in urban areas or 1,200,000 in rural areas
- The expected accident frequency for active devices with gates, as calculated by the USDOT Accident Prediction Formula including five-year accident history, exceeds 0.5 (per year). If the highway is a part of the designated National Highway System, the expected accident frequency for active devices with gates, as calculated by the USDOT Accident Prediction Formula including five-year accident history, exceeds 0.2 (per year)
- Vehicle delay exceeds 30 vehicle hours per day with consideration for cost effectiveness
- Whenever a new grade separation is constructed, whether it replaces an existing highway-rail crossing, consideration should be given to the possibility of closing one or more adjacent crossings. In addition, the railroad should be consulted prior to starting design to determine the railroad's future clear span requirements for the tracks crossed
- Utilize Table 2 for light rail transit grade separations

Table 2 Light Rail Transit Grade Separation Criteria

Trains Per Hour	Peak-Hour Volume (Vehicles per Lane)
60	200
40	400
20	600

Other State's Closure Case Studies

Research initiatives have been conducted to determine the effectiveness of grade crossing consolidation and closure programs. In 1998, Russel and Mutabazi[6] developed a model to prioritize Kansas' best consolidation candidates. Their recommendations supported the use of traffic engineering expertise and strong public involvement to close crossings. They also recommended evaluating corridors of crossings as a group rather than focusing on the closure of specific crossings.

In 2015 Johnson[7] developed a spreadsheet based tool to rank grade crossings for consolidation. This tool was tested for its sensitivity on urban and rural Iowa grade crossings. The factors with the highest sensitivity in this study were AADT, alternative distance traveled (ALTDIST), emergency services proximity (EMSDIST), farm-to-market or primary road system status (RDSYS), school proximity (SCHDIST), school location count in a radius around the crossing (SCHFRQ), and truck AADT.

In 2016, the Montana Department of Transportation[8], completed a grade separation study. This study developed a two-tier screening process which reduced a list of 5,200 crossings to 10 candidates for separation. The crossings were first screened by "removing private, closed, and pedestrian crossings, as well as crossings with zero train movements."[8] The resultant 941 crossings were screened based on AADT and ranked based on the Montana Priority Index, functional classification, and average train speeds.

In 2018, Solemani et al[9], aimed to create a comprehensive reference document for highlighting the impact factors at grade crossings, incentive programs and models for grade crossing consolidation. Following that study, In 2020, Soleimani et al[10], utilized state of the art methods such as "Text Mining Techniques, and Geospatial Analysis in addition to the XGboost Machine Learning algorithm"[9] to propose grade crossings for consolidation. Specifically, text mining algorithms analyzed police crash narrative data to map the most frequently used words. Geospatial analysis included "nearby schools, distance to nearby hospitals, type of land use in crossing's surrounding area, flood zone areas around the crossing, and the number of intersections in different distance thresholds." [9]

Several States have published information on how they decide which crossings to eliminate. In California, the "California Public Utilities Commission establishes the highway-rail Grade Separation Priority List for grade separation projects by July 1st of each year."[11] However, the methodology by which this separation list is created is not publicized. In Iowa, priorities for grade crossing elimination funding are determined through a benefit cost analysis. "This analysis takes into consideration the extent of vehicle and train traffic at the crossing, speed of trains, certain characteristics of the crossing, effectiveness of the proposed improvement, estimated cost of the improvement and other factors. Generally, those crossings with a high probability for a serious crash with a proposed improvement anticipated to be effective and cost efficient will receive the highest priority."[12]

In Minnesota, the closure criteria within consolidation projects include number of crossings closed, risk factors, and deficient geometry.[13] Specifically if two of the following criteria are met, a project is eligible.

A. "The train speeds at the crossing are 40 miles per hour (60 kilometers per hour) or greater, the roadway carries four or more lanes of traffic, and either: (1) the roadway immediately preceding the crossing has a posted speed of 30 miles per hour (50 kilometers per hour) or greater and a current ADT of 5,000 vehicles or more; or (2) the roadway immediately preceding the crossing has a posted speed of 55 miles per hour (90 kilometers per hour) or greater and a current ADT of 3,000 vehicles or more.
B. There are active warning devices, and there has been a vehicle-train accident at the grade crossing involving a fatality or two property damage or personal injury accidents within the last five years.
C. An increase in public safety would result from construction of the grade separation by eliminating another safety problem area such as an accident-prone roadway intersection."[14]

In Kansas, the three criteria for elimination consideration are, "a rural or city connecting link state highway crossing, main line railroad traffic, excluding industrial spur tracks, and Route classification must be "B" or "C" or be on the National Highway System (NHS)"[15]. In Texas, the following factors are considered for grade crossing elimination according to the Railroad-Highway Grade Crossing Handbook - Revised Second Edition, Appendix H: State Crossing Consolidations and Closures, State Laws and Regulations Summary.[16]

- Traffic analysis of proposed roadway network
- Density of crossings, especially when closer than ¼ mile apart
- Support from local community
- Sight distance restrictions
- Traffic and train counts (existing and future)
- Roadway speed limit
- Train speed

In Illinois, the following factors are considered for grade crossing elimination according to the Railroad-Highway Grade Crossing Handbook - Revised Second Edition, Appendix H: State Crossing Consolidations and Closures, State Laws and Regulations Summary.[17]

- Timetable speed of passenger trains.
- Distance to an alternate crossing.
- Collision history for the last five years.
- Number of vehicular traffic and posted speed limits.
- Number of freight trains and their timetable speeds.
- Type of warning device present at the grade crossing.
- Alignments of the roadway and railroad, and the angle of intersection of those

alignments.

- Use of the grade crossings by trucks carrying hazardous material, vehicles carrying passengers for hire, and school buses.
- Use of the grade crossing by emergency vehicles. 625 ILCS 5/18c-7401 (1999).

In Indiana, the following factors are considered for grade crossing elimination according to the Railroad-Highway Grade Crossing Handbook - Revised Second Edition, Appendix H: State Crossing Consolidations and Closures, State Laws and Regulations Summary.[17]

- Timetable speed of passenger trains operated through the crossing.
- Distance to an alternate crossing.
- Collision history of the crossing for the five years preceding INDOT's or the unit's consideration.
- Amount of vehicular traffic and posted speed limits for the crossing.
- Amount of freight trains and their timetable speeds operated through the crossing.
- Type of warning device present at the crossing, if any.
- Alignment of the roadway and the railroad, and the angle of the intersection of an alignment at the crossing.
- Use of the crossing by:
  - Trucks carrying hazardous materials.
  - Vehicles carrying passengers for hire.
  - School buses; and
  - Emergency vehicles.
- Other appropriate criteria as determined by INDOT. Ind. Code Ann. §8-6-7.7-3.1(Burns 1998 Supplement).

In Louisiana, the following factors are considered for grade crossing elimination according to the Railroad-Highway Grade Crossing Handbook - Revised Second Edition, Appendix H: State Crossing Consolidations and Closures, State Laws and Regulations Summary.[17]

- Total number of daily vehicular use at crossing.
- Total number of trains passing the crossing daily.
- Alternative routes and distance to such routes.
- Timetable speeds of trains passing the crossing.
- Collision history of the crossing.
- Type of warning device presently at the crossing.
- Degree of difficulty involved in improvement of roadway approach to the crossing or in providing adequate warning devices.
- Use of the crossing by vehicles carrying hazardous materials, vehicles carrying passengers for hire, and school buses.
- Use of grade crossing by emergency vehicles.
- Sight distance and reduced visibility at the crossings.
- Angle of intersection of alignments of the roadway and the railroad.

- Redundancy of crossings in the area.
- Proximity to a new crossing or a recently upgraded crossing.
- Availability and responsibility of user of private crossing.
- Other factors LADOTD determines necessary in the development of this criteria. La. Rev. Stat. Ann. § 48:390 (West 1999).

GRADE CROSSING PRIORITIZATION METHODS

Grade crossing prioritization has been studied and improved over the past 30 years. Between 1986 to 2020, several state agencies and universities have evaluated, tested, and developed new methods to prioritize grade crossings.[18] These efforts led to the development of prioritization models like Illinois Hazard Index Formula, Revised Texas Priority Index and Nevada's Revised Grade Crossing Hazard Index Model. A summary of the utilization of different prioritization models used can be seen in Figure 2 and Table 3.

Table 3 U.S. Prioritization Approach Summary

Methodology	States Using the Approach
State Specific Methodology	16
USDOT Accident Prediction Model	12
New Hampshire Hazard Index	5
NCHRP 50	1
Peabody-Dimmick	3
Texas Priority Index	1
Unidentified	9

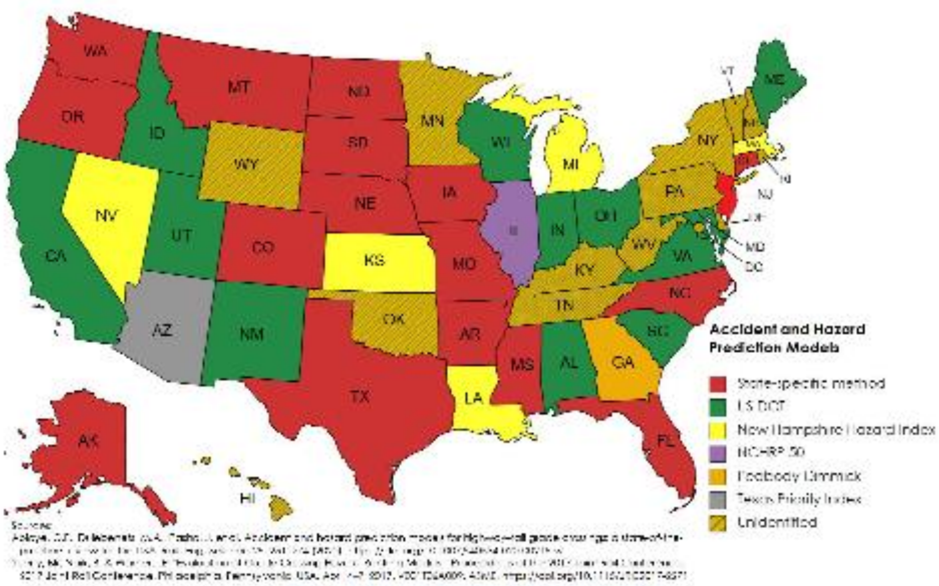

Figure 2 U.S. Prioritization Approach Summary

In the following section, the primary state-specific prioritization research efforts are summarized, describing their motivation and results. Secondly, the state-of-the-art methods using advanced mathematical or statistical approaches are outlined. A summary of the preeminent accident and hazard prediction models, the formulae, variables, and supporting tables can be found in Appendix B.

State Specific Prioritization Studies

Research by Sperry et al in 2016[19] and Abioye et al in 2020[18] performed state-of-practice reviews for the accident and hazard prediction models used in the U.S. These studies summarized State-based research focusing on evaluating and improving grade crossing prioritization. An overview of the different studies can be seen in Table 4.

Table 4 Summary of State Efforts[18]

Study Conducted	Year	Interviews or Surveys	Review of existing models	Evaluation of the existing models	New model development	Decision support tools
Virginia	1986	✓	✓	✓		
Alabama	1994	✓	✓	✓		
Oklahoma	1995				✓	
Illinois	2000	✓	✓	✓	✓	
Missouri	2003	✓	✓	✓	✓	
Tennessee	2012		✓	✓		✓
Texas	2013	✓	✓	✓	✓	
Iowa	2015	✓	✓	✓		✓
Pennsylvania	2016		✓	✓		
Nevada	2017	✓	✓	✓	✓	
Ohio	2017	✓	✓	✓		
Washington	2017		✓		✓	✓
Florida	2020		✓	✓	✓	✓

Virginia (1986)[20]

In 1986 Faghri and Desmetsky[20] conducted a survey of 45 State DOT's and discovered 13 different accident and hazard prediction models.[18] The analysis of the survey results indicated that many States used a combination of their own models and expert opinion. However, a plurality of States used the USDOT Accident Prediction Formula. Five models were also evaluated by prioritizing grade crossings in Virginia; (USDOT, Peabody-Dimmick, NCHRP No. 50, Coleman-Stewart, and New Hampshire Model). The study found that the USDOT model outperformed the other models and was recommended for use by the Virginia Department of Highways and Transportation.[20]

Alabama (1994)[21]

In 1994 Bowman[21] evaluated prioritization models for the State of Alabama. Like Faghri and Demetsky, the results of the study showed that most States used the USDOT Accident prediction formula or custom accident and hazard prediction formulas. It was also discovered that some States use public complaints, railroad company recommendations, accident histories, and field inspections to prioritize crossings.[18]

Oklahoma (1995)[22]

In 1995, Webb[22] studied the Oklahoma hazard index model and proposed several improvements. The intention of these improvements was to add additional considerations and variables to the prediction formula. Elements such as hazardous material traffic, the reflectivity of markings, and crossing angle were incorporated into a revised formula and tested using a dataset of Oklahoma crossings.

Illinois (2000)[23]

In 2000, Elzohairy and Benekohal[23] surveyed 49 states to identify grade crossing improvement project ranking methods. According to Abioye et al. (2020);

> "The following criteria were identified as important for ranking highway-rail grade crossings (HRGCs):
> (i) higher hazard indexes and higher number of predicted accidents.
> (ii) site review of vehicle types (mass transit, school buses).
> (iii) benefit–cost analysis.
> (iv) public concerns and complaints.
> (v) engineering judgment and HRGC geometry.
> (vi) sight distance; and
> (vii) service condition."

This survey initiated the development of the Illinois Hazard Index Formula, which was later adopted by other States.

Missouri (2003)[24]

In 2003, Qureshi et al.[24], Missouri DOT and the University of Missouri-Columbia/Rolla evaluated different accident and prediction models. The study found that the Illinois Hazard Index Formula was best suited for prioritizing active crossings and the California Hazard Rating Formula was best suited for prioritizing for passive crossings based on test dataset from Missouri.

Tennessee (2012)[25]

In 2012, a study was conducted by the University of Memphis and the Tennessee DOT.[25] Two optimization models were created to efficiently allocate capital for grade crossing improvement projects. The USDOT Accident prediction model, Tennessee's standard model, was compared to compared to other models (Peabody-Dimmick, New Hamphire Hazard Index Formula, Illinois Hazard Index, Connecticut Hazard Index Formula, and California Hazard Index Formula) and a mathematical logit model. The logit model took input variables of maximum train speed, number of trains, number of switch trains, a binary variable of urban and rural and the number of main rail road tracks to predict three categories of accidents, fatalities, injuries, and property damage only. From an accident reduction perspective, the logit model prioritized crossings more efficiently than the alternatives. Key performance indicators for the comparison were derived from the 2007 Rail–Highway grade crossing handbook's resource allocation procedure.[26]

Texas (2013)[27]

In 2013, Weissman et al. developed and evaluated the Revised Texas Priority Index as an improvement to the existing Texas priority index. The revised index was "based on a newly developed crash prediction equation, warrants for active warning devices at passive crossings, and a passive crossing prioritization index based on Utility Theory principles"[27]. Both indexes were tested on a dataset of over 9,000 grade crossings using accident data from 2011. The results showed that the revised formula "was able to identify more hazardous HRGCs as compared to the Texas Priority Index Formula"[18].

Iowa (2015)[28]

In 2015, the State of Iowa[28] initiated a study to design a better methodology for ranking grade crossings to improve efficient funding allocation. A benefit cost ratio was used to rank the crossings based on available Section 130 program funding. Based on the results of this study, Iowa DOT adopted a revised benefit-cost ratio and is expected to "result in five fewer fatalities and an increased safety benefit that totals nearly $10 million, over a 10-year period"[28]. In conjunction with this study Hans et al[29] developed an excel-based decision support tool to assist prioritizing grade crossings using the Iowa DOT's selected prioritization methods.

Pennsylvania (2016)[30]

In 2016, Gannet Fleming, Inc.[30] reviewed PennDOT's, other DOT's, and Federal approaches for grade crossing prioritization. This search included a review of federally required state action plans and research sponsored by the Transportation Research Board (TRB) and the American Public Transportation Association (APTA) for developing hazard indexes. This study serves as a basis for the further development of a PennDOT Hazard index, tailored to the unique features of Pennsylvania grade crossings.

Nevada (2017)[31]

In 2017, Ryan and Mielke[31] aimed to improve on Nevada DOT's currently adopted modified New Hampshire Index formula. The research team reviewed other prioritization indexes, interviewed western DOT experts from Arizona, Oregon, and Utah, and convened an expert panel from Federal Railroad Administration (FRA), Federal Highway Administration (FHWA), Union Pacific and Nevada DOT. The study resulted in a revised hazard index model as a replacement which utilizes "crash/near miss data, existing warning devices, highway speed, number and type of tracks, and the crossing angle."[31]

Ohio (2017)[19]

In 2017, Sperry et al[19], examined hazard ranking models for grade crossing project selection to educate Ohio DOT and other government agencies with the best practices in grade crossing prioritization. The research team conducted an extensive literature review and series of interviews from 8 States. It was discovered that most States utilized the USDOT Accident Prediction model, and 11 States use State-specific models. The study recommended the continued use of the USDOT model in Ohio.

Washington (2017)[32]

In 2017, the Joint Transportation Committee of the Washington State Legislature[32] initiated a study to prioritize grade crossings throughout the State of Washington. The committee and industry partners reviewed accident and engineering data for the State's crossing inventory and developed a framework for prioritization. This framework was implemented in a decision support tool that consisted of an online mapping tool and database. The decision support tool presented a top-50 grade crossing for upgrade or elimination.

Florida (2020)[33]

In 2020, Dulebenets et al[33], developed a decision support tool titled "HRX Safety Improvement" to assist Florida DOT personnel in prioritizing grade crossings. The developed system could both prioritize crossings based on the Florida Priority Index Formula and minimize system-wide hazards. As part of this study, and to prove its efficacy, this methodology was applied to system-wide crossings in Florida. The results of the system testing showed the sensitivity to changing budgets, severity weights, countermeasures and crossing types.

State-of-the-Art Methods

In addition to the State agency studies, advanced mathematical and statistical methods have been investigated to improve the prioritization of grade crossings. These include the use of negative binomial regression, logit models, probit models, environmental-specific studies, and international grade crossing research.

In 2002 Austin and Carson[34] developed a negative binomial regression model to prioritize crossings. Negative binomial regression is the determination of the relationship between input variables (traffic, train volume) and output variables (accidents) when the data follows a negative binomial distribution. A negative binomial distribution models the number of successes in a sequence of binary outcome trials until a specified number of failures occur. The development of this model was motivated by the limited number of explanatory variables in existing prioritization methods.

In 2006, Oh and Doohee[35], compared U.S. models to existing Korean grade crossing prioritization models. Within this study, they applied a gamma probability model to deal with limited variation between explanatory variables.

In 2010, Hu et al[36], developed a logit model to prioritize grade crossings in Taiwan. Logit models use input variables to model the probability of a binary outcome, such as "accident" or "no accident." In 2018, Khan et al[37], developed a binary logit regression model to predict accidents likelihood at grade crossings. Accident data from 2000-2016 was used in this model development and results showed that the number of trains, train speed, number of tracks, and lanes all affect accident likelihood.

In 2010, Yan et al[38] developed a hierarchical tree-based regression (HTBR) to predict and analyze passive crossings using FRA safety database information. This study was able to prioritize the crossings and present safety improvements such as stop-sign treatments. In 2014, Hao and Daniel[39] developed a probit model to evaluate driver injury severity at highway rail grade crossings. A probit model is a type of regression whose input variables can exist in two states, such as active crossing vs. passive crossing. The study showed that peak hour factors, visibility, motor vehicle speed, and other variables affected injury severity at grade crossings.

In 2014, Chadwick et al[40] studied high-speed rail and heavy axel loads operations in the U.S.. This study outlined challenges in grade crossing accident prediction. In 2017, Hao et al[41], studied the effects of foggy weather on injury severity at U.S. grade crossings.

In 2016, Hao et al[42] developed a probit model for determining injury severity of truck drivers at highway-rail grade crossing in the U.S. This was motivated by the high proportion of grade crossing accidents that involve trucks at grade crossings. In 2016, Lu and Tolliver[43] developed a Poisson regression model to handle the issue of over-dispersion and small sample size of the input variables.

In 2020, Mathew and Benekohal[60] proposed the ZINDOT model to predict the expected accidents frequency at a highway-rail grade crossing. To do so, the proposed methodology applies a zero-inflated negative binomial model by using the variables incorporated in the USDOT Accident Prediction Formula. The results showed that the ZINDOT model is capable of identifying the grade crossings with the higher number of accidents in Illinois and Texas.

In 2021, Another study, conducted by Keramati[61], generated a framework to identify hazardous HRGCs in North Dakota by using a competing risk model with hazard-ranking approaches. By using the competing risk model, one can analyze the grade crossing crash occurrence and the severity likelihoods simultaneously. Moreover, the risk analysis was carried out by employing spatial risk analysis and the risk matrix. Results showed that decision-makers are able to identify grade crossing with higher safety and operational needs by using one or a combination of hazard-ranking approaches proposed in this study.

Additionally, as summarized by Abioye et al[18], studies have been conducted to study, investigate, and improve prioritization in throughout the European Union[44], Canada[45–48], Great Britain[49,50], Hungary[51], Finland[52], France[53,54], Serbia[55,56] and Australia[57–59].

CONCLUSIONS AND RECOMMENDATIONS

This paper presents information in support of grade crossing elimination and prioritization in New Jersey. The elimination of grade crossings with the intention of reducing risk can improve public safety, decrease financial burdens, and improve service to the public. This is reinforced by federal guidance in 23 CFR 646.214(c) where "all crossings of railroads and highways at grade shall be eliminated where there is full control of access on the highway (a freeway) regardless of the volume of railroad or highway traffic." The eliminations of crossings have the highest safety increase by separating train and vehicle traffic. Additionally, highway delays and maintenance costs may be decreased. However, the elimination of crossings is costly and may have the adverse effect of increasing traffic and risk at nearby crossings.

To address these challenges, the FRA promotes grade crossing consolidation, where corridors and clusters of crossings are eliminated strategically. Grade crossing elimination and consolidation can be prompted by a variety of factors including, "locations with more than four crossings per railroad route-mile with fewer than 2,000 vehicles per day and more than two trains per day."[3]

Grade crossing prioritization varies greatly across the U.S. Many states utilize custom built hazard indexes or federally available accident prediction models. Each of these models was selected by the State agency responsible for maintaining grade crossings within their States. The optimal formulas for several states have been selected through studies conducted between 1986 and 2020. In addition, research continues to utilize advance mathematical processes to prioritize crossing projects more efficiently.

Based on the results of this literature review, accident history, highway traffic, emergency vehicle usage, distance to nearby critical civil infrastructure, distance to alternate crossings, train platforms and crossing geometry will be used to evaluate and rank the crossings in New Jersey for closure. However, a detailed review of the available data and crossing inventory is likely to increase the number of variables and will guide the selection of a prioritization model.

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APPENDIX A: NJT SELECTED GRADE CROSSINGS

Line Name	Milepost	Number of Tracks	Roadway Name	Roadway Type	Roadway Lanes	Town	County
Pascack Valley Line	21.7	1	Orchard St	Local Road	2	Hillsdale	Bergen
Pascack Valley Line	21.6	1	Park Ave	Local Road	1	Hillsdale	Bergen
Pascack Valley Line	21.5	1	Hillsdale Ave	County Road	2	Hillsdale	Bergen
Pascack Valley Line	21.4	1	Washington St	Local Road	3	Hillsdale	Bergen
Pascack Valley Line	21.2	1	Industrial Rd	Local Road	2	Westwood	Bergen
Pascack Valley Line	21.0	1	Lake St	Local Road	3	Westwood	Bergen
Pascack Valley Line	20.8	1	Irvington St	Local Road	2	Westwood	Bergen
Pascack Valley Line	20.6	1	Westwood Ave	County Road	5	Westwood	Bergen
Pascack Valley Line	20.5	1	First St	Local Road	3	Westwood	Bergen
Pascack Valley Line	14.2	1	Temple Ave	Local Road	2	Hackensack	Bergen
Pascack Valley Line	14.1	1	Main St	County Road	2	Hackensack	Bergen
Pascack Valley Line	13.9	1	Euclid Ave	Local Road	2	Hackensack	Bergen
Pascack Valley Line	13.8	1	Clinton Place	Local Road	2	Hackensack	Bergen
Pascack Valley Line	13.7	1	Anderson St	Local Road	2	Hackensack	Bergen
Pascack Valley Line	13.6	1	Passaic St	County Road	2	Hackensack	Bergen
Pascack Valley Line	13.4	1	Berry St	Local Road	2	Hackensack	Bergen
Pascack Valley Line	13.2	1	Central Ave	County Road	2	Hackensack	Bergen
Pascack Valley Line	13.0	1	Beech St	Ped Xing	0	Hackensack	Bergen
Pascack Valley Line	12.9	1	Atlantic St	Local Road	2	Hackensack	Bergen
Atlantic City Line	30.3	1	Orchard St	Local Road	2	Hammonton	Atlantic
Atlantic City Line	30.4	1	Bellevue Ave	State Highway	2	Hammonton	Atlantic
Atlantic City Line	30.5	1	Passmore Ave	Local Road	2	Hammonton	Atlantic
Atlantic City Line	30.6	1	Line St	Local Road	2	Hammonton	Atlantic
Atlantic City Line	30.8	1	11th St	Local Road	2	Hammonton	Atlantic
Atlantic City Line	31.0	1	Park Ave	Local Road	2	Hammonton	Atlantic
North Jersey Coast Line	33.4	2	Shore Rd	Local Road	2	Spring Lake	Monmouth
North Jersey Coast Line	33.3	2	Ocean Rd	Local Road	2	Spring Lake	Monmouth
North Jersey Coast Line	33.0	2	Monmouth Ave	Local Road	2	Spring Lake	Monmouth
North Jersey Coast Line	32.7	2	Warren Ave	Local Road	2	Spring Lake	Monmouth
North Jersey Coast Line	32.5	2	Brighton Ave	Local Road	2	Spring Lake	Monmouth
North Jersey Coast Line	32.4	2	St. Clair Ave	Local Road	2	Spring Lake	Monmouth

24

Line Name	Milep ost	Number of Tracks	Roadway Name	Roadway Type	Roadway Lanes	Town	County
North Jersey Coast Line	32.3	2	Ludlow Ave	Local Road	2	Spring Lake	Monmo uth
North Jersey Coast Line	32.1	2	Church St	Local Road	2	Spring Lake	Monmo uth
North Jersey Coast Line	31.9	2	Wall Rd	Local Road	2	Spring Lake	Monmo uth
North Jersey Coast Line	31.4	2	Eighteenth Ave	County Road	2	Belmar	Monmo uth
North Jersey Coast Line	31.2	2	Seventeenth Ave	Local Road	2	Belmar	Monmo uth
North Jersey Coast Line	31.0	2	Sixteenth Ave	Local Road	2	Belmar	Monmo uth
North Jersey Coast Line	31.0	2	Thirteenth Ave	Local Road	2	Belmar	Monmo uth
North Jersey Coast Line	30.9	2	Twelfth Ave	Local Road	2	Belmar	Monmo uth
North Jersey Coast Line	30.7	2	Tenth Ave	Local Road	2	Belmar	Monmo uth
North Jersey Coast Line	30.6	2	Eighth Ave	State Highway	2	Belmar	Monmo uth
North Jersey Coast Line	30.5	2	Seventh Ave	Local Road	2	Belmar	Monmo uth
North Jersey Coast Line	29.3	2	Evergreen Ave	Local Road	2	Bradley Beach	Monmo uth
North Jersey Coast Line	29.2	2	Fourth Ave	Local Road	2	Bradley Beach	Monmo uth
North Jersey Coast Line	29.1	2	Brinley Ave	County Road	2	Bradley Beach	Monmo uth
North Jersey Coast Line	29.0	2	Lareine Ave	Local Road	2	Bradley Beach	Monmo uth
North Jersey Coast Line	28.7	2	Eleventh Ave	Local Road	2	Neptune	Monmo uth
North Jersey Coast Line	28.5	2	Corlies Ave	State Highway	4	Neptune	Monmo uth
North Jersey Coast Line	28.2	2	Springwood Lake Ave	Local Road	2	Asbury Park	Monmo uth
North Jersey Coast Line	28.0	2	Bangs Ave	Local Road	2	Asbury Park	Monmo uth
North Jersey Coast Line	27.9	2	Monroe Ave	Local Road	2	Asbury Park	Monmo uth
North Jersey Coast Line	27.8	2	Asbury Ave	County Road	2	Asbury Park	Monmo uth
North Jersey Coast Line	27.7	2	First Ave	Local Road	2	Asbury Park	Monmo uth
North Jersey Coast Line	27.7	2	Second Ave	Local Road	2	Asbury Park	Monmo uth
North Jersey Coast Line	27.6	2	Third Ave	Local Road	2	Asbury Park	Monmo uth
North Jersey Coast Line	27.5	2	Fourth Ave	Local Road	2	Asbury Park	Monmo uth
North Jersey Coast Line	27.4	2	Fifth Ave	Local Road	2	Asbury Park	Monmo uth
North Jersey Coast Line	27.3	2	Sunset Ave	Local Road	2	Asbury Park	Monmo uth
North Jersey Coast Line	27.3	2	Sixth Ave	Local Road	2	Asbury Park	Monmo uth
North Jersey Coast Line	27.0	2	Grassmere Ave	County Road	2	Interlaken	Monmo uth
North Jersey Coast Line	26.6	2	Corlies Ave	Local Road	2	Allenhurst	Monmo uth
North Jersey Coast Line	26.6	2	Spier Ave	Local Road	2	Allenhurst	Monmo uth
North Jersey Coast Line	26.0	2	Drummond Ave	Local Road	2	Deal	Monmo uth
North Jersey Coast Line	25.9	2	Roseld Ave	Local Road	2	Deal	Monmo uth

Line Name	Milepost	Number of Tracks	Roadway Name	Roadway Type	Roadway Lanes	Town	County
North Jersey Coast Line	25.5	2	Sherman Ave	Local Road	2	Deal	Monmouth
North Jersey Coast Line	25.4	2	Grant Ave	Local Road	2	Deal	Monmouth
North Jersey Coast Line	25.1	2	Roosevelt Ave	Local Road	2	Deal	Monmouth
North Jersey Coast Line	24.6	2	Elberon Station Pedestrian Xing	Ped Xing	0	Long Branch	Monmouth
North Jersey Coast Line	23.4	2	Cedar Ave	County Road	2	Long Branch	Monmouth
North Jersey Coast Line	23.2	2	Brighton Ave	Local Road	2	Long Branch	Monmouth
North Jersey Coast Line	23.1	2	West End Ave	Local Road	2	Long Branch	Monmouth
Montclair Line	14.9	2	Normal Ave	County Road	2	Montclair	Essex
Montclair Line	14.7	2	Mt. Hebron Rd	Local Road	2	Montclair	Essex
Montclair Line	14.3	2	Laurel Place	Local Road	2	Montclair	Essex
Montclair Line	14.0	2	Jerome Place	Local Road	2	Montclair	Essex
Montclair Line	13.8	2	Lorraine Ave	Local Road	2	Montclair	Essex
Montclair Line	13.7	2	Bellevue Ave	Local Road	2	Montclair	Essex
Montclair Line	12.7	2	N. Fullerton Ave	Local Road	2	Montclair	Essex
Montclair Line	12.0	2	Walnut St	Local Road	2	Montclair	Essex
Montclair Line	11.9	2	Grove St	County Road	2	Montclair	Essex
Montclair Line	11.8	2	Claremont Ave	Local Road	2	Montclair	Essex
Montclair Line	11.7	2	Pine St	Local Road	2	Montclair	Essex
Main/Bergen County Line	13.8	2	Midland Ave	Local Road	2	Elmwood Park	Bergen
Main/Bergen County Line	13.6	2	Market St	County Road	4	Elmwood Park	Bergen
Main/Bergen County Line	12.9	2	Midland Ave	Local Road	2	Garfield	Bergen
Main/Bergen County Line	12.7	2	Outwater Lane	County Road	2	Garfield	Bergen
Main/Bergen County Line	12.0	2	Van Winkle Ave	Local Road	2	Garfield	Bergen
Main/Bergen County Line	11.7	2	Monroe St	Local Road	2	Garfield	Bergen
Main/Bergen County Line	11.5	2	Somerset St	Local Road	1	Garfield	Bergen
Main/Bergen County Line	11.3	2	Hobart Place	Local Road	2	Garfield	Bergen
Morristown Line	38.3	2	Orchard St	Local Road	2	Dover	Morris
Morristown Line	38.2	2	Morris St	County Road	2	Dover	Morris
North Jersey Coast Line	16.6	2	Chestnut St	Local Road	2	Red Bank	Monmouth
North Jersey Coast Line	16.4	2	Monmouth St / Bridge St	Local Road	4	Red Bank	Monmouth
North Jersey Coast Line	16.3	2	Shrewsbury Ave	County Road	2	Red Bank	Monmouth
Main/Bergen County Line	26.9	2	Goertzen Plaza	Local Road	2	Ramsey	Bergen
Main/Bergen County Line	26.6	2	Main St	County Road	2	Ramsey	Bergen
Main/Bergen County Line	24.0	3	Chestnut St	Local Road	2	Allendale	Bergen
Main/Bergen County Line	22.5	3	Hollywood Ave	Local Road	2	Ho Ho Kus	Bergen
Main/Bergen County Line	22.2	3	Warren Rd	Local Road	2	Ho Ho Kus	Bergen

APPENDIX B: PRIORITIZATION MODEL SUMMARIES

Accident Prediction Models

The State-based studies provide an overview for the performance of various grade crossing prioritization methods. Many States use the number of predicted accidents to rank grade crossings for treatment. The following list of accident prediction models were summarized by Abioye et al in 2020[18]. For each model the creator, year, formulas, and explanation of variables are presented. The following is a list of all accident prediction models presented in this review.

- The Coleman–Stewart Model
- The Iowa Accident Prediction Formula
- The Jaqua Formula
- The NCHRP Report 50 Accident Prediction Formula
- The Peabody–Dimmick Formula
- The USDOT Accident Prediction Formula

The Coleman–Stewart Model

This model was developed by Coleman and Stewart in 1976. The formula is described as follows.

$$\lg A = B_0 + B_1 \lg C + B_2 \lg T_{CS} + B_3 (\lg T_{CS})^2 \tag{1}$$

A is the Average number of accidents per HRGC per year
C = Average daily vehicular movements
T_{CS} = Average daily train movements
B_0, B_1, B_2, B_3 = Location Specific Variables

Figure 3 shows a summary of location specific variables associated with different populations (urban vs. rural), safety devices (gates, lights, signs etc.), and number of tracks (single vs. multiples).

Item	B_0	B_1	B_2	B_3	Item	B_0	B_1	B_2	B_3
Single-track urban					*Multiple-track urban*				
Automatic gates	2.17	0.16	0.96	0.35	Automatic gates	2.58	0.23	1.40	0.42
Flashing lights	2.85	0.37	1.16	0.42	Flashing lights	2.50	0.36	0.68	0.09
Crossbucks	− 2.38	0.26	0.78	− 0.18	Crossbucks	− 2.19	0.32	0.63	− 0.02
Other active	2.13	0.30	0.72	0.30	Other active	2.16	0.36	0.19	0.08
Stop signs	2.98	0.42	1.96	1.13	Stop signs	1.43	0.09	0.18	0.16
None	− 2.46	0.16	1.24	− 0.56	None	− 3.00	0.41	0.63	− 0.02
Item	B_0	B_1	B_2	B_3	Item	B_0	B_1	B_2	B_3
Single-track rural					*Multiple-track rural*				
Automatic gates	− 1.42	0.08	− 0.15	0.25	Automatic gates	− 1.63	0.22	− 0.17	0.05
Flashing lights	− 3.56	0.67	0.92	− 0.38	Flashing lights	− 2.75	0.38	1.07	− 0.36
Crossbucks	2.77	0.40	0.89	0.29	Crossbucks	2.49	0.46	0.50	0.54
Other active	2.25	0.34	0.34	0.01	Other active	2.32	0.33	0.80	0.35
Stop signs	2.97	0.61	0.02	0.29	Stop signs	1.87	0.18	0.67	0.34
None	3.62	0.67	0.22	0.26	None				

Figure 3 Coleman-Stewart Model Coefficients[18]

The Iowa Accident Prediction Formula

This model was developed by Iowa DOT and its main formula is as follows.

$$EF = AADT^{12\text{ a.m.}-6\text{ a.m.}} \times T^{12\text{ a.m.}-6\text{ a.m.}} + AADT^{6\text{ a.m.}-12\text{ p.m.}} \times T^{6\text{ a.m.}-12\text{ p.m.}} + AADT^{12\text{ p.m.}-6\text{ p.m.}} \times T^{12\text{ p.m.}-6\text{ p.m.}} + AADT^{6\text{ p.m.}-12\text{ a.m.}} \times T^{6\text{ p.m.}-12\text{ a.m.}}$$

divided by the greater of

$$[(AADT^{12\text{ a.m.}-6\text{ a.m.}})^2 + (AADT^{6\text{ a.m.}-12\text{ p.m.}})^2 + (AADT^{12\text{ p.m.}-6\text{ p.m.}})^2 + (AADT^{6\text{ p.m.}-12\text{ a.m.}})^2]$$

or

$$[(T^{12\text{ a.m.}-6\text{ a.m.}})^2 + (T^{6\text{ a.m.}-12\text{ p.m.}})^2 + (T^{12\text{ p.m.}-6\text{ p.m.}})^2 + (T^{6\text{ p.m.}-12\text{ a.m.}})^2] \quad (2)$$

$AADT^{12\text{ a.m.}-6\text{ a.m.}}$ = percentage of annual average daily traffic (AADT) between 12:00 a.m. and 6:00 a.m.
$AADT^{6\text{ a.m.}-12\text{ p.m.}}$ = percentage of AADT between 6:00 a.m. and 12:00 p.m.
$AADT^{12\text{ p.m.}-6\text{ p.m.}}$ = percentage of AADT between 12:00 p.m. and 6:00 p.m.
$AADT^{6\text{ p.m.}-12\text{ a.m.}}$ = percentage of AADT between 6:00 p.m. and 12:00 a.m.
$T^{12\text{ a.m.}-6\text{ a.m.}}$ = percentage of trains between 12:00 a.m. and 6:00 a.m.
$T^{6\text{ a.m.}-12\text{ p.m.}}$ = percentage of trains between 6:00 a.m. and 12:00 p.m.
$T^{12\text{ p.m.}-6\text{ p.m.}}$ = percentage of trains between 12:00 p.m. and 6:00 p.m.
$T^{6\text{ p.m.}-12\text{ a.m.}}$ = percentage of trains between 6:00 p.m. and 12:00 a.m.

The exposure factor, EF, is used to calculate the exposure E, of a given grade crossing.

$$E = 1.35EF \times AADT \times T \quad (3)$$

$AADT$ = annual average daily traffic
T = number of trains per day

The exposure is then used to calculate the number of predicted accidents, PA.

$$PA = 0.0006938\left[\frac{E+0.2}{0.2}\right]^{0.37}\left[\frac{d+0.2}{0.2}\right]^{0.1781} e^{(0.0077ms)}e^{[-0.5966(hp-1)]} \quad (4)$$

d = daylight thru trains per day
ms = maximum timetable speed
hp = 1 if an HRGC is on a paved road, 2 if an HRGC is on a dirt or gravel road

The predicted accidents are then adjusted to PA^{adj}, based on the number of accidents in the last 5 years.

$$PA^{adj} = 0.65\frac{PA\left[\frac{1}{0.05+PA}\right]+N_5}{\left[\frac{1}{0.05+PA}\right]+5} \quad (5)$$

An alternate formula, below, can be used if the intersecting roadway is a highway.

$$PA = 0.0003351\left[\frac{E+0.2}{0.2}\right]^{0.4106}\left[\frac{d+0.2}{0.2}\right]^{0.1131} e^{(0.1917mt)}e^{[0.1826(hl-1)]} \quad (6)$$

$$PA^{adj} = 0.5001\frac{PA\left[\frac{1}{0.05+PA}\right]+N_5}{\left[\frac{1}{0.05+PA}\right]+5} \quad (7)$$

mt = number of main tracks
hl = number of highway lanes

Additionally, the number of fatal accidents, PA^{fat}, injury accidents, PA^{cas}, and property accidents, PA^{prop}, can be isolated.

$$PA = 0.0005745\left[\frac{E+0.2}{2}\right]^{0.2942}\left[\frac{d+0.2}{0.2}\right]^{0.1781} e^{(0.1512mt)}e^{[0.142(hl-1)]} \quad (8)$$

$$PA^{adj} = 0.5725\frac{PA\left[\frac{1}{0.05+PA}\right]+N_5}{\left[\frac{1}{0.05+PA}\right]+5} \quad (9)$$

$$PA^{fat} = \frac{PA^{adj}}{1+440.9ms^{-0.9981}(T+1)^{-0.0873}(ST+1)^{0.0872}e^{(0.3571ht)}} \quad (10)$$

$$PA^{cas} = \frac{PA^{adj}}{1+[4.481ms^{-0.343}e^{0.1153mt}e^{0.2960ht}]} \quad (11)$$

$$PA^{inj} = PA^{cas} - PA^{fat} \quad (12)$$

$$PA^{prop} = PA^{adj} - PA^{cas} \tag{13}$$

ST = number of switch trains per day
ht = 1 if an HRGC is in urban settings, 0 if an HRGC is in rural settings

The Jaqua Formula

This formula was developed by the State of Oregon and its primary formula is as follows.

$$ACC5 = \frac{ABC}{1610} \tag{14}$$

$$A = \sum_{i=1}^{n} T_i \left(\frac{C_i V}{3S_i} + V\right) \tag{15}$$

$ACC5$ = accident prediction for the next 5 years
A = exposure factor
n = number of train types
T_i = number of trains of type i
S_i = speed of a train of type i
V = AADT
B = hazard rating (depends on number of tracks, speed of vehicles and trains, number of blind quadrants, number of lanes, angle of intersection, approach grade, curvature of roadway, existence of entrances and exits to the streets as well as the street intersections near an HRGC)
C = protection factor (depends on type of area [urban vs. rural] and the type of existing warning devices at the HRGCs)

The NCHRP Report 50 Accident Prediction Formula

This model was developed within the research efforts of the National Cooperative Highway Research Program (NCHRP) Report 50. The formula is as follows.

$$N = A \times B \times T_{nc} \tag{16}$$

N = Accidents per year
A = Daily Highway Vehicles
B = Active Warning Devices
T_{nc} = Train volume per Day

Variables for the daily highway vehicles, and active warning devices can be seen in Figure 4 and Figure 5 respectively.

Vehicles per day (10-year AADT)	A	Vehicles per day (10-year AADT)	A
250	0.000347	9000	0.011435
500	0.000694	10,000	0.012674
1000	0.001377	12,000	0.015012
2000	0.002627	14,000	0.017315
3000	0.003981	16,000	0.019549
4000	0.005208	18,000	0.021736
5000	0.006516	20,000	0.023877
6000	0.007720	25,000	0.029051
7000	0.009005	30,000	0.034757
8000	0.010278		

Figure 4 NCHRP Report 50 Accident Prediction Formula A Values based on 10-year AADT[18]

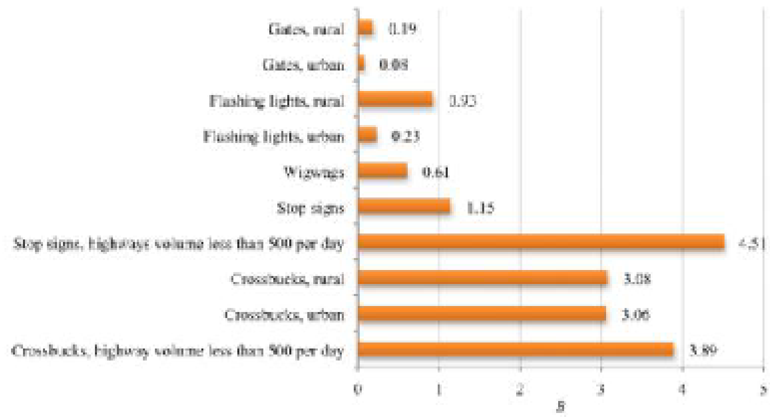

Figure 5 NCHRP Report 50 Accident Prediction Formula B Values[18]

The Peabody–Dimmick Formula

This formula was developed by the US Bureau of Public Roads in 1941 and is as follows.

$$A_5 = K + \frac{1.28V^{0.170} \times T_{pd}^{0.151}}{P^{0.171}} \quad (17)$$

- A_5 = expected number of accidents in 5 years
- V = annual average daily traffic factor
- T_{pd} = average daily train traffic factor
- P = protection coefficient
- K = additional parameter

The average annual daily traffic factor can be determined by Figure 6. The average daily train factor can be determined by Figure 7. The protection coefficient can be determined by Figure 8. The additional parameter, K, can be determined by the following formula and Figure 9.

$$l_u = 1.28\frac{V^a \times T^b}{P^c} \tag{18}$$

Within formula 18, V^a, T^b, and P^c are the accident factors (i.e., the annual average daily traffic factor, the average daily train traffic factor, and the protection coefficient).

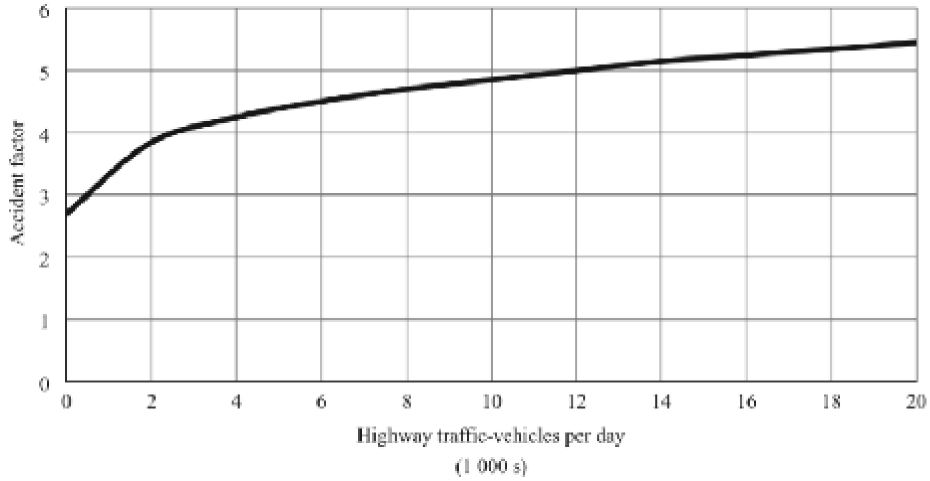

Figure 6 Peabody–Dimmick Formula[18] Highway Traffic Accident Factor

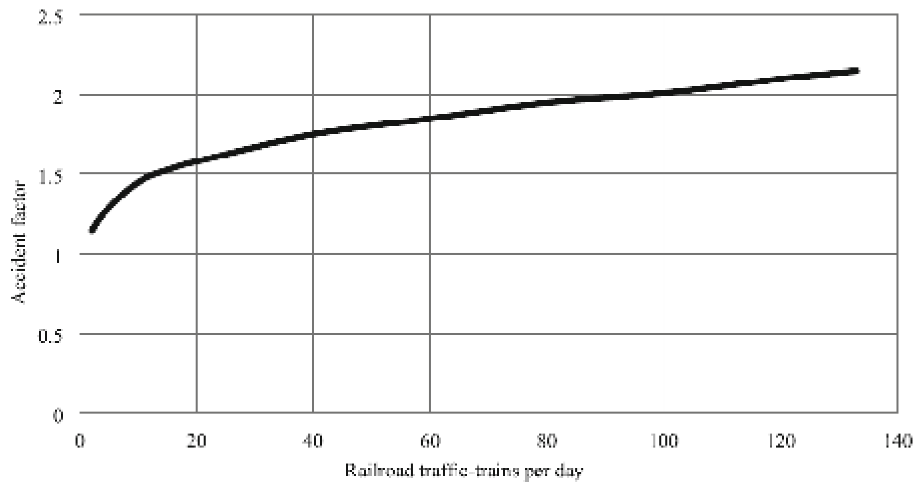

Figure 7 Peabody–Dimmick Formula[18] Railroad Train Traffic Accident Factor

32

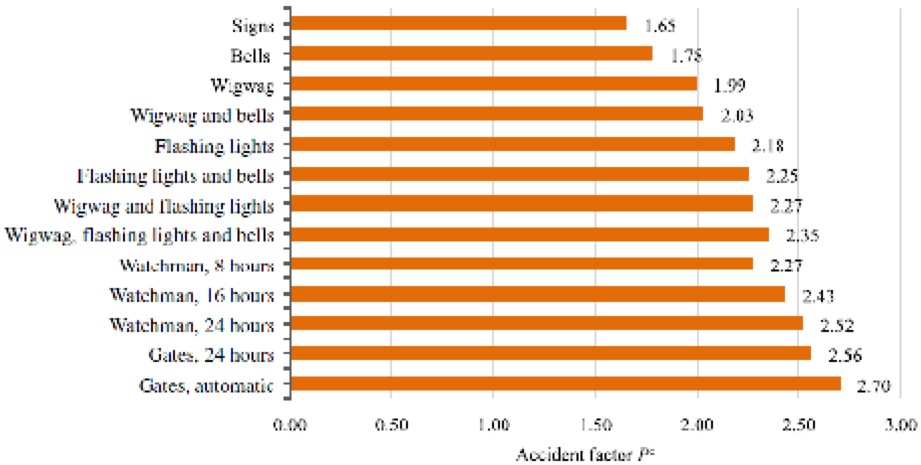

Figure 8 Peabody–Dimmick Formula[18] Protection Coefficient

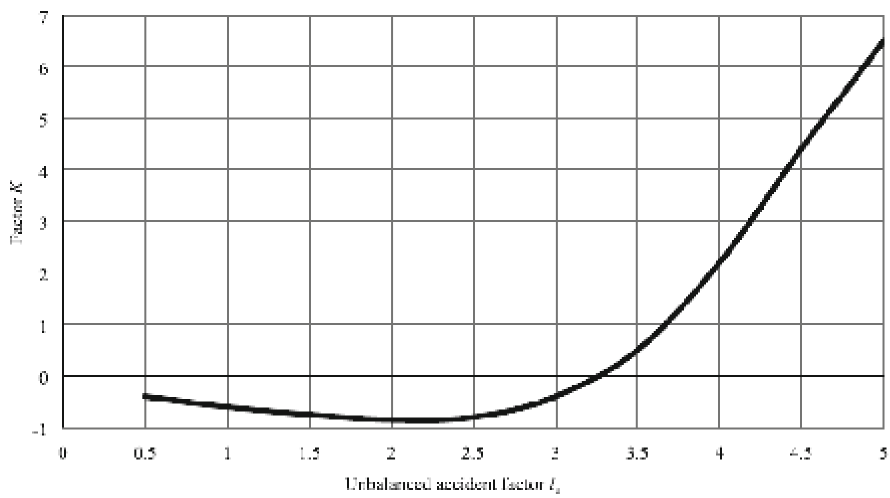

Figure 9 Peabody–Dimmick Formula[18] Unbalanced Accident Factor

The USDOT Accident Prediction Formula

This model was developed by the USDOT and was finalized in 1986. Its coefficients have been updated periodically to account for changes in traffic patterns and technological developments. The formula is as follows.

$$a = K \times EI \times MT \times DT \times HP \times MS \times HT \times HL \tag{19}$$

a = initial accident prediction, accidents per year
K = formula constant
EI = factor for exposure index based on product of highway and train traffic
MT = factor for number of main tracks
DT = factor for number of through trains per day during daylight
HP = factor for highway paved, yes or no
MS = factor for maximum timetable speed
HT = factor for highway type
HL = factor for number of highway lanes

Figure 10 shows the grade crossing characteristic factors for the initial USDOT Accident Prediction Formula.

Crossing category	Formula constant K	Exposure index factor EI	Main tracks factor MT	Day thru trains factor DT	Highway paved factor HP	Maximum speed factor MS	Highway type factor HT	Highway lanes factor HL
Passive	0.002268	$\left(\frac{c \times t+0.2}{0.2}\right)^{0.3334}$	$e^{0.2094mt}$	$\left(\frac{d+0.2}{0.2}\right)^{0.1336}$	$e^{-0.6160(hp-1)}$	$e^{0.0077ms}$	$e^{-0.1000(ht-1)}$	1.0
Flashing lights	0.003646	$\left(\frac{c \times t+0.2}{0.2}\right)^{0.2953}$	$e^{0.1088mt}$	$\left(\frac{d+0.2}{0.2}\right)^{0.0470}$	1.0	1.0	1.0	$e^{0.1380(hl-1)}$
Gates	0.001088	$\left(\frac{c \times t+0.2}{0.2}\right)^{0.3116}$	$e^{0.2912mt}$	1.0	1.0	1.0	1.0	$e^{0.1036(hl-1)}$

c denotes the annual average number of highway vehicles per day (total in both directions); t is the average total train movements per day; mt is the number of main tracks; d is the average number of thru trains per day during daylight; hp is the highway paved (1.0 for paved and 2.0 for unpaved); ms is the maximum timetable speed in mph; ht is the highway type factor value; hl is the number of highway lanes

Highway type	Inventory code	ht
Rural		
Interstate	01	1
Other principal arterial	02	2
Minor arterial	06	3
Major collector	07	4
Minor collector	08	5
Local	09	6
Urban		
Interstate	11	1
Other freeway and expressway	12	2
Other principal arterial	14	3
Minor arterial	16	4
Collector	17	5
Local	19	6

Figure 10 Grade Crossing Characteristic Factors For Initial USDOT Accident Prediction Formula[18]

After an initial prediction is made a second prediction is calculated using the following formula.

$$B = \frac{T_0}{T_0 + T_y}(a) + \frac{T_0}{T_0 + T_y}\left(\frac{N}{T_y}\right) \tag{20}$$

B = second accident prediction, accidents per year
a = initial accident prediction, accidents per year
$\frac{N}{T}$ = accident history prediction, accidents per year
N = number of accidents observed in T_y years

T_0 = formula weighting factor, $T_0 = \frac{1}{0.05+a}$

After both calculations are completed a final accident prediction is made with the following formula.

$$final\ accident\ prediction = B \times A \tag{20}$$

A = normalizing constant

The normalizing constants are adjusted at regular intervals and can be seen in Figure 11.

Table 6 Values of the normalizing constants for the accident prediction and resource allocation procedure

Warning device groups	New	Prior year constants							
	2010	2007	2005	2003	1998	1992	1990	1988	1986
Passive	0.4613	0.6768	0.6407	0.6500	0.7159	0.8239	0.9417	0.8778	0.8644
Flashing lights	0.2918	0.4605	0.5233	0.5001	0.5292	0.5935	0.8345	0.8013	0.8887
Gates	0.4614	0.6039	0.6513	0.5725	0.4921	0.5714	0.8901	0.8911	0.8131

Figure 11 Value of the normalizing constants for the accident prediction and resource allocation procedure[18]

Hazard Prediction Models

In addition to accident prediction models, many States use a hazard rating to rank grade crossings for treatment. The following list of hazard rating models were summarized by Abioye et al in 2020[18]. For each model the creator, year, formula, and explanation of variables are presented. The following is a list of all hazard rating models presented in this review.

- The Arkansas Hazard Rating Formula
- The California Hazard Rating Formula
- The Connecticut Hazard Rating Formula
- The Florida Accident Prediction and Safety Index Formula
- The Illinois Hazard Index Formula
- The Kansas Design Hazard Rating Formula
- The Michigan Hazard Index Formula
- The Missouri Exposure Index Formula
- The Nevada Hazard Index Formula
- The New Hampshire Hazard Index Formula
- The New Mexico Hazard Index Formula
- The North Carolina Investigative Index Formula
- The Revised Texas Priority Index Formula
- The South Dakota Hazard Index Formula
- The Texas Priority Index Formula

The Arkansas Hazard Rating Formula

This formula was developed by the Arkansas Highway and Transportation Department and is as follows.

$$AHR = HTP \times RTP \times ARP \tag{21}$$

AHR = Arkansas Hazard Rating of an HRGC
HTP = highway traffic points, 5 points maximum (depending on ADT), up to 75% of points depend on number of trains, rest depend on number of side and main tracks at an HRGC
ARP = accident record points, 4 points maximum (depending on number of accidents over past 15 years)

The California Hazard Rating Formula

This formula was developed by the California Public Utilities Commission and is as follows.

$$CaHI = \frac{V \times T \times PF}{1000} + AH \tag{22}$$

$CaHI$ = California Hazard Index
V = number of vehicles
T = number of trains
PF = protection factor (1.00 for stop signals or crossbucks, 0.67 for wigwags, 0.33 for flashing lights, and 0.13 for gates)
AH = accident history (total number of accidents in last 10 years multiplied by factor of 3)

The Connecticut Hazard Rating Formula

This formula was developed by the Connecticut Department of Transportation and is as follows.

$$CoHI = \frac{(T+1)(A+1) \times AADT \times PF}{100} \tag{23}$$

$CoHI$ = Connecticut Hazard Index
$AADT$ = average annual daily traffic
T = number of trains per day
PF = protection factor (1.25 for passive warning devices, 1.00 for stop signal control, 0.75 for stop signals and protection control, 0.75 for manually activated traffic signals, 0.25 for railroad flashing lights, 0.25 for traffic signal control preemption, 0.01 for gates with railroad flashing lights, 0.001 for inactive rail line)
A = accident history (total number of accidents in last 5 years)

The Florida Accident Prediction and Safety Index Formula

This formula was developed by Florida Department of Transportation. The predicted number of accidents in a 4-year period with passive, t_p, or active, t_a, can be calculated.

$$t_p = -8.075 + 0.318 \ln S_t + 0.484 \ln T + 0.437 \ln A + 0.387 \ln V_v + \left(0.28 - 0.28\frac{MASD}{RSSD}\right) + \left(0.33 - 1.23\frac{MCSD}{RSSD}\right) + 0.15 N_{xbucks} \tag{24}$$

36

$$y = \frac{e^{0.968t_p+1.109}}{4} \quad (25)$$

$$t_a = -8.075 + 0.318 \ln S_t + 0.166 \ln T + 0.293 \ln A + 0.387 \ln V_v + \left(0.28 - 0.28\frac{MASD}{RSSD}\right) + 0.225(L-2) - 0.233P_g \quad (26)$$

A = vehicles per day or annual average daily traffic
L = number of lanes
$MASD$ = actual minimum stopping distance along a highway
$MCSD$ = clear sight distance (ability to see an approaching train along a highway, recorded for the four quadrants established by the intersection of the railroad tracks and that highway)
$RSSD$ = required stopping sight distance on wet pavement
S_t = maximum speed of a train
T = yearly average number of trains per day
V_v = posted vehicle speed limit unless geometrics dictates a lower speed
N_{xbucks} = total number of crossbucks at an HRGC
P_g = gate presence indicator (1 if gated, 0 if not)

Following those calculations, the predicted number of accidents per year, y, at a grade crossing can be calculated.

$$y = \frac{e^{0.938t_a+1.109}}{4} \quad (27)$$

Once the prediction number of accidents is determined they are adjusted to, Y, based on accident history.

$$Y = y\sqrt{\frac{H}{yP}} \quad (28)$$

y = accident prediction based on the regression model
H = number of accidents for the 6-year history or since the year of last improvement
P = number of years of the accident history period

A safety index, R,can then be determined.

$$R = X(1 - \sqrt{Y}) \quad (29)$$

Y = adjusted accident prediction value

37

X = 90 when less than 10 school buses per day traverse an HRGC, 85 when 10 or more school buses traverse an HRGC with active traffic control devices without gates, 80 when 10 or more school buses per day traverse an HRGC with passive traffic control devices

The Illinois Hazard Index Formula

This formula was developed by the State of Illinois to calculate the Illinois hazard index, IHI, and is as follows.

$$\mathrm{IHI} = 10^{-6}\mathrm{A}^{2.59088}\mathrm{B}^{0.09673}\mathrm{C}^{0.40277}\mathrm{D}^{0.59262}(15.59\mathrm{N}^{5.60977} + \mathrm{PF}) \quad (30)$$

$$\mathrm{A} = \ln(\mathrm{ADT} \times \mathrm{NTT}) \quad (31)$$

ADT = average daily traffic
NTT = number of total trains per day
B = maximum timetable speed in mph
C = number of main and other tracks
D = number of highway lanes
N = average number of accidents per year (generally, a 5-year period is considered)
PF = protection factor (86.39 for crossbucks, 68.97 for flashing lights, 37.57 for gates)

The Kansas Design Hazard Rating Formula

This formula was developed by the Kansas DOT to determine the Kansas Design Hazard Rating, $KDHR$.

$$KDHR = \frac{A(B + C + D)}{4} \quad (32)$$

$$A = \frac{HT(2NFT + NST)}{400} \quad (33)$$

HT = highway traffic
NST = number of slow trains (switch trains are not included)

$$B = 2\sqrt[3]{\frac{8000}{SMSD}} \quad (34)$$

$SMSD$ = sum of maximum sight distance 4 ways

$$C = \sqrt{\frac{90}{AI}} \quad (35)$$

AI = angle of intersection
D = main track factor (1.00 for 1 track, 1.50 for 2 tracks, 1.80 for 3 tracks, 2.00 for

38

4 tracks)

The Michigan Hazard Index Formula

The Michigan Hazard Index is determined by using the New Hampshire Hazard Index Formula with a modified protection factor (PF) found in Figure 12.

Protection type	Factor
Flashing light signals with cantilever arms, half-roadway gates, and traffic signal interconnection	0.05
Flashing light signals with cantilever arms and half-roadway gates	0.08
Flashing light signals with half-roadway gates	0.11
Flashing light signals with cantilever arms and traffic signal interconnect	0.24
Flashing light signals with cantilever arms	0.27
Flashing light signals	0.30
Stop and flag procedures	0.75
Stop sign	0.80
Reflectorized crossbuck with or without a yield sign	1.00

Figure 12 Protection Factor used by Michigan Hazard Index Formula

The Missouri Exposure Index Formula

This formula was developed by the Missouri DOT to determine the Missouri Exposure Index, MEI.

$$MEI = TI + SDO \times TI \tag{36}$$

For active upgrade: $MEI = TI$

$$SDO = \frac{RSD - ASD}{RSD} \tag{37}$$

RSD = required sight distance
ASD = actual sight distance

$$TI = \frac{(VM \times VS)(FM \times FS + PM \times PS + 10SM)}{10{,}000} \tag{38}$$

VM = vehicle movements
VS = vehicle speed
FM = freight train movements
FS = freight train speed
PM = passenger train movements
PS = passenger train speed
SM = switching movements

The Nevada Hazard Index Formula

This formula was developed by Ryan and Mielke to determine the Nevada Hazard Index, NHI, and is as follows.

$$NHI = \sqrt{EI} \times ANMF \times PF \times HSF \times RSF \times TCF \times CAF \tag{39}$$

EI = exposure index, product of average daily highway traffic and daily train volume
$ANMF$ = accident and near miss factor

$$ANMF = 1.3^{A+\frac{N}{3}} \quad (40)$$

A = accidents within past 5 years
N = number of near misses within past 3 years
PF = protection factor (0.15 for 4 quad gate or gates with medians, 0.30 for gates only, 1.00 for flashing lights or passive)
HSF = highway speed factor (0.50 for 0 to 15 mph, 1.00 for 20 to 35 mph, 1.50 for 40 to 65 mph, 2.00 for 70 mph or above)
RSF = rail speed factor (1.00 for 0 to 59 mph, 1.50 for 60 mph and above)
TCF = track configuration factor (1.25 for 1 siding/other track, 1.50 for 2 siding/other tracks, 2.00 for 3 or more siding/other tracks)
CAF = HRGC angle factor (2.00 for 0° to 30°, 1.50 for 30° to 60°, 1.00 for 60° to 90°)

The New Hampshire Hazard Index Formula

This formula was developed by the New Hampshire DOT to calculate the New Hampshire Hazard Index, $NHHI$, and is as follows.

$$NHHI = V \times T_{nh} \times PF \quad (41)$$

V = AADT
T_{nh} = Annual volume of trains
PF = Protection factor 1.00 for stop signs, 0.60 for flashing lights, and 0.10 for gates

The New Mexico Hazard Index Formula

This formula was developed by the New Mexico State Highway and Transportation Department based on the Modified New Hampshire Hazard Index Formula. It is intended to calculate the New Mexico Hazard Index, $NMHI$, and is as follows.

$$NMHI = \frac{TADT \times VADT \times PF}{100} SD_f \times T_s \times AH_f \quad (42)$$

$TADT$ = train ADT
$VADT$ = highway vehicle ADT
PF = protection factor (0.11 for gates, 0.20 for lights, 0.34 for wigwags, 0.58 for signs, 1.00 for crossbucks, 2.00 for no protection)
SD_f = sight distance factor (1.0 for no restrictions, 1.2 for restrictions at one quadrant, 1.5 for restrictions at more than one quadrant)
T_s = train speed in mph

$$AH_f = A + B + C \quad (43)$$

A = 0.10 for each property damage only accident
B = 0.20 for each injury accident
C = 0.30 for each fatal accident

The North Carolina Investigative Index Formula

This formula was developed by the North Carolina DOT to calculate the North Carolina Investigative Index, $NCII$, and is as follows.

$$NCII = \frac{PF \times ADT \times TV \times TSF \times TF}{160} + \left(\frac{70A}{Y}\right)^2 + SDF \tag{44}$$

PF = protection factor (1.0 for no warning devices or crossbucks, 0.50 for traffic signals, 0.20 for flashing lights, 0.10 for gates)
ADT = average daily traffic (when school buses use an HRGC, add $N_p/1.2$ [N_p denotes number of school bus passengers] to ADT, when passenger trains use an HRGC, multiply ADT by average vehicle occupancy, which is 1.2)
TV = train volume
TSF = train speed factor, $TSF = \frac{V_{ma}}{50} + 0.8$ and V_{ma} = maximum allowable train speed
TF = track factor (depends on number of through tracks and number of total tracks)
$\frac{A}{Y}$ = number of train-vehicle accidents per year, and 10-year accident history required
SDF = sight distance factor, $SDF = 16\,\Sigma(\frac{\mathrm{SDF_n}}{4})$, SDF_n = sight distance factor for quadrant n (0 for clear sight, 2 for average sight, 4 for poor sight)

The Revised Texas Priority Index Formula

This formula was developed by Weissmann et al. to calculate the Revised Texas Priority Index, TPI_{rev}, and is as follows.

$$TPI_{rev} = 1000\hat{\mu}(A_5 + 0.1) \tag{45}$$

$$\begin{aligned}\hat{\mu} = \exp\,[&-6.9240 + PF + 0.2587hp - 0.3722ht + 0.0706hl + 0.0656tt + 0.0022ASD \\ &+ 0.0143mst^{max} + 0.0126mst^{min} + 1.0024\lg(T + 0.5) \\ &+0.4653\lg(AADT) - 0.2160NIP + 0.0092msv]\end{aligned} \tag{46}$$

$\hat{\mu}$ = predicted number of accidents per year at an HRGC
PF = protection factor (0.5061 for flashing lights, -0.2006 for gates, 0.0000 for passive)
hp = highway pavement factor (1 for paved, 2 for unpaved)
ht = urban/rural designation factor (1 for urban, 2 for rural)
hl = number of traffic lanes
tt = number of main and other tracks

ASD = actual sight distance, approach 1
mst^{max} = maximum train speed (through trains)
mst^{min} = minimum train speed (switching trains)
T = daily train volume
$AADT$ = vehicular AADT
NIP = nearby roadway intersection presence (1 if present, 2 if not present)
msv = higher roadway speed limit between approach 1 and approach 2
A_5 = number of accidents in last 5 years at an HRGC

$$AF_{pas} = 1.5(nw + c) \tag{47}$$

AF_{pas} = adjustment factor for warranted passive HRGCs
nw = number of warrants met
c = number of accidents in most recent 5-year period

The South Dakota Hazard Index Formula

This formula was developed by the State of South Dakota to calculate the South Dakota Hazard Index, $SDHI$, and is as follows.

$$SDHI = \frac{TV \times ADT \times PF \times OF}{5} \tag{48}$$

TV = trains per day
ADT = average daily highway traffic
PF = HRGC protection factor
OF = obstruction factor

The Texas Priority Index Formula

This formula was developed by the Texas DOT to calculate the Texas Priority Index, TPI, and is as follows.

$$TPI = V \times T \times 0.1S \times PF \times 0.01A^{1.15} \tag{49}$$

V = average daily traffic volume
PF = protection factor (1.00 for passive, 0.70 for mast-mounted flashing lights, 0.15 for cantilever flashing lights, 0.10 for gates)
A = train accidents in past 5 years (default = 1)

APPENDIX C: ACCIDENT PREDICTION AND HAZARD INDEX KEY FACTORS

Understanding the key factors for prioritizing crossings is imperative to effective data gathering and grade crossing elimination ranking. **Error! Reference source not found.** shows a summary of the common factors used in accident prediction models. Variables were combined in several instances to provide an aggregate view of the formula features.

Table 5 Grade Crossing Accident Prediction Model Features

	Coleman -Stewart	Iowa Accident Prediction Formula	Jaqua Formula	NCHRP Report 50 Accident Prediction Formula	Peabody-Dimmick	USDOT Accident Prediction Formula
Train Traffic	✓	✓	✓	✓	✓	✓
Vehicle Traffic	✓	✓	✓	✓	✓	✓
Protection Features	✓		✓	✓	✓	✓
Historical Accident Data	✓	✓		✓		✓
Number of Tracks	✓	✓	✓			✓
Population Density	✓	✓	✓			
Train Speed		✓	✓			✓
Highway Lanes		✓	✓			✓
Train Types		✓	✓			
Train Schedule (Daytime vs. Night Time)		✓				✓
Highway Vehicle Speed			✓			✓
Roadway Material		✓				✓
Highway Geometry, Grade, Curvature			✓			
Nearby Entrance and Exits			✓			

Train traffic and vehicle traffic, usually in the form of AADT, are present in every accident prediction formula. Following this, protection features are present in nearly all accident prediction models and consist of custom factors associated with the presence of light, gates, and other safety equipment. The remainder of the variables, such as historical accident data, number of tracks etc., are present in four or less of the six models presented.

The Jaqua formula considers the largest variation of variables out of all the different models. The unique features include the consideration of nearby entrances and exits to the highway and highway geometry like curvature, grade, and sight distance. The Iowa Accident Prediction Model and the USDOT Accident Prediction Model consider ten different variables, including the number of tracks, train speed, train schedule, number of highway lanes, etc.

Error! Reference source not found. shows a summary of the common factors used in hazard prediction models. Of the 15 models chosen in this study nearly all utilize highway, train traffic, protection features, and accident records to determine the relative hazard of a grade crossing. Less commonly used are values like train speed, highway sight distance, number of train tracks, type of tracks, highway speeds, and highway lanes.

The revised Texas priority index and the Florida accident prediction model consider the greatest number of variables. The original Texas Priority Index Formula and the New Hampshire Hazard Index consider the fewest variables.

Table 6 Grade Crossing Hazard Prediction Model Features

	The Arkansas Hazard Rating Formula	The California Hazard Rating Formula	The Connecticut Hazard Rating Formula	The Florida Accident Prediction and Safety Index	The Illinois Hazard Index Formula	The Kansas Design Hazard Rating Formula	The Michigan Hazard Index Formula	The Missouri Exposure Index Formula	The Nevada Hazard Index Formula	The New Hampshire Hazard Index Formula	The New Mexico Hazard Index Formula	The North Carolina Investigative Index Formula	The Revised Texas Priority Index Formula	The South Dakota Hazard Index Formula	The Texas Priority Index Formula
Highway Traffic	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Train Traffic	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Protection Features		✓	✓	✓	✓		✓		✓	✓	✓	✓	✓	✓	✓
Accident Records	✓	✓	✓	✓	✓		✓		✓		✓	✓	✓		✓
Train Speed				✓	✓		✓	✓	✓		✓	✓	✓		
Highway Sight Distance				✓		✓		✓			✓	✓		✓	
Train Tracks and Type	✓				✓	✓	✓		✓			✓	✓		
Highway Speed				✓				✓	✓				✓		
Highway Lanes				✓	✓		✓						✓		
Highway Traffic Types				✓								✓			
Highway Geometry						✓			✓						
Near Misses									✓						
Population Density													✓		
Highway Stopping Distance				✓											
Highway Pavement													✓		
Nearby Intersections													✓		
Train Types								✓							