Civil and Environmental Engineering

FLORIDA A&M UNIVERSITY-FLORIDA STATE UNIVERSITY (FAMU-FSU) COLLEGE OF ENGINEERING

Selection of Level Crossings for Closure in the State of Florida: An Optimization-based Approach

Project Number: BED30-977-04

A Technical Report Submitted to the Florida Department of Transportation, Freight and Rail Office

FINAL REPORT

FDOT Project Manager: **Eugene Jules**, Freight and Rail Planner, Freight and Rail Office

Principal Investigator:
Maxim A. Dulebenets, Ph.D., P.E.
Associate Professor
Department of Civil & Environmental Engineering
Florida A&M University-Florida State University
Phone: +1(850) 410-6621
E-mail: mdulebenets@eng.famu.fsu.edu

Co-Principal Investigator:
Ren Moses, Ph.D., P.E.
Professor
Department of Civil & Environmental Engineering
Florida A&M University-Florida State University
Phone: +1(850) 410-6191
E-mail: moses@eng.famu.fsu.edu

Co-Principal Investigator:
John Sobanjo, Ph.D., P.E.
Professor
Department of Civil & Environmental Engineering
Florida A&M University-Florida State University
Phone: +1(850) 410-6153
E-mail: sobanjo@eng.famu.fsu.edu

Co-Principal Investigator:
Eren E. Ozguven, Ph.D.
Associate Professor
Department of Civil & Environmental Engineering
Florida A&M University-Florida State University
Phone: +1(850) 410-6146
E-mail: eozguven@eng.famu.fsu.edu

Research Assistant:
Zeinab Elmi, Ph.D.
Postdoctoral Research Associate
Department of Civil & Environmental Engineering
Florida A&M University-Florida State University
E-mail: ze20a@fsu.edu

Research Assistant:
Bokang Li, B.Sc.
Graduate Research Assistant
Department of Civil & Environmental Engineering
Florida A&M University-Florida State University
E-mail: bl22a@fsu.edu

June 2024

DISCLAIMER

The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the State of Florida Department of Transportation.

METRIC CONVERSION CHART

When You Know	Multiply by	To Find
Length		
inches (in)	25.4	millimeters (mm)
feet (ft)	0.305	meters (m)
yards (yd)	0.914	meters (m)
miles (mi)	1.61	kilometers (km)
Volume		
fluid ounces (fl oz)	29.57	milliliters (mL)
gallons (gal)	3.785	liters (L)
cubic feet (ft^3)	0.028	meters cubed (m^3)
cubic yards (yd^3)	0.765	meters cubed (m^3)
Area		
square inches (in^2)	645.1	millimeters squared (mm^2)
square feet (ft^2)	0.093	meters squared (m^2)
square yards (yd^2)	0.836	meters squared (m^2)
acres	0.405	hectares (ha)
square miles (mi^2)	2.59	kilometers squared (km^2)

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle	5. Report Date
Selection of Level Crossings for Closure in the State of Florida: An Optimization-based Approach	06/30/2024
	6. Performing Organization Code 59-1961248
7. Author(s) Maxim A. Dulebenets, Ph.D., P.E.; Ren Moses, Ph.D., P.E.; John Sobanjo, Ph.D., P.E.; Eren E. Ozguven, Ph.D.; Zeinab Elmi, Ph.D.; Bokang Li	8. Performing Organization Report No. 101504
9. Performing Organization Name and Address Florida A&M University-Florida State University 2035 E Paul Dirac Dr., Sliger Building, Suite 275 Tallahassee, FL 32310, USA	10. Work Unit No. (TRAIS)
	11. Contract or Grant No. BED30-977-04
12. Sponsoring Agency Name and Address Florida Department of Transportation 605 Suwannee Street, MS 30 Tallahassee, FL 32399	13. Type of Report and Period Covered Final Report Period Covered: 06/15/2022-06/30/2024
	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

Rail transportation plays a crucial role for the development of the State of Florida. However, collisions at level crossings (i.e., locations where highway segments intersect a given railroad segment at the same elevation) are one of the major concerns across the state. Implementation of different countermeasures (e.g., wigwags, flashing lights, gates, cameras) is considered a common approach to improve safety at level crossings. Nevertheless, the funding for level crossing safety improvement projects is limited and does not allow upgrading all the hazardous crossings across the state. Closure of level crossings is another alternative that can be used to address the issue of level crossing safety and assist with building a reliable, well-connected, and safe multimodal transportation network. As a part of this project, a new optimization model is proposed with the goal of maximizing the total benefit from level crossing closures, including safety benefits, economic benefits, and environmental benefits. A heuristic algorithm is developed to solve the proposed optimization model. Additionally, a Web application called "HRX_Safety_Improvement" is designed as a part of this project. The "HRX_Safety_Improvement" Web application aims to assess the benefits of closing level crossings and prioritize level crossings for closures. Last but not least, a number of sensitivity analyses are conducted to demonstrate the potential of the proposed methodology. The experiments show that the developed mathematical model and Web application can serve as an effective decision support system and assist with maximizing the total benefit associated with closures under different total budget availability scenarios, sets of benefit weight values, and various crossing type scenarios.

17. Key Words	18. Distribution Statement
Level crossings; crossing collisions; traffic delays; vehicle emissions; level crossing closures; decision support systems	No restrictions

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	108	

ACKNOWLEDGEMENTS

This project was sponsored by the State of Florida Department of Transportation (FDOT). The Principal Investigators would like to thank the FDOT Project Manager Mr. Eugene Jules and the FDOT Freight and Rail Office for their valuable feedback throughout the project activities.

EXECUTIVE SUMMARY

Rail transportation plays a crucial role for the development of the State of Florida. However, collisions at level crossings (i.e., locations where highway segments intersect a given railroad segment at the same elevation) are one of the major concerns across the state. Implementation of different countermeasures (e.g., wigwags, flashing lights, gates, cameras) is considered a common approach to improve safety at level crossings. Nevertheless, the funding for level crossing safety improvement projects is limited and does not allow upgrading all the hazardous crossings across the state. Closure of level crossings is another alternative that can be used to address the issue of level crossing safety and assist with building a reliable, well-connected, and safe multimodal transportation network.

As a part of this project, a new optimization model was proposed with the goal of maximizing the total benefit from level crossing closures. The benefits from crossing closures were categorized into three groups, including the following: (1) safety benefits; (2) economic benefits; and (3) environmental benefits. The proposed mathematical model can also incorporate certain practical considerations when assessing the level crossing closure decisions (e.g., proximity of a given level crossing to other level crossings, the frequency of using a given level crossing when providing emergency services, potential highway traffic diversion to alternative level crossings and routes). A heuristic algorithm was developed to solve the proposed optimization model. Additionally, a Web application called "HRX_Safety_Improvement" was designed as a part of this project. The "HRX_Safety_Improvement" Web application aims to assess the benefits of closing level crossings and prioritize level crossings for closures.

Furthermore, a number of sensitivity analyses were conducted during this project. Specifically, the sensitivity of the developed mathematical model to the following attributes was analyzed: (1) changes in the total available budget; and (2) changes in the benefit weight values. Moreover, the decisions on level crossing closures for various types of level crossings (e.g., public, private, and both public and private) were analyzed. The aforementioned sensitivity analyses focused on several performance indicators, including the following: (1) changes in the number of level crossings selected for closures; (2) changes in the total safety benefits due to level crossing closures; (3) changes in the total economic benefits and delays due to level crossing closures; and (4) changes in the total environmental benefits due to level crossing closures.

Based on the numerical experiments that were conducted as a part of this project, it can be concluded that the proposed methodology, including the developed mathematical model and Web application, can serve as an effective decision support system for the Florida Department of Transportation (FDOT) personnel and assist with maximizing the total benefit associated with closures under different total budget availability scenarios, sets of benefit weight values, and various crossing type scenarios. Furthermore, the proposed methodology can effectively incorporate other considerations that are taken into account by the FDOT personnel throughout decision making during the selection of level crossings for closure in the State of Florida (e.g., eligibility of each crossing for closure based on specific practical features, changing cost of level crossing closures).

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

This section of the report contains some background information for this project, which includes the following items: (1) rail transportation in Florida; (2) level crossings in Florida; (3) objectives of this project. In addition, the structure of this report will be described at the end of this section.

1.1. Rail Transportation in Florida

The Association of American Railroads (AAR) placed Florida at number "23" for total number of railroads in the United States in 2017 (15 freight railroads) and number "24" for railroad mileage (with more than 2,700 miles of mainline railroads). The revenue that railroads generate each year is used to categorize them. Classification of railroad companies is determined by the following revenue thresholds (FDOT, 2020):

- Class I railroads: carrier operating revenues for Class I railroads exceed $250 million annually.
- Class II railroads: carrier operating revenues for Class I railroads range between $20 million and $250 million annually.
- Class III railroads: carrier operating revenues for Class III railroads are less than $20 million annually.

Florida's freight rail system is served by two Class I railroads (CSX Transportation and Norfolk Southern Corp.), one Class II railroad, and numerous Class III railroads classified as switching and terminal railroads or short lines. There are 3,843 total miles of railroad in Florida, with 2,742 of those being mainline (FDOT, 2020). Over fifty percent of the state's total rail mileage is owned by CSX, making it the largest railroad in the state. Although some of the railroad's mileage is operated by short lines, the Florida East Coast (FEC) Railway is the second-largest owner at 15 percent. The FDOT is the third largest owner, but all of its miles are operated by third parties (FDOT, 2020). The mileage and coverage of the rail system across the state are shown in Figure 1 and Figure 2, respectively.

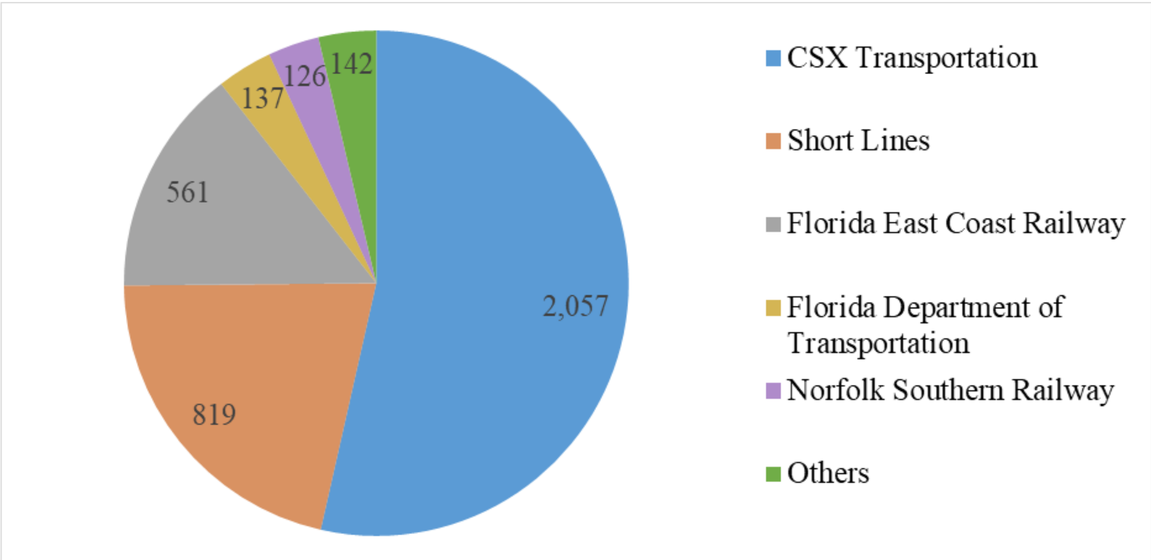


Figure 1 The total rail mileage across Florida.

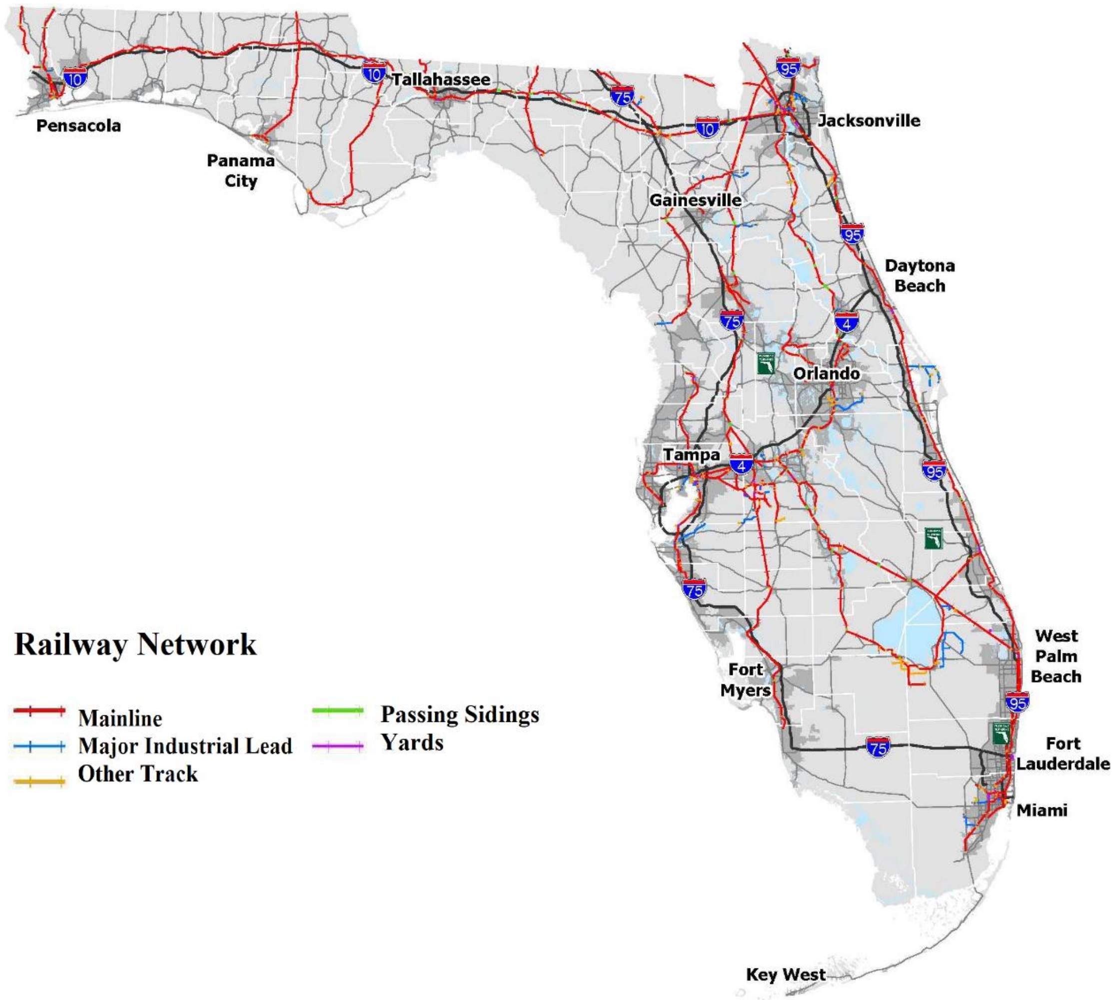


Figure 2 The rail coverage across Florida.
Source: FDOT (2020). Freight Mobility and Trade Plan

Florida was ranked 11th in the country with 44.1 million originated rail tons and fourth with 72.3 million terminated rail tons in 2017. Due to Florida's geography, the majority of rail traffic originates or terminates in the state, as opposed to passing-through rail traffic. In terms of total rail tons and rail carloads, Florida was ranked 32nd with 85.5 million tons and 1,737,200 rail carloads. The statistics highlight the state's status as a consumer state (FDOT, 2020).

1.2. Level Crossings in Florida

1.2.1. Basic Features of Level Crossings in Florida

The level crossings in Florida are the main focus of this project. According to the Federal Railroad Administration (FRA) crossing inventory database, Florida has a total 9,329 crossings, including underpasses, overpasses, and level crossings, where highway segments intersect a railroad at the same elevation (FRA, 2022a). Figure 3 depicts the distribution of Florida's crossings by crossing position, showing that the vast majority of the state's crossings (8,813 crossings) are highway-rail grade crossings (i.e., level crossings). The numbers for railroad over and under were 70 and 446, respectively.

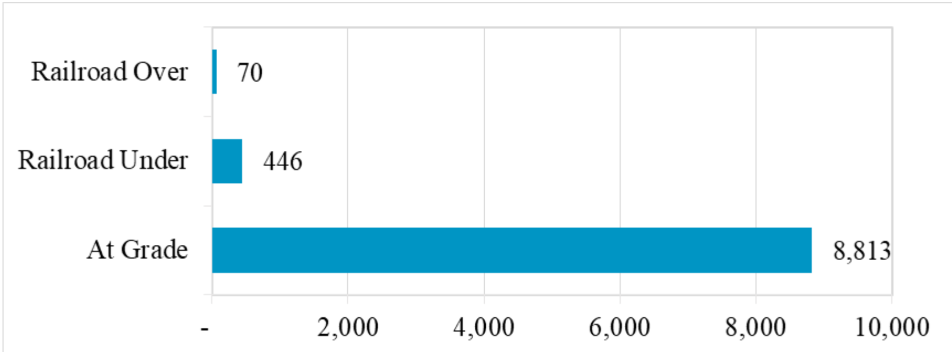


Figure 3 Distribution of crossings in Florida by crossing position.

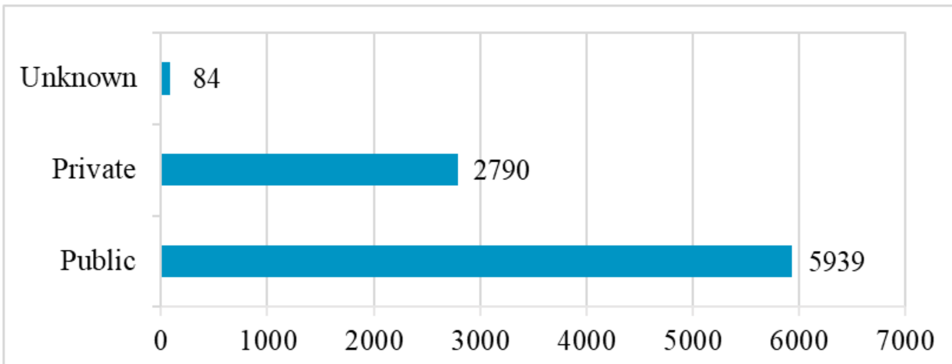


Figure 4 Distribution of level crossings in Florida by ownership type.

Table 1 Distribution of level crossings in Florida by warning device type.

Warning Device Type	Number of Level Crossings
All Other Gates	2,802
Unknown	2,390
Crossbucks	1,762
No Signs or Signals	638
Flashing Lights	606
Stop Signs	322
Four Quad (Full Barrier Gates)	141
Special Active Warning Devices	100
Highway Traffic Signals, Wigwags, Bells, or Other Activated	44
Other Signs or Signals	8

Figure 4 shows the distribution of Florida's level crossings by ownership type. According to the FRA crossing inventory database, 31.7% of level crossings in Florida (or 2,790 out of 8,813 level crossings) were privately owned. With 5,939 level crossings (or 67.4% of level crossings), the majority of level crossings in Florida were publicly owned. Furthermore, the ownership of 84 level crossings in Florida was not specified. Table 1 presents the distribution of Florida's level crossings by warning device type. Active warning devices were installed at a total of 3,693 grade crossings in Florida (e.g., gates, flashing lights, highway traffic signals, wigwags, bells, or other active warning devices). On the other hand, passive warning devices were installed at 2,092 grade crossings in Florida (e.g., stop signs, crossbucks, or other signs or signals). At 638 level crossings, no signs or signals were installed. The type of warning devices for 2,390 level crossings was unknown. When a level crossing attribute isn't listed in the FRA crossing inventory database, "unknown" will be used in this report.

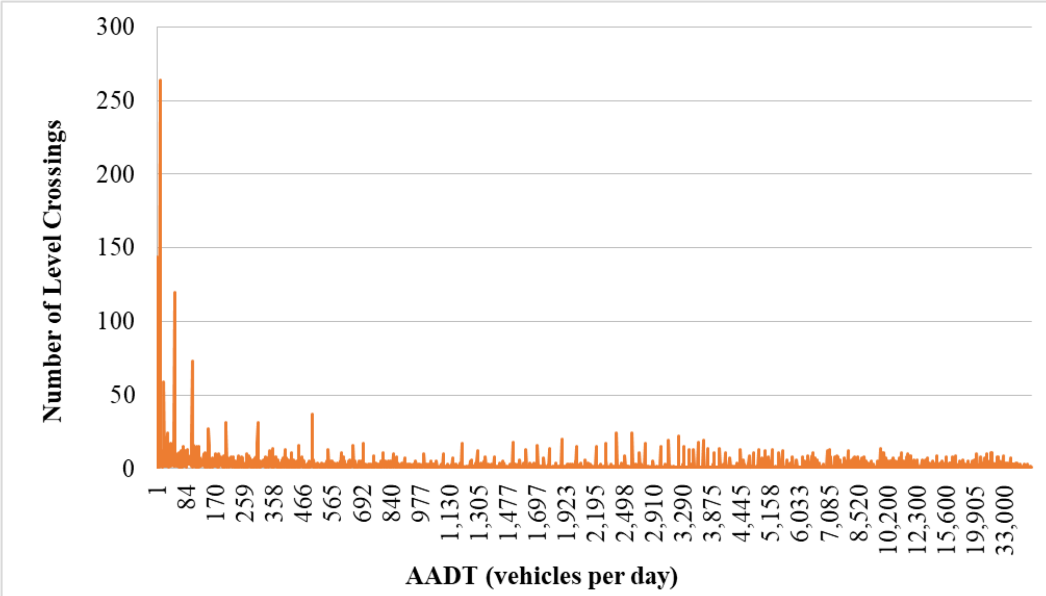


Figure 5 Distribution of level crossings in Florida by AADT.

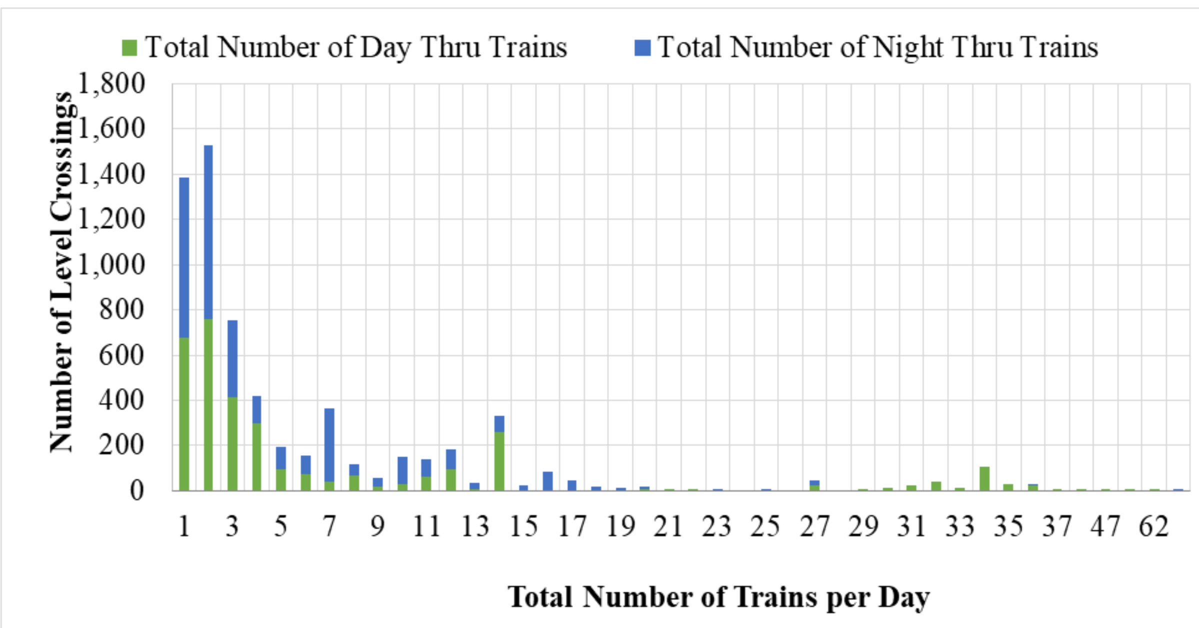


Figure 6 Distribution of level crossings in Florida by total number of trains per day.

Figure 5 illustrates the distribution of Florida's level crossings by Annual Average Daily Traffic (AADT). According to the FRA crossing inventory database, 6,388 level crossings in Florida (or 72.5% of all level crossings) had a positive AADT. For a total of 83 level crossings (or 0.9% of level crossings), the AADT was zero (i.e., less than one vehicle traversing the crossing per day on average). It should be noted that in the FRA crossing inventory database, AADT was not specified for 2,342 level crossings (or 26.6% of level crossings). Figure 6 depicts the distribution of Florida's level crossings by total number of trains per day (i.e., the day thru trains and the night thru trains). It was observed that a total of 41.3% of Florida's level crossings had a positive number of trains per day. According to the FRA crossing inventory database, 58.7% of Florida's level crossings accommodated less than one train per day on average.

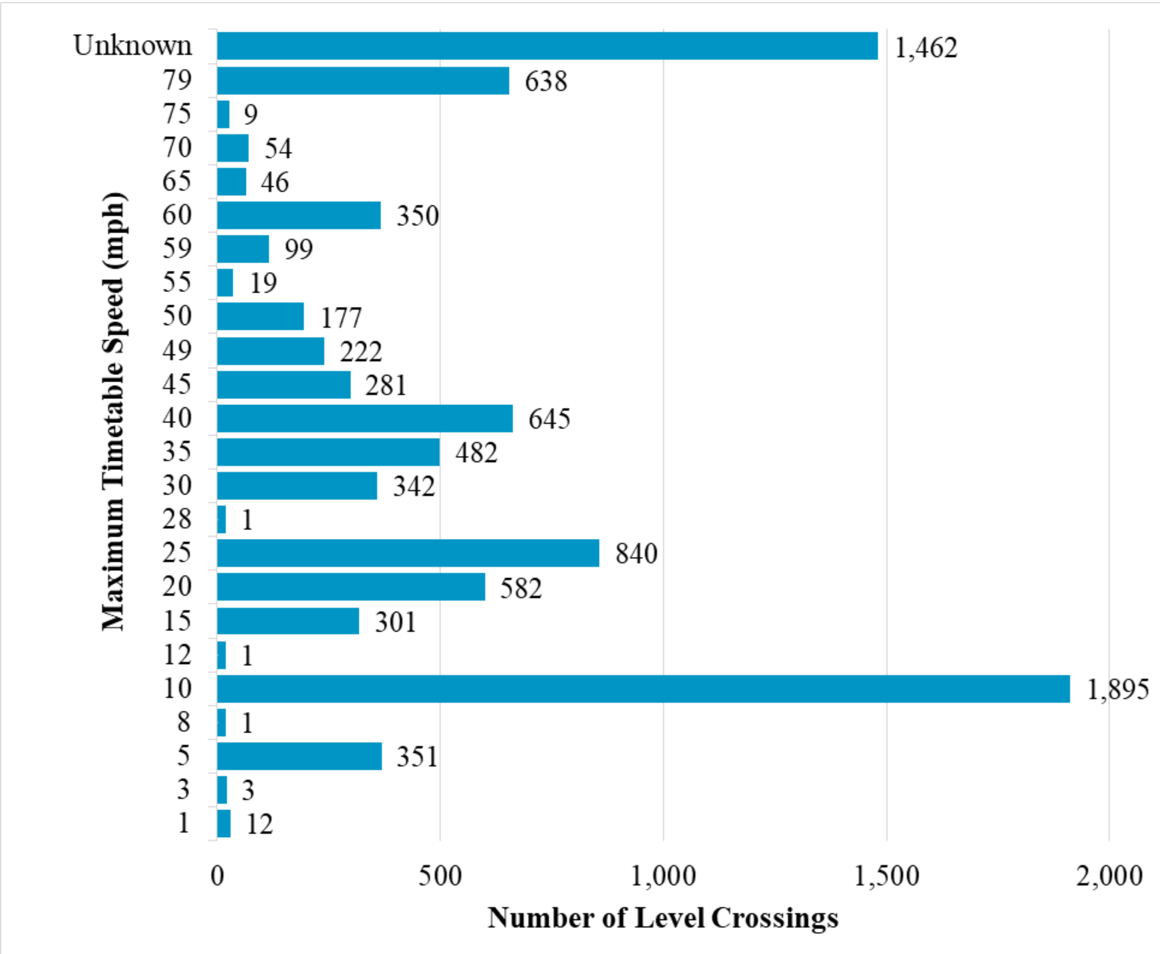


Figure 7 Distribution of level crossings in Florida by maximum timetable speed.

Figure 7 demonstrates the distribution of Florida's level crossings by maximum timetable speed, revealing that the maximum and minimum values at Florida's level crossings were 79 mph and 1 mph, respectively. The maximum timetable speed was 10 mph for a significant portion of level crossings in Florida (1,895 level crossings or 21.5% of level crossings). The FRA crossing inventory database revealed that 1,462 crossings (16.2% of all level crossings) in Florida had no maximum timetable speed specified. Figure 8 depicts the distribution of Florida's level crossings based on the total number of tracks disaggregated by the main tracks and the other tracks. The minimum number of main tracks at level crossings in Florida was zero (i.e., no main tracks), and the maximum number of main tracks was seven. According to the FRA crossing inventory database, the majority of Florida's level crossings (60.3% of all level crossings) had a single main track. A total of 29 level crossings had four or more main tracks. As for the other tracks, a total of 1,795 level crossings (20.4% of all level crossings) had one other track.

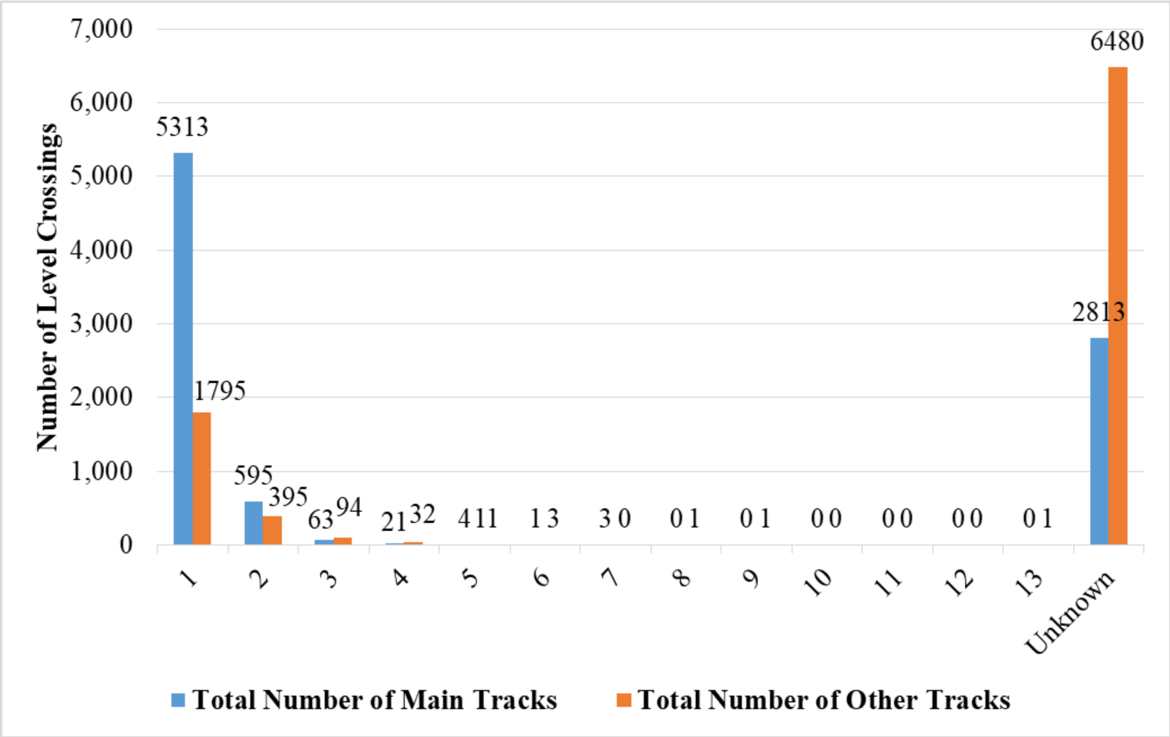


Figure 8 Distribution of level crossings in Florida by total number of tracks.

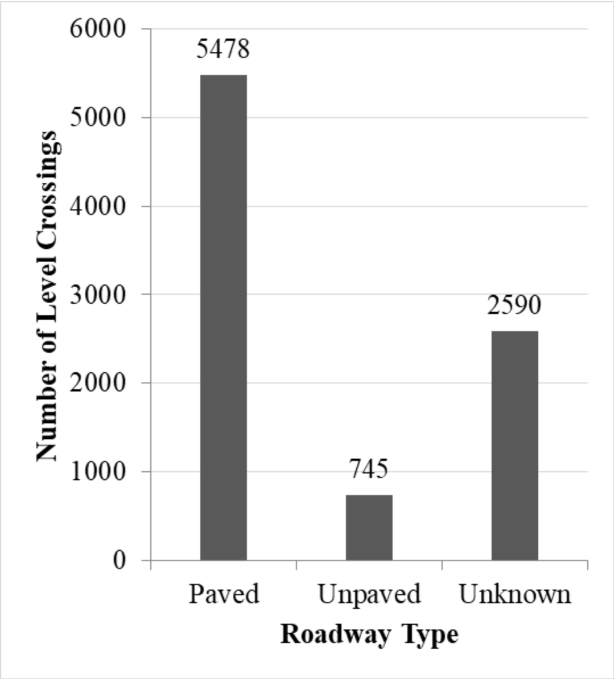


Figure 9 Distribution of level crossings in Florida by roadway type.

Figure 9 depicts the distribution of level crossings in Florida based on roadway type. According to the FRA crossing inventory database, Florida has 5,478 paved level crossings (or 62.2% of all level crossings) and 745 unpaved level crossings (or 8.5% of all level crossings). For 2,590 level crossings (or 29.4% of level crossings), the roadway type was not specified. Figure 10 demonstrates the distribution of Florida's level crossings by illumination type. According to the FRA crossing inventory database, 1,615 level crossings in Florida (or 18.3% of all level crossings) were illuminated, while 2,437 level crossings (or 27.7% of all level crossings) were unilluminated. For 4,761 level crossings (or 54.0% of level crossings), no illumination type was specified.

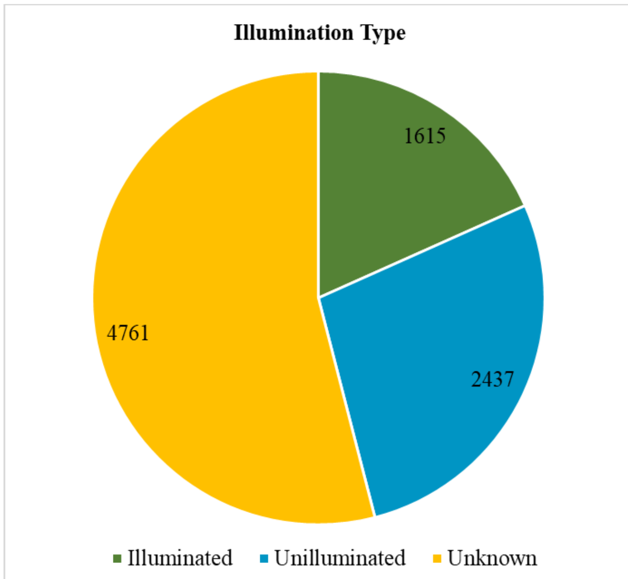


Figure 10 Distribution of level crossings in Florida by illumination type.

Table 2 shows the distribution of Florida's level crossings by crossing surface, where a large portion had asphalt surfaces (2,620 level crossings or 29.7% of all level crossings). Surface material wasn't specified for 2,440 level crossings (or 27.7% of all level crossings). Asphalt and timber surfaces were used on 1,613 level crossings (or 18.3% of all level crossings), while concrete surfaces were used on 1,337 level crossings (or 15.2% of all level crossings). Furthermore, 282 level crossings (or 3.2% of all level crossings) had timber surfaces, while 269 level crossings (or 3.1% of all level crossings) had unconsolidated surfaces. The rest of level crossing surface materials (252 level crossings or 2.9% of level crossings) were rubber, metal, or combinations of surface materials. Figure 11 depicts the distribution of level crossings in Florida by number of traffic lanes crossing the railroad. Florida's level crossings were intersected by up to nine traffic lanes, according to the FRA crossing inventory database. A total of 351 level crossings (or 4.0% of all level crossings) were intersected by single traffic lanes, while 4,942 level crossings (or 56.1% of all level crossings) were intersected by two traffic lanes. A total of 951 level crossings (or 10.8% of level crossings) was crossed by 3-9 traffic lanes. The number of intersecting lanes at 2,569 level crossings (or 29.2% of level crossings) was not specified.

Table 2 Distribution of level crossings in Florida by crossing surface.

Crossing Surface	Number of Level Crossings
Asphalt	2,620
Unknown	2,440
Asphalt and Timber	1,613
Concrete	1,337
Timber	282
Unconsolidated	269
Rubber	154
Other	37
Asphalt and Concrete	21
Concrete and Rubber	21
Asphalt, Timber, and Concrete	8
Asphalt and Rubber	4
Metal	3
Asphalt, Timber, Concrete, and Rubber	1
Asphalt and Timber	1
Asphalt, Concrete, and Rubber	1
Asphalt and Metal	1

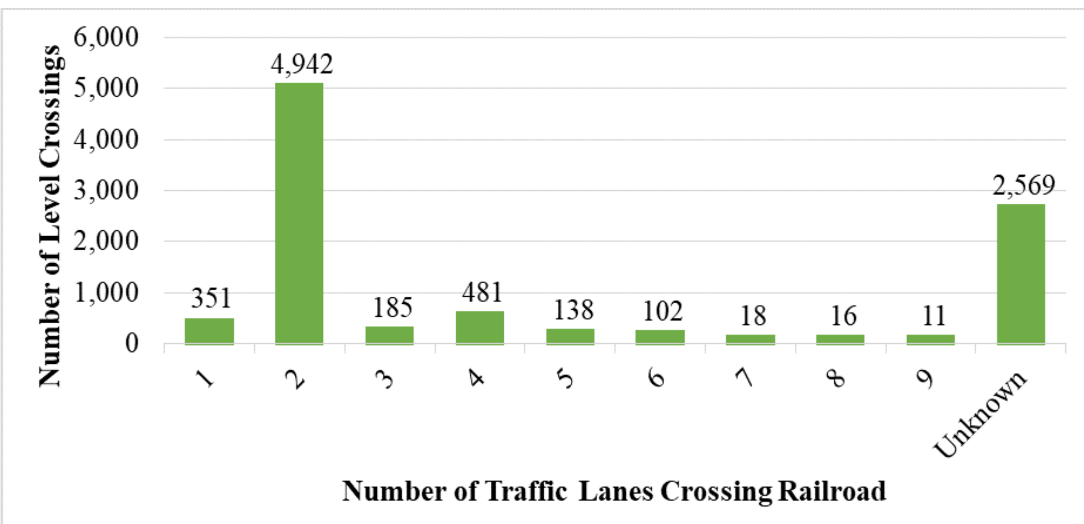


Figure 11 Distribution of level crossings in Florida by number of traffic lanes crossing railroad.

Figure 12 presents the distribution of Florida's level crossings according to the functional classification of the road at the crossing. According to the FRA crossing inventory database, 2,100 roads (or 23.8% of roads) at the level crossings in Florida were classified as rural roads. In addition, 4,036 roads at the level crossings (45.8% of all roads) were classified as urban roads. The FRA crossing inventory database did not list the functional classification of roads at 2,677 level crossings (or 30.4% of level crossings).

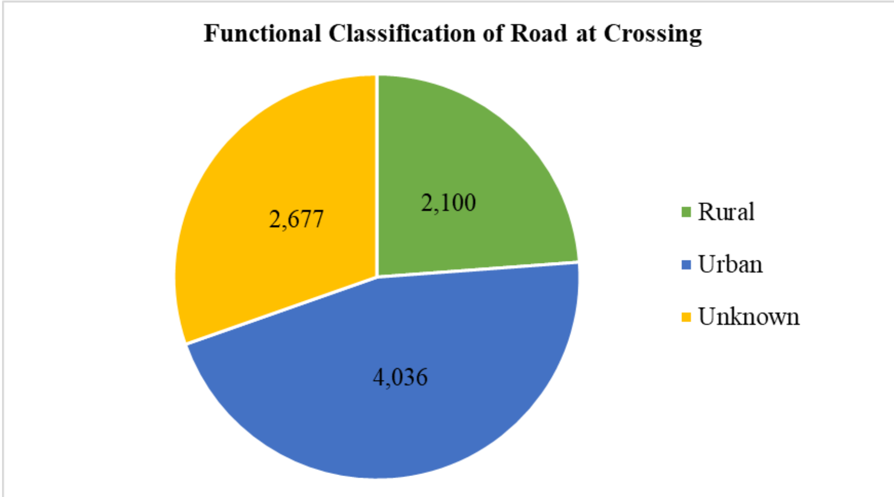


Figure 12 Distribution of level crossings in Florida by functional classification of road at crossing.

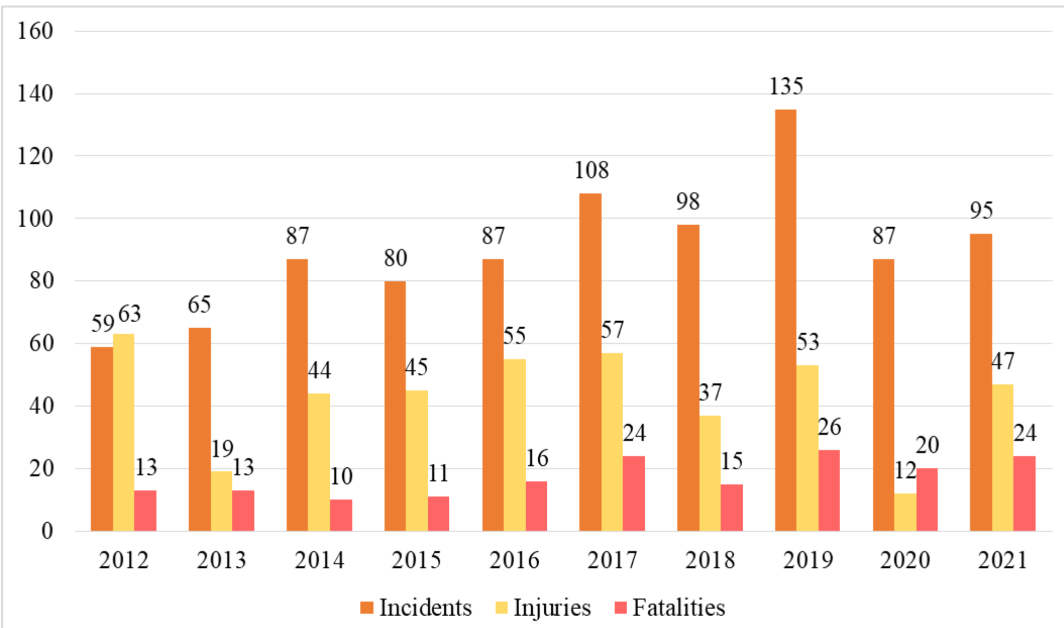


Figure 13 Accident statistics for level crossings in Florida (2012 to 2021).

1.2.2. Safety Issues at Level Crossings in Florida

A highway-rail incident is any collision between a rail user and a highway user at a designated crossing site, including walkways, sidewalks, etc., that is connected to the crossing (FDOT, 2010). Figure 13 depicts the number of level crossing accidents/incidents, injuries, and fatalities in Florida between 2012 and 2021 based on the FRA level crossing accident database (FRA, 2022b). According to Figure 13, there were 901 highway-rail grade accidents in Florida between 2012 and 2021, with an average of 90.1 accidents per year. Furthermore, these 901 highway-rail grade crossing accidents resulted in 432 injuries and 172 fatalities. Therefore, safety issues at the level crossings in Florida must be investigated and mitigated. It should be noted that the accident statistics presented in Figure 13 may change due to updates to the FRA database of level crossing accidents.

To evaluate the characteristics of the level crossings in Florida that experienced accidents within the previous five years, a statistical analysis was carried out for the 2017-2021 time period. The FRA level crossing accident database and the crossing inventory database were used in this analysis. Note that a total of 15 level crossings were eliminated from the analysis, since they were recorded in the FRA level crossing accident database but were not present in the FRA crossing inventory database. These level crossings include: '272603X', '272609N', '272610H', '272612W', '272613D', '272618M', '621533A', '623257G', '623263K', '624663G', '627635N', '627741W', '629169N', '968621W', and '968622D'. It was discovered that 369 level crossings in Florida experienced at least one accident between 2017 and 2021. Figure 14 depicts the distribution of level crossings in Florida that experienced accidents between 2017 and 2021 by type of ownership. According to the statistical analysis for ownership type, 51 level crossings (or 13.8% of level crossings) in Florida that had accidents between 2017 and 2021 were privately owned. However, the majority of the level crossings in Florida that had accidents between 2017 and 2021 were public level crossings (318 level crossings or 86.2% of level crossings).

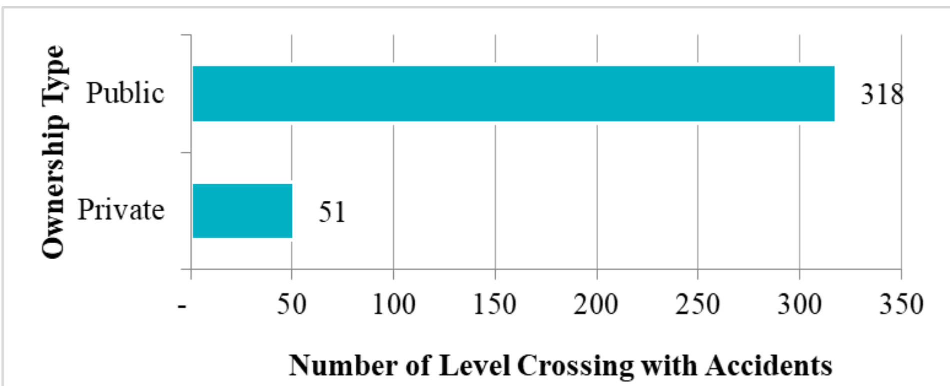


Figure 14 Distribution of level crossings that experienced accidents between 2017 and 2021 in Florida by ownership type.

Table 3 Distribution of level crossings that experienced accidents between 2017 and 2021 in Florida by warning device type.

Warning Device Type	Number of Level Crossings with Accidents
Highway Traffic Signals, Wigwags, Bells, or Other Activated	2
Stop Signs	3
No Signs or Signals	7
Flashing Lights	14
Crossbucks	21
Unknown	45
Four Quad (Full Barrier Gates)	52
All Other Gates	225
Total	369

Table 3 shows the distribution of Florida's level crossings that experienced accidents from 2017 to 2021 by warning device type. Among the 369 level crossings in Florida that had accidents between 2017 and 2021, 293 (or 79.4% of level crossings) had active warning devices (e.g., gates, flashing lights, highway traffic signals, wigwags, bells, or other active warning devices). On the other hand, passive warning devices (e.g., stop signs, crossbucks) were installed at 24 level crossings (or 6.5% of level crossings). At seven level crossings (or 1.9% of level crossings), no signs or signals were installed. Warning devices for 45 level crossings (or 12.2% of level crossings) were not specified in the FRA crossing inventory database. Figure 15 shows the distribution of Florida's level crossings that had accidents between 2017 and 2021 by AADT. The statistical analysis for AADT revealed that of the 369 level crossings in Florida that experienced accidents between 2017 and 2021, 326 (or 88.3% of level crossings) had a positive AADT. The maximum AADT found among these level crossings was 63,000 vehicles per day. In the FRA crossing inventory database, AADT was not specified for 43 level crossings (or 11.7% of level crossings).

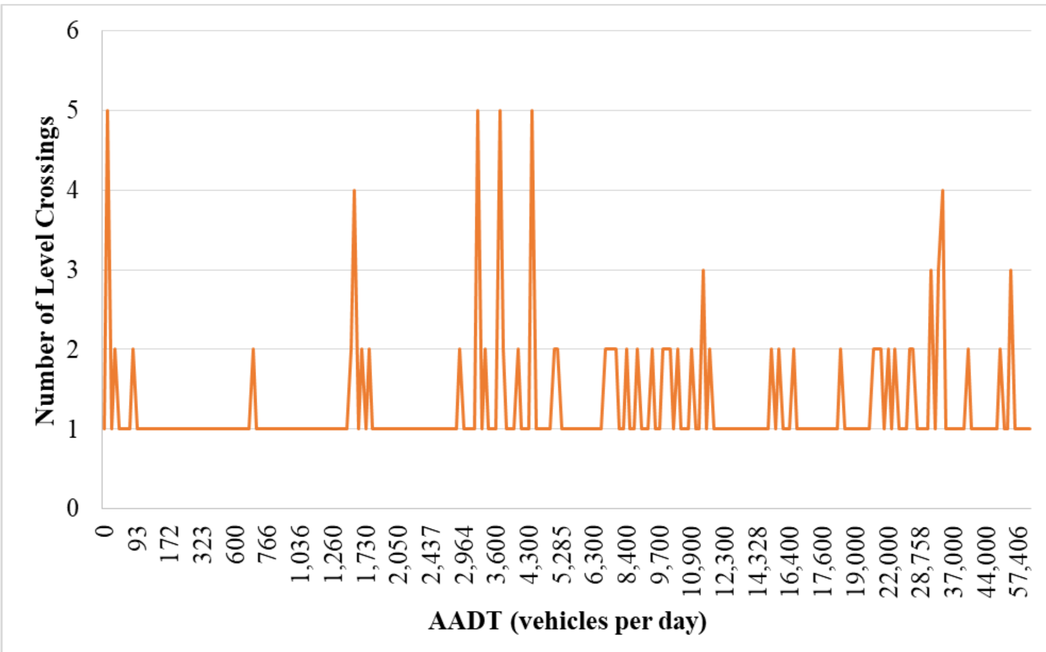


Figure 15 Distribution of level crossings that experienced accidents between 2017 and 2021 in Florida by AADT.

Figure 16 shows the distribution of Florida's level crossings that had accidents between 2017 and 2021 by total number of trains per day (i.e., the day thru trains and the night thru trains). It was found that 82.1% of the 369 Florida level crossings that experienced accidents between 2017 and 2021 had a positive number of trains per day. Furthermore, 17.9% of level crossings had less than one train per day. Figure 17 shows the distribution of Florida's level crossings that experienced accidents between 2017 and 2021 by maximum timetable speed. Among the 369 Florida's level crossings that experienced accidents between 2017 and 2021, the maximum value of the maximum timetable speed was 79 mph, and the minimum value was 10 mph. In Florida, 116 level crossings (31.4% of level crossings) that experienced accidents from 2017 to 2021 had a maximum timetable speed of 79 mph. The FRA crossing inventory database did not specify the maximum timetable speed for eight level crossings.

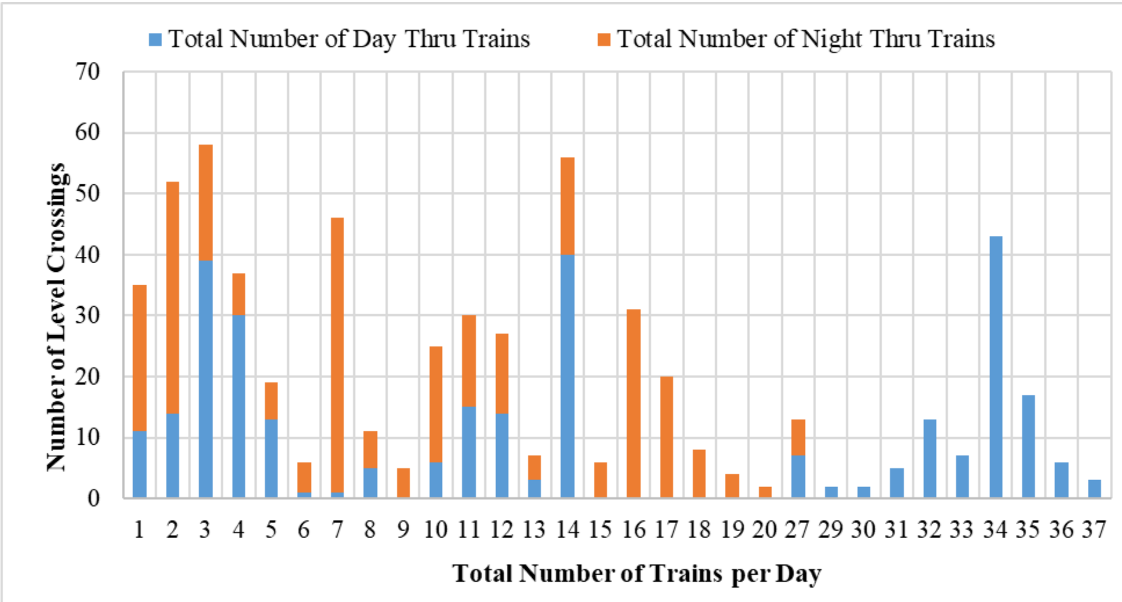


Figure 16 Distribution of level crossings that experienced accidents between 2017 and 2021 in Florida by total number of trains per day.

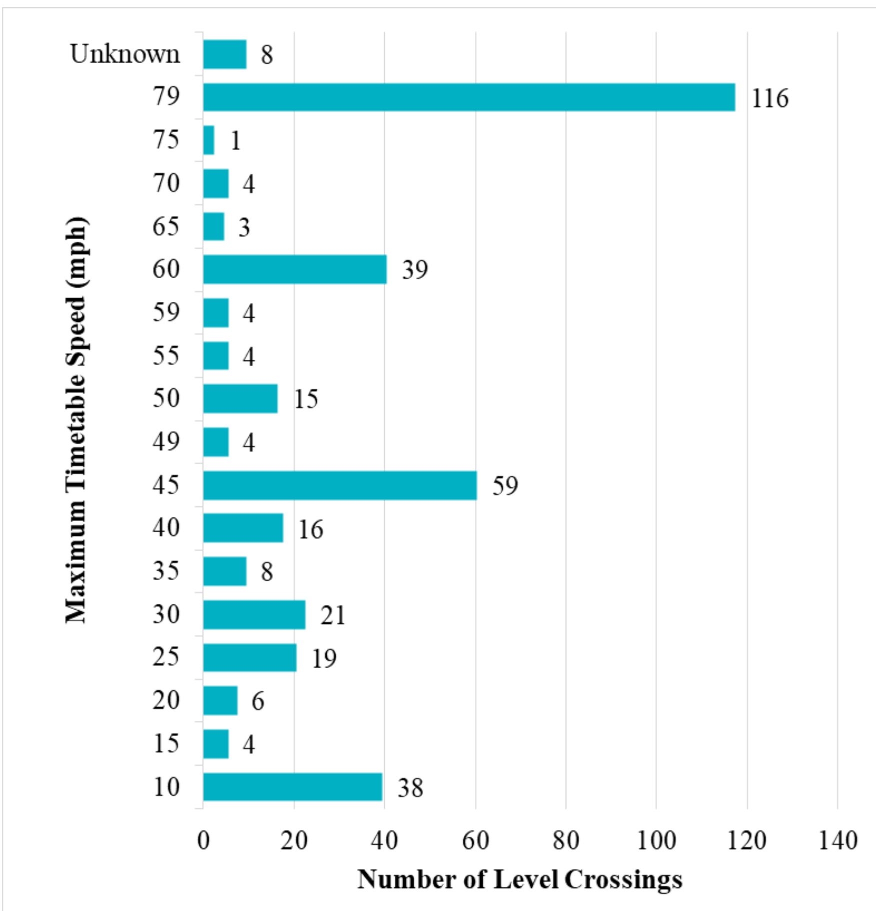


Figure 17 Distribution of level crossings that experienced accidents between 2017 and 2021 in Florida by maximum timetable speed.

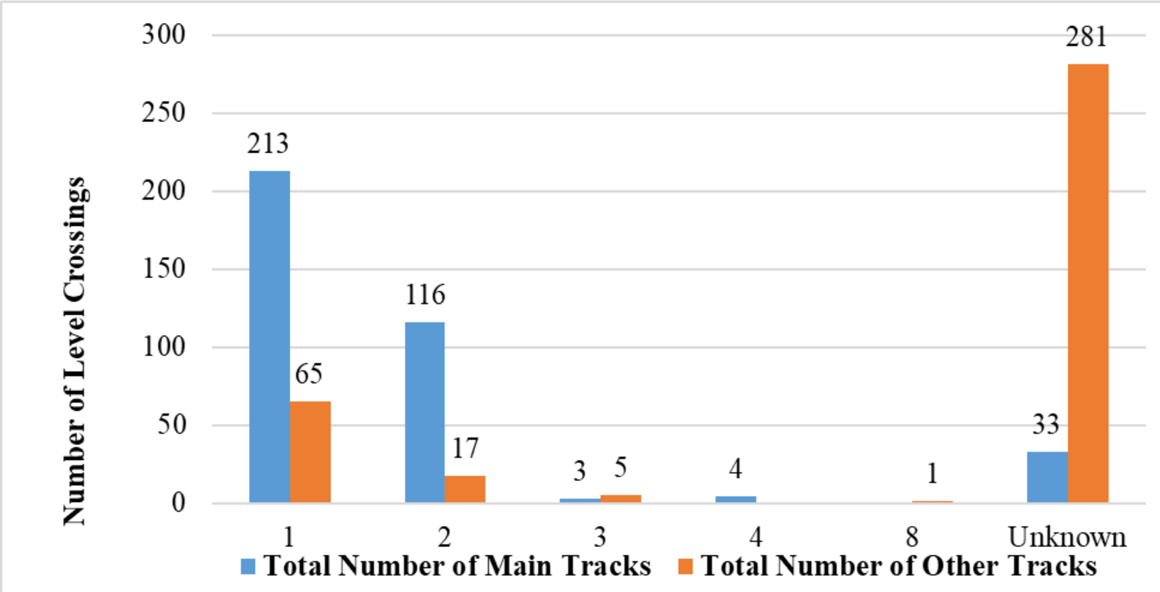


Figure 18 Distribution of level crossings that experienced accidents between 2017 and 2021 in Florida by total number of tracks.

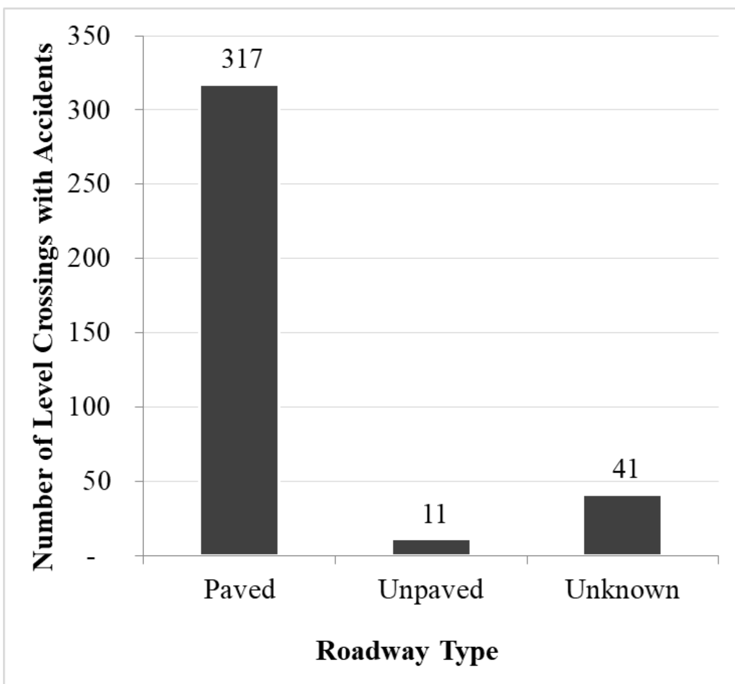


Figure 19 Distribution of level crossings that experienced accidents between 2017 and 2021 in Florida by roadway type.

Figure 18 depicts the distribution of Florida's level crossings that had accidents between 2017 and 2021 based on the total number of tracks disaggregated by the main tracks and the other tracks. The minimum number of main tracks at level crossings in Florida was zero (i.e., no main tracks), and the maximum number of main tracks was four. According to the FRA crossing inventory database, the majority of Florida's level crossings that experienced accidents between 2017 and 2021 (57.7% of all level crossings) had a single main track. A total of 4 level crossings had four main tracks. As for the other tracks, a total of 65 level crossings (17.6% of all level crossings) had one other track. Figure 19 depicts the distribution of level crossings in Florida that experienced accidents between 2017 and 2021 by roadway type. The statistical analysis for roadway type revealed that, of the 369 level crossings in Florida that experienced accidents between 2017 and 2021, 317 level crossings (or 85.9% of level crossings) were paved and 11 level crossings (or 3.0% of level crossings) were unpaved. The road type was not specified in the FRA crossing inventory database for 41 level crossings (or 11.1% of level crossings).

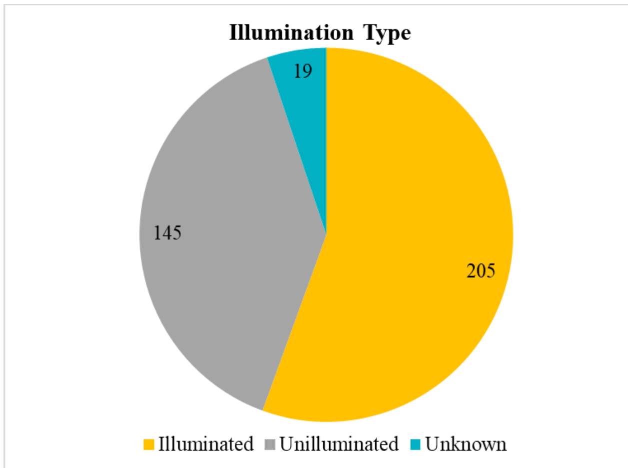


Figure 20 Distribution of level crossings that experienced accidents between 2017 and 2021 in Florida by illumination type.

Figure 20 depicts the distribution of Florida's level crossings that experienced accidents between 2017 and 2021 by type of illumination. The statistical analysis for illumination type showed that, out of 369 level crossings in Florida that had accidents between 2017 and 2021, 205 (or 55.6% of level crossings) were illuminated, and 145 (or 39.3% of level crossings) were not. In the FRA crossing inventory database, the type of illumination was not specified for 19 level crossings (or 5.1% of level crossings) in Florida that experienced accidents between 2017 and 2021. Table 4 shows the distribution of Florida's level crossings that had accidents between 2017 and 2021 by crossing surface. Most of the level crossings had concrete surfaces (210 level crossings or 56.9% of level crossings). A total of 59 level crossings (or 16.0% of all level crossings) had asphalt surfaces, while 58 level crossings (or 15.7% of all level crossings) had asphalt and timber surfaces. Furthermore, five level crossings had concrete and rubber surfaces, four level crossings had rubber surfaces, and three level crossings had timber surfaces. Other surface material combinations (e.g., asphalt and concrete) were discovered at two level crossings. The surface material information for 28 level crossings (or 7.6% of level crossings) was not specified.

Figure 21 shows distribution of Florida's level crossings that had accidents between 2017 and 2021 by number of traffic lanes crossing railroad. It was determined that among the 369 level crossings in Florida that experienced accidents between 2017 and 2021, the level crossings were intersected by up to nine traffic lanes. A total of 10 level crossings (or 2.7% of level crossings) were intersected by single traffic lanes, while 167 level crossings (or 45.3% of level crossings) were intersected by two traffic lanes. A total of 152 level crossings (or 41.2% of level crossings) were crossed by 3-9 traffic lanes. Furthermore, the number of intersecting lanes was not specified for 40 level crossings (or 10.8% of level crossings).

Table 4 Distribution of level crossings that experienced accidents between 2017 and 2021 in Florida by crossing surface.

Crossing Surface	Number of Level Crossings with Accidents
Concrete	210
Asphalt	59
Asphalt and Timber	58
Concrete and Rubber	5
Rubber	4
Timber	3
Asphalt and Concrete	2
Unknown	28

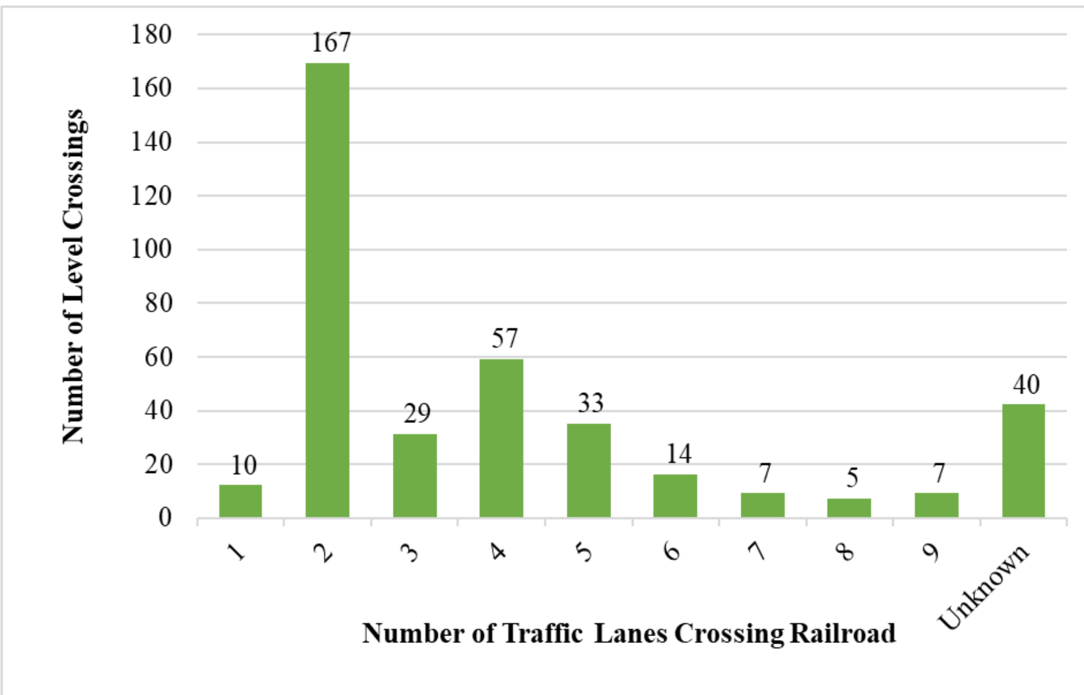


Figure 21 Distribution of level crossings that experienced accidents between 2017 and 2021 in Florida by number of traffic lanes crossing railroad.

Figure 22 depicts the distribution of Florida's level crossings that experienced accidents between 2017 and 2021 based on the functional classification of the road at the level crossing. Among the 369 level crossings in Florida that had accidents between 2017 and 2021, 37 roads (or 10.0% of the roads) were classified as rural roads. Additionally, 288 roads (or 78.0% of all roads) were classified as urban roads at the level crossings. The FRA crossing inventory database did not specify the functional classification of roads at 44 level crossings (11.9% of roads).

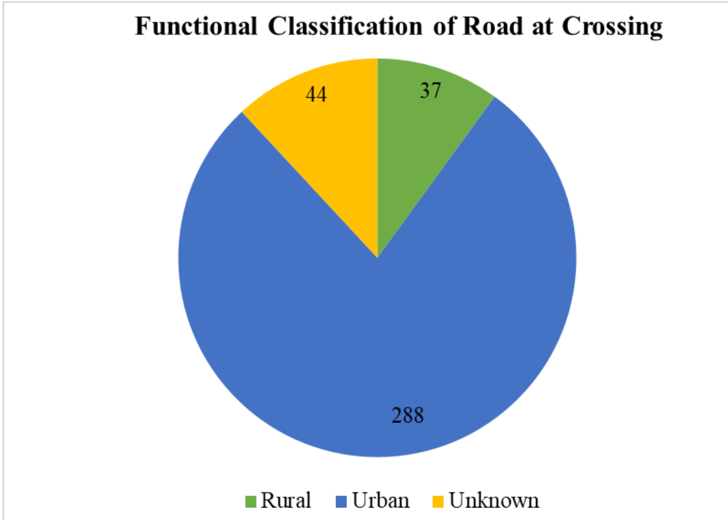


Figure 22 Distribution of level crossings that experienced accidents between 2017 and 2021 in Florida by functional classification of road at crossing.

1.3. Objectives of This Project

Given the high number of accidents reported each year, safety at level crossings is a major concern. Despite the COVID-19 lockdowns, there were more than 80 collisions between highway vehicles and trains at Florida's level crossings in 2020 (FRA, 2022b). The use of various countermeasures (e.g., wigwags, flashing lights, gates, and cameras) is regarded as a common approach to improving safety at level crossings. However, the limited funding for level crossing safety improvement projects prevents the state from upgrading all hazardous crossings. Closure of level crossings is another option for addressing the level crossing safety issue and contributing to the development of a reliable, well-connected, and secure multimodal transportation network. Consequently, the objective of this project is to develop an optimization model that will assist the FDOT personnel with the selection of level crossings for closure, taking into account the existing crossing exposure to rail and roadway traffic, the percentage of trucks, the number of school buses traversing the level crossing each day, and other relevant factors. The level crossings will be chosen for closure based on the objective function of the proposed optimization model. Once the optimization model is finalized, a Web-based application will be created to help the FDOT decide which level crossings should be closed. In addition, a series of case studies will be conducted with the Web-based application to demonstrate some managerial implications from the level crossing closures in Florida. This project is anticipated to improve the safety of highway users and rail users at Florida's level crossings. At the same time, ensuring the continuity of passenger and freight flows, reducing delays at highway-rail grade crossings, and reducing vehicle emissions in the vicinity of Florida's level crossings will be accomplished as well.

1.4. Report Structure

The report is organized as follows in terms of its technical structure. The second section provides a comprehensive review of the pertinent studies, focusing on the following points: (1) state-of-the-art efforts on level crossing closures; (2) state DOT efforts on level crossing closures; and (3) FDOT efforts on level crossing closures. The third section presents an optimization model for selection of level crossings for closure, aiming to maximize the total benefit from these closures.

The fourth section discusses the solution algorithm that was developed to solve the proposed optimization model and required input data. The fifth section focuses on the main purpose of the Web application that was designed as a part of this project, as well as the guidelines for using the Web application. The sixth section presents a detailed description of the computational experiments, which were conducted to demonstrate applicability of the developed methodology for determining the level crossings that have to be closed in the State of Florida. The last section is devoted to the main concluding remarks associated with this project.

2. LITERATURE REVIEW

2.1. State-of-the-Art Efforts on Level Crossing Closures

As a part of the closure program, unnecessary and redundant level crossings have to be identified for a given area. The consolidation program removes a few redundant level crossings in the same vicinity to decrease the total number of level crossings. Removing level crossings is often regarded as the most cost-effective means of preventing future collisions. An essential part of the DOT Action Plan to increase level crossing safety, as described by Murphy (1995), is the elimination of unused and redundant level crossings. The main impediment to removing redundant crossings is primarily local opposition. Almost every proposal to close a level crossing is met with local concerns regarding emergency vehicle response time, traffic delays, neighborhood effects, and public inconvenience. Murphy (1995) outlined a strategy for successfully implementing a level crossing consolidation project in collaboration with local communities.

Salvagin and Taylor (1997) discussed some of the major elements of the Rail-Highway Crossing Safety Action Plan, including the following: (1) traffic law enforcement at level crossings; (2) rail corridor improvement and safety reviews; (3) Operation Lifesaver and increased public education; (4) private crossing safety; (5) research and data development; and (6) prevention of trespassing. The study mainly concentrated on rail corridor safety and proposed a methodology to meet the goals of the level crossing safety action plan. The proposed methodology enabled the selection of crossings for consolidation, aiming to divert the existing traffic to a safer crossing with minimal inconvenience and delays. The level crossing consolidation was performed considering operational characteristics of level crossings. Russell and Mutabazi (1998) discussed level crossing consolidation projects in Kansas and proposed a three-phase approach. Throughout Phase I, a total of eight level crossing attributes were primarily investigated, including the roadway type, AADT, accessibility, obstruction, crossing angle, approach horizontal alignment, approach vertical alignment, and rideability. In Phase II, the initial list of level crossing attributes was refined, and different weights were assigned to the selected attributes. Phase III also focused on further refining the selected level crossing attributes. The proposed methodology could assist with the identification of level crossings for closure and obtain support from local authorities and communities.

Caird et al. (2002) aimed to determine human factors that lead to collisions at crossings and recommended appropriate safety improvement actions based on the top contributing factors. Related standards to the level crossings and common countermeasures in Canada were examined in the first phase of the research. Then, a group of contributing factors to level crossing accidents was formed to discover their correlations, effectiveness, and costs. It was found that intentional acts (e.g., drive around fully-deployed gates) and driver distraction (e.g., cell phone use) were common accident causes. Furthermore, based on the study results, closing level crossings to enhance safety could reduce violations, accidents, injuries, and fatalities by 100% at the level crossing site. The Australian Transport Council developed the Australian National Railway Level Crossing Safety Strategy, which is widely accepted to improve level crossing safety in Australia. The Strategy Action Plan was implemented with the cooperation of all major interested parties. The report highlighted that the level crossing safety improvement can be effectively achieved by allocating additional funds for railway level crossing closures (Hughes, 2003).

Closures of level crossings are regarded as one of the most effective safety improvement programs. Even though closing level crossings can be extremely challenging, if not impossible, incentive programs can simplify the process. One of these programs is level crossing consolidation, which evaluates the practicality of crossing closure. After investigating a group of level crossings as part of the consolidation program, redundant level crossings will be identified and closed. Alternative routes are utilized to compensate for these closures. The federal government encourages the closure of abundant level crossings while redirecting the traffic flow to adjacent level crossings equipped with active countermeasures. Nearly 30% of level crossings in the U.S. were eliminated due to the consolidation program or railroad abandonment during the 1975-2001 time period. Mok and Savage (2005) investigated the accident history at level crossings sites in 49 states from 1975 to 2001 and found that collisions and deaths significantly decreased. Additionally, Mok and Savage (2005) analyzed a collection of randomly chosen data to find the contribution of level crossing closure to the number of accidents. The results showed that closing 10% of level crossings decreased the number of accidents and deaths by 5.1% and fatalities by 2.7%, respectively.

The Rail Safety and Standards Board (RSSB) studied level crossing closure procedures in Europe and other countries in two phases (RSSB, 2006). First, the level crossing closure process in Great Britain was examined to provide a benchmark for comparisons between Great Britain and other countries. After that, political and administrative processes related to level crossing closures were analyzed. Then, RSSB (2006) conducted semi-structured interviews in nine shortlisted countries. Findings for different countries are as follow:

- UK: Railways were the most likely parties to initiate the level crossing opening or closing procedures but must get the highway authority’s approval. Generally, the applicant should provide the necessary funds for crossing closure.
- Australia: Crossing closures require ministerial approval. The national government often covers the costs.
- Belgium: The infrastructure authority funds a crossing closure program.
- France: Local authorities make closure decisions without accepting any appeals, and the provincial government covers 70% of costs.
- Germany: The government promotes the closure of level crossings for safety. The highway authorities, infrastructure owner, and federal government fund safety improvements equally.
- Ireland: Local authorities have jurisdiction over level crossing closures.
- Malaysia: A grade-separated alternative should be administered in case of level crossing closure.
- Netherlands: The existing policies prioritize accident reduction over reducing the number of crossings.
- Sweden: All parties will share the costs based on how much they benefit from level crossing closures.
- United States: All 49 states in the U.S. have varying standards and policies for crossing closures. Federal funding can cover around 90% of crossing closure costs.

According to Woods (2007), most public level crossings have existed since Britain built the original railways in the 19th century. Railroad construction was generally only allowed with a parliamentary permission, which required the railroad to guarantee the road access that existed before the railway was designed. According to Woods (2007), Britain has no simple or easy procedure for closing level crossings. Between 1980 and 1990, several attempts were made to close a level crossing in Willesborough. Several private parliamentary bills had to be amended over several years before the level crossing closure could be approved. The purpose of the Sealed Corridor program is to either upgrade or close all level crossings at the rail corridor passing between Charlotte and Raleigh (North Carolina, U.S.). Bien-Aime (2009) evaluated the advancements at level crossings between Charlotte and Raleigh that were closed or upgraded with warning devices. The sealed corridor included a total of 216 level crossings, out of which 44 crossings were private crossings. According to the results, the program consolidated all possible level crossings while upgrading the remainder. Implementing the sealed corridor concept decreased the accidents substantially and saved approximately 19 lives between 1995 and 2004 after upgrading or closing a total of 189 crossings.

Taylor and Crawford (2009) employed a four-stage assessment program to prioritize level crossings for grade separation in the Melbourne Metropolitan Area (Australia). The first stage identified sites that could be permanently closed and have the lowest grade separation priority. The following criteria were considered to choose first-stage crossing closure candidates: local roadway functional classification, crossings with less than 5,000 vehicles per day, a roadway with no public service functions, and an adjacent alternate route to manage redirected traffic. The study found that 8 of 177 sites could be permanently closed. The second stage of the assessment eliminated level crossings that were unlikely to cause future safety or traffic concerns based on the exposure value, which was computed based the daily forecast of traffic and train volumes. The third stage entailed developing and implementing a methodology for prioritization, considering community preferences, transport connectivity, noise and visual impacts, and air quality impacts. The adopted metrics were mostly assessed by providing a certain rating based on the individual site assessment. The fourth stage entailed recommending a small list of level crossings for separation. Hellman and Ngamdung (2010) conducted a reliability assessment for the four-quadrant gate/vehicle detection equipment, which was installed on the rail corridor connecting St. Louis and Chicago. The study pointed out some of the difficulties that could be caused by level crossing closures, including potential disruptions to local communities and environmental implications. The opposition of local residents could be one of the main reasons preventing the implementation of level crossing closures.

Level crossings are one of the most dangerous elements of railway operations, and new technologies are decreasing the risks for rail and road users. Closure of level crossings could be an effective alternative for accident prevention. Crossing upgrades with appropriate countermeasures could be another alternative, when closures are not possible. Nelson (2010) summarized the numerous risk-reduction strategies (e.g., crossing upgrades and countermeasures, level crossing closures, and other technology, such as flashers embedded in the pavement) currently in use worldwide. Khattak and Thompson (2012) presented a standard method for evaluating the expected yearly accident costs at the Nebraska level crossings, as well as the possible advantages of eliminating level crossings. The study created spreadsheets that could be used to estimate the economic consequences of accidents based on various factors, such as roadway/railway traffic, vehicle travel times on alternative routes, and delays experienced by trains. According to the study findings, the primary costs of accidents were found to be the deaths and injuries, while the supply chain and logistics costs were found to be the secondary costs.

Chadwick et al. (2014) presented an overview of the challenges that arise at level crossings when high-speed passenger and heavy freight rail use the same tracks. According to Chadwick et al. (2014), crossings that have experienced collisions in the past can be upgraded to have more stringent warning systems. The study pointed out that level crossings with passenger trains passing at a speed of more than 125 mph should be considered for grade separation or closure based on the federal regulations. Closure of crossings would lead to a 100% reduction in terms of accidents, injuries, fatalities, and violations.

Johnson (2015) pointed out that the consolidation of level crossings could yield safety and operational benefits but is often viewed as a source of disagreement between different parties. The study developed a spreadsheet-based tool that could be used to rank level crossings for consolidation. The following factors were considered throughout the prioritization: AADT, out of distance travel (i.e., the difference between the alternate route length and the original roadway segment intersecting the level crossing), truck AADT, primary or farm-to-market road system status, emergency services (EMS) location proximity count, distance to nearest EMS location, school location proximity count, distance to nearest school location, and alternate route crash rate. The proposed methodology was applied for the level crossings located in Iowa. The same methodology was adopted in the research conducted by Hans et al. (2015). Rezvani et al. (2015) provided a framework for analyzing the costs and benefits of projects aimed at improving the safety of level crossings. By estimating the costs of level crossing improvements and the benefits of accident reduction, the benefit-cost analysis method was used to identify high-risk level crossings and select appropriate countermeasures. The expected cost for the crossing closures included: delay and redirecting costs for trucks and trains along with supply chain costs for trucks and trains. The supply chain costs were calculated based on the hourly values of delay. The industry standards were adopted throughout the analyses that were conducted as a part of the conducted study.

De Gruyter and Currie (2016) assessed potential benefits of grade separation, including safety improvements, road vehicle delay reduction, rail vehicle delay reduction, vehicle operation cost reduction, increased traffic flow volumes, and improved connectivity and accessibility. It was mentioned that the cost of grade separation could vary significantly from one location to another. The study also pointed out that level crossing closures could assist with addressing the negative externalities associated with level crossing operations. To improve safety, Codjoe et al. (2018) looked into the existing and potential future incentive programs to encourage the elimination of level crossings. To this end, a survey was developed and sent to state and railroad agencies. According to the DOT survey responses, 16 states did not have incentive programs for consolidating or closing level crossings. The analysis showed that the percentage of closed level crossings was the lowest in the states that did not propose any incentive program. The study indicated that even though the federal government supports the states in offering cash incentives for the closure of public level crossings, the funding is not sufficient for most local governments to consider it a significant incentive. In addition, the high costs associated with track relocation make cash incentives impractical. According to the reviewed literature, having a mathematical formula assisting in the selection of level crossings for closure establishes a solid scientific foundation and generally is well-received by the local community. The study identified several novel incentives that could be effective in Louisiana, such as a strategy for level crossing consolidation, incentives to reduce crime rates, and plans to improve environmental sustainability.

According to Evans and Hughes (2019), between 2003 and 2017 in Britain, the number of level crossings with railway-controlled countermeasures (e.g., manually-controlled barriers) reduced by 5%, automatic level crossings (e.g., the ones equipped with the automatic half-barrier) by 8%, and level crossings with a passive control device by 45%. The expense and effort necessary to close different types of crossings are reflected in these changes. Level crossings with automatic or railway-controlled countermeasures are typically located on busy public roadways, and their closure may necessitate the construction of a bridge or an underpass. On the other hand, level crossings with passive countermeasures are usually private and located on agricultural roads; thus, they may only have a small number of registered users. If all parties reach an agreement, many of these level crossings could be closed. From 2003 to 2017, 1,766 level crossings with passive countermeasures were closed; 62% of the remaining level crossings were still categorized as infrequently used.

Gabree et al. (2019) analyzed the accidents and inventory of level crossings in the U.S. between 1986 and 2015. Over 60,000 public level crossings were closed for the considered time period, and the number of level crossings equipped with active countermeasures rose from 34% to 55%. As a result of these changes, the number of casualties decreased by more than 60%. The study used hierarchical linear models to predict if changes in crossing inventory in each state could affect the number of accidents per AADT. The findings showed that a decrease in the proportion of passive crossings was the most influential predictor affecting the number of accidents with injuries and/or fatalities. As a result, while installing gates at level crossings could improve safety, eliminating level crossing equipped with passive countermeasures might be the most effective option.

Social, environmental, safety, and economic factors influence level crossing consolidation programs. Soleimani et al. (2019) designed an accurate model by analyzing the impacts of 40 factors in selecting level crossings for closure. The study relied on machine learning approaches, such as random forest, XGboost, decision tree, and logistic regression, as opposed to previous studies that relied exclusively on expert opinion to determine the most critical factors for the consolidation program. The results showed that XGboost outperformed the other approaches due to its specificity, high precision in prediction tests, and sensitivity. Additionally, the proposed model had an overall accuracy of 0.991. Finally, a simplified version of the model with fewer variables was developed for practical implementation. The simplified version with 14 factors performed similarly to the full model in terms of accuracy. The following 14 factors were considered: (1) in or near city; (2) night thru train movement (6 pm to 6 am); (3) crossing surface (main track); (4) crossbuck assemblies; (5) day thru train movement; (6) maximum timetable speed; (7) total count of flashing light pair; (8) total switching trains; (9) average number of school buses passing over the crossing on a school day; (10) typical maximum speed; (11) typical minimum speed; (12) AADT; (13) estimated percent of trucks; and (14) intersecting roadway within 500 ft. According to the study findings, 62% of the level crossings in Louisiana should be consolidated or closed.

Setiawan et al. (2020) underlined that highways and rail tracks are essential for the transportation of passengers and freight. One of the challenges with the land transportation in Indonesia is the high number of current crossings between highways and railways. Many of these crossings are semi-automated and have a considerable impact on traffic. Grade separation and removal of redundant and unnecessary level crossings would be essential for improving safety of highway and rail users. Mathew et al. (2021) presented a multi-criteria strategy for evaluating level crossings for consolidation, grade separation, or other substantial upgrades. The proposed multi-criteria method considered four distinct factors: livability, economic factors, environmental factors, and safety. A case study was carried out to establish the priority of level crossings at two distinct railway tracks, and the findings were compared to the judgment of experts.

East Baton Rouge (Louisiana) saw 57 level crossing accidents between 2015 and 2019, with thirteen injuries and $346,875 of car damages. Consolidation programs aid with the closure of redundant crossings, hence reducing the likelihood of a collision. Nevertheless, selecting the best candidate for consolidation is difficult. In contrast to earlier research, which exclusively depended on expert judgment to identify the most critical parameters for the consolidation program, Soleimani et al. (2021) utilized machine learning, text mining techniques, and geospatial analysis to gather the data from crossings and determine the best candidates for consolidation. The study incorporated the impacts of crossing features, accident reports, and geographical factors. The spatial attributes of every crossing were investigated (e.g., proximity to schools, hospitals, and emergency centers). The proposed model had an overall accuracy of 88%. The analysis results indicated that 15% of the considered level crossings in Louisiana should be closed or require safety improvements.

According to the Indonesia transport ministry, the shortest distance between two adjacent level crossings should be 800 meters. This rule has not been implemented at the Lamongan Regency crossings. As a result, accidents frequently happen at the level crossings JPL 294, 285, and 297. Furthermore, no guards are stationed at JPL 294 and 297. Handoko et al. (2022) investigated the public consensus on the proposed removal of JPL 294 and 297, and diversion of traffic to JPL 295 as the primary level crossing. The feedback of 100 residents was considered in the research. The study computed the exposure of level crossings to highway vehicles and vehicle queuing using a descriptive quantitative method. It was found that JPL 295 could experience up to 249 vehicles per hour, with the longest vehicle queues reaching up to 23 meters. The study also considered the factors associated with safety benefits and pubic convenience. As a result of the conducted analyses, it was found that approximately 66.8% of the population agreed with the level crossing closure plan.

Qiu (2022) developed a risk-based framework for ranking level crossings based on the best candidates for closures. The proposed framework contained a preliminary screening and cost-benefit analysis module. All crossings in the area of interest were first examined in the preliminary screening step based on pre-established criteria. The level crossings that should not be closed due to their significance to the road traffic flow were eliminated from the preliminary list. The cost-benefit analysis module was then applied to all individual crossings in the candidate set. This module calculated the expected safety benefit, travel time, and construction cost. A set of accident risk models based on accident frequency and severity were used to estimate the safety benefit of closing a crossing. These models were calibrated using the most recent crossing inventory data and a six-year accident history (2013-2018). An accessibility analysis tool was created in ArcMap based on the road and railway network spatial data. An accessibility analysis tool estimated the extra travel time road users would experience due to a crossing closure. The life-cycle benefit-cost ratios of all candidate crossings for closure were calculated and used to rank them. Three case studies were conducted for the Canadian provinces to examine the application and rationality of the proposed framework. The results showed that the train and traffic volumes, train maximum speed, track angle, and number of tracks affected accident frequency, while the train maximum speed and road posted speed affected accident severity.

Crossings between highways and railroads raise safety concerns while posing a risk to traffic flow. To help reducing the total number of level crossings in Louisiana, Tian (2022) performed a research study to examine the present incentive schemes and collect the opinions of experts in Louisiana. The findings indicated that most of the Louisiana entities were worried about level crossing safety, while one-third supported removing level crossings. Along with safety, three other significant concerns were stated, including the following: traffic control, access for active transportation, and maintenance of facilities related to crossings. The study discovered five prominent incentive schemes utilized by other states, including the following: (1) road enhancement; (2) grade separation of the adjacent level crossing; (3) upgrading countermeasures at the adjacent level crossing; (4) funding incentives; and (5) track relocation. According to the study, the implementation of several incentive programs could more effectively facilitate level crossing closures than just one program.

2.2. State DOT Efforts on Level Crossing Closures

Highway-rail accidents at public and private crossings in the United States result in a large number of deaths and injuries. State authorities and railroad administrators bear a heavy financial burden as a result of these incidents, which result in service disruptions, damaged trains, tracks, and equipment. To reduce the number of vehicle-train accidents, the Federal Railroad Administration (FRA) set a goal of closing 25% of all crossings nationwide within a ten-year period since 1990s (Codjoe et al., 2018). Consistent with this goal, there have been over 18,000 level crossings closed since 2008 as a result of the FRA and state DOT collaborations. The 49 states of the United States have very different rules and policies when it comes to level crossing closures (RSSB, 2006). Up to 90% of the expenses of crossing closures can be covered by the federal discretionary funding. The following sections of the report elaborate more on different state DOT efforts on level crossing closures that have been conducted over the past years.

2.2.1. Highway-Rail Crossing Handbook

The Highway-Rail Crossing Handbook (U.S. DOT, 2019) has a set of recommendations on level crossing closures. In particular, there are federal regulations imposed for high-speed level crossings (see Table 5). Level crossings are not allowed on interstate highways. The existing FRA regulations stipulate that the level crossings with trains operating at speeds of more than 125 mph should be either closed or grade-separated. Moreover, for the rail tracks with Class 7 (speeds are within 111 mph and 125 mph), the responsible party should submit an application to the FRA. The application should propose a warning/barrier system that will be used along the rail tracks. The regulation does not specify a particular type of warning/barrier systems for Class 7 rail tracks. The FRA representatives generally decide whether the proposed warning/barrier system is sufficient after a thorough review of the submitted application.

Table 5 Federal requirements imposed for high-speed level crossings.

	Active	Warning/Barrier with FRA Approval	Grade Separation or Closure
Interstate Highways	Not Allowed	Not Allowed	Required
High-Speed Rail	> 79 mph	111-125 mph	> 125 mph

The Highway-Rail Crossing Handbook underlines that closures normally provide the highest level of safety for highway and railroad users because the point of conflict is completely eliminated. Closures can also reduce traffic delays due to vehicle queuing at level crossings and lower the associated level crossing maintenance costs. Nevertheless, the level crossing closure effects may have some negative externalities as well. The decision regarding crossing closure or safety upgrades should be made taking into account safety aspects, operational characteristics of the crossing, and cost considerations. As stated earlier, federal regulations require level crossing elimination if there is a full control of access to the freeway regardless of highway vehicle volumes and train volumes. In order to accurately assess the suitability of a given level crossing for closure, it is necessary to conduct a community travel study to determine common origin and destination points and how the potential closure might influence the travel patterns of highway users. Alternative routes should have an adequate capacity to serve the existing highway users in case of crossing closures. The impacts on pedestrian activities should be assessed as well.

Local and state authorities should also put more emphasis on closing redundant level crossings that are located in a close proximity to each other. Two types of costs should be considered when making a decision on level crossing closures. The first type accounts for the costs associated with keeping a given level crossing (e.g., safety-related costs, crossing maintenance costs, costs of additional safety upgrading when necessary). The second type accounts for the costs associated with closing a given level crossing (e.g., costs associated with additional travel, costs associated with proximity of emergency services and other critical facilities). Community, local authorities, and state authorities should ideally reach a consensus when making level crossing closure decisions. As indicated earlier, the procedures for level crossing closures vary by state. However, the following factors are normally considered:

- AADT and daily number of trains
- Train speed
- Number of tracks
- Type of materials being transported
- Level crossing location
- Visibility
- Distance to traffic signals
- Accident history

The Highway-Rail Crossing Handbook recommends a closure consideration for the locations where more than four crossings are present per railroad route-mile with more than two trains per day and less than 2,000 vehicles per day. Crossings that are often used by emergency vehicles must be considered as candidates for the installation of active traffic control devices or grade separation. Typically, the railroad authorities are responsible for the removal of traffic control devices (e.g., gates, flashing lights, and crossbucks), crossing surface, and drainage in case if a given level crossing is selected for closure. The highway authorities might be responsible for the removal of advance warning signs, making the adjustments to highway traffic control signals, installing warning and regulatory signs following the MUTCD standards, and removing highway surface approaches.

Along with the aforementioned considerations, the Highway-Rail Crossing Handbook recommends level crossing closures if at least one of the following criteria is met:

- An engineering study determines that a nearby level crossing, which could require safety improvements or grade separation, would provide acceptable access for the existing highway users.
- AADT is less than 1,000.
- Acceptable alternate access is available within one mile (measured long the railroad track).
- The length of the median trip made over a given level crossing will not increase by more than 2.5 miles.
- The railroad operations will block or occupy a given level crossing for an extended period of time on a regular basis, and it is not economically or physically practical to shift the railroad operations to another location or perform a grade separation. The locations that satisfy the aforementioned criteria include the following:
    - Level crossings in the vicinity of rail yards
    - Passing tracks used for holding trains
    - Train crews are mandated to stop on a regular basis to make crew changes
    - Level crossings located near train stations with long dwell time periods

2.2.2. California Public Utilities Commission (CPUC)

The safety of level crossings in California is under the jurisdiction of the California Public Utilities Commission (CPUC or Commission). The Commission is responsible for compiling the priority list of level crossings that have to be considered for closure or grade separation (CPUC, 2021). The priority list should be then provided to the California Transportation Commission (CTC) and the California Department of Transportation (Caltrans). Based on Section 190 of the California Streets and Highways Code (S&H Code), at least $15M should be allocated for level crossing safety improvement projects. The priority list of level crossings should be revised accordingly, once the funding decisions have been made for certain crossings. According to Section 2452 of the S&H Code, the Commission is fully responsible for selecting the criteria to be used in compiling the priority list of crossings for alteration or separation. Normally, a variety of factors are considered, including vehicular and train volumes, sight distance, accident history, crossing angle, and traffic delays due to crossing blockage events caused by passing trains.

In particular, the Commission uses two separate formulas to rank level crossings for safety improvements. The first formula is specifically designated to rank level crossings for elimination or grade separation and can be expressed as follows (CPUC, 2021):

$$P = \frac{V \cdot (T + 0.1 \cdot LRT) \cdot (AH + 1)}{C} + SCF \tag{2.1}$$

where: P = priority index; V = average daily vehicle traffic; T = average daily freight/commuter train traffic; LRT = average daily light rail train traffic; AH = accident history; C = project cost from the grade separation fund; SCF = special condition factor.

The second formula is specifically designated to rank the existing grade separations for reconstruction or alteration and can be expressed as follows (CPUC, 2021):

$$P = \frac{V \cdot (T + 0.1 \cdot LRT)}{C} + SF \tag{2.2}$$

where: P = priority index; V = average daily vehicle traffic; T = average daily freight/commuter train traffic; LRT = average daily light rail train traffic; C = project cost from the grade separation fund; SF = separation factor.

The special condition and separation factors are used to explicitly account for sight distance, crossing angle, and traffic delays due to crossing blockage events caused by passing trains.

2.2.3. Georgia Department of Transportation (GDOT)

According to the Georgia Administrative Code (GAC), the Georgia Department of Transportation (GDOT) and local governments set the criteria for closing level crossings (GAC, 2022). The goal is to improve vehicle and train safety at level crossings. The criteria outlined in section 672-16-.04, factors stated in O.C.G.A. (Official Code of Georgia Annotated) Section 32-6-193.1, and public hearing comments are all weighed to evaluate whether a given public level crossing should be removed or remain open (GAC, 2022). Under Georgia Code 32-6-193.1, any inconvenience caused by traffic rerouting, including but not limited to emergency vehicle traffic, must be weighed against any benefits gained from eliminating the level crossing. In general, the following factors are considered while determining the eligibility of a level crossing closure (Georgia Code, 2022):

- Number and speed of passenger and freight trains
- Distance from alternative level crossings
- The crossing accident history over the past five years
- Type of countermeasures installed at the level crossing
- Horizontal and vertical alignments of the highway and railroad
- The maximum speed allowed at the level crossing
- The daily traffic volume
- The impact of crossing closure on the accessibility to: (A) government facilities (federal, state, or municipal); (B) business or industry; and (C) medical facilities, such as hospitals and public health departments

- Type of vehicles using the level crossing: (A) school buses; (B) vehicles with hazardous substances; (C) emergency vehicles; (D) private or public utility vehicles (e.g., water, natural gas, sewer, and maintenance vehicles); and (E) passenger-carrying vehicles

The railroad authorities may file a petition to eliminate a level crossing on a given public highway and barricade the approach without building overpasses or underpasses (Georgia Code, 2022). The petition should contain all the necessary information, including the factors listed above. The written petition should be made to the department along with a $500 filing fee. The GDOT and/or local authorities will perform a public hearing before deciding whether to deny or grant the petition submitted by the railroad authorities. If the authorized departmental representatives or local authorities confirm the necessity of level crossing closure, they will issue an approval order in writing. Similarly, if the authorized departmental representatives or local authorities deny the necessity of level crossing closure, they will issue a denial order in writing. If the closure order is issued, the railroad authorities will be responsible for physical removal of the crossing from railroad tracks and two feet beyond the ends of crossties on each crossing side. The department and/or local authorities will be responsible for the highway approach removal (Georgia Code, 2022).

It is a standard procedure for the GDOT to check nearby crossings for the possibility of closure whenever it evaluates the need to upgrade warning devices at a given level crossing or when implementing new grade separations (GDOT, 2011). The GDOT does leverage the Section 130 Program funds for crossing closures, including the level crossings that already have active warning devices. The GDOT closely works with the local authorities and provides incentives for crossing closures and warning device improvements. Installation of new countermeasures, upgrading the existing warning devices, and implementation of closures were found to be effective alternatives for improving safety of highway and railroad users at level crossings (GDOT, 2011).

2.2.4. Iowa Department of Transportation (Iowa DOT)

The Iowa Department of Transportation underlines the importance of developing a systematic approach for identifying low-volume candidate level crossings for potential closures (Iowa DOT, 2012). Economic and engineering perspectives should be directly accounted for throughout the process. Some of the critical empirical factors to be considered when selecting level crossings for closures include, but are not limited to, the following (Iowa DOT, 2012): current protection, population, required safety upgrades, train and roadway traffic volumes, crossing angle, speed of trains and vehicles, type and number of tracks, type of cargo being carried by trains and vehicles, level crossing location, sight distance, accident history, and distance to traffic signals. Economic and engineering factors include (Iowa DOT, 2012): needs associated with emergency services, other crossing alternatives, and anticipated costs involved.

The Iowa DOT and the Institute for Transportation at Iowa State University collaborated to develop a technique to assist the governmental agencies and railroad authorities with level crossing closure decisions. To assess and rank all public level crossings for consolidation, the project team designed a weighted-index approach and a supporting Microsoft Excel spreadsheet tool (Hans et al., 2015). According to Hans et al. (2015), while safety may be the traditional justification for level crossing consolidation, safety does not have to be the only deciding factor.

The weighted-index method produced a single index that considered all essential aspects after weighing and ranking all relevant criteria based on stakeholder priorities. The following factors were considered throughout prioritization: AADT, out of distance travel (i.e., the difference between the alternate route length and the original roadway segment intersecting the level crossing), truck AADT, primary or farm-to-market road system status, emergency services (EMS) location proximity count, distance to nearest EMS location, school location proximity count, distance to nearest school location, and alternate route crash rate. The proposed methodology can assist different stakeholders to better understand the necessity of level crossing closures based on a large variety of criteria.

2.2.5. Louisiana Department of Transportation and Development (LA DOTD)

The State of Louisiana has 5,262 level crossings with 2,425 private level crossings (Codjoe et al., 2018). Regarding recorded highway-rail accidents, Louisiana is ranked among the top states in the U.S. with 87 accidents, 31 injuries, and 6 fatalities recorded for the year of 2017. The FRA requires the states with high accident numbers to prepare a State Action Plan (SAP) to enhance the safety of level crossings. As a result, the 2015 Louisiana SAP identified specific options to improve crossing safety, including the elimination of unnecessary level crossings (Codjoe et al., 2018). The main consolidation/closure project procedures in SAP can be listed as follows (Rutter et al., 2016):

- ***Action:*** to create a list of prospective candidates for closures/consolidations based on the policy of the LA DOTD, as well as the law of the state.
- ***Purpose:*** to close unnecessary redundant level crossings, provide a list of candidates for closure, and enhance public safety throughout the state.
- ***Responsible Parties:*** LA DOTD.
- ***Timetable:*** For each year, compile a list of potential closure candidates and submit it to the Railroad Safety Program Committee. At least two of these initial candidate closure/consolidation procedures should start each year.

Crossing closure projects can benefit railroads by lowering maintenance costs, enhancing safety, and reducing travel time (Tian et al., 2022). Railroads that contribute to the closure or consolidation of crossings are often rewarded with matching shares and monetary incentives. Louisiana had closed 47% of its level crossings as of January 2018. Six Class I railroads are in charge of the rail network in the State of Louisiana. The various programs undertaken by the railroad companies are described below (Tian et al., 2022):

- The first measure the BNSF Railway takes into consideration to avoid level crossing accidents is to close the crossing. The BNSF Railway consistently provides different incentive programs for traffic rerouting, level crossing closure, and consolidation. The incentive funds are available not only for public level crossings but for private level crossings as well. Starting 2000, the BNSF Railway Company has closed over 3,000 level crossings within a 6-year time span.
- The NS Railway, similar to the BNSF Railway, opposes opening new level crossings and promotes removing level crossings whenever possible. An application should be officially submitted to the NS Railway, so a detailed evaluation of the potential level

crossing closure could be conducted. The applicant should pay a $500 nonrefundable fee when submitting the application.
- The CSX Transportation collaborates with the FRA and state organizations by offering incentive payments to persuade communities to close their existing level crossings. To close a level crossing, the local government must conduct a study to determine the number of redundant crossings and the presence of three active nearby level crossings. CSX fully covers the cost of level crossing closures and generally agrees to contribute to the cost of highway improvements at the locations where level crossing closures were administered.
- UP has a program to consolidate multiple public crossings before establishing a new one to support the federal effort. Every time a new level crossing is opened, the railroad authorities ask the local community to participate in a study to determine three or more existing level crossings to close.

Tian et al. (2022) also presented a framework for level crossing closures. Based on the proposed framework, the local community is expected to hold public meetings and provide its input regarding safety perception, social cohesion, potential mobility concerns, and crime issues. The railroad authorities are anticipated to communicate regarding the available funding, near misses, and assist with the negotiations with private crossing owners. Based on the input received from the railroad authorities and local governments, the designated state agency will determine the list of candidate level crossings for closure, considering important physical and operational characteristics (e.g., AADT, train volume, train speed, number of tracks, distance to schools, proximity to emergency services, accident history, visibility, and presence of alternative routes).

2.2.6. Minnesota Department of Transportation (MnDOT)

The Rail Administration Section of the Minnesota Department of Transportation (MnDOT) is responsible for monitoring the safety performance of more 4,000 public level crossings across the state (Preston et al., 2016). Level crossing safety is one of the major concerns in the State of Minnesota. A total of 445 train-vehicle accidents were recorded at public level crossings in Minnesota between 2004 and 2013. Level crossing consolidation and closures are viewed as some of the effective alternatives for level crossing safety improvements. Approximately 500 level crossings have been already closed by the MnDOT. However, there are some system management and financial challenges associated with closing other crossings. Crossing closures allow a better management of the crossing inventory, decrease the associated maintenance costs for warning devices, and completely eliminate the risk of train-vehicle accidents (Preston et al., 2016). Level crossings that impose high risk to highway and railroad users are generally considered for closures. After a detailed review of accident data, the following factors were found to be the most important ones that define risky level crossings:

- ***Volumes:*** according to the data, the risk of an accident at a level crossing increases as the volume of road traffic, train traffic, and their cross product rises above certain minimum levels.
- ***Speeds:*** the higher the speed limit on the highway and the higher the maximum timetable speed of a train, the greater the risk of accidents at level crossings.
- ***Design:*** the risk is mainly impacted by two features of the level crossing design: the number of mainline tracks and the skew angle.

- ***Surroundings:*** distances to nearby intersections, distances to the closest crossing, clearing site distances, and approaching sight distances are the four factors that substantially affect the risk of accidents at level crossings. A higher risk is connected to any quadrant where the sight distance is not adequate.

Table 6 summarizes the rail and highway features that are utilized to identify risky level crossings (Preston et al., 2016).

Table 6 Suggested risk factors.

Risk Factors	Active		Passive	
	Minimum	Maximum	Minimum	Maximum
Volumes				
AADT	2,500	Unlimited	150	Unlimited
Number of trains per day	10	Unlimited	4	Unlimited
Volume cross product	20,000	Unlimited	750	Unlimited
Speeds				
Highway speed limit	45	Unlimited		
Maximum timetable speed	31	Unlimited	36	Unlimited
Design				
Number of main tracks	2	Unlimited		
Skew	>=15°		>=15°	
Surroundings				
Distance to the nearest intersection	1 foot	99 feet	40 feet	160 feet
Distance to the nearest crossing	0.5 mile	1 mile	0.5 mile	1.0 mile
Clearing sight distance	Any Quadrant Fails		Any Quadrant Fails	
Approaching sight distance			Any Quadrant Fails	

2.2.7. North Carolina Department of Transportation (NCDOT)

The North Carolina Department of Transportation (NCDOT) uses a specific formula, called an "Investigative Index", in order to identify level crossings that require safety improvements. The Investigative Index includes the following major attributes (NCDOT, 2019):

- Volume of trains
- Speed of trains
- Average daily highway traffic
- School bus passenger loads
- Existing warning devices
- Number of main rail tracks in use
- Number of side rail tracks in use
- Accident history

The level crossings that have the highest values of the Investigative Index receive higher priority for safety improvements. Normally, the NCDOT selects approximately 100 level crossings for upgrading every year (NCDOT, 2019). Around $9 million are allocated for safety improvement projects in North Carolina. Local authorities are required to partially cover the cost of installing warning devices at level crossings that are located on municipal streets rather than state-maintained highways. In case the city decides not to participate in the level crossing safety improvement program, the NCDOT excludes the crossing from the State Transportation Improvement Program. However, a more detailed consideration might be given to the same crossing in the future. When it comes to level crossing closures, the NCDOT typically considers a large variety of factors, including the following (U.S. DOT, 2019):

- Closely spaced crossings on the same highway or street network within a quarter mile of each other
- Redirecting traffic to an adjacent crossing safely and efficiently
- Crossings with a high accident rate
- Crossings with poor visibility due to track curvature, intersection angle, trees, or other obstructions
- Several nearby crossings when the new crossing is built
- Nearby crossings where one of the crossings has been upgraded with new signaling devices
- Complex crossings with severe operational issues or where it is challenging to provide effective warning devices due to lengthy switching procedures, multiple tracks, or long duration of level crossing blockage events
- Private crossings with no identifiable responsible owner
- Private crossing owners who cannot or will not invest in improving a private crossing, and an alternate route to get to the other side of the tracks is readily available

2.2.8. Ohio Department of Transportation (ODOT)

According to the Public Utilities Commission of Ohio (PUCO), the State of Ohio is ranked as the fifth state in the U.S. in terms of rail traffic with more than 5,000 miles to rail tracks and 5,700 public level crossings (PUCO, 2018). Some parts of the state experience a significant number of accidents at level crossings that cause traffic blockage and human casualties. Between 2003 and 2018, the PUCO has approved the installation of more than 3,300 safety upgrades at level crossings, and a total of 54 crossing upgrades were administered in 2018. Public level crossing closures is considered as one of the alternatives to improve the safety of highway and railroad users in the State of Ohio (PUCO, 2018). The Ohio Rail Development Commission (ORDC) underlines that a variety of considerations should be made when deciding on level crossing closures (e.g., on-site survey of level crossing locations, impacts on railroad and highway traffic, impacts on pedestrians, impacts on emergency services, preferences of railroad authorities, preferences of local authorities, and preferences of the community) (ORDC, 2022). The state has also an authority to close level crossings via procedures that can be initiated either by railroad authorities of local authorities.

According to §4907.471 of the Ohio Revised Code (ORC), the PUCO must assess if the level crossing can be closed to vehicular traffic or pedestrian traffic or both (ORC, 1993). Also, the possibility of shifting the traffic to other crossings should be evaluated. The Commission will take the following factors into account while making this decision (ORC, 1993):

- The number of level crossings in one mile of the proposed level crossing for closure

- Vehicle and train traffic at the proposed level crossing for closure and alternate level crossings
- Increased traffic at alternate level crossings due to proposed level crossing closures
- Road conditions at alternate level crossings
- Alternative crossing sight distances and existing obstruction
- Types of warning devices at alternate level crossings
- The effect of the closure of the level crossing on traffic, enterprises, emergency vehicles, and other municipal and populated areas
- Other closure considerations the Commission may consider

In case the Commission determines that there is no an urgent need for crossing closure, and if the crossing is located on a street within a municipality, the Commission will administer a public hearing on the subject of potential crossing closure (ORC, 1993). The purpose of the hearing will be to receive the feedback regarding potential impacts of the crossing closure on pedestrian and vehicular patterns within the municipal corporation. The Commission will also assess the costs of level crossing closure for the cases when the railroad authorities or local authorities apply for closure and the crossing is located under the railroad jurisdiction. The railroad authorities or local authorities reserve the right to appeal the final decision of the Commission to the Supreme Court (ORC, 1993).

2.2.9. Oregon Department of Transportation (ODOT)

Safety, freight mobility, and local transportation system connectivity are all issues that the Oregon Department of Transportation (ODOT) must address, as the Oregon's regulatory body responsible for public level crossings (ODOT, 2020). A review process should be initiated for adding new crossings, modifying the existing crossings, or eliminating the existing crossings. The completed applications must be sent to the ODOT Rail and Public Transit Division, which will evaluate each application and will work with other relevant parties to initiate opening or closing of crossings. Along with safety considerations, local mobility is also of a great importance, since level crossings enable vehicular circulation and provide important routes for local bicycles and pedestrians. Following the state statute requirements, the ODOT should also assess the possibilities of crossing closures to eliminate potential points of conflict between highway vehicles and trains. Available resources, expected project costs, anticipated benefits, and negative effects on local communities should be taken into consideration when evaluating level crossing closure decisions (ODOT, 2020).

The ODOT Rail and Public Transit Division has a specific set of criteria that are used to evaluate each application for level crossing opening, alteration, or closing. The criteria include the following (ODOT, 2020):

- Public safety (driver behavior, accident history, truck/train speed, mix of highway vehicles, and physical characteristics)
- Necessity (freight mobility, land usage, and safer alternative access)
- Public convenience (maintenance expenses, maximum freight mobility, blockages, circulation of traffic, no modal conflicts, and future development of land use)
- General welfare (reduced liability, future effects on land use, economic impacts, and effects on emergency vehicles)

Following the application evaluation, if the railroad, public road authority, and the ODOT agree to move forward, the ODOT will create a Notice of Proposed Action for the Crossing Section Manager and other parties. An administrative hearing procedure is available if the parties cannot come to an agreement and the applicant wants to move forward with the project (ODOT, 2020).

2.2.10. Texas Department of Transportation (TxDOT)

The Texas Department of Transportation (TxDOT) collaboratively works with the railroad authorities and local authorities on level crossing closures. The TxDOT provides funding to the local authorities for the following activities (TxDOT, 2015):

- Removal of the existing pavement at a given level crossing
- Build an adequate highway terminus at the removed level crossing
- Install appropriate signs in the vicinity of the crossing acknowledging its closure
- Upgrading the existing railroad-related signals
- Enhance the existing streets that are located in the vicinity of the closed level crossing to make sure that the diverted traffic will be handled effectively

The TxDOT does not provide any funds to the railroad companies, since crossing closures are expected to benefit these companies. An agreement between the TxDOT, railroad authorities, and local authorities should be signed before the crossing closure activities could be administered. The TxDOT manages two funding programs for the elimination of redundant non-essential level crossings in Texas: (1) the Federal Signal Program; and (2) the Basic Closure Program. Based on the Federal Signal Program, the TxDOT can provide up to $150,000 to the local authorities for level crossing closure and enhance safety in the vicinity of the closed level crossing. The railroad authorities can participate in the program and contribute monetary funds as well. The Basic Closure Program is more limited in terms of funding and provides only up to $7,500 to the local authorities, assuming at least matching funds allocated by the railroad authorities (TxDOT, 2015).

The following criteria are generally considered by the TxDOT, railroad authorities, and local authorities when making level crossing closure decisions (TxDOT, 2017):

- Level crossings along the same highway within a quarter mile of one another
- Level crossings where road traffic can be diverted to neighboring crossings
- Level crossings with a high accident history
- Low-sight-distance level crossings due to the crossing angle, surrounding trees, or other types of obstruction
- Adjacent level crossings where one crossing has upgraded signal devices or have been replaced with a bridge
- Multiple neighboring crossings where a new level crossing is being constructed

2.3. FDOT Efforts on Level Crossing Closures

Following Florida Statute 341.302, the Florida Department of Transportation (FDOT) is required to manage the opening and closure of public level crossings (FDOT, 2022). The level crossing opening-closure program encourages the development of a multimodal network that is reliable, safe, and well-connected. The program achieves this goal by identifying hazardous, redundant, and unnecessary public level crossings for potential roadway closure. The FDOT employs a multi-step process to implement the opening-closure program successfully (FDOT, 2022).

According to the Florida Department of State (FDS), to open or close public level crossings, the FDOT accepts applications from the following entities (FDS, 2022):

- The governmental party with the authority over the highway
- Railway companies with operating trains through the level crossing
- Any other parties with the authority over the public level crossing

Closure applications from individual residents or groups, such as community organizations, will be also accepted. The railroad crossing opening/closing application forms which should be filled by interested parties are shown in Appendix A. The FDOT reviews the applications to confirm that all the required information has been submitted (FDOT, 2022). Moreover, the FDOT ensures that the crossing requested for closure/opening is a public one. Then, the FDOT seeks responses from all the affected parties (e.g., if the city submits an opening request, the FDOT will ask the railroad to state their position). The FDOT is responsible for the preliminary evaluation, but the applicant is the one who has the burden of proof regarding the opening or closing of a level crossing. The FDOT may assist in negotiation between the affected parties in order to address disagreements. The FDOT will draft a Stipulation of Parties if the application satisfies the requirements of the Florida Administrative Code (FAC) and if it is approved by all of the involved parties. The opening or closing of the level crossing is granted after the execution of the Stipulation of Parties, which serves as the Final Order to open or close a level crossing (FDOT, 2022).

Suppose the affected parties are unable to reach an agreement. In that case, the FDOT will issue a Notice of Intent to approve or reject the opening or closure of the level crossing based on the information provided during the course of the application process. After receiving the Notice of Administrative Hearing Rights and the Notice of Intent, all parties will have a period of 21 days during which they can submit a request for an administrative hearing. When the Notice of Intent is accepted by all parties or when the petitioning party does not make a request for a hearing, the FDOT will execute and release the Final Order. If a petition for an administrative hearing is filed within the allotted time frame of 21 days, the FDOT will forward the request to the Division of Administrative Hearings to schedule a hearing (FDOT, 2022). Following the conclusion of the hearing, an Administrative Law Judge will draft a Recommended Order for the parties involved. Then, the Secretary of the FDOT will execute the Final Order, which may differ from the Recommended Order that the Administrative Law Judge issued earlier. The aforementioned steps and procedures that are performed as a part of the opening-closure program are illustrated in Figure 23.

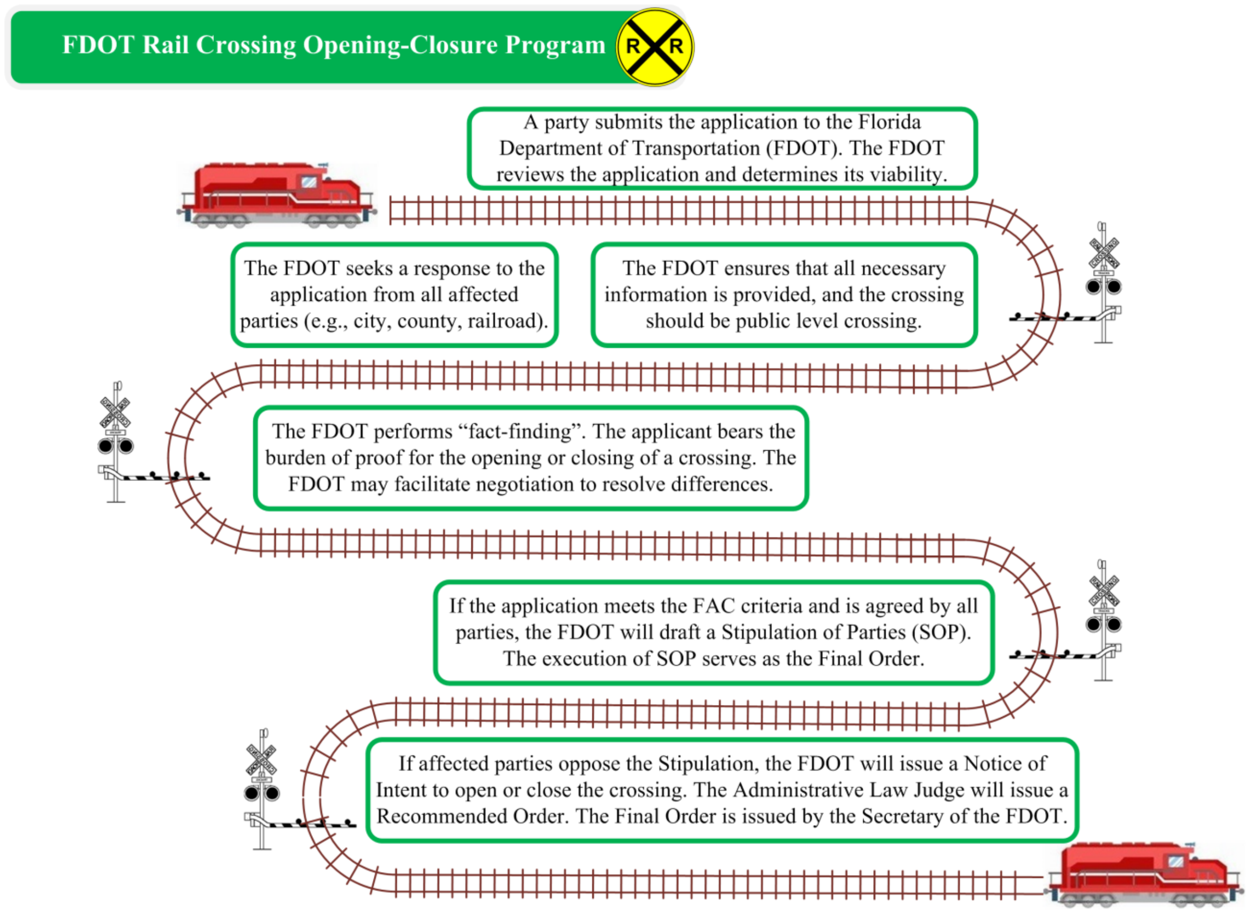


Figure 23 Public level crossings – opening and closure.

When preparing an application for the level crossing closure request, the following information should be provided to the FDOT (FDOT, 2022):

- The name or number of the roadway
- The city or county in which the level crossing is located
- Applicant contact information (i.e., office location, telephone, and physical address)
- Number of the crossing based on the crossing inventory
- The authority that has the jurisdiction over the street or roadway (e.g., city, county, or state)
- Another popular name for the roadway in the local area
- The operating railway
- The railroad milepost

In addition, the party must explain whether the level crossing closure application is for roadway removal or rail removal or both. Suppose all parties, applicant, railroad, and Department, fail to reach an agreement on the rail crossing closure via the Stipulation of Parties. In that case, the applicant must demonstrate that the closure meets the criteria outlined in the Florida Administrative Code Rule 14-57.012. A questionnaire has been provided to assist the FDOT in evaluating the criteria. The following criteria will be evaluated using the questionnaire (FDOT, 2022):

A. Safety

- The safety impacts of level crossing closure on drivers, pedestrians, cyclists, and rail personnel
- Proposed safety measures for adjacent level crossings
- The highway traffic control devices and traffic signals at adjacent level crossings that could be upgraded if the subject crossing is closed
- The distance of level crossing from the nearest intersection (the street name should be provided as well)
- Possible obstructions, such as buildings, fences, or vegetation
- The primary traffic generators (e.g., businesses, recreational areas, shopping malls, special events, etc.) in the adjacent area, as well as their type, location, and distance from the subject crossing
- Whether or not the crossing is located on an evacuation route
- Analyzing traffic operations and safety, as well as assessing traffic problems caused by the level crossing closure (the analysis should include all nearby level crossings and roadways, as well as the anticipated increase in traffic on these roadways due to rerouting)

B. Necessity for rail and vehicle traffic

- The necessity of the existence of level crossing to access a property
- Description of land use on each side of the rail crossing
- The names of churches, schools, or hospitals within a mile or less of the subject crossing
- Annual Average Daily Traffic (AADT) at the level crossing site
- Level of service at the level crossing
- An estimated percentage of truck traffic at the considered level crossing
- The number of trips made by trucks carrying hazardous materials per day or week through the level crossing
- Number of school buses that use the level crossing daily
- Number of pedestrians and bike riders that use the level crossing (daily or weekly)
- Whether the level crossing is on a local transit route
- The existence of any corridor studies or other preliminary traffic engineering studies relevant to the subject crossing

C. Alternate routes

- Effects on road access for property owners should the crossing be closed
- The availability of alternative routes in the event that the crossing is closed and the presence of traffic signals on alternative routes
- The effect of a crossing closure on the AADT at nearby public crossings
- Added travel time and distance between two points during peak hours when using alternate routes (nearest intersection or major access) on either side of the crossing

D. Effect on rail operations and expenses

- Number and type of rail tracks at the subject level crossing
- The presence of the rail sidings or switches at the location of the subject level crossing
- The availability of the nearby rail yard and its distance to the subject level crossing
- Number of daily train movements (number of switching or thru trains; number of passenger or freight trains)
- The approximate times during the day and evening that the level crossing is blocked
- The approximate length of time (i.e., minutes) that the crossing is blocked
- Minimum and maximum train speeds at the subject crossing
- The anticipated expansion of tracks and/or train movements
- The distance from the subject crossing to adjacent public crossings

E. Excessive restriction to emergency type vehicles resulting from closure

- The opinion of the Sheriff/Police Chief and the Fire Chief on the proposed level crossing closure
- Determining whether it is a typical emergency rescue route (based on observations, city/county responses, or traffic studies)
- Number of emergency rescue vehicles have used the crossing to respond to calls in the past 2-3 years

F. Design of the level crossing and road approaches

- The condition of crossing surface, rail warning devices (including pavement markings, signs, and highway traffic signals), sidewalks, bike lanes, and approaches on each side of subject level crossing
- Whether or not the level crossing surface and track are elevated above the roads on either side (i.e., hump crossing)
- The vehicular design speed at the subject level crossing
- Number of lanes at the subject level crossing
- Crossing width
- Roadway condition at the subject level crossing

G. Presence of multiple tracks and their effect upon railroad and highway operations

- The number of tracks at the location
- The number of train movements and the types of trains that run on each track (passenger, thru freight, or switching freight, and the number of cars)

The application must be accompanied by relevant maps, aerial photographs, and other documentation. The attributes and information required to open a level crossing are similar to those needed for an application to close the level crossing. However, the applicant must indicate whether the opening application is for a new rail line construction, a new roadway construction, or a conversion of a private level crossing to a public one, or a combination of the aforementioned options. Additionally, a questionnaire has been made available for level crossing opening to aid the FDOT in assessing the criteria for level crossing opening. The following criteria should be considered for the level crossing opening application (FDOT, 2022):

A. Safety

- The safety effects of crossing opening on drivers, pedestrians, cyclists, and rail personnel
- Whether or not the grade separation option was considered when designing the crossing
- Determining which existing crossings will be proposed for closure in order to mitigate the negative effects on safety caused by a proposed new crossing
- Designed safety measures for the proposed level crossing
- The distance from the proposed level crossing to the nearest intersection (include the street name as well)
- Whether or not structures would be constructed near the crossing intersection
- The primary traffic generators (e.g., businesses, recreational areas, shopping malls, special events, etc.) in the adjacent area, as well as their type, location, and distance from the proposed level crossing
- Conduct traffic operations and safety analysis, evaluating railroad crossing traffic issues, train traffic movements, and railroad preemption (the analysis should incorporate all proposed developments in the immediate vicinity as well as the predicted increase in traffic resulting from the proposed developments)

B. Necessity for rail and vehicle traffic

- Necessity of the opening the proposed level crossing
- Providing excerpts from the Comprehensive Plan or any other relevant transportation plans for the proposed level crossing
- Description of land use on each side of the proposed level crossing
- Predicted Annual Average Daily Traffic (AADT) at the proposed level crossing
- Level of service at the proposed level crossing
- Expected AADT and service level in 5 years at the proposed level crossing
- Predicted percentage of truck traffic and anticipated truck traffic in 5 years
- The number of trips made by trucks carrying hazardous materials per day or week through the proposed level crossing
- Number of school buses using the proposed level crossing daily or weekly
- Estimated number of trips made by emergency vehicles per day or week
- The predicted number of pedestrians and bike riders who will use the proposed level crossing, as well as the predicted number of users in 5 years
- The existence of any corridor studies or other preliminary traffic engineering studies relevant to the proposed level crossing

C. Alternate routes

- Access roads available to property owners if the proposed level crossing is not there
- Routes currently used or intended for use if the proposed level crossing is not approved
- Existing traffic signals on these routes
- The proposed crossing impact on the AADT at nearby public crossings

D. Effect on rail operations and expenses

- Number and type of rail tracks at the proposed level crossing
- The presence of the rail sidings or switches in the location of the proposed crossing
- The availability of the nearby rail yard and its distance to the proposed crossing

- Number of current daily train movements (number of switching or thru trains; number of passenger or freight trains)
- The approximate times during the day and evening that the crossing will be blocked
- The approximate length of time (i.e., minutes) that the crossing is blocked
- Minimum and maximum train speeds at the proposed level crossing
- The anticipated expansion of tracks and/or train movements
- The distance from the proposed level crossing to adjacent public level crossings
- Estimated costs of the proposed level crossing installation and annual maintenance, as well as identification of the parties responsible for those costs

E. Closure of one or more public crossings to offset opening a new crossing

- Identify crossing closure candidates that could offset the opening of the proposed level crossing

F. Design of the level crossing and road approaches

- Submitting design plans that include the location of sidewalks, bike lanes, and traffic control devices, such as pavement markings, signs, and highway traffic signals
- Proposed future modifications (e.g., Phase I can be a 2-lane roadway, and a left-turn lane will be added in Phase II)
- The vehicular design speed at the proposed level crossing
- Number of divided or undivided through or turn lanes at the proposed level crossing

G. Presence of multiple tracks and their effect upon railroad and highway operations

- The number of tracks at the location of the proposed level crossing
- The number of train movements and the types of trains that run on each track (passenger, thru freight, or switching freight and the number of cars)

3. OPTIMIZATION MODEL DEVELOPMENT

3.1. Proposed Optimization Model

A detailed description of the main notations to be used throughout the development of the optimization model for the selection of level crossings for closure is presented in this section. Furthermore, a detailed description of the decision problem addressed herein is provided. Then, a mathematical formulation for the integer optimization model with the goal of maximizing the total benefit from level crossing closures is showcased in this section as well.

3.1.1. Main Notations

This section of the report explains the main notations of the proposed integer programming model, including sets, decision variable, and parameters.

Sets

$X = \{1, \ldots, n\}$	set of level crossings (level crossings)

Decision Variable

$\boldsymbol{z}_x \in \mathbb{B}\ \forall x \in X$	=1 if level crossing x is selected for closure (=0 otherwise)

Parameters

$n \in \mathbb{N}$	number of level crossings (level crossings)
$TB_x \in \mathbb{R}^+\ \forall x \in X$	total benefit associated with the closure of level crossing x (no units)
$Safe_x \in \mathbb{R}^+\ \forall x \in X$	safety benefits associated with the closure of level crossing x (no units)
$Econ_x \in \mathbb{R}^+\ \forall x \in X$	economic benefits associated with the closure of level crossing x (no units)
$Envi_x \in \mathbb{R}^+\ \forall x \in X$	environmental benefits associated with the closure of level crossing x (no units)
$W^{safe}, W^{econ}, W^{envi} \in \mathbb{R}^+$	weights associated with safety, economic, and environmental benefits, respectively (vary from 0.0 to 1.0)
$y_x \in \mathbb{B}\ \forall x \in X$	=1 if level crossing x can be potentially selected for closure (=0 otherwise)
$X^{max} \in \mathbb{N}$	maximum number of level crossings that can be closed for the considered planning time horizon (level crossings)
$CC_x \in \mathbb{R}^+\ \forall x \in X$	cost of closing level crossing x (USD)
$TPB \in \mathbb{R}^+$	total planned budget for level crossing closures (USD)

3.1.2. Problem Description

Assume that there are $X = \{1, \ldots, n\}$ level crossings in a given geographical location (e.g., the State of Florida) that are considered for closure. The closure of each level crossing is expected to bring certain benefits to local communities and relevant stakeholders ($TB_x, x \in X$ – no units), including the following: (1) safety benefits – $Safe_x, x \in X$ (no units); (2) economic benefits – $Econ_x, x \in X$ (no units); and (3) environmental benefits – $Envi_x, x \in X$ (no units). Each type of benefits can be perceived differently by imposing particular weight values (W^{safe}, W^{econ}, and W^{envi} denote the weights associated with safety, economic, and environmental benefits, respectively). Certain practical considerations have to be accounted for when assessing the level crossing closure decisions (e.g., proximity of a given level crossing to other level crossings, the frequency of using a given level crossing when providing emergency services, potential highway traffic diversion to alternative level crossings and routes). As an example, it may not be practical to close a given level crossing if it is heavily used by emergency services, and the alternative routes can cause a substantial travel time increase for highway users).

Moreover, a significant number of level crossing closures may not be desirable for local communities and relevant stakeholders (e.g., Florida Department of Transportation and local authorities), as these closures can cause inconvenience to the public and may even result in modal shifts. Therefore, an upper bound on the number of level crossings that can be closed for the considered planning horizon (X^{max} – level crossings) will be set in the proposed optimization model. Each level crossing closure is assumed to incur a specific cost ($CC_x, x \in X$ – USD). The relevant stakeholders have a certain limit for the total planned budget for level crossing closures (TPB – USD). The main objective of the decision problem addressed herein is to determine the level crossings that have to be closed in a given geographical location, aiming to maximize the total benefit associated with closures and considering the total planned budget limitation along with the upper bound on the number of level crossing closures.

3.1.3. Model Formulation

An integer programming formulation for the Selection of Level Crossings for Closure (**SLCC**) Optimization Problem is presented in this section of the report.

Selection of Level Crossings for Closure (**SLCC**):

$$maximize \sum_{x \in X} TB_x \cdot \boldsymbol{z}_x \quad (3.1)$$

Subject to:

$$TB_x = Safe_x \cdot W^{safe} + Econ_x \cdot W^{econ} + Envi_x \cdot W^{envi} \ \forall x \in X \quad (3.2)$$

$$\boldsymbol{z}_x \le y_x \ \forall x \in X \quad (3.3)$$

$$\sum_{x \in X} \boldsymbol{z}_x \le X^{max} \quad (3.4)$$

$$\sum_{x \in X} CC_x \cdot \boldsymbol{z}_x \le TPB \quad (3.5)$$

$$\boldsymbol{z}_x, y_x \in \mathbb{B} \ \forall x \in X \quad (3.6)$$

$$n, X^{max} \in \mathbb{N} \quad (3.7)$$

$$TB_x, Safe_x, Econ_x, Envi_x, W^{safe}, W^{econ}, W^{envi}, CC_x, TPB \in \mathbb{R}^+ \ \forall x \in X \quad (3.8)$$

The objective function (3.1) aims to maximize the total benefit associated with level crossing closures in a given geographical location. Constraint set (3.2) estimates the total benefit associated with the closure of a given level crossing, including safety benefits, economic benefits, and environmental benefits. Constraint set (3.3) indicates that a given level crossing can be selected for closure if and only if such a decision is practically feasible. Constraint set (3.4) imposes an upper bound on the maximum number of level crossings that can be closed for the considered planning time horizon. Constraint set (3.5) enforces that the total cost to be incurred due to level crossing closures cannot exceed the total planned budget for level crossing closures.

Constraint sets (3.6), (3.7), and (3.8) define the nature of the decision variable and parameters of the **SLCC** optimization model.

3.2. Estimation of Safety Benefits

The Florida Priority Index Formula can be used to assess the overall hazard of a level crossing to train-vehicle collisions ($OH_x, x \in X$ – no units) based on the average daily volume of highway vehicles, average daily volume of trains, speed of trains, protection factor, and an incident history parameter. The incident history parameter can be calculated for a given level crossing as the total number of incidents in the last 5 years or since the year of last improvement (when there was an upgrade). The Florida Priority Index estimated for level crossing x ($FPI_x, x \in X$) can be computed using the following formula (Dulebenets et al., 2020; Dulebenets et al., 2021):

$$FPI_x = V_x \cdot T_x \cdot (0.1 \cdot S_x) \cdot PF_x \cdot \left(0.01 \cdot {A_x}^{1.15}\right) \tag{3.9}$$

where:
FPI_x – is the Florida Priority Index estimated for level crossing x (no units);
V_x – is the average daily volume of highway vehicles recorded for level crossing x (vehicles per day);
T_x – is the average daily volume of trains recorded for level crossing x (trains per day);
S_x – is the speed of trains recorded for level crossing x (mph);
PF_x – is the protection factor for level crossing x (PF = 0.10 for gates; PF = 0.70 for flashing lights; PF = 1.00 for passive);
A_x – is the incident history parameter for level crossing x (incidents); this parameter can be estimated as the total number of incidents in the last 5 years or since the year of last improvement (when there was an upgrade).

The overall level crossing hazard can be further disaggregated into the following hazard severity categories (U.S. DOT, 2014): (1) Fatality Incidents – these incidents involve at least one fatality; (2) Casualty Incidents – these incidents involve at least one fatality or injury; (3) Injury Incidents – these incidents involve at least one injury but no fatality; and (4) Property Damage Only Incidents – these incidents involve no fatalities or injuries; only property damage is reported. Based on the methodology established by the U.S. DOT, the fatality hazard at a level crossing can be quantified using the following relationship (U.S. DOT, 2014):

$$FH_x = \frac{OH_x}{1 + KF \cdot MS_x^{FH} \cdot TT_x \cdot TS_x \cdot UR_x^{FH}} \ \forall x \in X \tag{3.10}$$

$$KF = 440.9 \tag{3.11}$$

$$MS_x^{FH} = {ms_x}^{-0.9981} \ \forall x \in X \tag{3.12}$$

$$TT_x = (thru_x + 1)^{-0.0872} \ \forall x \in X \tag{3.13}$$

$$TS_x = (switch_x + 1)^{0.0872} \ \forall x \in X \tag{3.14}$$

$$UR_x^{FH} = e^{0.3571 \cdot urban_x} \ \forall x \in X \tag{3.15}$$

where:
FH_x – is the fatality hazard at level crossing x (no units);
OH_x – is the overall hazard at level crossing x (no units);
ms_x – is the maximum timetable train speed at level crossing x (miles per hour); $ms_x = S_x \ \forall x \in X$. Assume $ms_x = 1, x \in X$ when there are no data available.

$thru_x$ – is the number of through trains per day at level crossing x (trains per day). Assume $thru_x = 1, x \in X$ when there are no data available.
$switch_x$ – is the number of switch trains per day at level crossing x (trains per day). Assume $switch_x = 1, x \in X$ when there are no data available.
$urban_x$ = 1 if level crossing x is urban, else $urban_x = 0$. Assume $urban_x = 0, x \in X$ when there are no data available.

Based on the methodology established by the U.S. DOT, the casualty hazard at a level crossing can be quantified using the following relationship (U.S. DOT, 2014):

$$CH_x = \frac{OH_x}{1 + KC \cdot MS_x^{CH} \cdot TK_x \cdot UR_x^{CH}} \ \forall x \in X \tag{3.16}$$

$$KC = 4.481 \tag{3.17}$$

$$MS_x^{CH} = {ms_x}^{-0.3430} \ \forall x \in X \tag{3.18}$$

$$TK_x = e^{0.1153 \cdot tracks_x} \ \forall x \in X \tag{3.19}$$

$$UR_x^{CH} = e^{0.2960 \cdot urban_x} \ \forall x \in X \tag{3.20}$$

where:
CH_x – is the casualty hazard at level crossing x (no units);
$tracks_x$ – is the number of railroad tracks at level crossing x (tracks). Assume $tracks_x = 1, x \in X$ when there are no data available.

The injury hazard at a level crossing can be computed as the difference between the casualty hazard and the fatality hazard at that level crossing as follows (U.S. DOT, 2014):

$$IH_x = CH_x - FH_x \ \forall x \in X \tag{3.21}$$

where:
IH_x – is the injury hazard at level crossing x (no units).

The property damage hazard at a level crossing can be computed as follows (U.S. DOT, 2014):

$$PH_x = OH_x - FH_x - IH_x \ \forall x \in X \tag{3.22}$$

where:
PH_x – is the property damage hazard at level crossing x (no units).

Let $S = \{1, \dots, k\}$ be the set of hazard severity categories for level crossings (i.e., fatality hazard, injury hazard, and property damage hazard). Let $W_s^{acc}, s \in S$ be the weight associated with hazard severity category s (can vary from 0.0 to 1.0). Let $HS_{xs}, x \in X, s \in S$ be the hazard of severity s at level crossing x (no units). Then, the safety benefits associated with the closure of level crossing x required in the **SLCC** mathematical model can be quantified using the following relationship:

$$Safe_x = \sum_{s \in S} HS_{xs} \cdot W_s^{acc} \ \forall x \in X \tag{3.23}$$

Note that the hazard severity weight values can be set by the user (e.g., the Florida Department of Transportation) based on the societal costs of level crossing incidents for a given geographical location. Based on the previous studies, the weights for fatality hazard, injury hazard, and property damage hazard could be assumed to be 0.90, 0.09, and 0.01, respectively (Dulebenets et al., 2021).

3.3. Estimation of Economic Benefits

The economic benefits will be assessed by the reduction in traffic delays from level crossing closures along with the reduction in the associated operations and maintenance costs. The traffic delay reduction is expected to improve continuity of passenger and freight flows, which is also expected to promote the economic development of a given geographical location. The following approach will be used for the estimation of traffic delays at level crossings based on the existing literature (Dulebenets et al., 2021). The effective time during which a train blocks level crossing x with the existing warning devices ($EBT_x^0, x \in X$ – seconds) can be estimated as follows (ITE, 2006; CUTR, 2014; STB, 2020; Dulebenets et al., 2021):

$$EBT_x^0 = CCD_x^0 + \frac{L_x}{1.47 \cdot SC_x} \ \forall x \in X \tag{3.24}$$

where:

$CCD_x^0, x \in X$ – is the current delay time for level crossing x with the existing warning devices (seconds);

$L_x, x \in X$ – is the average length of trains for level crossing x (ft);

$SC_x, x \in X$ – is the average speed of trains for level crossing x (mph);

1.47 – is the conversion factor from mph to ft/second.

The train speed at level crossings can be set based on the maximum timetable train speed values that are available in the FRA crossing inventory database. Furthermore, reasonable upper and lower bounds should be considered when setting the average speed of trains passing through level crossings. Let SC^{min} be the minimum average speed of trains at level crossings (mph), and SC^{max} be the maximum average speed of trains at level crossings (mph). Therefore, $SC^{min} \leq SC_x \leq SC^{max} \ \forall x \in X$. Assume $T_x, x \in X$ is the average number of trains passing through level crossing x per day. Let $V_x, x \in X$ be the average number of vehicles passing through level crossing x per day. Assume that trains and vehicles are uniformly arriving at level crossing x throughout the day, which is a common supposition in the literature (NCHRP, 1987; Okitsu et al., 2010; STB, 2020). Then, there will be a total of T_x crossing blockage occurrences for a given day. The average number of vehicles, which are queued at level crossing x with the existing warning devices during each blockage event ($VQ_x^0, x \in X$ – vehicles), can be computed based on a 15-min daily traffic volume and percentage of the 15-min time interval affected by the crossing blockage event based on the following equation (NCHRP, 1987; Jusayan, 2015):

$$VQ_x^0 = \left(\frac{V_x}{24 \cdot 4}\right) \cdot \left(\frac{EBT_x^0}{900}\right) \ \forall x \in X \tag{3.25}$$

where:

$\left(\frac{V_x}{24 \cdot 4}\right), x \in X$ – is the 15-min daily traffic volume (vehicles);

"900" – is the number of seconds in a 15-min time interval.

A 15-min daily traffic volume was adopted in the equation for vehicle queue estimation, as it is highly unlikely that a significant percentage of vehicles (e.g., hourly volume) will experience the crossing blockage event (NCHRP, 1987; Jusayan, 2015). A total of $(VQ_x^0/2)$ highway vehicles will be queued in one direction, while the remaining amount of $(VQ_x^0/2)$ highway vehicles will be queued in the opposite direction. Such a supposition can be adjusted accordingly in case an exact directional distribution of vehicles is available for a given level crossing. The overall delay to be experienced by queued vehicles as a result of each blockage of level crossing x with the existing warning devices ($ODB_x^0, x \in X$ – seconds) with n_x highway lanes can be computed based on the following equation (NCHRP, 1987):

$$ODB_x^0 = \left(\frac{EBT_x^0}{2} \cdot VQ_x^0\right) + \left(\frac{VQ_x^0}{2 \cdot n_x}\right)^2 \quad \forall x \in X \qquad (3.26)$$

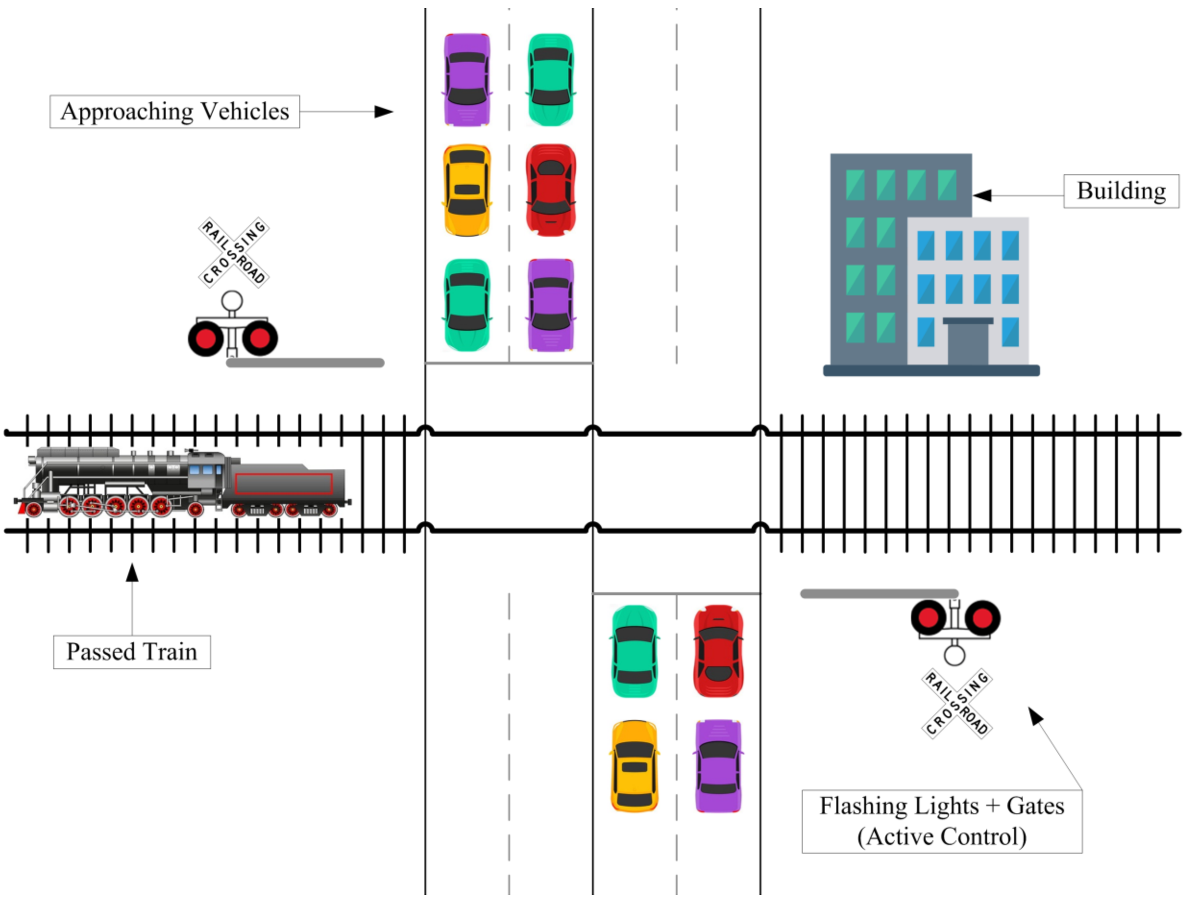


Figure 24 Queue dissipation time calculation.

The term $\left(\frac{VQ_x^0}{2 \cdot n_x}\right)^2$ is used is equation (3.26) to capture the time required for queue dissipation ($QDT_x^0, x \in X$ – seconds) after the train passes level crossing x (see Figure 24): $QDT_x^0 = \left(\frac{VQ_x^0}{2 \cdot n_x}\right)^2 \ \forall x \in X$. Once the train passes a given level crossing, there will be a total of $\left(\frac{VQ_x^0}{2 \cdot n_x}\right)$ vehicles queued in each highway lane (n_x highway lanes are assumed to be available in one direction, and n_x highway lanes are assumed to be available in the opposite direction, which constitute to the term “$2 \cdot n_x$” in the denominator). Suppose that the headway between two consecutive vehicles is set to 2 seconds (NCHRP, 1987). Then, the total queue dissipation time for the first vehicle in each lane will be zero seconds. In the meantime, the total queue dissipation time for the last vehicle in each lane will be $(2) \cdot \left(\frac{VQ_x^0}{2 \cdot n_x}\right)$ seconds. The average queue dissipation time will comprise $(2) \cdot \left(\frac{VQ_x^0}{2 \cdot n_x}\right)/2$, and the total queue dissipation time will comprise $[(2) \cdot \left(\frac{VQ_x^0}{2 \cdot n_x}\right)/2] \cdot \left(\frac{VQ_x^0}{2 \cdot n_x}\right) = \left(\frac{VQ_x^0}{2 \cdot n_x}\right)^2$ seconds (NCHRP, 1987). Moreover, the term $(EBT_x^0/2)$ is applied in equation (3.26) in order to capture for the average effective blockage time per vehicle, since not all the vehicles will experience the same delays.

The overall delay to be incurred at level crossing x with the existing warning devices per day ($OD_x^0, x \in X$ – hours) can be computed based on the number of blockage occurrences at that crossing per day ($T_x, x \in X$) and the overall delay experienced by queued vehicles during each blockage occurrence (ODB_x^0, $x \in X$ – seconds) based on the following equation:

$$OD_x^0 = \frac{T_x \cdot ODB_x^0}{3600} = \left(\frac{T_x}{3600}\right) \cdot ODB_x^0 = \left(\frac{T_x}{3600}\right) \cdot \left[\left(\frac{CCD_x^0 + \frac{L_x}{1.47 \cdot SC_x}}{2} \cdot VQ_x^0\right) + \left(\frac{VQ_x^0}{2 \cdot n_x}\right)^2\right] \forall x \in X \tag{3.27}$$

where:
“3600” – conversion factor from seconds to hours;
$CCD_x^0, x \in X$ – is the current delay time for level crossing x with the existing warning devices (seconds);
$L_x, x \in X$ – is the average train length for level crossing x (ft);
$SC_x, x \in X$ – is the average train speed for level crossing x (mph);
“1.47” – is the conversion factor from mph to ft/second;
$VQ_x^0, x \in X$ – is the average number of vehicles queued at level crossing x with the existing warning devices during each blockage (vehicles);
$n_x, x \in X$ – is the number of highway lanes intersecting level crossing x (lanes).

Then, the economic benefits associated with the closure of level crossing x required in the **SLCC** mathematical model can be quantified using the following relationship:

$$Econ_x = C_x^{delay} \cdot \left(\frac{T_x}{3600}\right) \cdot \left[\left(\frac{CCD_x^0 + \frac{L_x}{1.47 \cdot SC_x}}{2} \cdot VQ_x^0\right) + \left(\frac{VQ_x^0}{2 \cdot n_x}\right)^2\right] + C_x^{OM} \ \forall x \in X \tag{3.28}$$

where:
$C_x^{delay}, x \in X$ – unit cost of traffic delays at level crossing x (USD/hour);
$C_x^{OM}, x \in X$ – daily operations and maintenance costs for level crossing x (USD per day).

Note that the operations and maintenance costs should be provided per day for consistency, since the overall delay to be incurred at each level crossing is calculated per day as well using the daily vehicular and train volumes. Rezvani et al. (2015) reported that the average value of passenger time comprises 12.50 USD/hour, whereas the average value of truck driver time comprises 23.70 USD/hour. Furthermore, Mathew et al. (2021) reported that the average travel time cost for passenger vehicles is about 13 USD/hour, whereas the average travel time cost for commercial vehicles is about 25.80 USD/hour. Such information can be used to set the values of the $C_x^{delay}, x \in X$ parameter. Regarding the operations and maintenance costs, the values suggested by the U.S. DOT for level crossings with different types of existing protection can be used in calculations – see Table 7 (U.S. DOT, 2014). The field "WdCode" is adopted from the FRA crossing inventory database to denote particular level crossing protection classes.

Table 7 Operations and maintenance cost of different types of crossings.

a/a	Existing Type of Protection	O&M Cost, USD per Year	WdCode
1	Passive	200	1, 2, 3, 4
2	Flashing lights	1,800	5, 6, 7
3	Gates	2,500	8
4	4-quadrant gated crossings without detection	3,500	8
5	4-quadrant gated crossings with detection	5,000	9
6	4-quadrant gated crossings with 60' medians	25,000	9
7	Mountable curbs at gated crossings	3,500	9
8	Barrier curbs at gated crossings	3,500	9
9	One-way street at gated crossings	3,500	9
10	Photo enforcement at gated crossings	25,000	9

3.4. Estimation of Environmental Benefits

The environmental benefits will be assessed by the reduction in fuel consumption by vehicles queued at level crossings after closures. Typically, the fuel consumption of vehicles in the idle mode (e.g., vehicles queued at level crossings) is proportional to the idling time (e.g., vehicle delays at level crossings). The existing traffic simulation packages apply specific coefficients to estimate the fuel consumption of vehicles in the idle mode. As an example, the AIMSUN traffic simulation software uses 0.330 ml/second to covert the time spent in the idle mode into fuel consumption (AIMSUN, 2014). Therefore, the fuel consumption of vehicles queued at level crossing x in the idle mode ($FC_x, x \in X$ – gal) can be estimated based on the following relationship:

$$FC_x = \frac{FC_x^0}{3785.41} \cdot T_x \cdot \left[\left(\frac{CCD_x^0 + \frac{L_x}{1.47 \cdot SC_x}}{2} \cdot VQ_x^0 \right) + \left(\frac{VQ_x^0}{2 \cdot n_x} \right)^2 \right] \quad \forall x \in X \qquad (3.29)$$

Note that the factor "3785.41" is used in equation (3.29) to convert milliliters to gallons. The term $FC_x^0, x \in X$ (ml/second) represents the unit fuel consumption per unit of time (assumed to be 0.330 ml/second but can be adjusted by the user as needed). The fuel consumption is proportional to the amount of emissions produced (i.e., higher fuel consumption will result in higher emission rates in the vicinity of level crossings, which can negatively affect the quality of life for local populations). Assuming that the environmental benefits are represented by the fuel consumption of vehicles queued at level crossings after closures, the environmental benefits associated with the closure of level crossing x required in the **SLCC** mathematical model can be quantified using the following relationship:

$$Envi_x = \frac{FC_x^0}{3785.41} \cdot T_x \cdot \left[\left(\frac{CCD_x^0 + \frac{L_x}{1.47 \cdot SC_x}}{2} \cdot VQ_x^0 \right) + \left(\frac{VQ_x^0}{2 \cdot n_x} \right)^2 \right] \forall x \in X \qquad (3.30)$$

3.5. Additional Considerations for Level Crossing Closures

Along with the safety, economic, and environmental benefits, some additional factors can be considered when making decisions on level crossing closures. Some useful information can be collected from the FRA crossing inventory database and the FRA crossing accident database, including the following (FRA, 2022a; FRA, 2022b):

Operating Railroad

- ThruTrains – total number of through trains (daylight through + night time through) (trains);
- TotalSwt – total number of switching trains (trains);
- TotalTrains – total number of trains (daylight through + night time through + switching) (trains);
- TotTracks – number of main and other tracks (tracks); and
- MaxTtSpd – maximum timetable speed (mph).

Public Highway

- Aadt – annual average daily traffic (AADT) count;
- EmrgncySrvc – emergency services route (1 = yes; 2 = no);
- HwyClassCD – functional classification of road at crossing (0 = rural; 1 = urban);
- HwySpeed – highway speed limit (mph);
- PctTruk – estimated percent of trucks; and
- SchlBsCnt – average number of school bus count per day (buses).

Physical Characteristics

- HwyNear – intersecting roadway within 500 feet? (1 = yes; 2 = no);
- HwyPved – is roadway/pathway paved? (1 = yes; 2 = no);
- Illumina – is crossing illuminated? (1 = yes; 2 = no);
- TraficLn – number of traffic lanes crossing railroad (lanes);
- XAngle – smallest crossing angle (1 = 0° – 29°; 2 = 30° – 59°; 3 = 60° – 90°); and
- XSurfaceIDs – crossing surface (11 = timber; 12 = asphalt; 13 = asphalt and timber; 14 = concrete; 15 = concrete and rubber; 16 = rubber; 17 = metal; 18 = unconsolidated; 19 = composite; 20 = other [specify]).

Highway Traffic Control Devices

- AwdIDate – installation date of current active warning devices;

- HwynrSig – does nearby highway intersection have traffic signals? (1 = yes; 2 = no);
- MonitorDev – highway monitoring devices (0 = none; 1 = yes-photo/video recording; 2 = yes-vehicle presence detection);
- PaveMrkIDs – pavement markings (0 = none; 1 = stop lines; 2 = railroad crossing symbols; 3 = dynamic envelope);
- PrempType – highway traffic signal preemption (1 = simultaneous; 2 = advance); and
- WdCode – warning device code (1 = no signs or signals; 2 = other signs or signals; 3 = crossbucks; 4 = stop signs; 5 = special active warning devices; 6 = highway traffic signals, wigwags, bells, or other activated; 7 = flashing lights; 8 = all other gates; 9 = four quad (full barrier) gates.

<u>Other</u>

- AH5 – 5-year incident history (incidents);
- DevelTypID – type of land use (11 = open space; 12 = residential; 13 = commercial; 14 = industrial; 15 = institutional; 16 = farm; 17 = recreational; 18 = railroad yard);
- TypeTrnSrvcIDs – type of train service (11 = freight; 12 = intercity passenger; 13 = commuter; 14 = transit; 15 = shared use transit; 16 = tourist/other);
- TypeXing – crossing type (2 = private; 3 = public); and
- Whistban – quiet zone (0 = no; 1 = 24 hour; 2 = partial; 3 = Chicago excused).

Several previous studies applied specific weights to different factors (including the ones listed above) to select level crossings for closure (Russell and Mutabazi, 1998; Hans et al., 2015; Johnson, 2015; Mathew et al., 2021). However, the inclusion of all these factors into the objective function of the **SLCC** optimization model will require assigning a particular weight value to each factor, which will be challenging from the practical point of view. Therefore, this project suggests conducting the primary selection of level crossings for closure using the **SLCC** optimization model, and the aforementioned factors (i.e., operating railroad factors, public highway factors, factors associated with physical characteristics, factors associated with highway traffic control devices, and other factors) can be used as secondary criteria throughout the decision making.

4. SOLUTION ALGORITHM FOR THE OPTIMIZATION MODEL

4.1. Model Complexity

The **SLCC** mathematical model that was developed as a part of this project to select level crossings for closure has similarities with the knapsack problem. The knapsack problem is viewed as a combinatorial decision problem with the objective of accommodating a set of items with various values and weights in the knapsack, such that the overall value of items inside the knapsack is maximized (Güntzer and Jungnickel, 2000; Fréville, 2004; Bazgan et al., 2009; Gurski et al., 2019; Cacchiani et al., 2022). When solving the knapsack problem, it is necessary to explicitly consider the knapsack capacity constraint (i.e., the overall weight of items inside the knapsack should not exceed the knapsack carrying capacity). There are evident similarities between the **SLCC** mathematical model and a typical knapsack problem, as the objective of the **SLCC** mathematical model is to select level crossings for closure in a given geographical location and maximize the overall benefit from these closures. The **SLCC** mathematical model directly considers the total planned budget as an operational constraint along with other important features (e.g., feasibility of crossing closures; maximum number of level crossings that can be closed for the considered planning time horizon; importance of safety, economic, and environmental benefits that can be obtained from crossing closures).

In terms of computational complexity, the decision problems that can be reduced to the general knapsack problem typically have NP-complete computational complexity (Dulebenets et al., 2020; Dulebenets et al., 2021). A variety of solution methods have been proposed for the knapsack problem over the past years, which can be classified into the following three broad categories: (1) exact optimization methods (Gilmore and Gomory, 1966; Green, 1967; Marsten and Morin, 1976; Isaka, 1983; Ibaraki, 1987); (2) heuristic methods (Toyoda, 1975; Hanafi et al., 1996; Chekuri and Khanna, 2005); and (3) metaheuristic methods (Drexl, 1988; Dammeyer and Voss, 1991; Khuri et al., 1994). Exact optimization methods provide a global optimal solution for the knapsack problem and its variations. However, due to the computational complexity of the knapsack problem, exact optimization methods may take a significant amount of time to provide solutions for large-scale problem instances of the knapsack problem.

Heuristic and metaheuristic methods, on the other hand, do not guarantee global optimality of the solutions for the knapsack problem and its variations. However, these solutions can be obtained much faster compared to exact optimization methods (Bruni et al., 2018; Kavoosi et al., 2019; Kavoosi et al., 2020a,b; Accorsi and Vigo, 2021; Singh et al., 2022a,b; Zhang et al., 2022). Heuristic methods are typically recognized as problem-specific methods, whereas metaheuristic approaches can be applied to a wide array of decision problems with appropriate modifications (Hussain et a., 2019; Pasha et al., 2021; Singh et al., 2021; Singh et al., 2022c; Dulebenets, 2023; Rajwar et al., 2023; Sarhani et al., 2023). Along with heuristic and metaheuristic methods, there are also hybrid optimization methods that directly consider problem-specific properties and apply additional optimization procedures as well (Dulebenets, 2021; Fathollahi-Fard et al., 2021; Asghari et al., 2022; Pasha et al., 2022; Li et al., 2023).

4.2. Proposed Algorithm

Sorting heuristics were found to be popular for the knapsack problem (Dulebenets et al., 2020; Dulebenets et al., 2021). Therefore, this study will use the algorithm, which is inspired by certain sorting principles, given the evident similarities of the **SLCC** mathematical model and the knapsack problem. The proposed heuristic algorithm, which will be further referred to as the Profitable Selection of Crossings for Closure Heuristic (PSCCH), prioritizes level crossings for closure based on the potential benefits that can be obtained from these closures and directly considers the total cost of closure for each crossing along with the feasibility of level crossings for closure. The main steps of the PSCCH algorithm are outlined in **Algorithm 1**.

Algorithm 1: The Profitable Selection of Crossings for Closure Heuristic (PSCCH)

$\boldsymbol{PSCCH}(X, TB, y, X^{max}, CC, TPB)$

in: $X = \{1, \dots, n\}$ - set of level crossings; TB - total benefit associated with crossing closure; y - crossing eligibility for closure; X^{max} - maximum number of level crossings that can be closed; CC - cost of crossing closure; TPB - total planned budget

out: $\boldsymbol{z}$ - selection of level crossings for closure

0: $|\boldsymbol{z}| \leftarrow n$ ◃ Initialization
1: $x \leftarrow 1$
2: **for all** $x \in X$ **do**
3: $\quad TBCR_x \leftarrow TB_x / CC_x$ ◃ Estimate the total benefit-to-cost ratio
4: $\quad List \leftarrow List \cup \{x\}$ ◃ Add the crossing to the closure priority list
5: **end for**
6: $List \leftarrow \boldsymbol{sort}(List, y, TBCR)$ ◃ Sort the closure priority list based on $TBCR$
7: $RB \leftarrow TPB$ ◃ Set the remaining budget to the total planned budget
8: **while** $List \neq \varnothing$ **and** $RB \geq min(CC)$ **and** $\sum_{x \in X} \boldsymbol{z}_x < X^{max}$ **do**
9: $\quad x \leftarrow List_1$ ◃ Select the first level crossing in the closure priority list
10: $\quad$ **if** $RB \geq CC_x$ **do**
11: $\qquad \boldsymbol{z}_x \leftarrow 1$ ◃ Assign the selected crossing for closure
12: $\qquad RB \leftarrow RB - CC_x$ ◃ Update the remaining budget
13: $\qquad List \leftarrow List - \{x\}$ ◃ Remove the crossing from the closure priority list
14: $\quad$ **else**
15: $\qquad List \leftarrow List - \{x\}$ ◃ Remove the crossing from the closure priority list
16: $\quad$ **end if**
17: **end while**
18: **return** $\boldsymbol{z}$

The PSCCH algorithm begins with the initialization of the data structure for the main decision variable of the **SLCC** mathematical model (i.e., $\boldsymbol{z}_x, x \in X$) in step 1. Then, the PSCCH enters the first loop (steps 1 through 5), where the total benefit-to-cost ratio is estimated for each level crossing (step 3), and the closure priority list is iteratively constructed (step 4). The level crossings in the closure priority list are sorted based on their total benefit-to-cost ratios in the descending order in step 6. Furthermore, the level crossings that are not eligible for closure are eliminated from the analysis in step 6. The remaining budget for level crossing closures is set to the total planned budget in step 7.

After that, the PSCCH algorithm enters the second loop represented by steps 8 through 17. Within the loop, the PSCCH selects the first level crossing in the closure priority list (step 9). Then, the algorithm checks whether the remaining budget is sufficient to administer the closure of selected level crossing (steps 10 through 16). If the remaining budget is sufficient, the selected level crossing will be assigned for closure (step 11), the remaining budget will be updated considering the cost of closing the selected level crossing (step 12), and the closure priority list will be updated by removing the crossing that was assigned for closure (step 13). If the remaining budget is not sufficient to administer the closure of the selected level crossing, the closure priority list will be updated by removing the selected crossing without assigning it for closure (step 15). Steps 8 through 17 are iteratively repeated by the PSCCH algorithm until one of the following criteria is met: (1) all level crossings from the closure priority list have been assigned for closure, and the list is empty; (2) the remaining budget is not sufficient to administer closure of any level crossings in the closure priority list; and (3) the number of level crossings selected for closures reaches the upper bound on the number of level crossings that can be closed for the considered planning time horizon. The PSCCH terminates in step 18 and provides the list of level crossings that have to be considered for closure (i.e., the value of the main decision variable of the **SLCC** mathematical model).

4.3. Input Data Required for the Developed Optimization Model and Solution Algorithm

The developed optimization model and solution algorithm will require certain input data. Different publicly available sources were used to set the values of input parameters of the **SLCC** mathematical model in the present study, and the details are provided in the following sections of the report.

4.3.1. Estimation of Safety Benefits from Level Crossing Closures

The estimation of safety benefits from level crossing closures requires the information on basic physical and operational characteristics of level crossings, including the average daily volume of highway vehicles, average daily volume of trains, number of through trains per day, number of switch trains per day, speed of trains, existing protection, urban or rural designation, and number of railroad tracks. This information can be obtained from the FRA crossing inventory database (FRA, 2022a). Furthermore, the Florida Priority Index Formula, which is used to quantify potential vulnerability of level crossings to accidents, directly relies on the accident history for the last 5 years. The accident information for each level crossing can be obtained from the FRA crossing accident database (FRA, 2022b).

As discussed earlier, the overall level crossing hazard estimated using the Florida Priority Index Formula can be further disaggregated into the following hazard severity categories (U.S. DOT, 2014): (1) Fatality Accidents – these accidents involve at least one fatality; (2) Casualty Accidents – these accidents involve at least one fatality or injury; (3) Injury Accidents – these accidents involve at least one injury but no fatality; and (4) Property Damage Only Accidents – these accidents involve no fatalities or injuries; only property damage is reported. The hazard severity weight values (directly used in the estimated of safety benefits from level crossing closures) can be set by the user (e.g., the Florida Department of Transportation) based on the societal costs of level crossing accidents for a given geographical location. According to the previous studies, the weights for fatality hazard, injury hazard, and property damage hazard could be assumed to be 0.90, 0.09, and 0.01, respectively (Dulebenets et al., 2021).

4.3.2. Estimation of Economic Benefits from Level Crossing Closures

The economic benefits were assessed in this study by the reduction in traffic delays from level crossing closures along with the reduction in the associated operations and maintenance costs.

The estimation of economic benefits from level crossing closures requires the information on basic physical and operational characteristics of level crossings, including the average number of trains passing through level crossings per day, average number of vehicles passing through level crossings per day, speed of trains, and number of highway lanes intersecting each level crossing. This information can be obtained from the FRA crossing inventory database (FRA, 2022a). The average length of trains passing through level crossings can be set to 7,000 ft (GAO, 2019). The train speed at level crossings can be set based on the maximum timetable train speed values that are available in the FRA crossing inventory database. Furthermore, reasonable upper and lower bounds (i.e., SC^{max} and SC^{min}) should be considered when setting the average speed of trains passing through level crossings. The value of SC^{min} can be set to 20 mph, whereas the value of SC^{max} can be set to 49 mph. The current delay time values for different types of crossing protection classes are presented in Table 7 (Dulebenets et al., 2021). The notation "CCDe" is used to denote the differentiation of delay time values based on the level crossing protection class (i.e., currently installed warning devices and countermeasures). To prevent abnormal values for the queue dissipation time at level crossings, it was assumed that the maximum queue length per lane at level crossings should not exceed $VQ^{max} = 8$ vehicles. Moreover, it was assumed that the maximum queue dissipation time at level crossings should not exceed $QDT^{max} = 60$ seconds.

Table 8 The current delay time values for different level crossing protection classes.

a/a	Protection Class	WdCode	CCDe, sec
1	no signs or signals	1	0.00
2	other signs or signals	2	5.00
3	crossbucks	3	5.00
4	stop signs	4	5.00
5	special active warning devices	5	10.00
6	highway traffic signals, wigwags, bells, or other activated	6	10.00
7	flashing lights	7	10.00
8	all other gates	8	35.00
9	four quad (full barrier) gates	9	40.00

Table 9 Operations and maintenance cost of different types of crossings.

a/a	Existing Type of Protection	O&M Cost, USD per Year	WdCode
1	Passive	200	1, 2, 3, 4
2	Flashing lights	1,800	5, 6, 7
3	Gates	2,500	8
4	4-quadrant gated crossings without detection	3,500	8
5	4-quadrant gated crossings with detection	5,000	9
6	4-quadrant gated crossings with 60' medians	25,000	9
7	Mountable curbs at gated crossings	3,500	9
8	Barrier curbs at gated crossings	3,500	9
9	One-way street at gated crossings	3,500	9
10	Photo enforcement at gated crossings	25,000	9

The unit cost of delays at level crossings was set to $C^{delay} = 20$ USD per hour (Rezvani et al., 2015; Mathew et al., 2021). Regarding the operations and maintenance costs ($C_x^{OM}, x \in X$), the values suggested by the U.S. DOT for level crossings with different types of existing protection can be used in calculations – see Table 9 (U.S. DOT, 2014). The field "WdCode" is adopted from the FRA crossing inventory database to denote particular level crossing protection classes. The values of all the parameters were set using the data reported in the available literature (AREMA, 2004; ITE, 2006; Rezvani et al., 2015; GAO, 2019; U.S. DOT, 2019; Mathew et al., 2021) but can be modified by the user as needed.

4.3.3. Estimation of Environmental Benefits from Level Crossing Closures

The environmental benefits were assessed in this study by the reduction in fuel consumption by vehicles queued at level crossings after closures. The fuel consumption of vehicles queued at level crossings in the idle mode was assumed to be proportional to the total delay with the application of an appropriate coefficient. This approach was found to be common and widely used by the existing traffic simulation packages. The fuel consumption coefficient was set to 0.330 ml/second to convert the time spent in the idle mode into fuel consumption (AIMSUN, 2014). However, it can be adjusted by the user depending on the type of vehicles, type of fuel, and other operational features. Additional factors were applied to convert milliliters to gallons, when estimating the total amount of fuel burnt by vehicles queued at level crossings in the idle mode.

4.3.4. Weight Values for Different Types of Benefits

Safety, economic, and environmental benefits can be perceived differently by local communities and relevant stakeholders in different geographical locations. In some locations, economic benefits can be perceived as more important than environmental benefits, and vice versa. Safety benefits are likely to be viewed as more important than economic and environmental benefits. Therefore, the **SLCC** optimization model includes three types of weights (W^{safe}, W^{econ}, and W^{envi}) to capture the importance of safety, economic, and environmental benefits. Based on the available literature, the default values of the weights for safety, economic, and environmental benefits were set to $W^{safe} = 0.70$, $W^{econ} = 0.15$, and $W^{envi} = 0.15$ (Mathew et al., 2021). However, without loss of generality, the weight values can be adjusted by the appropriate stakeholders as needed, considering specific characteristics of a given geographical location.

5. WEB APPLICATION DESIGN

In this section, a Web application called “HRX_Safety_Improvement” (“HRX” is an abbreviation for “highway-rail grade crossing”) is introduced. Its primary function is to identify the best level crossing candidates for closure in Florida by considering different practical factors, such as the highest benefit-to-cost ratio, available budget, and the maximum number of crossings that can be closed. Once the analysis is completed, the Web application will generate a list of ranked candidate level crossings for closure. This report provides information about the main purpose of the Web application, as well as the guidelines for using the Web application.

5.1. Purpose of the Web Application

Florida’s passenger and freight traffic has increased because of the state’s thriving economy and expanding population. There are advantages to this growth, but there are also costs to consider. In Florida, there is a serious problem with level crossing collisions involving highway vehicles and passing trains. However, safety measures, such as closure of level crossings, grade separation, and other alternatives, could significantly cut down on the frequency with which these tragedies occur. The State of Florida cannot afford to upgrade all potentially dangerous crossings within a given planning time (often one year). As a part of the efforts to provide a safe and dependable multimodal transportation network, the possibility of closing some of these crossings is being explored. As an integral component of this project, an optimization model was established with the purpose of aiding the FDOT authorities in the identification of level crossings that would yield the greatest benefits upon closure, considering the limited available budget and basic operational characteristics. After that, a Web application was built using the developed optimization model as a foundation. Based on the estimated total budget, the Web application “HRX_Safety_Improvement” suggests a list of level crossings that could be closed for a given planning period in order to reach the highest benefit-to-cost ratios and improve the safety of passenger and freight traffic in the State of Florida.

5.2. User Guidelines

The following sections contain some fundamental instructions for using the Web application “HRX_Safety_Improvement”. They cover various aspects, such as the key assumptions made, user interface, input requirements, benefit estimations for the **SLCC** optimization model, steps required to edit the original data for level crossings, procedure for the selection of level crossings for closure, and how to handle errors.

5.2.1. Major Assumptions

The “HRX_Safety_Improvement” Web application estimates economic, environmental, and safety benefits, as well as delays and operational and maintenance costs due to level crossing closures. The Web application requires data with some fundamental features of level crossing operational and physical characteristics which can be obtained from the FRA level crossing inventory database. The following assumptions have been made for the input values related to the level crossings characteristics:

- ✓ If the information regarding whether a level crossing is owned by a public or a private entity is lacking, it will not be included in the study. This is because the crossing may be abandoned or under the jurisdiction of a private corporation, not the State of Florida.

- ✓ Certain predictors in the Florida Priority Index (FPI) Formula will assume a value of "1.00" in case the FRA level crossing inventory database has no data or a zero value for these predictors. Specifically, these predictors are AADT, total switch trains per day, total thru trains per day, number of main and other tracks, and maximum train timetable speed. This will prevent the level crossing FPI values from being aberrant (e.g., "-∞", "+∞").
- ✓ If the information on protection for a level crossing is unavailable, the lowest protection factor value of "1.00" will be used in the study. This is used at grade crossings where there are no protective measures or passive warning devices. This strategy will ensure that the level crossings will be included in the analysis even if there isn't enough information about their protection, and the results for those crossings will be more conservative.
- ✓ When a road intersects a railroad and its classification is unclear, it is assumed to be a rural road. For the level crossings under consideration, this supposition will result in more conservative estimates of the hazard severity.
- ✓ To estimate delay values, the "HRX_Safety_Improvement" Web application needs the details about the frequency with which trains block a level crossing as well as the amount of time that vehicles must wait during each blockage. A variety of delay factors, such as the delay time for a specific countermeasure at the crossing, the average length and speed of trains, the average number of daily vehicles, and the number of highway lanes, are considered. To avoid aberrant delay values (e.g., "-∞", "+∞"), the Web application assumes the number of traffic lanes is 1 if the FRA crossing inventory database does not report the information regarding the number of traffic lanes or reports a zero value.
- ✓ The countermeasure effectiveness factors were obtained from Dulebenets et al. (2021). If multiple values are available, the lowest number will be utilized to remain conservative.

To maximize the overall benefits of level crossing closures, the **SLCC** mathematical model was developed to determine which level crossings should be closed within a specific geographic area. The **SLCC** model mathematically resembles the well-known knapsack problem. The closure viability, the maximum number of level crossings that can be closed within a given timeframe, and the significance of safety, economic, and environmental benefits are all considered by the model. In addition, the total budget allocated for closures is considered as a practical constraint. The research by Dulebenets et al. (2020) and Dulebenets et al. (2021) demonstrates that sorting heuristics is a common solution to the knapsack problem. Therefore, this study employed a sorting heuristic algorithm. This algorithm, known as the Profitable Selection of Crossings for Closure Heuristic (PSCCH), ranks level crossings based on the potential benefits that could be realized by closing them. The heuristic considers both the total available budget and the viability of closing each crossing. The following assumptions were made during the selection process for level crossing closures:

- ✓ The PSCCH algorithm prioritizes level crossings in descending order based on their benefit-to-cost ratios, with only eligible crossings considered for closure. Assuming a sufficient budget is available, priority is given to removing crossings that yield the highest benefit-to-cost ratios.
- ✓ The weight values for hazard severity categories were taken from the previous studies (Dulebenets et al., 2021) and set at 0.90 for fatality, 0.09 for injury, and 0.01 for property damage, but can be adjusted by users as needed.

- ✓ Since no other prediction methods were available, the GradeDec severity prediction method and the FPI values were utilized to estimate the potential hazard severity of the level crossings.
- ✓ It was assumed that by using the appropriate coefficient, the fuel consumption of vehicles queuing at level crossings would be proportional to the overall delay.
- ✓ The **SLCC** optimization model includes three different weights to account for the importance of safety, economic, and environmental benefits. The default values for safety, economic, and environmental weights were assumed based on the existing literature to be 0.70, 0.15, and 0.15, respectively. However, stakeholders can change these weight values without affecting the model's general applicability to suit the unique characteristics of a specific geographic area.

5.2.2. User Interface

Figure 25 shows the interface of the "HRX_Safety_Improvement" Web application. The Web application homepage has three push buttons each of which leads into three different Web pages: (1) "**Estimate Benefits**"; (2) "**Original Data**"; and (3) "**Selection of Crossings for Closure**". The first one is made to estimate the benefits of level crossing closures. The second button is designed to show the inventory of level crossings with their corresponding "**CC**" and "**Y**" values. The last push button will lead to a new Web page with the list of selected level crossings for closure that are recommended after the optimization process.

Moreover, the Web application homepage has three text fields: (1) "**Prediction Year**"; (2) "**Total Planned Budget**"; and (3) "**Upper Bound on Number of Crossing Closures**". These text boxes allow the user to specify parameters for the selection process, including selecting the year for which the expected benefits of crossing closures are to be calculated, the overall budget available for the project, and the maximum number of crossings to be closed. In addition, there is a drop-down box for the crossing type selection, and the user can select the types of level crossings to analyze by clicking the "**Crossing Type**" drop-down box. The options are "**Public Only**", "**Private Only**" and "**Both**".

The Web application will compute the benefit values of crossing closures once the user clicks the "**Estimate Benefits**" push button after entering all the required information. A table containing the results and pertinent data will be shown. By pushing the "**Original Data**" button, the inventory of level crossings with their corresponding "**CC**" and "**Y**" values will be shown in a table. The "**CC**" value defines the closure cost for each level crossing and the "**Y**" value specifies the possibility of closing a given level crossing. The third push button of the Web application "**Selection of Crossings for Closure**" assists the user to identify level crossings for closure. The "HRX_Safety_Improvement" Web application will employ the benefit-to-cost ratio analysis and consider the total available budget to determine which level crossings should be closed. The selected level crossings and related data will be listed in a table after the execution has been successfully completed.

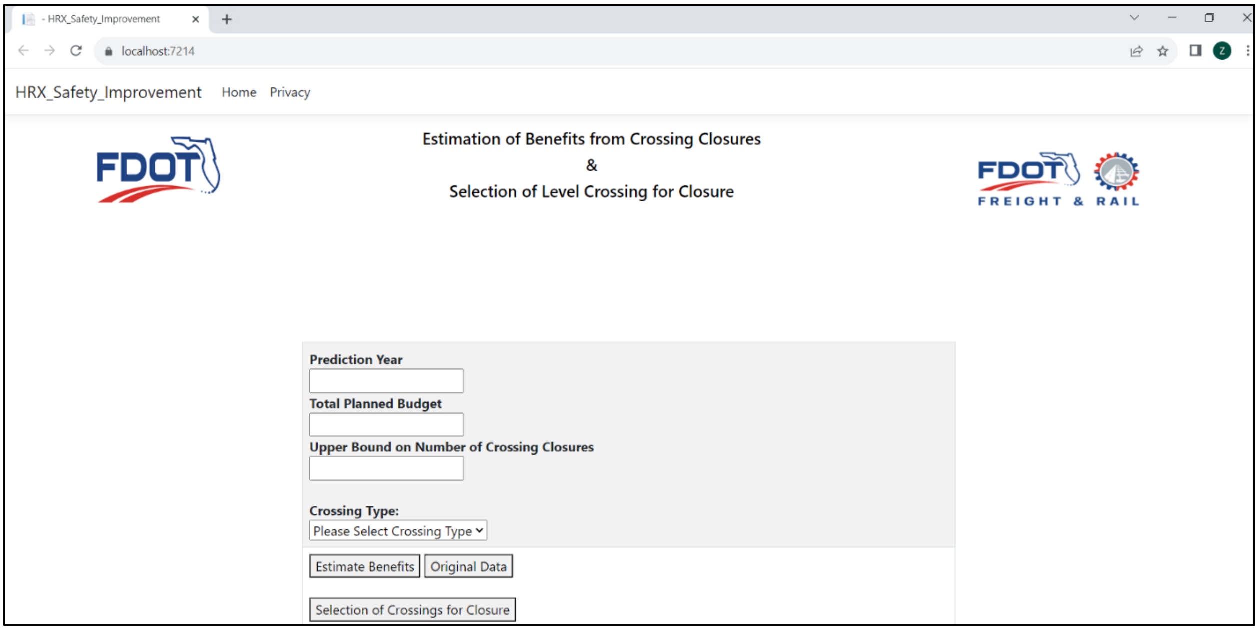


Figure 25 The homepage of the "HRX_Safety_Improvement" Web application for level crossing closures.

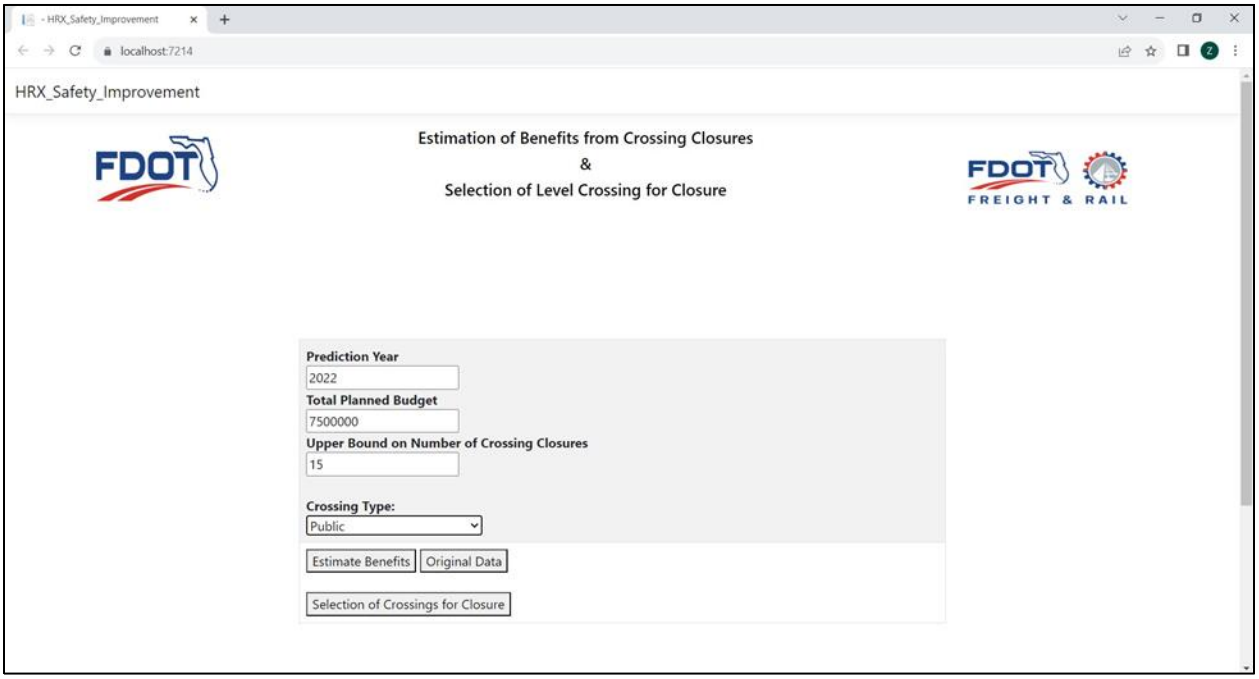


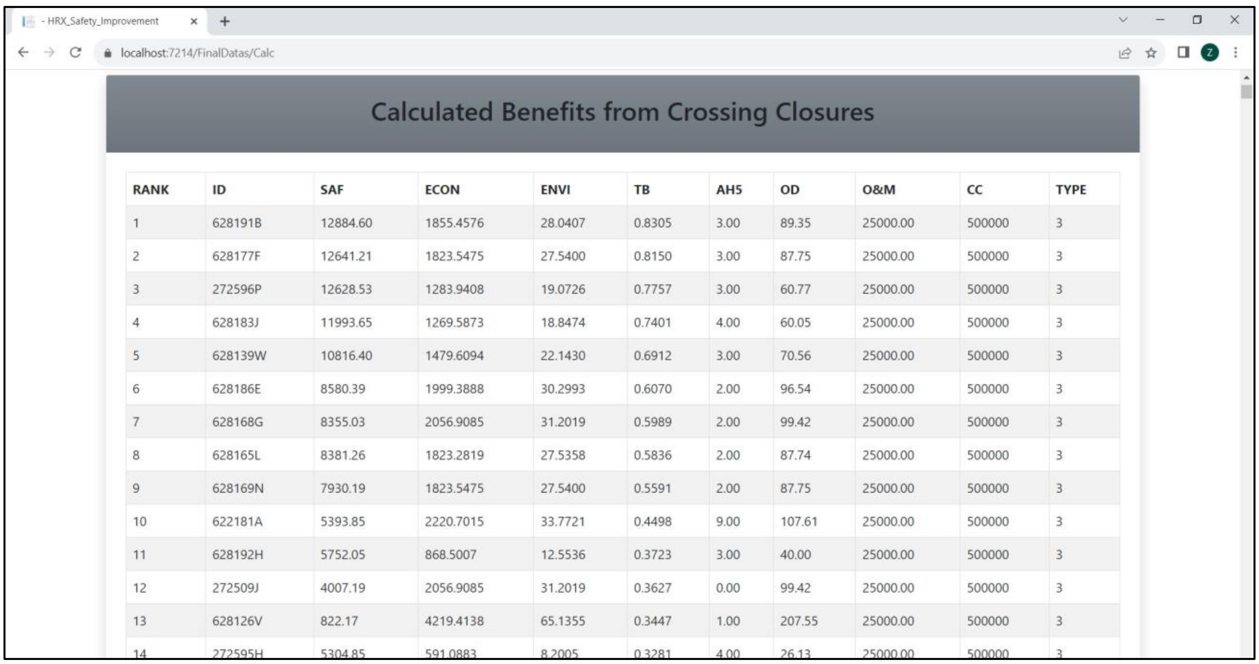
Figure 26 Inserting necessary data for input values.

5.2.3. Benefit Estimations for the SLCC Optimization Model

To evaluate the benefits of level crossing closures, users must enter the prediction year in the appropriate textbox of the Web application (see Figure 26). Based on the specified prediction year, the "HRX_Safety_Improvement" Web application will estimate the safety benefits obtained from level crossing closures. Users should provide two more input values: the "**Total Planned Budget**" and the "**Upper Bound on Number of Crossing Closures**" (as shown in Figure 26), which are not directly used at the stage of estimating the benefits from crossing closures but will be used later for the selection of level crossings for closures. Public and private level crossings can be distinguished by the “HRX_Safety_Improvement” Web application. The “**Crossing Type**” drop-down menu allows the user to select whether to estimate the benefits for public level crossings, private level crossings, or both types of level crossings (as shown in Figure 26). After completing all the aforementioned steps and providing necessary input data, the user can estimate the benefits from level crossing closures by clicking the “**Estimate Benefits**” push button.

SLCC Data Output

The “HRX_Safety_Improvement” Web application displays the obtained benefit values and associated information of the selected level crossings in a table named “**Calculated Benefits from Crossing Closures**”. The table has multiple columns of data. Each row corresponds to a particular level crossing. Figure 27 and Figure 28 depict an illustration of the table, which contains the information on public level crossings throughout the State of Florida.



RANK	ID	SAF	ECON	ENVI	TB	AHS	OD	O&M	CC	TYPE
1	628191B	12884.60	1855.4576	28.0407	0.8305	3.00	89.35	25000.00	500000	3
2	628177F	12641.21	1823.5475	27.5400	0.8150	3.00	87.75	25000.00	500000	3
3	272596P	12628.53	1283.9408	19.0726	0.7757	3.00	60.77	25000.00	500000	3
4	628183J	11993.65	1269.5873	18.8474	0.7401	4.00	60.05	25000.00	500000	3
5	628139W	10816.40	1479.6094	22.1430	0.6912	3.00	70.56	25000.00	500000	3
6	628186E	8580.39	1999.3888	30.2993	0.6070	2.00	96.54	25000.00	500000	3
7	628168G	8355.03	2056.9085	31.2019	0.5989	2.00	99.42	25000.00	500000	3
8	628165L	8381.26	1823.2819	27.5358	0.5836	2.00	87.74	25000.00	500000	3
9	628169N	7930.19	1823.5475	27.5400	0.5591	2.00	87.75	25000.00	500000	3
10	622181A	5393.85	2220.7015	33.7721	0.4498	9.00	107.61	25000.00	500000	3
11	628192H	5752.05	868.5007	12.5536	0.3723	3.00	40.00	25000.00	500000	3
12	272509J	4007.19	2056.9085	31.2019	0.3627	0.00	99.42	25000.00	500000	3
13	628126V	822.17	4219.4138	65.1355	0.3447	1.00	207.55	25000.00	500000	3
14	272595H	5304.85	591.0883	8.2005	0.3281	4.00	26.13	25000.00	500000	3

Figure 27 Calculated benefits from crossing closures.

5925	627230L	0.01	1.3344	0.0123	0.0001	0.00	0.04	200.00	500000	3
5926	626969T	0.10	1.2482	0.0110	0.0001	0.00	0.04	200.00	500000	3
5927	627348B	0.10	1.2482	0.0110	0.0001	0.00	0.04	200.00	500000	3
5928	627341D	0.10	1.2482	0.0110	0.0001	0.00	0.04	200.00	500000	3
5929	627257V	0.10	1.2482	0.0110	0.0001	0.00	0.04	200.00	500000	3
5930	627360H	0.10	1.2482	0.0110	0.0001	0.00	0.04	200.00	500000	3
5931	627270J	0.10	1.2482	0.0110	0.0001	0.00	0.04	200.00	500000	3
5932	627264F	0.10	1.2482	0.0110	0.0001	0.00	0.04	200.00	500000	3
5933	627368M	0.10	1.2399	0.0109	0.0001	0.00	0.03	200.00	500000	3
5934	627259J	0.10	1.2399	0.0109	0.0001	0.00	0.03	200.00	500000	3
5935	622586C	0.09	1.2399	0.0109	0.0001	0.00	0.03	200.00	500000	3
5936	624742T	0.07	1.2482	0.0110	0.0001	0.00	0.04	200.00	500000	3
5937	624744G	0.01	1.2482	0.0110	0.0001	0.00	0.04	200.00	500000	3
5938	627260D	0.01	1.2482	0.0110	0.0001	0.00	0.04	200.00	500000	3
5939	624662A	0.01	1.2399	0.0109	0.0001	0.00	0.03	200.00	500000	3

Figure 28 Calculated benefits from crossing closures (Cont'd).

Legend

COLUMN	DESCRIPTION
RANK	rank/index of a level crossing based on the total benefit from closure
ID	crossing inventory number
SAF	safety benefits associated with the closure of level crossing
ECON	economic benefits associated with the closure of level crossing
ENVI	environmental benefits associated with the closure of level crossing
TB	total benefit (normalized) associated with the closure of level crossing
AH5	5 year accident history (accidents)
OD	total reduction in traffic delays associated with the closure of level crossing (hours/day)
O&M	total reduction in yearly operational and maintenance costs associated with the closure of level crossing (USD/year)
CC	cost of closing level crossing (USD)
TYPE	crossing type (2 = private; 3 = public)

Figure 29 The "**Legend**" table for the calculated benefits from crossing closures.

In the considered example, the data for a total of 5,939 public level crossings is provided (see Figure 28) based on the FRA level crossing inventory file that was retrieved in May of 2022. The table includes multiple column headers, each reflecting a different feature of level crossings evaluated to estimate their respective benefit values and determine certain other important operational and physical attributes. Figure 29 shows the "**Legend**" table, which has a detailed explanation of each heading in the "**Calculated Benefits from Crossing Closures**" table. The components included in the "**Legend**" table are as follows:

- RANK - rank/index of a level crossing based on the total benefit from closure;
- ID - crossing inventory number;
- SAF - safety benefits associated with the closure of level crossing;
- ECON - economic benefits associated with the closure of level crossing;
- ENVI - environmental benefits associated with the closure of level crossing;

- TB - total benefit (normalized) associated with the closure of level crossing;
- AH5 - 5-year accident history (accidents);
- OD - total reduction in traffic delays associated with the closure of level crossing (hours/day);
- O&M - total reduction in yearly operational and maintenance costs associated with the closure of level crossing (USD/year);
- CC - cost associated with closing each level crossing; and
- TYPE - crossing type (2 = private; 3 = public).

5.2.4. Editing Original Data

The "**Original Data**" push button of the "HRX_Safety_Improvement" Web application is responsible for showing the inventory of the level crossings with their corresponding parameters. Users should provide all necessary input values before clicking on the "**Original Data**" button (as shown in Figure 30). By clicking on the "**Original Data**" button in the "HRX_Safety_Improvement" Web application, the Web application will lead to a new Web page with the supporting table. The "**Original Data**" table has the following three columns: "**ID**", "**y(x)**", and "**CC(x)**" (see Figure 31).

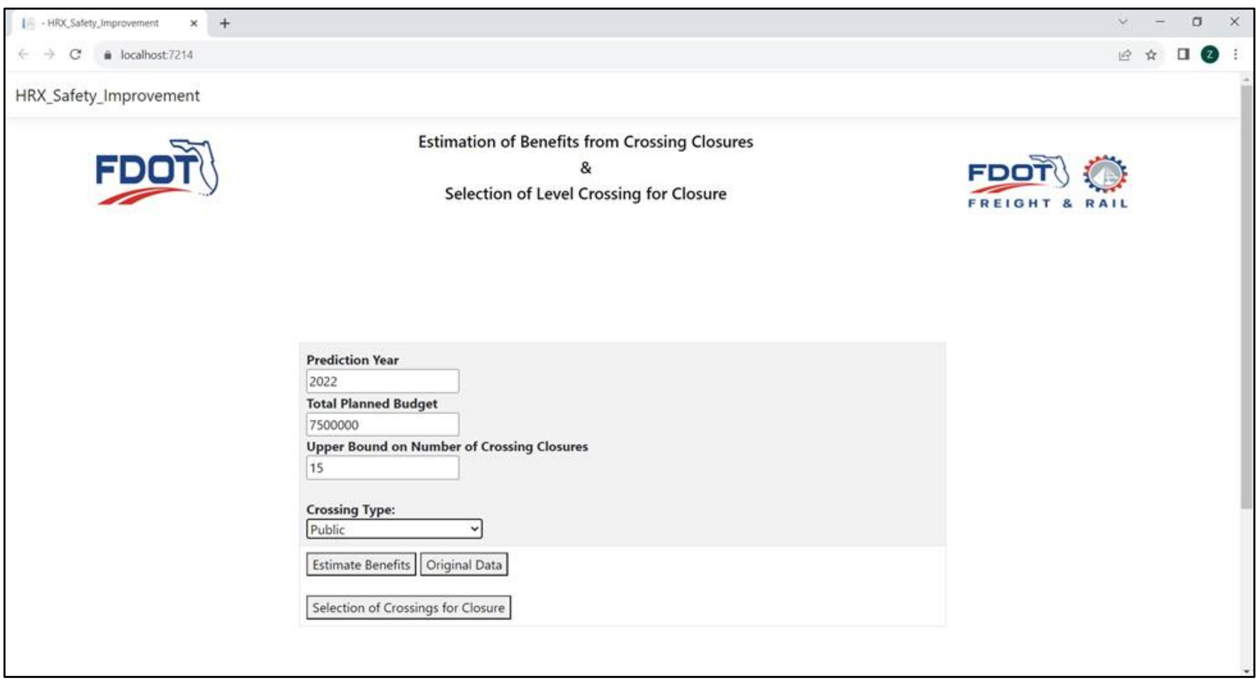


Figure 30 Inserting necessary data for input values.

Figure 31 shows the "**Legend**" table, which has a detailed explanation of each heading in the "**Original Data**" table. The components included in the "**Legend**" table are as follows:

- ID: This column shows the crossing inventory number of the level crossings based on the chosen crossing type on the homepage.

- Y: This column shows whether each level crossing is eligible for closure or not, with a value of "1" indicating eligibility and "0" indicating ineligibility. To reflect the eligibility status, the “HRX_Safety_Improvement” Web application will automatically get the predefined database values, which are set to “1” by default. The eligibility status of each level crossing for closure can be edited by users to meet their needs and considerations.

- CC: This column outlines the cost associated with closing each level crossing (see Figure 31). The cost values will be taken from the database (set to “500000” by default). The parameters related to the cost of closing each level crossing can be modified by users to suit their specific requirements.

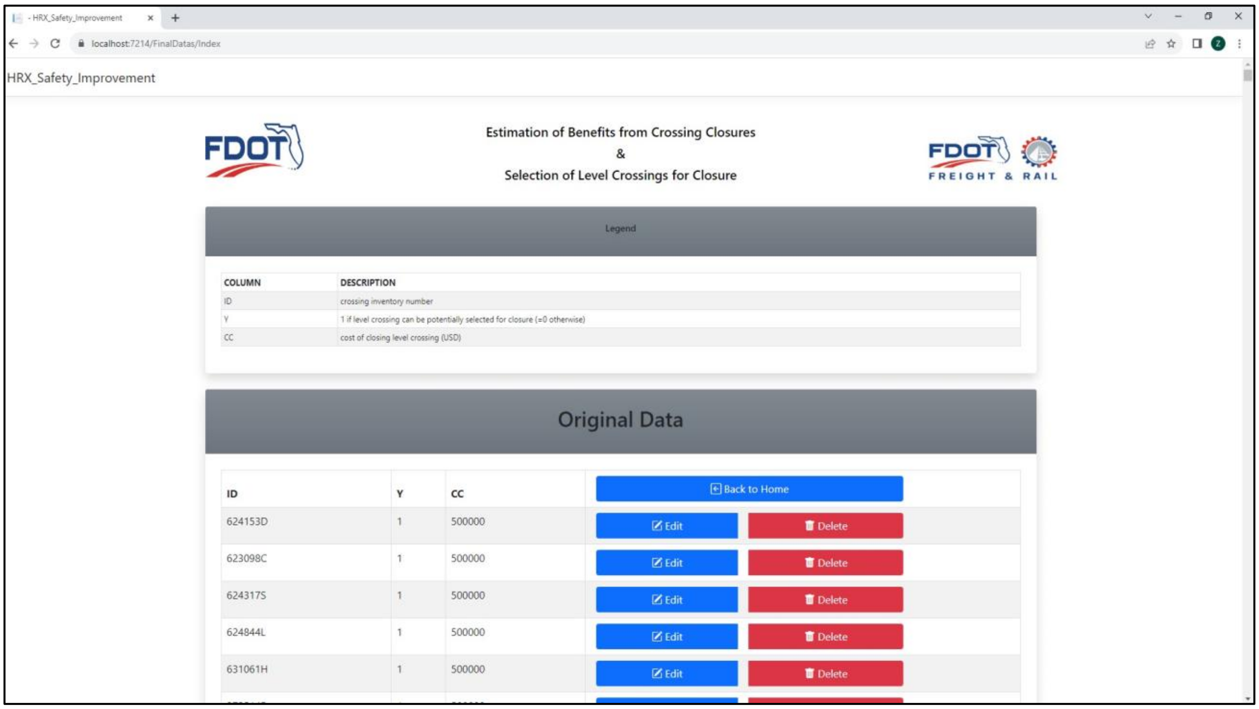


Figure 31 The “**Original Data**” table and corresponding parameters.

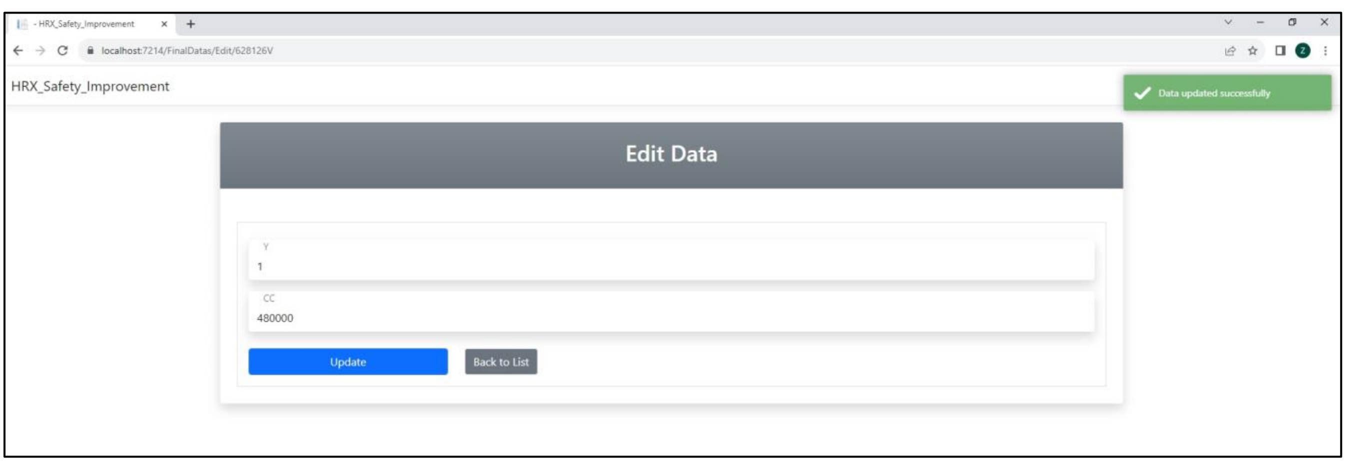


Figure 32 Editing the “**CC**” value for a level crossing.

By clicking on the “**Edit**” button in each row, the Web application will lead to a new Web page, where the corresponding values of the “**Y**” and “**CC**” for each level crossing can be modified (see Figure 32). In Figure 32, the “**CC**” value of “500,000” was changed to “480,000”. By clicking the “**Update**” button, the new value for “**CC**” will be updated in the database, and the successful update notification will pop up (see Figure 32).

By clicking on the “**Delete**” button in a given row, the Web application will lead to a new Web page, where the chosen level crossing can be deleted from the database (see Figure 33). By clicking the “**Delete**” button, the chosen level crossing will be deleted from the database, and the successful delete notification will pop up (see Figure 33).

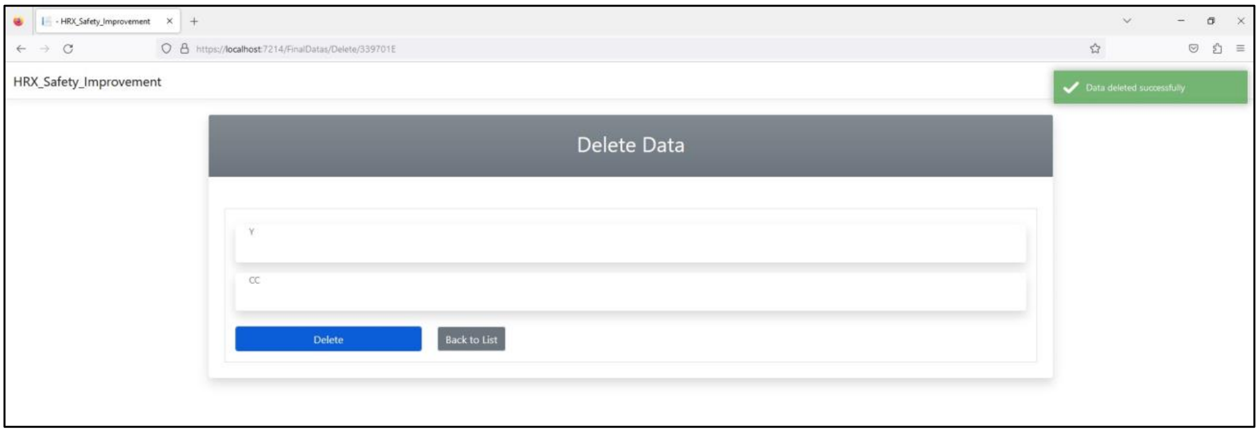


Figure 33 Deleting a specific level crossing from the database.

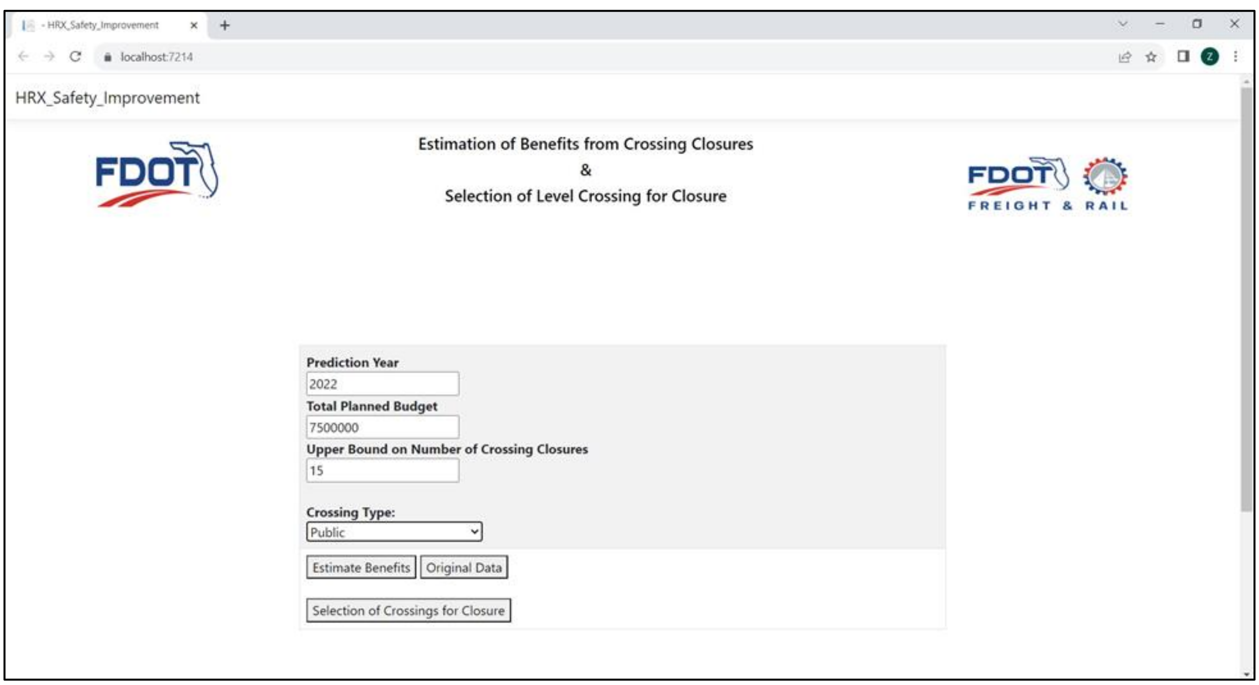


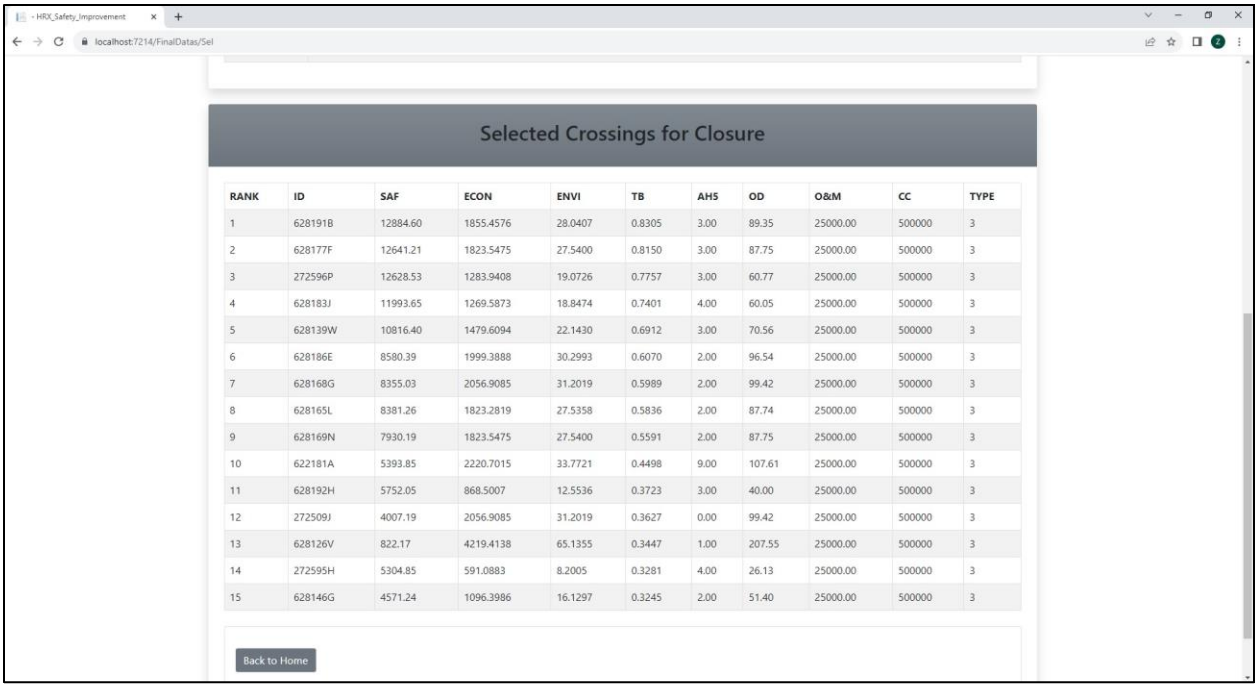
Figure 34 Inserting necessary data for input values.

5.2.5. Procedure for the Selection of Level Crossings for Closure

The “**Selection of Crossings for Closure**” push button of the “HRX_Safety_Improvement” Web application is responsible for determining the level crossings that should be considered for closure. Users should provide all necessary input values in this section before clicking on the “**Selection of Crossings for Closure**” button (as shown in Figure 34). By clicking on the “**Selection of Crossings for Closure**” button in the “HRX_Safety_Improvement” Web application, the user can formally execute the analysis.

SLCC Optimization Results

After the analysis has been completed using the “**Selection of Crossings for Closure**” push button, the crossings that are suggested for closure and their associated attribute values are displayed in a “**Selected Crossings for Closure**” table in the new Web page, as shown in Figure 35.



Selected Crossings for Closure

RANK	ID	SAF	ECON	ENVI	TB	AH5	OD	O&M	CC	TYPE
1	628191B	12884.60	1855.4576	28.0407	0.8305	3.00	89.35	25000.00	500000	3
2	628177F	12641.21	1823.5475	27.5400	0.8150	3.00	87.75	25000.00	500000	3
3	272596P	12628.53	1283.9408	19.0726	0.7757	3.00	60.77	25000.00	500000	3
4	628183J	11993.65	1269.5873	18.8474	0.7401	4.00	60.05	25000.00	500000	3
5	628139W	10816.40	1479.6094	22.1430	0.6912	3.00	70.56	25000.00	500000	3
6	628186E	8580.39	1999.3888	30.2993	0.6070	2.00	96.54	25000.00	500000	3
7	628168G	8355.03	2056.9085	31.2019	0.5989	2.00	99.42	25000.00	500000	3
8	628165L	8381.26	1823.2819	27.5358	0.5836	2.00	87.74	25000.00	500000	3
9	628169N	7930.19	1823.5475	27.5400	0.5591	2.00	87.75	25000.00	500000	3
10	622181A	5393.85	2220.7015	33.7721	0.4498	9.00	107.61	25000.00	500000	3
11	628192H	5752.05	868.5007	12.5536	0.3723	3.00	40.00	25000.00	500000	3
12	272509J	4007.19	2056.9085	31.2019	0.3627	0.00	99.42	25000.00	500000	3
13	628126V	822.17	4219.4138	65.1355	0.3447	1.00	207.55	25000.00	500000	3
14	272595H	5304.85	591.0883	8.2005	0.3281	4.00	26.13	25000.00	500000	3
15	628146G	4571.24	1096.3986	16.1297	0.3245	2.00	51.40	25000.00	500000	3

Back to Home

Figure 35 The selected crossings for closure displayed in the table.

The “**Legend**” table contains the following information on the characteristics of the results (see Figure 36):

- RANK - rank/index of a level crossing based on the total benefit from closure;
- ID - crossing inventory number;
- SAF - safety benefits associated with the closure of level crossing;
- ECON - economic benefits associated with the closure of level crossing;
- ENVI - environmental benefits associated with the closure of level crossing;
- TB - total benefit (normalized) associated with the closure of level crossing;
- AH5 - 5-year accident history (accidents);

- OD - total reduction in traffic delays associated with the closure of level crossing (hours/day);
- O&M - total reduction in yearly operational and maintenance costs associated with the closure of level crossing (USD/year);
- CC - cost associated with closing each level crossing; and
- TYPE - crossing type (2 = private; 3 = public).

Figure 36 The "**Legend**" sheet for the selected crossings for closure.

5.2.6. Error Messages

As indicated earlier, the "HRX_Safety_Improvement" Web application requires the user to input certain parameters, including the "**Prediction Year**", "**Total Planned Budget**", and "**Upper Bound on Number of Crossing Closures**". Furthermore, the level crossing type to be considered in the analysis should be specified as well using the "**Crossing Type**" drop-down menu. In case the user decides to press any of the push-buttons (e.g., "**Estimate Benefits**", "**Original Data**", or "**Selection of Crossings for Closure**") before specifying all the required input data values, the "HRX_Safety_Improvement" Web application will return the error message, reminding the user to enter the required input data. Figure 37, Figure 38, Figure 39, and Figure 40 show examples of error messages when the user does not specify the "**Prediction Year**", "**Total Planned Budget**", "**Upper Bound on Number of Crossing Closures**", and "**Crossing Type**", respectively.

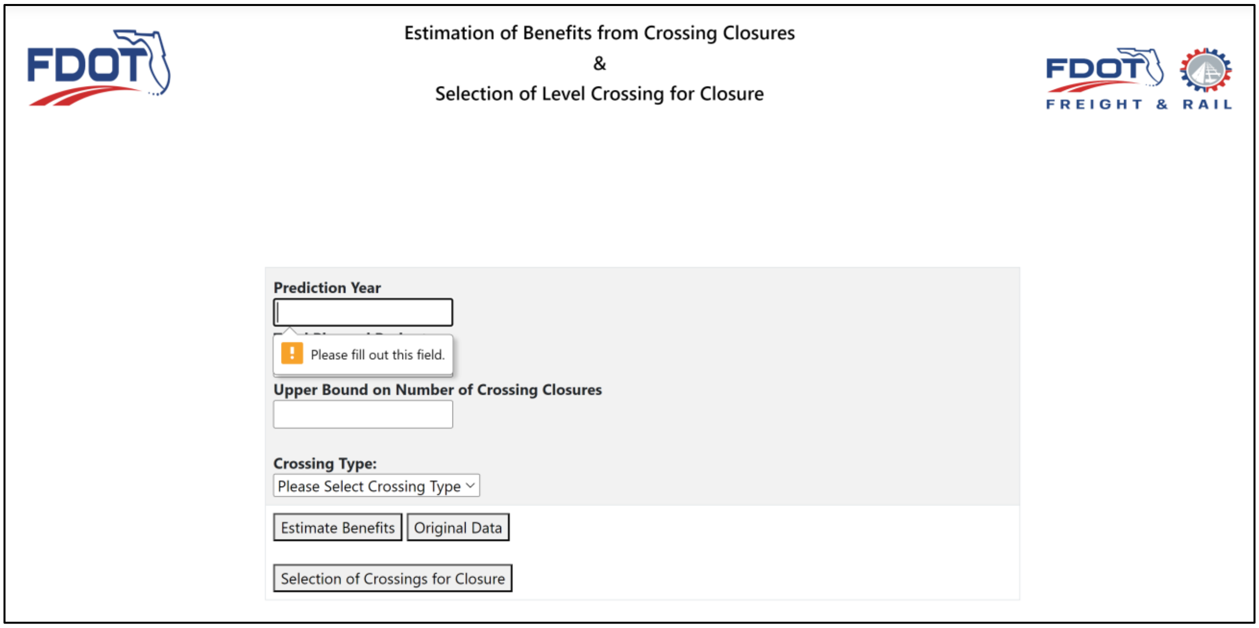


Figure 37 Errors related to the undefined user inputs.

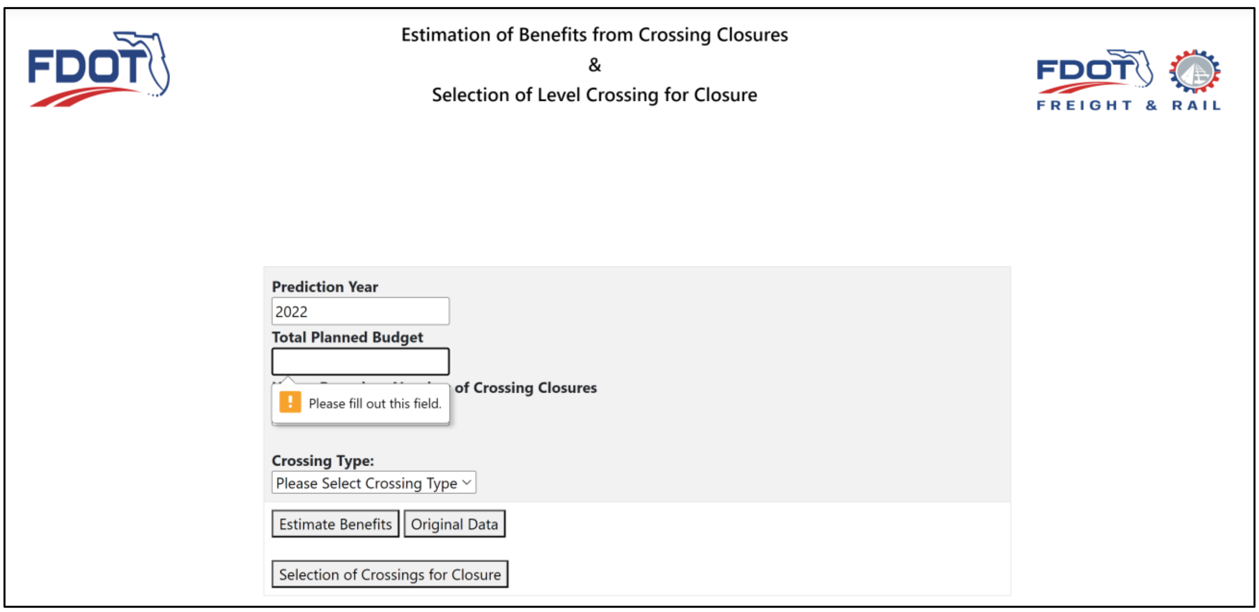


Figure 38 Errors related to the undefined user inputs (Cont'd).

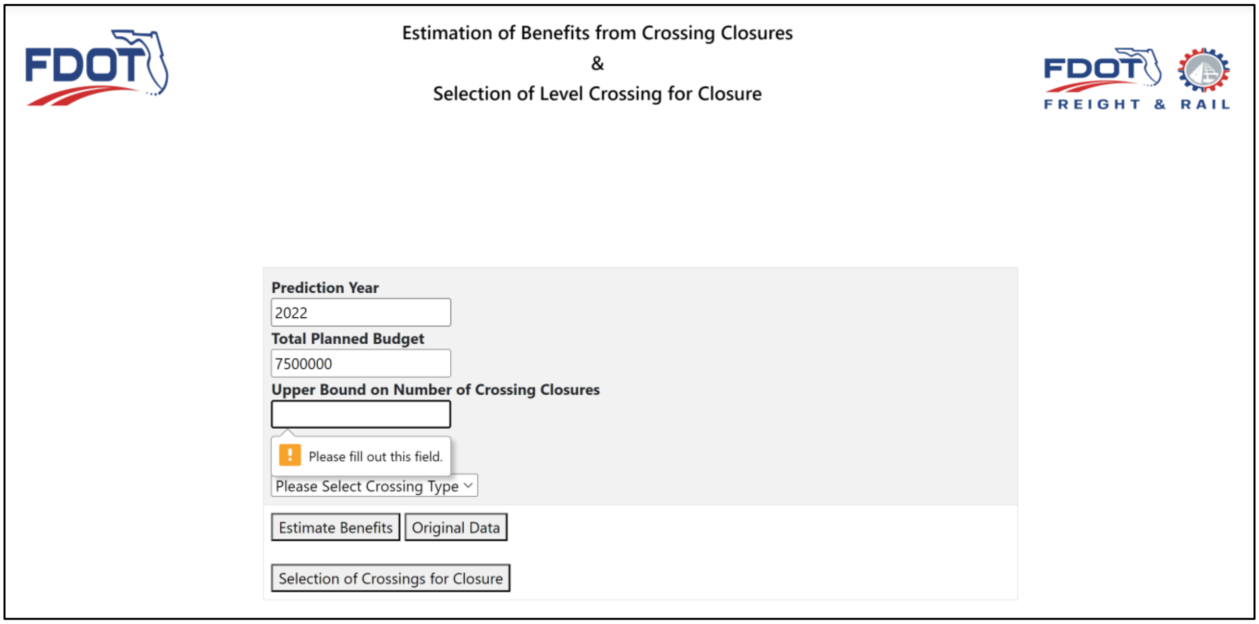


Figure 39 Errors related to the undefined user inputs (Cont'd).

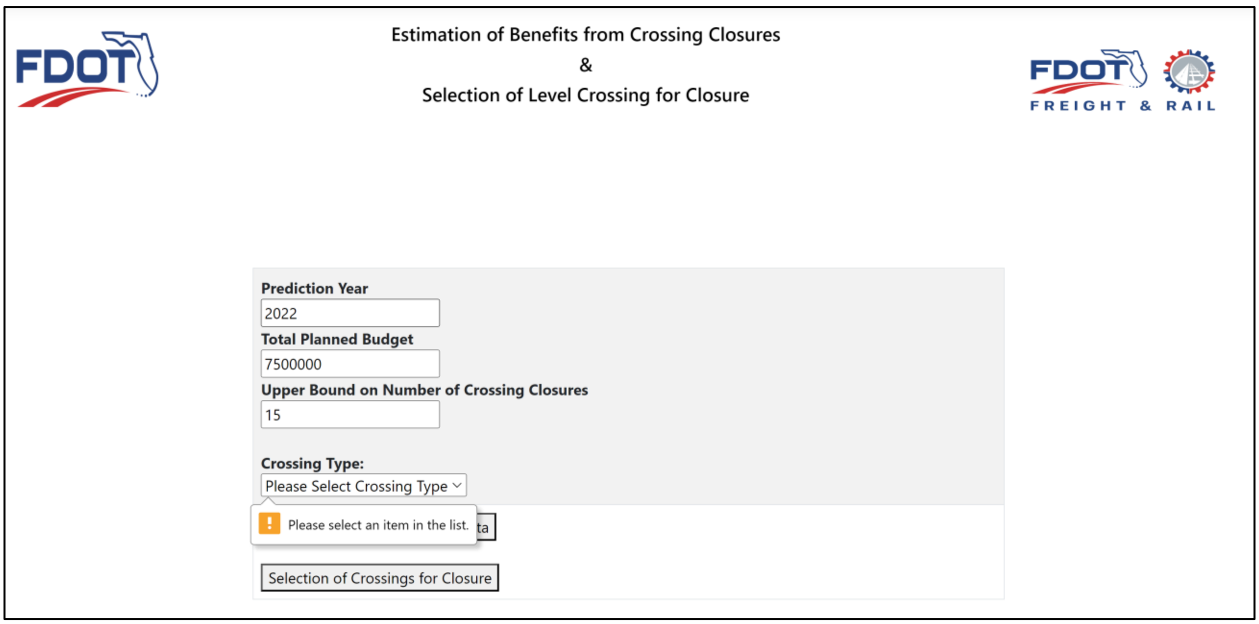


Figure 40 Errors related to the undefined user inputs (Cont'd).

6. METHODOLOGY APPLICATION

This particular section of the technical report presents a detailed description of the computational experiments, which were conducted to demonstrate applicability of the developed methodology for determining the level crossings that have to be closed in the State of Florida and maximizing the total benefit associated with closures, considering the total planned budget limitation along with the upper bound on the number of level crossing closures in the State of Florida. In particular, the following types of analyses were conducted as a part of this project: (1) sensitivity analysis for the total available budget; (2) sensitivity analysis for the benefit weight values; and (3) analysis of level crossing closures decisions for various types of level crossings.

6.1. Sensitivity Analysis for the Total Available Budget

Under this section of the technical report, the impact of the total available budget on selection of level crossings for closure in the State of Florida is investigated. Specifically, a total of 12 scenarios were developed by increasing the total available budget from \$7.5M to \$13.0M with an increment of \$0.5M. All the 5,939 public level crossings in the State of Florida were investigated throughout the conducted sensitivity analysis, extracted from the Federal Railroad Administration (FRA) crossing inventory database (FRA, 2022a). The default benefit weight values were assumed (W^{safe} = 0.70, W^{econ} = 0.15, and W^{envi} = 0.15). The developed **SLCC** optimization model was solved using the PSCCH algorithm in order to perform the sensitivity analysis for the total available budget.

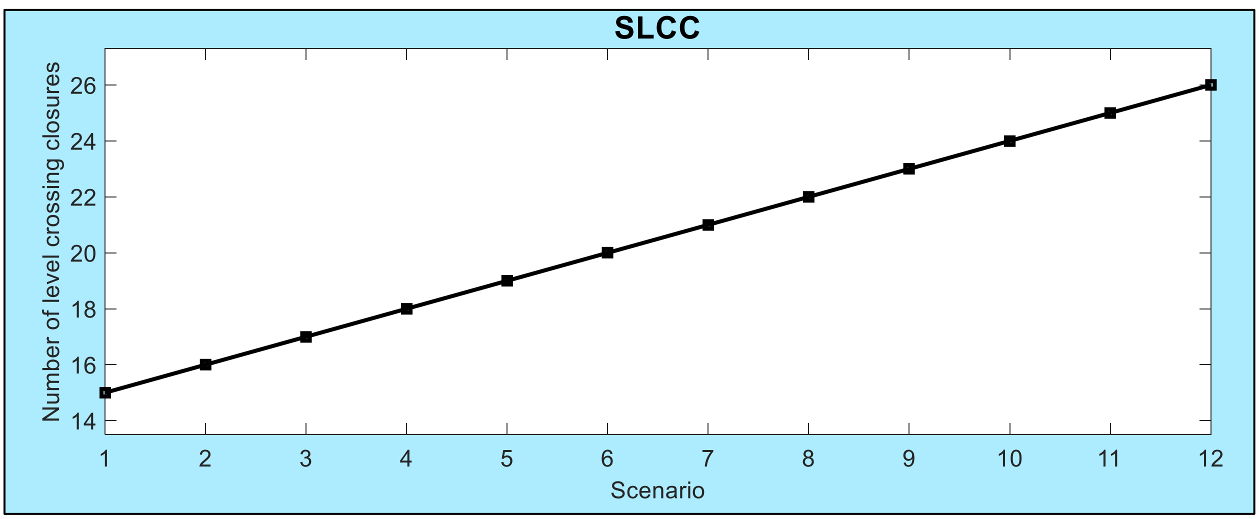


Figure 41 The total number of level crossings selected by **SLCC** for closure for the considered budget availability scenarios (analysis #1).

6.1.1. The Impact of the Total Available Budget on the Number of Level Crossing Closures

Figure 41 depicts the total number of level crossings selected for closure by **SLCC** for every case of the considered budget availability scenarios. A total of 15 and 26 level crossings out of 5,939 public level crossings in the State of Florida were selected for closure with the lowest available budget (i.e., \$7.5M) and the highest available budget (i.e., \$13.0M), respectively, for scenarios 1 and 12. As presumed, the total number of level crossings selected by **SLCC** for closure increased with the increase of total available budget. It can be observed that the function, which represents the total number of level crossings selected by **SLCC** for closure based on the total available budget, is linear. This finding can be explained by the fact that the average cost of crossing closures was assumed to be $500,000 and did not change from one crossing to another. Consideration of different crossing closure costs is likely to cause nonlinearity of this function.

6.1.2. The Impact of the Total Available Budget on the Total Safety Benefits due to Level Crossing Closures

Figure 42 depicts the impact of total available budget on the total safety benefits due to level crossing closures in the State of Florida for every case of the considered budget availability scenarios. It can be observed that the total safety benefits due to level crossing closures suggested by **SLCC** clearly changed after increasing the total available budget and increased from $1.201 \cdot 10^5$ (i.e., scenario 1) to $1.564 \cdot 10^5$ (i.e., scenario 12). Such a pattern can be justified by the fact that the safety benefits were associated with the number of level crossings selected for closure (i.e., the total number of level crossings, which were selected for closure by **SLCC**, increased with the increase of total available budget, which increased the total safety benefits as well). Thus, it can be concluded that the total safety benefits were positively related to the change in total available budget. The relationship between the total available budget and the total safety benefits can be described using a nonlinear function.

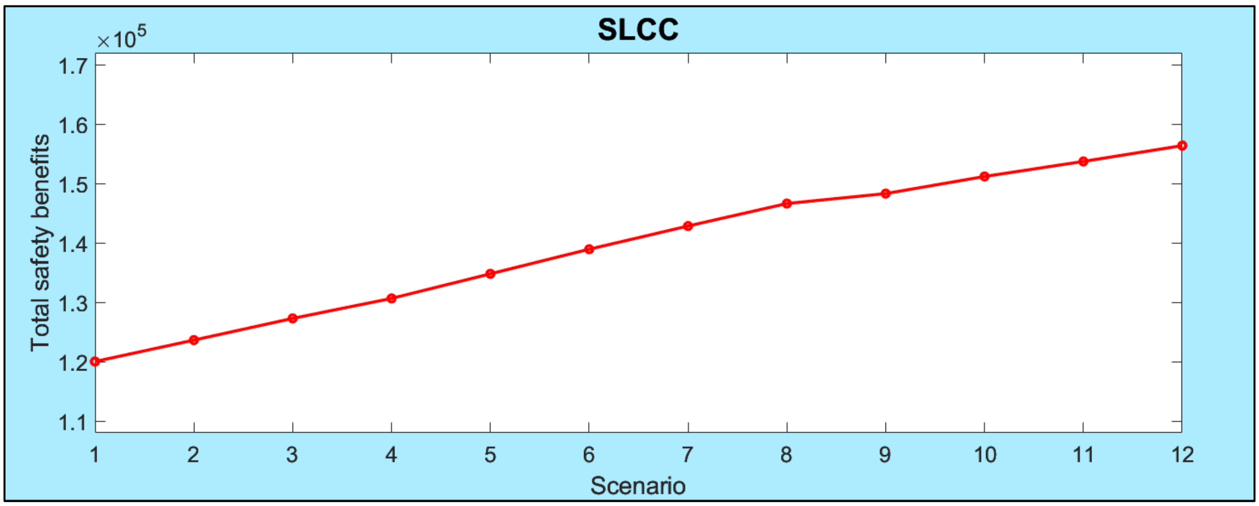


Figure 42 The impact of total available budget on the total safety benefits due to level crossing closures suggested by **SLCC** (analysis #1).

6.1.3. The Impact of the Total Available Budget on the Total Economic Benefits and Delays due to Level Crossing Closures

Figure 43 depicts the impact of total available budget on the total economic benefits due to level crossing closures in the State of Florida for every case of the considered budget availability scenarios. It can be observed that the total economic benefits due to level crossing closures suggested by **SLCC** clearly changed after increasing the total available budget and increased from $2.647 \cdot 10^4$ (i.e., scenario 1) to $4.287 \cdot 10^4$ (i.e., scenario 12). Such a pattern can be justified by the fact that the economic benefits were associated with the number of level crossings selected for closure (i.e., the total number of level crossings, which were selected for closure by **SLCC**, increased with the increase of total available budget, which increased the total economic benefits as well). Thus, it can be concluded that the total economic benefits were positively related to the change in total available budget. The relationship between the total available budget and the total economic benefits can be described using a nonlinear function.

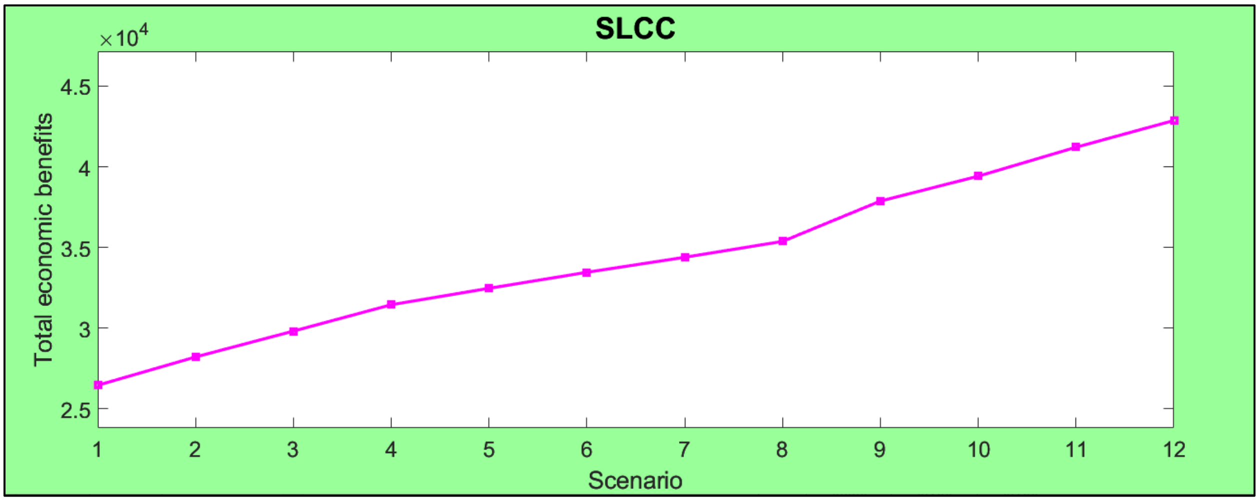


Figure 43 The impact of total available budget on the total economic benefits due to level crossing closures suggested by **SLCC** (analysis #1).

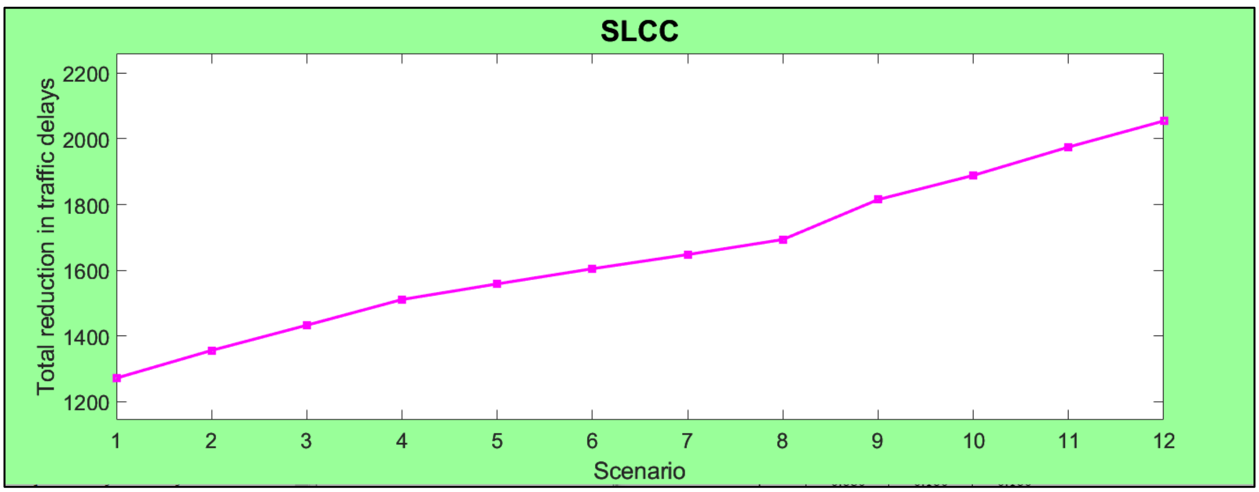


Figure 44 The impact of total available budget on the total reduction in traffic delays due to level crossing closures suggested by **SLCC** (analysis #1).

Figure 44 depicts the impact of total available budget on the total reduction in traffic delays due to level crossing closures in the State of Florida for every case of the considered budget availability scenarios. It can be observed that the total reduction in traffic delays due to level crossing closures suggested by **SLCC** clearly changed after increasing the total available budget and increased from 1,272.044 (i.e., scenario 1) to 2,054.237 (i.e., scenario 12). Such a pattern can be justified by the fact that the total reduction in traffic delays was associated with the number of level crossings selected for closure (i.e., the total number of level crossings, which were selected for closure by **SLCC**, increased with the increase of total available budget, which increased the total reduction in traffic delays as well). Thus, it can be concluded that the total reduction in traffic delays was positively related to the change in total available budget. The relationship between the total available budget and the total reduction in traffic delays can be described using a nonlinear function.

6.1.4. The Impact of the Total Available Budget on the Total Environmental Benefits due to Level Crossing Closures

Figure 45 depicts the impact of total available budget on the total environmental benefits due to level crossing closures in the State of Florida for every case of the considered budget availability scenarios. It can be observed that the total environmental benefits due to level crossing closures suggested by **SLCC** clearly changed after increasing the total available budget and increased from 399.2140 (i.e., scenario 1) to 644.6947 (i.e., scenario 12). Such a pattern can be justified by the fact that the environmental benefits were associated with the number of level crossings selected for closure (i.e., the total number of level crossings, which were selected for closure by **SLCC**, increased with the increase of total available budget, which increased the total environmental benefits as well). Thus, it can be concluded that the total environmental benefits were positively related to the change in total available budget. The relationship between the total available budget and the total environmental benefits can be described using a nonlinear function.

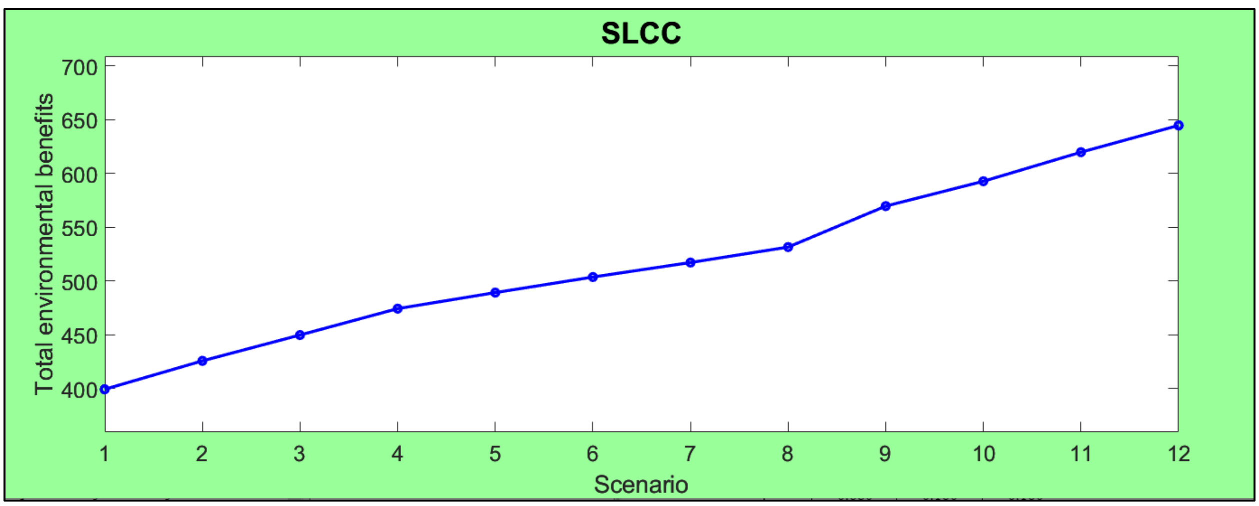


Figure 45 The impact of total available budget on the total environmental benefits due to level crossing closures suggested by **SLCC** (analysis #1).

6.2. Sensitivity Analysis for the Benefit Weight Values

Under this section of the technical report, the impact of the total available budget on selection of level crossings for closure in the State of Florida is investigated. Specifically, a total of 24 scenarios were developed by changing the associated benefit weight values. The investigated safety benefit weight values, economic benefit weight values, and environmental benefit weight values are presented in Table 10 for the considered scenarios. Note that the terms W^{safe}, W^{econ}, and W^{envi} in Table 10 stand for the safety benefit weight values, economic benefit weight values, and environmental benefit weight values, respectively. All the 5,939 public level crossings in the State of Florida, extracted from the FRA crossing inventory database (FRA, 2022a), were investigated throughout the conducted sensitivity analysis. The total available budget was set to $7.5M. The **SLCC** optimization model was solved using the PSCCH algorithm in order to perform the sensitivity analysis for the multiple sets of values for the benefit weights.

Table 10 Developed scenarios for the benefit weight values.

Scenario	W^{safe}	W^{econ}	W^{envi}
1	0.500	0.250	0.250
2	0.560	0.220	0.220
3	0.620	0.190	0.190
4	0.680	0.160	0.160
5	0.740	0.130	0.130
6	0.800	0.100	0.100
7	0.860	0.070	0.070
8	0.920	0.040	0.040
9	0.500	0.125	0.375
10	0.560	0.110	0.330
11	0.620	0.095	0.285
12	0.680	0.080	0.240
13	0.740	0.065	0.195
14	0.800	0.050	0.150
15	0.860	0.035	0.105
16	0.920	0.020	0.060
17	0.500	0.375	0.125
18	0.560	0.330	0.110
19	0.620	0.285	0.095
20	0.680	0.240	0.080
21	0.740	0.195	0.065
22	0.800	0.150	0.050
23	0.860	0.105	0.035
24	0.920	0.060	0.020

6.2.1. The Impact of the Benefit Weight Values on the Number of Level Crossing Closures

Figure 46 depicts the total number of level crossings, which were selected for closure by **SLCC**, for every case of the developed benefit weight scenarios. A total of 15 level crossings out of 5,939 public level crossings in the State of Florida were selected for closure for all the considered 24 scenarios of benefit weight values, when the **SLCC** optimization model was solved by the developed heuristic algorithm. This finding can be explained by the fact that the average cost of crossing closures was assumed to be $500,000 and did not change from one crossing to another. Although different level crossings were selected for closure for different benefit weight scenarios, their cost of closure was not altered (hence, 15 level crossings were closed in each scenario). This pattern is anticipated to change when different closure costs are assigned to the considered level crossings.

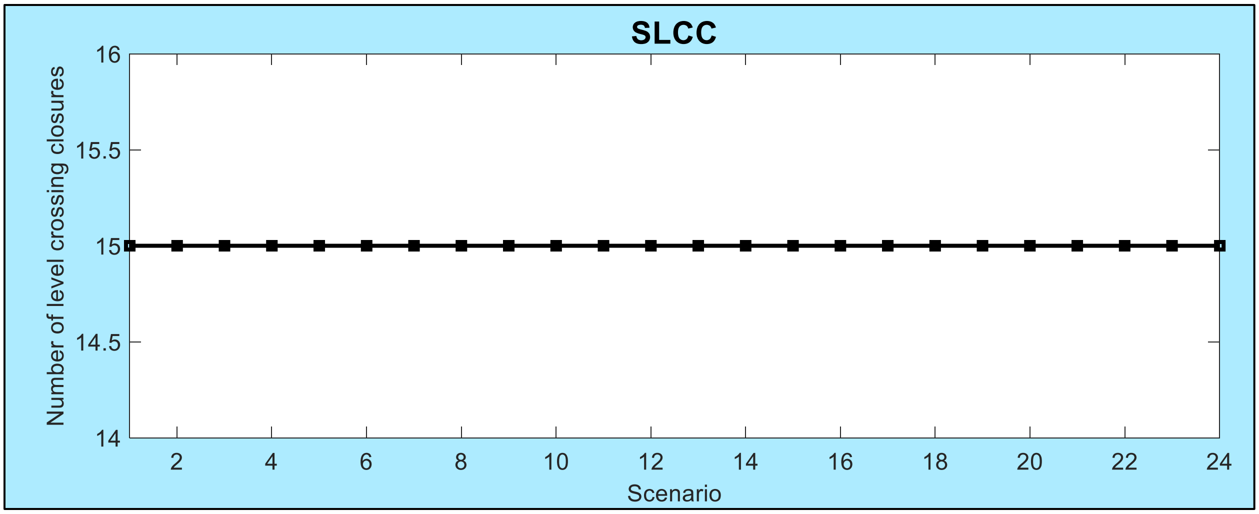


Figure 46 The total number of level crossings selected by **SLCC** for closure for the considered benefit weight value scenarios (analysis #2).

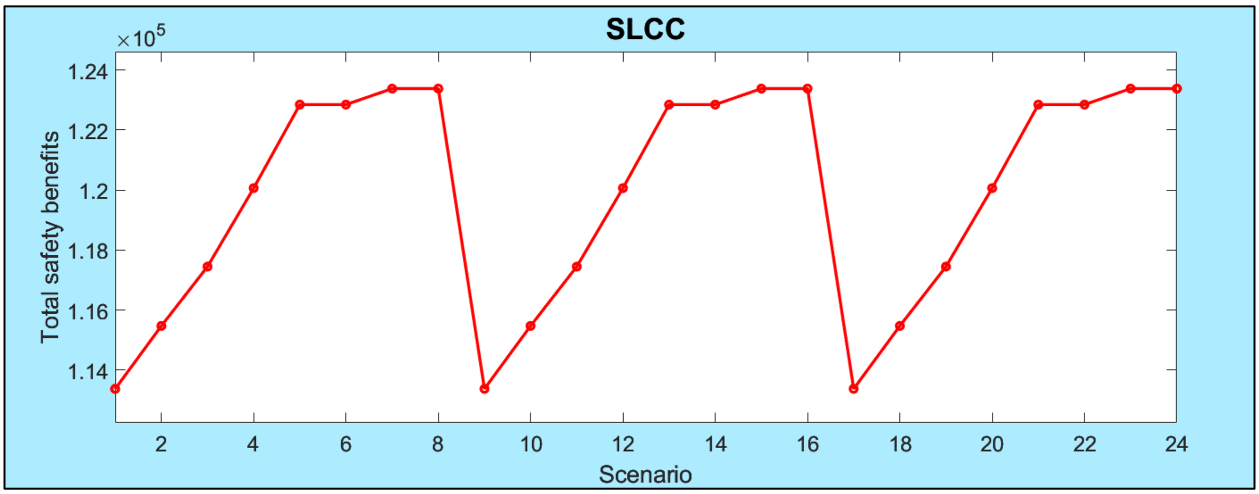


Figure 47 The impact of benefit weight values on the total safety benefits due to level crossing closures suggested by **SLCC** (analysis #2).

6.2.2. The Impact of the Benefit Weight Values on the Total Safety Benefits due to Level Crossing Closures

Figure 47 depicts the impact of benefit weight values on the total safety benefits due to level crossing closures in the State of Florida for every case of the developed benefit weight value scenarios. It can be observed that the total safety benefits due to level crossing closures suggested by **SLCC** clearly changed after increasing the safety benefit weight value and increased from $1.134 \cdot 10^5$ (i.e., scenarios 1, 9, and 17) to $1.234 \cdot 10^5$ (i.e., scenario 8, 16, and 24), given the fact that the number of level crossings selected for closure remained unchanged for all the considered scenarios. Such a pattern can be justified by the fact that the safety benefit weight values were higher for scenarios 8, 16, and 24 and lower for scenarios 1, 9, and 17. Thus, it can be concluded that the total safety benefits due to level crossing closures were directly related to the change in benefit weight values. Hence, higher safety benefits from level crossing closures can be achieved by the relevant stakeholders by increasing the safety benefit weight values. The relationship between the total safety benefits and the benefit weight values can be described using a nonlinear function.

6.2.3. The Impact of the Benefit Weight Values on the Total Economic Benefits and Delays due to Level Crossing Closures

Figure 48 depicts the impact of benefit weight values on the total economic benefits due to level crossing closures in the State of Florida for every case of the developed benefit weight value scenarios. It can be observed that the total economic benefits due to level crossing closures suggested by **SLCC** clearly changed after decreasing the economic benefit weight value and decreased from $2.977 \cdot 10^4$ (i.e., scenarios 1, 9, and 17) to $2.327 \cdot 10^4$ (i.e., scenario 8, 16, and 24), given the fact that the number of level crossings selected for closure remained unchanged for all the considered scenarios. Such a pattern can be justified by the fact that the economic benefit weight values were higher for scenarios 1, 9, and 17 and lower for scenarios 8, 16, and 24. Thus, it can be concluded that the total economic benefits due to level crossing closures were directly related to the change in benefit weight values. Hence, higher economic benefits from level crossing closures can be achieved by the relevant stakeholders by increasing the economic benefit weight values. The relationship between the total economic benefits and the benefit weight values can be described using a nonlinear function.

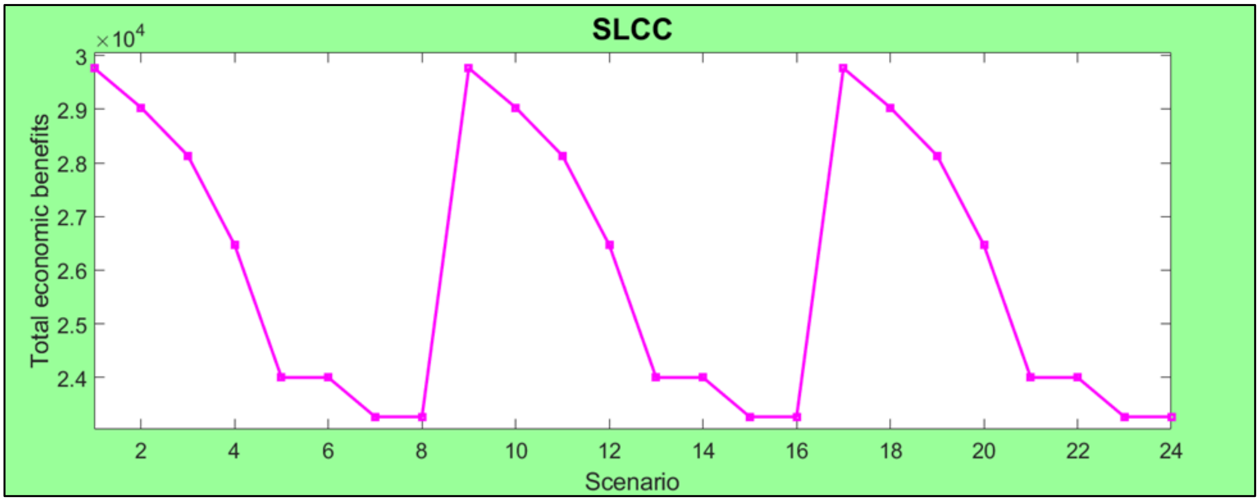


Figure 48 The impact of benefit weight values on the total economic benefits due to level crossing closures suggested by **SLCC** (analysis #2).

Figure 49 depicts the impact of benefit weight values on the total reduction in traffic delays due to level crossing closures in the State of Florida for every case of the developed benefit weight value scenarios. It can be observed that the total reduction in traffic delays due to level crossing closures suggested by **SLCC** clearly changed after decreasing the economic benefit weight value and decreased from 1,436.858 (i.e., scenarios 1, 9, and 17) to 1,111.990 (i.e., scenario 8, 16, and 24), given the fact that the number of level crossings selected for closure remained unchanged for all the considered scenarios. Such a pattern can be justified by the fact that the economic benefit weight values that are associated with the reduction in traffic delays were higher for scenarios 1, 9, and 17 and lower for scenarios 8, 16, and 24. Thus, it can be concluded that the total reduction in traffic delays due to level crossing closures was directly related to the change in benefit weight values. Hence, a higher reduction in traffic delays from level crossing closures can be achieved by the relevant stakeholders by increasing the economic benefit weight values. The relationship between the total reduction in traffic delays and the benefit weight values can be described using a nonlinear function.

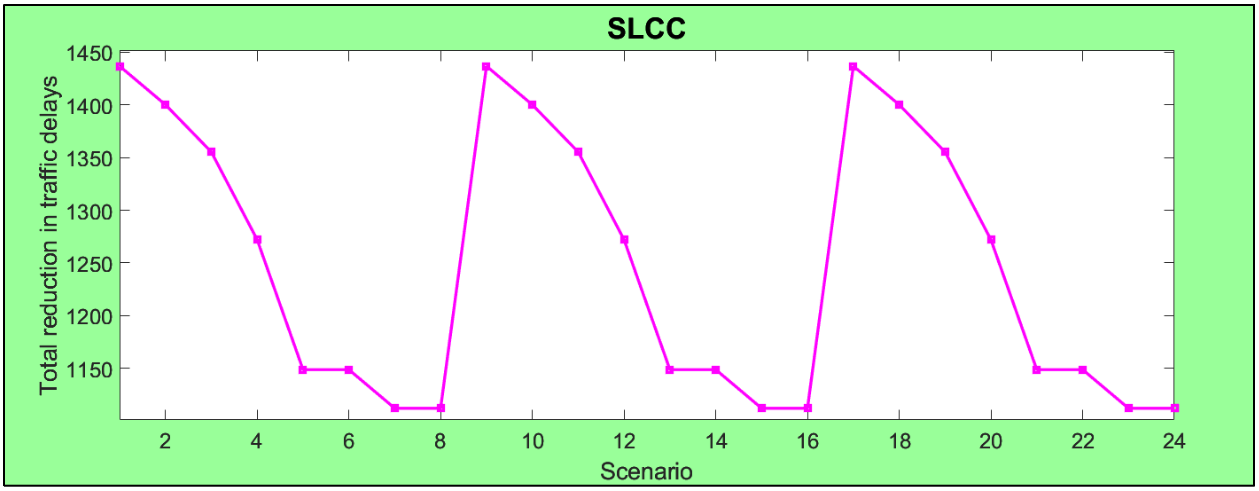


Figure 49 The impact of benefit weight values on the total reduction in traffic delays due to level crossing closures suggested by **SLCC** (analysis #2).

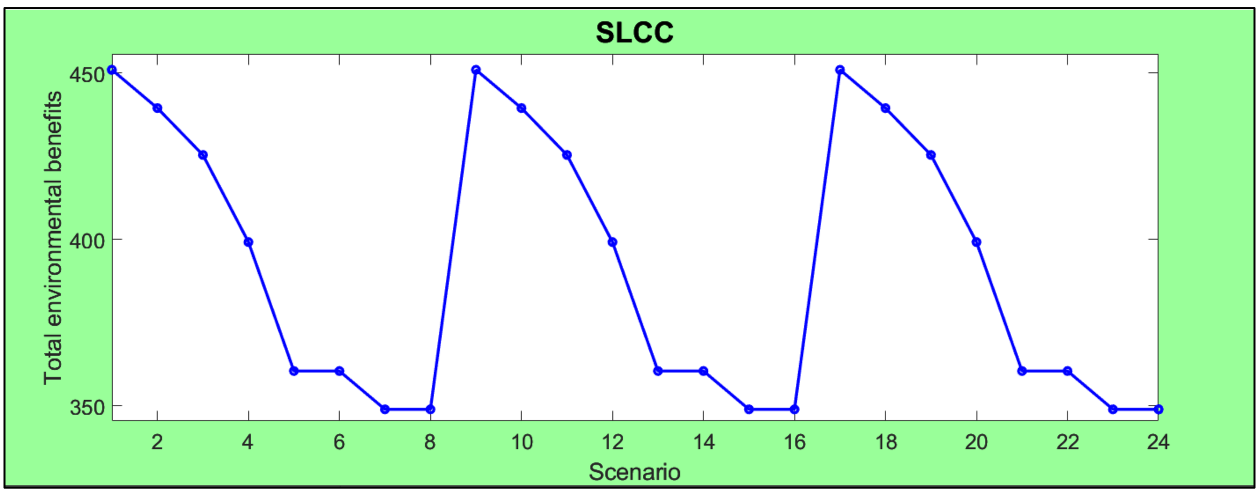


Figure 50 The impact of benefit weight values on the total environmental benefits due to level crossing closures suggested by **SLCC** (analysis #2).

6.2.4. The Impact of the Benefit Weight Values on the Total Environmental Benefits due to Level Crossing Closures

Figure 50 depicts the impact of benefit weight values on the total environmental benefits due to level crossing closures in the State of Florida for every case of the developed benefit weight value scenarios. It can be observed that the total environmental benefits due to level crossing closures suggested by **SLCC** clearly changed after decreasing the environmental benefit weight value and decreased from 450.938 (i.e., scenarios 1, 9, and 17) to 348.983 (i.e., scenario 8, 16, and 24), given the fact that the number of level crossings selected for closure remained unchanged for all the considered scenarios. Such a pattern can be justified by the fact that the environmental benefit weight values were higher for scenarios 1, 9, and 17 and lower for scenarios 8, 16, and 24. Thus, it can be concluded that the total environmental benefits due to level crossing closures were directly related to the change in benefit weight values. Hence, higher environmental benefits from level crossing closures can be achieved by the relevant stakeholders by increasing the environmental benefit weight values. The relationship between the total environmental benefits and the benefit weight values can be described using a nonlinear function.

6.3. Level Crossing Decisions for Various Crossing Types

Under this section of the technical report, the impact of various crossing types on the total benefits due to level crossing closures in the State of Florida is investigated. A total of 3 scenarios were developed by changing the type of level crossings analyzed. Specifically, in scenario 1, all the 5,939 public level crossings in the State of Florida were investigated. All the 2,790 private level crossings in the State of Florida were selected for the analysis in scenario 2. Furthermore, in scenario 3, the selection of level crossing closures was conducted among all the 8,729 public and private level crossings in the State of Florida. The required information regarding physical and operational characteristics of public and private level crossings in the State of Florida was extracted from the FRA crossing inventory database (FRA, 2022a). Note that the level crossings, which did not have any information regarding the crossing type in the FRA crossing inventory database (i.e., public or private), were discarded from the analysis. Moreover, the total available budget was set equal to \$7.5M. The default benefit weight values were assumed (W^{safe} = 0.70, W^{econ} = 0.15, and W^{envi} = 0.15). The developed **SLCC** optimization model was solved using the PSCCH algorithm in order to perform the analysis and comparison among various crossing types.

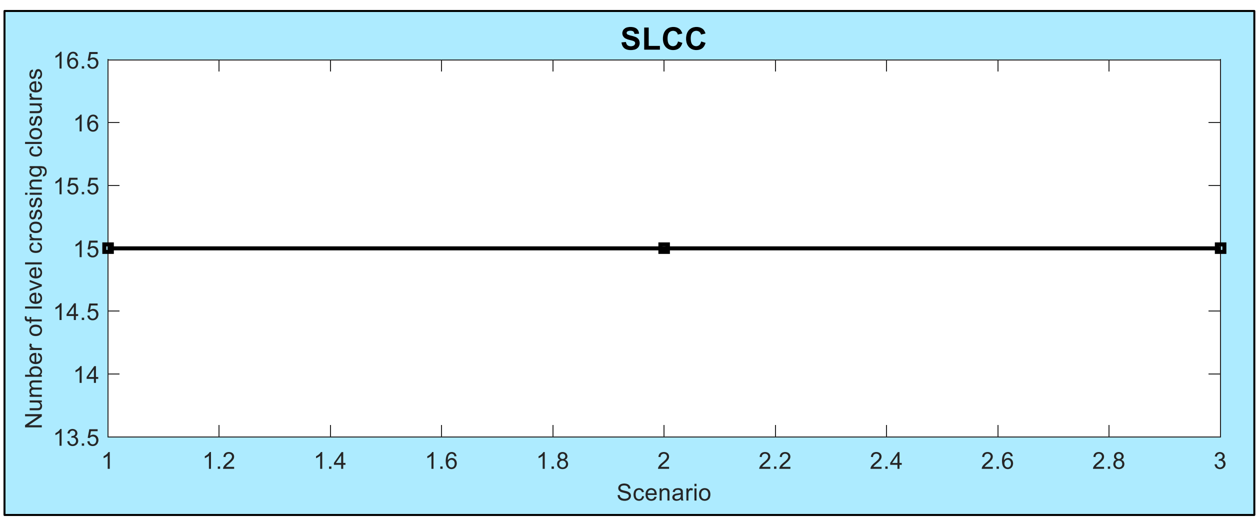


Figure 51 The total number of level crossings selected by **SLCC** for closure for the considered crossing type scenarios (analysis #3).

6.3.1. The Impact of the Crossing Type on the Number of Level Crossing Closures

Figure 51 depicts the total number of level crossings, which were selected for closure by **SLCC**, for every case of the considered crossing type scenarios. A total of 15 level crossings were selected for all the considered scenarios of crossing types in the State of Florida (i.e., public level crossings, private level crossings, and both types of crossings). This finding can be explained by the fact that the average cost of crossing closures was assumed to be $500,000 and did not change from one crossing to another for public and private level crossings. Although different level crossings were selected for closure for different crossing type scenarios, their cost of closure was not altered (hence, 15 level crossings were closed in each scenario). This pattern is anticipated to change when different closure costs are assigned to the considered level crossings.

6.3.2. The Impact of the Crossing Type on the Total Safety Benefits due to Level Crossing Closures

Figure 52 depicts the impact of level crossing type on the total safety benefits due to level crossing closures in the State of Florida for every case of the developed crossing type scenarios. It can be observed that the total safety benefits due to level crossing closures suggested by **SLCC** in the State of Florida decreased substantially from scenario 1 to scenario 2 (with the change of the considered level crossings from public to private). Specifically, the total safety benefits decreased from $1.201 \cdot 10^5$ in scenario 1 to $5.596 \cdot 10^3$ in scenario 2. Such a finding can be justified by the fact that public level crossings are generally exposed to larger rail and highway traffic volumes when comparing to private level crossings. Therefore, the closures of public level crossings yielded higher safety benefits when comparing to the closures of private level crossings. As for scenario 3, when considering public and private level crossings for closures at the same time, the total safety benefits due to closures comprised $1.201 \cdot 10^5$, which is exactly the same value as the one that was recorded for scenario 1. Such a pattern can be justified by the fact that all the level crossings selected for closures in scenario 3 were public. Hence, the total safety benefits due to the closures of level crossings selected in scenario 3 were same as the total safety benefits due to the closures of level crossings selected in scenario 1.

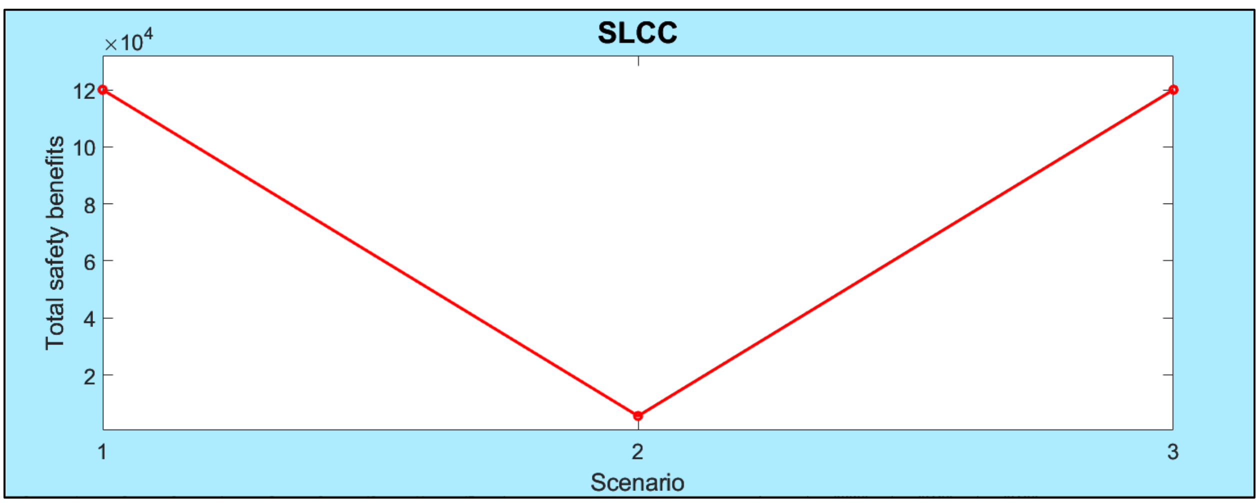


Figure 52 The impact of crossing types on the total safety benefits due to level crossing closures suggested by **SLCC** (analysis #3).

6.3.3. The Impact of the Crossing Type on the Total Economic Benefits and Delays due to Level Crossing Closures

Figure 53 depicts the impact of level crossing type on the total economic benefits due to level crossing closures in the State of Florida for every case of the developed crossing type scenarios. It can be observed that the total economic benefits due to level crossing closures suggested by **SLCC** in the State of Florida decreased substantially from scenario 1 to scenario 2 (with the change of the considered level crossings from public to private). Specifically, the total economic benefits decreased from $2.647 \cdot 10^4$ in scenario 1 to $1.689 \cdot 10^3$ in scenario 2. Such a finding can be justified by the fact that public level crossings are generally exposed to larger rail and highway traffic volumes when comparing to private level crossings. Therefore, the closures of public level crossings yielded higher economic benefits when comparing to the closures of private level crossings. As for scenario 3, when considering public and private level crossings for closures at the same time, the total economic benefits due to closures comprised $2.647 \cdot 10^4$, which is exactly the same value as the one that was recorded for scenario 1. Such a pattern can be justified by the fact that all the level crossings selected for closures in scenario 3 were public. Hence, the total economic benefits due to the closures of level crossings selected in scenario 3 were same as the total economic benefits due to the closures of level crossings selected in scenario 1.

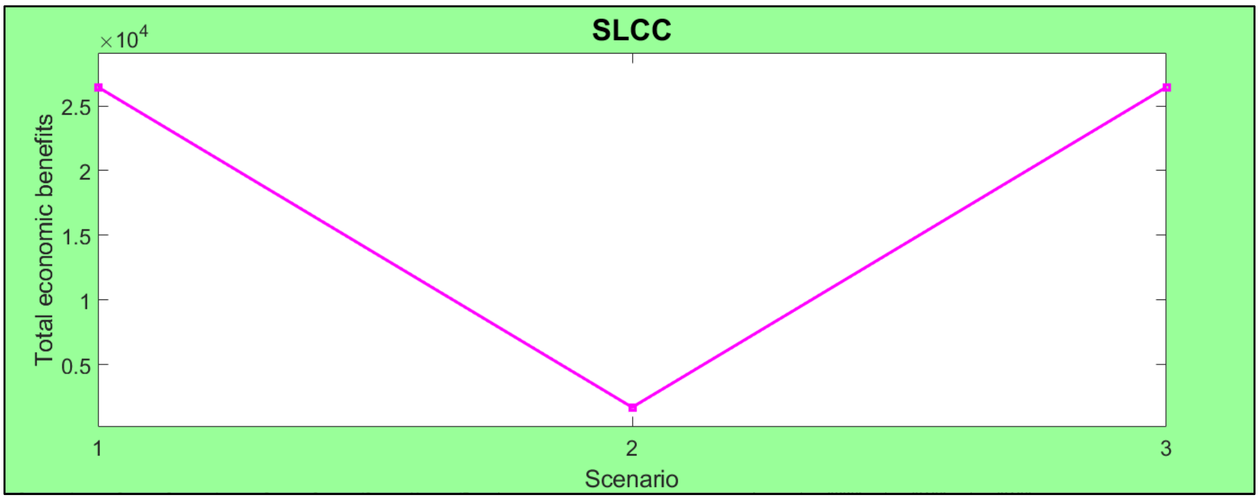


Figure 53 The impact of crossing types on the total economic benefits due to level crossing closures suggested by **SLCC** (analysis #3).

Figure 54 depicts the impact of level crossing type on the total reduction in traffic delays due to level crossing closures in the State of Florida for every case of the developed crossing type scenarios. It can be observed that the total reduction in traffic delays due to level crossing closures suggested by **SLCC** in the State of Florida decreased substantially from scenario 1 to scenario 2 (with the change of the considered level crossings from public to private). Specifically, the total reduction in traffic delays decreased from 1,272.044 in scenario 1 to 84.058 in scenario 2. Such a finding can be justified by the fact that public level crossings are generally exposed to larger rail and highway traffic volumes when comparing to private level crossings. Therefore, the closures of public level crossings yielded a higher reduction in traffic delays when comparing to the closures of private level crossings. As for scenario 3, when considering public and private level crossings for closures at the same time, the total reduction in traffic delays due to closures comprised 1,272.044, which is exactly the same value as the one that was recorded for scenario 1. Such a pattern can be justified by the fact that all the level crossings selected for closures in scenario 3 were public. Hence, the total reduction in traffic delays due to the closures of level crossings selected in scenario 3 was same as the total reduction in traffic delays due to the closures of level crossings selected in scenario 1.

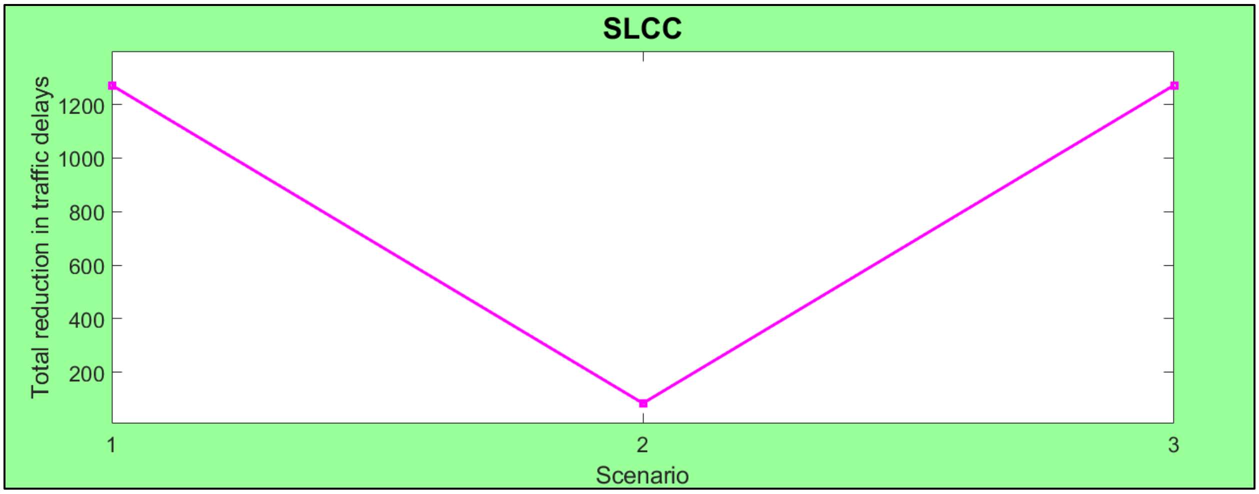


Figure 54 The impact of crossing types on the total reduction in traffic delays due to level crossing closures suggested by **SLCC** (analysis #3).

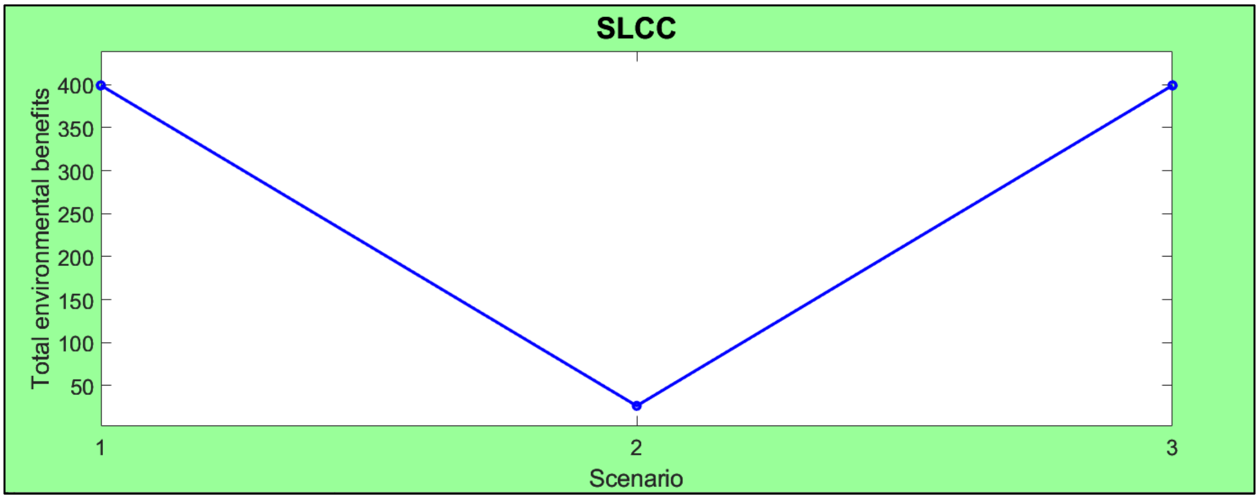


Figure 55 The impact of crossing types on the total environmental benefits due to level crossing closures suggested by **SLCC** (analysis #3).

6.3.4. The Impact of the Crossing Type on the Total Environmental Benefits due to Level Crossing Closures

Figure 55 depicts the impact of level crossing type on the total environmental benefits due to level crossing closures in the State of Florida for every case of the developed crossing type scenarios. It can be observed that the total environmental benefits due to level crossing closures suggested by **SLCC** in the State of Florida decreased substantially from scenario 1 to scenario 2 (with the change of the considered level crossings from public to private). Specifically, the total environmental benefits decreased from 399.214 in scenario 1 to 26.380 in scenario 2. Such a finding can be justified by the fact that public level crossings are generally exposed to larger rail and highway traffic volumes when comparing to private level crossings. Therefore, the closures of public level crossings yielded higher environmental benefits when comparing to the closures of private level crossings. As for scenario 3, when considering public and private level crossings for closures at the same time, the total environmental benefits due to closures comprised 399.214, which is exactly the same value as the one that was recorded for scenario 1. Such a pattern can be justified by the fact that all the level crossings selected for closures in scenario 3 were public. Hence, the total environmental benefits due to the closures of level crossings selected in scenario 3 were same as the total environmental benefits due to the closures of level crossings selected in scenario 1.

7. CONCLUSIONS

Rail transportation plays a crucial role for the development of the State of Florida. However, collisions at level crossings (i.e., locations where highway segments intersect a given railroad segment at the same elevation) are one of the major concerns across the state. Implementation of different countermeasures (e.g., wigwags, flashing lights, gates, cameras) is considered a common approach to improve safety at level crossings. However, the funding for level crossing safety improvement projects is limited and does not allow upgrading all the hazardous crossings across the state. Closure of level crossings is another alternative that can be used to address the issue of level crossing safety and assist with building a reliable, well-connected, and safe multimodal transportation network. In order to achieve safety, economic, and environmental benefits from level crossing closures, it is important to select and close appropriate level crossings. However, similar to implementation of countermeasures, the closure of all the level crossings in the State of Florida is not economically and practically feasible because there are a significant number of public and private level crossings in Florida. Hence, the total benefits of level crossing closures need to be assessed to prioritize these crossings for closure.

As a part of this project, a new optimization model, called the Selection of Level Crossings for Closure (**SLCC**), was proposed with the goal of maximizing the total benefit from level crossing closures. The benefits from crossing closures were categorized into three groups, including the following: (1) safety benefits; (2) economic benefits; and (3) environmental benefits. The importance of benefits can be controlled by imposing specific weights. The proposed mathematical model can also incorporate certain practical considerations when assessing the level crossing closure decisions (e.g., proximity of a given level crossing to other level crossings, the frequency of using a given level crossing when providing emergency services, potential highway traffic diversion to alternative level crossings and routes). Furthermore, the developed formulation directly captured an upper bound on the number of level crossings that can be closed for the considered planning horizon along with the cost of level crossing closures, as the relevant stakeholders normally have a certain limit for the total planned budget for level crossing closures and other practical considerations. A heuristic algorithm, called the Profitable Selection of Crossings for Closure Heuristic (PSCCH), was developed to solve the **SLCC** optimization model.

Moreover, a number of sensitivity analyses were conducted. Specifically, the sensitivity of the **SLCC** mathematical model to the following attributes was analyzed: (1) changes in the total available budget; and (2) changes in the benefit weight values. Furthermore, the decisions on level crossing closures for various types of level crossings (e.g., public, private, and both public and private) were analyzed. The aforementioned sensitivity analyses focused on several performance indicators, including the following: (1) changes in the number of level crossings selected for closures; (2) changes in the total safety benefits due to level crossing closures; (3) changes in the total economic benefits and delays due to level crossing closures; and (4) changes in the total environmental benefits due to level crossing closures. All the 5,939 public level crossings in the State of Florida were considered throughout the sensitivity analyses. Moreover, all the 2,790 private level crossings in the State of Florida were considered in the third analysis, along with the public level crossings.

Based on the numerical experiments that were conducted as a part of this project, it can be concluded that the proposed methodology, including the **SLCC** mathematical model and the PSCCH algorithm that was developed to solve the model, can serve as an effective decision support system for the Florida Department of Transportation (FDOT) personnel and assist with maximizing the total benefit associated with closures under different total budget availability scenarios, sets of benefit weight values, and various crossing type scenarios. Moreover, the proposed methodology can effectively incorporate other considerations that are taken into account by the FDOT personnel throughout decision making during the selection of level crossings for closure in the State of Florida (e.g., eligibility of each crossing for closure based on specific practical features).

Additionally, a Web application called “HRX_Safety_Improvement” was designed as a part of this project. The “HRX_Safety_Improvement” Web application aims to assess the benefits of closing level crossings and prioritize level crossings for closures. The benefits include economic, environmental, and safety benefits, as well as reduced delays and reduced operational and maintenance costs. To calculate these benefits, the Web application requires some basic information about the physical and operational characteristics of the level crossings, such as the number of trains and vehicles passing through them per day, train speed, number of highway lanes, existing protection, whether the crossing is in an urban or rural area, type of crossing, available budget, maximum number of possible crossings for closure, number of railroad tracks, among others. This information should be supplied to the Web application in the form of an Azure database and input values on the Web application’s homepage. Once the benefits are estimated by the Web application, the selection of level crossings for closure can be performed. The “HRX_Safety_Improvement” Web application directly deploys the PSCCH heuristic to identify the most profitable level crossings for closure. The results of the analysis are displayed in tables on the Web pages. This report outlined the Web application purpose and fundamental user guidelines. It is expected that the developed Web application can assist the FDOT personnel with the selection of level crossings for closure, improve safety of highway and railroad users across the State of Florida, and yield substantial economic and environmental benefits.

REFERENCES

Accorsi, L. and Vigo, D., 2021. A fast and scalable heuristic for the solution of large-scale capacitated vehicle routing problems. *Transportation Science*, 55(4), pp.832-856.

AIMSUN, 2014. *Aimsun 8 Dynamic Simulators Users' Manual, 2014*. TSS-Transport Simulation Systems.

AREMA, 2004. *Highway-Rail Grade Crossing Warning Systems*. Communications and Signal Manual, Section 3. Landover, MD.

Asghari, M., Afshari, H., Mirzapour Al-e-hashem, S.M.J., Fathollahi-Fard, A.M. and Dulebenets, M.A., 2022. Pricing and advertising decisions in a direct-sales closed-loop supply chain. *Computers & Industrial Engineering*, 171, p.108439.

Bazgan, C., Hugot, H. and Vanderpooten, D., 2009. Solving efficiently the 0–1 multi-objective knapsack problem. *Computers & Operations Research*, 36(1), pp. 260-279.

Bien-Aime, P., 2009. *North Carolina Sealed Corridor Phase I, II, and III Assessment*. [online]. Available at: https://rosap.ntl.bts.gov/view/dot/11951 [Accessed 13 July 2022].

Bruni, M.E., Beraldi, P. and Khodaparasti, S., 2018. A fast heuristic for routing in post-disaster humanitarian relief logistics. *Transportation Research Procedia*, 30, pp.304-313.

Cacchiani, V., Iori, M., Locatelli, A. and Martello, S., 2022. Knapsack problems—An overview of recent advances. Part II: Multiple, multidimensional, and quadratic knapsack problems. *Computers & Operations Research*, 143, p.105693.

Caird, J.K., Creaser, J.I., Edwards, C.J. and Dewar, R.E., 2002. *A human factors analysis of highway-railway grade crossing accidents in Canada*. [online]. Available at: https://trid.trb.org/view/660987 [Accessed 29 July 2022].

Chadwick, S.G., Zhou, N. and Saat, M.R., 2014. Highway-rail grade crossing safety challenges for shared operations of high-speed passenger and heavy freight rail in the US. *Safety Science*, 68, pp.128-137.

Chekuri, C. and Khanna, S., 2005. A polynomial time approximation scheme for the multiple knapsack problem. *SIAM Journal on Computing*, 35(3), pp. 713-728.

Codjoe, J., Soleimani, S., Ashley.G., 2018. *Research Incentive Programs for Closures of Public and Private Grade Crossings*. [online]. Available at: https://digitalcommons.lsu.edu/cgi/viewcontent.cgi?article=1020&context=transet_pubs [Accessed 29 July 2022].

CPUC, 2021. *Section 190, Grade Separation Program, California Public Utilities Commission, Rail Crossings and Engineering Branch*. [online]. Available at: https://www.cpuc.ca.gov/-/media/cpuc-website/divisions/rail-safety-division/rceb/190gradesepoverview-070121.pdf [Accessed 21 July 2022].

CUTR, 2014. *Coordinated Pre-Preemption of Traffic Signals to Enhance Railroad Grade Crossing Safety in Urban Areas and Estimation of Train Impacts to Arterial Travel Time Delay*. Prepared for the Florida Department of Transportation. [online]. Available at: https://rosap.ntl.bts.gov/view/dot/26860/dot_26860_DS1.pdf [Accessed 27 May 2020].

Dammeyer, F. and Voss, S., 1991. *Application of Tabu Search Strategies for Solving Multiconstraint Zero–One Knapsack Problems*. Working Paper, Technische Hochschule Darmstadt.

De Gruyter, C. and Currie, G., 2016. Rail-road crossing impacts: an international synthesis. *Transport Reviews*, 36(6), pp.793-815.

Drexl, A., 1988. A Simulated Annealing approach to the multiconstraint zero-one knapsack problem. *Computing*, 40(1), pp. 1-8.
Dulebenets, M.A., 2021. An Adaptive Polyploid Memetic Algorithm for scheduling trucks at a cross-docking terminal. *Information Sciences*, 565, pp.390-421.
Dulebenets, M.A., 2023. A Diffused Memetic Optimizer for reactive berth allocation and scheduling at marine container terminals in response to disruptions. *Swarm and Evolutionary Computation*, 80, p.101334.
Dulebenets, M.A., Moses, R., Sobanjo, J.O., Ozguven, E.E., Abioye, O.F., Kavoosi, M. and Pasha, J., 2020. *Development of the optimization model for improving safety at rail crossings in Florida*. A Technical Report Prepared for the Florida Department of Transportation, Tallahassee, FL, USA.
Dulebenets, M.A., Pasha, J., Moses, R., Sobanjo, J., Ozguven, E.E. and Singh, P., 2021. *Improving Safety at Highway-Rail Grade Crossings in Florida While Maintaining Continuity of Passenger and Freight Flows: A Multi-Objective Approach*. A Technical Report Prepared for the Florida Department of Transportation, Tallahassee, FL, USA.
Evans, A.W. and Hughes, P., 2019. Traverses, delays and fatalities at railway level crossings in Great Britain. *Accident Analysis & Prevention*, 129, pp.66-75.
Fathollahi-Fard, A.M., Dulebenets, M.A., Hajiaghaei–Keshteli, M., Tavakkoli-Moghaddam, R., Safaeian, M. and Mirzahosseinian, H., 2021. Two hybrid meta-heuristic algorithms for a dual-channel closed-loop supply chain network design problem in the tire industry under uncertainty. *Advanced Engineering Informatics*, 50, p.101418.
FDOT, 2010. *The Florida Rail System Plan: Investment Element*. [online]. Available at: https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/content/rail/plandevel/documents/finalinvestmentelement/a-2010flrailplan-investmentelement.pdf [Accessed 5 July 2022].
FDOT, 2020. *Freight Mobility and Trade Plan*. [online]. Available at: https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/rail/fmtp/april-2020/fmtp-tm-vp-april-2020.pdf?sfvrsn=5ec40f68_8 [Accessed 27 June 2022].
FDOT, 2022. *Opening Closure Program*. [online]. Available at: https://www.fdot.gov/rail/programs/opening-closure [Accessed 5 July 2022].
FDS, 2022. *Public Railroad-Highway Grade Crossings - Opening and Closure*. Available at: https://www.flrules.org/gateway/ruleno.asp?id=14-57.012 [Accessed 5 July 2022].
FRA, 2022a. *Highway-Rail Crossing Inventory Data*. [online]. Available at: https://safetydata.fra.dot.gov/officeofsafety/publicsite/downloaddbf.aspx [Accessed 27 June 2022].
FRA, 2022b. *Accident/Incident Data*. [online]. Available at: https://safetydata.fra.dot.gov/OfficeofSafety/publicsite/on_the_fly_download.aspx [Accessed 27 June 2022].
Fréville, A., 2004. *The multidimensional 0–1 knapsack problem: An overview*. European Journal of Operational Research, 155(1), pp. 1-21.
Gabree, S.H., Calabrese, C., Young, J., Mejia, B. and Prescott, J., 2019. *Review of Highway-Rail Grade Crossing Incidents 1986–2015: Trends and Potential Safety Gaps* (No. DOT/FRA/ORD-19/30). United States. Federal Railroad Administration. Office of Railroad Policy and Development.

GAC, 2022. *Chapter 672-16 CRITERIA FOR ELIMINATION OF HIGHWAY-RAIL GRADE CROSSINGS*. [online]. Available at: https://rules.sos.state.ga.us/gac/672-16 [Accessed 25 July 2022].

GAO, 2019. *RAIL SAFETY: Freight Trains are Getting Longer, and Additional Information is Needed to Assess Their Impact*. [online]. Available at: https://www.gao.gov/assets/700/699396.pdf [Accessed 25 July 2022].

GDOT, 2011. *State Highway-Rail Grade Crossing Action Plan*. [online]. Available at: http://www.dot.ga.gov/PartnerSmart/utilities/Documents/StateCrossingActionPlan.pdf#search=crossing%20closure [Accessed 25 July 2022].

Georgia Code, 2022. [online]. *GA. Code 32-6-193.1 Elimination of grade crossings by physical removal; procedures*. Available at: https://public.fastcase.com/9SKwsfNqTc6OieYDhNMyM%2B8xVjjCK2MXFOT8w7VRBW3SbkEPYBeTD8zFROPnYhjtIY2C9lZ8ixXc8WEHDsgxDw%3D%3D [Accessed 25 July 2022].

Gilmore, P.C. and Gomory, R.E., 1966. The theory and computation of knapsack functions. *Operations Research*, 14(6), pp. 1045-1074.

Green, C.J., 1967. *Two Algorithms for Solving Independent Multidimensional Knapsack Problems*. Management Sciences Report, no. 110, Carnegie institute of Technology, Graduate School of Industrial Administration, Pittsburgh, PA.

Güntzer, M.M. and Jungnickel, D., 2000. Approximate minimization algorithms for the 0/1 knapsack and subset-sum problem. *Operations Research Letters*, 26(2), pp. 55-66.

Gurski, F., Rehs, C. and Rethmann, J., 2019. Knapsack problems: A parameterized point of view. *Theoretical Computer Science*, 775, pp.93-108.

Hanafi, S., Fréville, A. and El Abdellaoui, A., 1996. *Comparison of heuristics for the 0–1 multidimensional knapsack problem*. In: I.H. Osman, J.P. Kelly, eds., Meta-Heuristics, 1st ed. Springer: Boston, MA, pp. 449-465.

Handoko, H., Rachman, N.F. and Kurniawan, F.A., 2022. Investigating Public Perception Toward The Level Crossing Without Railway Gate Crossing (Case Study: At JPL 297 and 294 Lamongan). *Journal of Railway Transportation and Technology*, 1(1), pp.37-45.

Hans, Z., Albrecht, C., Johnson, P. and Nlenanya, I., 2015. *Development of Railroad Highway Grade Crossing Consolidation Rating Formula* (No. WBS: 25-1121-0003-234). Mid-America Transportation Center.

Hellman, A. and Ngamdung, T., 2010. Illinois High-Speed Rail Four-Quadrant Gate Reliability Assessment. In *Joint Rail Conference* (Vol. 49064, pp. 445-454). Available at: https://asmedigitalcollection.asme.org/JRC/proceedings-abstract/JRC2010/445/347146 [Accessed 15 July 2022].

Hughes, B.P., 2003.*The Australian National Railway Level Crossing Safety Strategy*. In 26th Australasian Transport Research Forum. Wellington: ATRF.

Hussain, K., Mohd Salleh, M.N., Cheng, S. and Shi, Y., 2019. Metaheuristic research: a comprehensive survey. *Artificial Intelligence Review*, 52, pp.2191-2233.

Ibaraki, T., 1987. Enumerative Approaches to Combinatorial Optimization - Part II. *Annals of Operations Research*, 11.

Iowa DOT, 2012. *State of Iowa Highway-Rail Grade Crossing Safety Action Plan*. [online]. Available at: https://safety.fhwa.dot.gov/hsip/xings/docs/ia-sap.pdf [Accessed 26 July 2022].

Isaka, S., 1983. *Double Relaxation Dynamic Programming Methods for the Multi-Dimensional Knapsack Problem*. Master Thesis, Kyoto University.

ITE, 2006. *Preemption of Traffic Signals Near Railroad Crossings: An ITE Recommended Practice*. Institute of Transportation Engineers. [online]. Available at: https://www.ite.org/pub/?id=e1dca8bc%2D2354%2Dd714%2D51cd%2Dbd0091e7d820 [Accessed 27 May 2020].

Johnson, P.M., 2015. *An investigation of railroad-highway grade crossing consolidation rating in Iowa*. Master's Thesis, Iowa State University.

Jusayan, J., 2015. *Delay Due to Level Crossing*. [online]. Available at: https://levelcrossings.vic.gov.au/__data/assets/pdf_file [Accessed 27 September 2020].

Kavoosi, M., Dulebenets, M.A., Abioye, O., Pasha, J., Theophilus, O., Wang, H., Kampmann, R. and Mikijeljević, M., 2020b. Berth scheduling at marine container terminals. *Maritime Business Review*, 5(1), pp.30-36.

Kavoosi, M., Dulebenets, M.A., Abioye, O.F., Pasha, J., Wang, H. and Chi, H., 2019. An augmented self-adaptive parameter control in evolutionary computation: A case study for the berth scheduling problem. *Advanced Engineering Informatics*, 42, p.100972.

Kavoosi, M., Dulebenets, M.A., Pasha, J., Abioye, O.F., Moses, R., Sobanjo, J. and Ozguven, E.E., 2020a. Development of Algorithms for Effective Resource Allocation among Highway–Rail Grade Crossings: A Case Study for the State of Florida. *Energies*, 13(6), p.1419.

Khattak, A. and Thompson, E., 2012. *Development of a Methodology for Assessment of Crash Costs at Highway-Rail Grade Crossings in Nebraska* (No. 25-1121-0001-422). Mid-America Transportation Center.

Khuri, S., Bäck, T. and Heitkötter, J., 1994. The zero/one multiple knapsack problem and Genetic Algorithms. In: *Proceedings of the 1994 ACM Symposium on Applied Computing*. [online]. Phoenix, AZ: ACM, pp. 188-193. Available at: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.51.2713&rep=rep1&type=pdf [Accessed 01 Oct 2018].

Li, B., Elmi, Z., Manske, A., Jacobs, E., Lau, Y.Y., Chen, Q. and Dulebenets, M.A., 2023. Berth allocation and scheduling at marine container terminals: A state-of-the-art review of solution approaches and relevant scheduling attributes. *Journal of Computational Design and Engineering*, 10(4), pp.1707-1735.

Marsten, R.E. and Morin, T.L., 1976. *MMPD, a Computer Code for Solving Multiconstraint Knapsack Problems in Integer Variables*. User's Guide. Operations Research Center, MIT, Cambridge, MA.

Mathew, J., Benekohal, R.F., Berndt, M., Beckett, J. and McKerrow, J., 2021. Multi-criteria prioritization of highway-rail grade crossings for improvements: A case study. *Urban, Planning and Transport Research*, 9(1), pp.479-518.

Mok, S.C. and Savage, I., 2005. Why Has Safety Improved at Rail-Highway Grade Crossings?. *Risk Analysis: An International Journal*, 25(4), pp.867-881.

Murphy, J.F., 1995. *A Guide to Crossing Consolidation and Closure. In Third International Symposium on Railroad-Highway Grade Crossing Research and Safety Southeastern Transportation Center*. [online]. Available at: https://trid.trb.org/view/980922 [Accessed 23 July 2022].

NCDOT, 2019. *Crossing Safety Upgrades*. [online]. Available at: https://www.ncdot.gov/divisions/rail/Pages/crossing-safety-upgrades.aspx [Accessed 21 July 2022].

NCHRP, 1987. *National Cooperative Highway Research Program Report 288. Evaluating Grade-Separated Rail and Highway Crossing Alternatives*. [online]. Available at: http://onlinepubs.trb.org/Onlinepubs/nchrp/nchrp_rpt_288.pdf [Accessed 27 May 2020].

Nelson, A., 2010. Breaking down the barriers to safer crossings. *IRJ-International Railway Journal*, 50(5).

ODOT, 2020. *Oregon At-Grade Rail Crossings*. [online]. Available at: https://www.oregon.gov/odot/MCT/Rail_Safety/About-At-Grade-Rail-Crossings.pdf [Accessed 29 July 2022].

Okitsu, W., Louie, J., and Lo, K., 2010. Simulation-Free Railroad Grade Crossing Delay Calculations. Western District, *Institute of Transportation Engineers 2010 Annual Meeting*.

ORC, 1993. *Ohio Revised Code Section 4907.474 Closing crossings to vehicular traffic*. [online]. Available at: https://codes.ohio.gov/assets/laws/revised-code/authenticated/49/4907/4907.474/7-1-1993/4907.474-7-1-1993.pdf [Accessed 24 July 2022].

ORDC, 2022. *Ohio Highway-Rail Grade Crossing State Action Plan*. [online]. Available at: https://rail.ohio.gov/rail-in-ohio/resources/a-state-action-plan [Accessed 26 July 2022].

Pasha, J., Dulebenets, M.A., Fathollahi-Fard, A.M., Tian, G., Lau, Y.Y., Singh, P. and Liang, B., 2021. An integrated optimization method for tactical-level planning in liner shipping with heterogeneous ship fleet and environmental considerations. *Advanced Engineering Informatics*, 48, p.101299.

Pasha, J., Nwodu, A.L., Fathollahi-Fard, A.M., Tian, G., Li, Z., Wang, H. and Dulebenets, M.A., 2022. Exact and metaheuristic algorithms for the vehicle routing problem with a factory-in-a-box in multi-objective settings. *Advanced Engineering Informatics*, 52, p.101623.

Preston, H., Richfield, V. and Jensen, M., 2016. *Railroad Grade Crossing Safety Project Selection*. [online]. Available at: https://www.dot.state.mn.us/research/TS/2016/201625.pdf [Accessed 14 July 2022].

PUCO, 2018. *Rail Statistics Report*. [online]. Available at: https://puco.ohio.gov/static/industry-information/statistical-reports/grade-crossing-statistics/2018-rail-crossing-statistics/index.pdf [Accessed 27 July 2022].

Qiu, S., 2022. *A Risk-Based Decision Support Framework for Railway-Highway Grade Crossing Closures*. Master's Thesis, University of Waterloo.

Rajwar, K., Deep, K. and Das, S., 2023. An exhaustive review of the metaheuristic algorithms for search and optimization: Taxonomy, applications, and open challenges. *Artificial Intelligence Review*, 56(11), pp.13187-13257.

Rezvani, A.Z., Peach, M., Thomas, A., Cruz, R. and Kemmsies, W., 2015. Benefit-cost methodology for highway-railway grade crossing safety protocols as applied to transportation infrastructure project prioritization processes. *Transportation Research Procedia*, 8, pp.89-102.

RSSB, 2006. *Attitudes to processes and funding for crossing closures in other countries (T528 Report)*. [online]. Available at: https://www.sparkrail.org/Lists/Records/DispForm.aspx?ID=9669 [Accessed 13 July 2022].

Russell, E.R. and Mutabazi, M.I., 1998. Rail-highway grade crossing consolidation in Kansas. *Transportation Research Record*, 1648(1), pp.1-7.

Rutter, A., Morgan, C.A., Warner, J.E. and Graves, B., 2016. *Highway-Railway Grade Crossing Action Plan and Project Prioritization Noteworthy Practices Guide* (No. FHWA-SA-16-075). United States. Federal Highway Administration. Office of Safety Research and Development.

Salvagin, T.E. and Taylor, R.S., 1997. Corridor Approach to Railroad Crossing Consolidation. In *Institute of Transportation Engineers 67th annual Meeting. Institute of Transportation Engineers (ITE)*. [online]. Available at: https://trid.trb.org/view/485259 [Accessed 13 July 2022].

Sarhani, M., Voß, S. and Jovanovic, R., 2023. Initialization of metaheuristics: comprehensive review, critical analysis, and research directions. *International Transactions in Operational Research*, 30(6), pp.3361-3397.

Setiawan, D.M., Mahmudah, N. and Sully, R.H., 2020. Performance Analysis of Road Segment and Level Crossing (JPL) 340 KM 158+ 795 as Access to Adisutjipto International Airport of Yogyakarta. In *2nd International Symposium on Transportation Studies in Developing Countries (ISTSDC 2019)* (pp. 172-177). Atlantis Press.

Singh, P., Dulebenets, M.A., Pasha, J., Gonzalez, E.D.S., Lau, Y.Y. and Kampmann, R., 2021. Deployment of autonomous trains in rail transportation: Current trends and existing challenges. *IEEE Access*, 9, pp.91427-91461.

Singh, P., Elmi, Z., Lau, Y.Y., Borowska-Stefańska, M., Wiśniewski, S. and Dulebenets, M.A., 2022b. Blockchain and AI technology convergence: Applications in transportation systems. *Vehicular Communications*, 38, p.100521.

Singh, P., Elmi, Z., Meriga, V.K., Pasha, J. and Dulebenets, M.A., 2022a. Internet of Things for sustainable railway transportation: Past, present, and future. *Cleaner Logistics and Supply Chain*, 4, p.100065.

Singh, P., Pasha, J., Moses, R., Sobanjo, J., Ozguven, E.E. and Dulebenets, M.A., 2022c. Development of exact and heuristic optimization methods for safety improvement projects at level crossings under conflicting objectives. *Reliability Engineering & System Safety*, 220, p.108296.

Soleimani, S., Leitner, M. and Codjoe, J., 2021. Applying machine learning, text mining, and spatial analysis techniques to develop a highway-railroad grade crossing consolidation model. *Accident Analysis & Prevention*, 152, p.105985.

Soleimani, S., Mousa, S.R., Codjoe, J. and Leitner, M., 2019. A comprehensive railroad-highway grade crossing consolidation model: a machine learning approach. *Accident Analysis & Prevention*, 128, pp.65-77.

STB, 2020. *Appendix K – Transportation Safety and Delay. Northern Rail Extension Draft Environmental Impact Statement*. [online]. Available at: https://www.stb.gov/FD34658Files/Appendix_K_Trans_Safety_and_Delay.pdf [Accessed 27 May 2020].

Taylor, J. and Crawford, R., 2009. Prioritising road-rail level crossings for grade separation using a multi-criteria approach. In *32nd Australasian Transport Research Forum (ATRF)*, 2009, Auckland, New Zealand (Vol. 32).

Tian, G., 2022. Advantages and Disadvantages of Closing Rail Crossings: A Case Study from Louisiana. *Public Works Management & Policy*, p.1087724X221110230.

Tian, G., Izadi, M. and Stich, B., 2022. *The Impact of the Louisiana Grade Crossings: A Synthesis and System Analysis*. A technical report prepared for the Louisiana Department of Transportation and Development, New Orleans, LA, USA.

Toyoda, Y., 1975. A simplified algorithm for obtaining approximate solutions to zero-one programming problems. *Management Science*, 21(12), pp. 1417-1427.

TxDOT, 2015. *Rail-Highway Operations Manual, Texas Department of Transportation*. [online]. Available at: http://onlinemanuals.txdot.gov/txdotmanuals/rho/rho.pdf [Accessed 21 July 2022].

TxDOT, 2017. *Highway – Rail Grade Crossing Consolidation Program*. [online]. Available at: https://ftp.txdot.gov/pub/txdot-info/rail/crossings/consolidation.pdf [Accessed 15 July 2022].

U.S. DOT, 2014. *GradeDec.NET Reference Manual*. [online]. Available at: https://www.fra.dot.gov/Elib/Document/14852 [Accessed 24 September 2018].

U.S. DOT, 2019. *Highway-Rail Crossing Handbook*. Third Edition. [online]. Available at: https://safety.fhwa.dot.gov/hsip/xings/com_roaduser/fhwasa18040/fhwasa18040v2.pdf [Accessed 27 August 2022].

Woods, M., 2007. Public road level crossings in Great Britain. *Mechanics Transport Communications*, 3, pp.12-20.

Zhang, Z., Gong, J., Liu, J. and Chen, F., 2022. A fast two-stage hybrid meta-heuristic algorithm for robust corridor allocation problem. *Advanced Engineering Informatics*, 53, p.101700.

Appendix A. FDOT Level Crossing Closure and Opening Applications

Rule 14-57.010, F.A.C.

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION

RAILROAD GRADE CROSSING APPLICATION
CLOSING

725-090-66a
RAIL
06/18

ROAD NAME OR NUMBER	COUNTY/CITY NAME

A. IDENTIFICATION

Submitted By:

Applicant: ____________________

Office: ____________________

Telephone: ____________________

Address: ____________________

____

Application For:

Closing a public highway-rail grade crossing by:

☐ roadway removal
☐ rail removal

B. CROSSING LOCATION

FDOT/AAR Crossing Number: ____________________

Jurisdiction for Street or Roadway by Authority of: ☐ City ☐ County ☐ State

Local Popular Name of Street or Roadway: ____________________

Railroad Company: ____________________

Railroad Mile Post: ____________________

Submitted for the Applicant by: ____________________ DATE: __________
Name and Title

Application FDOT Review by: ____________________ DATE: __________
Central Rail Office

REFERENCES:
(Specific Legal Authority) 334.044 F.S.
(Law Implemented) 335.141 F.S.
(Administrative Rule) 14-57.012 F.A.C.

RAILROAD GRADE CROSSING APPLICATION CLOSING

CLOSING APPLICATION QUESTIONNAIRE

Maps, aerials, and supporting documentation must be provided with the application.

> If all parties, Applicant, Railroad, and Department, fail to agree to the rail crossing closure through a Stipulation of Parties, the Applicant must establish the closure meets the criteria found in Rule 14-57.012, Florida Administrative Code. This questionnaire will assist the Department in evaluating the criteria and is not intended to be an exclusive list of factors. If the information is not available or unknown, please mark N/A.

Florida Administrative Code criteria:

A) <u>Safety</u>

a-1. How will the crossing closure affect safety to drivers, pedestrians, cyclists, and rail personnel?
a-2. What, if any, safety measures are proposed for adjacent crossings?
a-3. Identify all highway traffic control devices and highway traffic signals at adjacent crossings that may be improved or upgraded if the subject crossing is closed.
a-4. What is the distance from the subject crossing to the nearest intersection? Identify the street.
a-5. Are there structures, fences, or vegetation near the subject crossing that inhibits sight distance?
a-6. Identify major traffic generators (i.e., businesses, shopping malls, recreational areas, special events, etc.) in this area. Specify type, location, and distance to subject crossing.
a-7. Is the crossing located on a designated evacuation route?
a-8. Provide a traffic operations and safety analysis, with traffic issues evaluated for the railroad crossing closure. This analysis should include all adjacent rail crossings and roadways in the immediate vicinity and the increase in traffic predicted on these roadways from rerouting.

B) <u>Necessity for rail and vehicle traffic</u>

b-1. Is the crossing necessary to access property?
b-2. Provide description of land use on each side of the rail crossing.
b-3. Are there any churches, schools, or hospitals within a mile or less of the subject crossing? Please list by name and location.
b-4. Annual Average Daily Traffic (AADT) at the crossing?
b-5. Level of service at the crossing?
b-6. Percentage of truck traffic?
b-7. Do trucks carrying hazardous materials use the crossing? If so, approximately how many trips per day or week?
b-8. How many school buses use the crossing daily?
b-9. What is the estimated number of pedestrians and bike riders that use the subject crossing (daily/weekly)?
b-10. Is the subject crossing on a local transit route?
b-11. Please provide any corridor studies or other preliminary traffic engineering studies that pertain to this crossing.

C) <u>Alternate Routes</u>

c-1. Are there access roads available to property owners if the crossing is closed?
c-2. Name routes that can be used if the crossing is closed?
c-3. Are there traffic signals on these routes?
c-4. How does the proposed crossing closure impact the AADT at nearby public crossings? Provide estimated traffic count changes.
c-5 By driving alternate routes, during peak times, calculate the additional travel time and distance between two points (nearest intersection or major access) on either side of the subject crossing. Provide calculated times, routes, and distances.

D) <u>Effect on rail operations and expenses</u>

d-1. Provide current number and type of rail tracks at the subject crossing.
d-2. Are there rail sidings or switches in the location of the subject crossing?
d-3. Is there a nearby rail yard? If so, what is the distance of the yard to the subject crossing.
d-4. Provide the current number of daily train movements (number of switching or thru trains; number of passenger or freight trains).
d-5. Provide the approximate times during the day and evening that the crossing is blocked.

d-6. Provide the approximate length of time (i.e., minutes) that the crossing is blocked.
d-7. Provide minimum and maximum train speeds at the subject crossing.
d-8. What is the anticipated expansion of tracks and/or train movements?
d-9. What is the distance from the subject crossing to adjacent public crossings? (Identify adjacent crossings by road name and crossing number.)

E) <u>Excessive restriction to emergency type vehicles resulting from closure</u>

e-1. Provide response from the Sheriff/Police Chief and Fire Chief to the proposed crossing closure.
e-2. Based on observation, the response from the City/County, or traffic studies, is this a route that emergency rescue would typically use?
e-3. How many emergency rescue vehicles have used the crossing to respond to calls in the past 2-3 years?

F) <u>Design of the grade crossing and road approaches</u>

f-1. Identify and describe the condition of: crossing surface, rail warning devices (including pavement markings, signs, and highway traffic signals), sidewalks, bike lanes, and approaches on each side of subject crossing.
f-2. Is the crossing surface and track higher than either side of the road (i.e., hump crossing)?
f-3. What is the vehicular design speed at the subject crossing?
f-4. Number of lanes at the crossing?
f-5. Width of crossing?
f-6. Condition of roadway?

G) <u>Presence of multiple tracks and their effect upon railroad and highway operations</u>

g-1. Please confirm the number of tracks at the location and identify each track.
g-2. How many train movements occur on each track and the types of trains that run on each track (passenger, thru freight, or switching freight and the number of cars)?

RAILROAD GRADE CROSSING APPLICATION OPENING

ROAD NAME OR NUMBER	COUNTY/CITY NAME

A. IDENTIFICATION

Submitted By:

Applicant: ____________________

Office: ____________________

Telephone: ____________________

Address: ____________________

____

Application For:

Opening a public highway-rail grade crossing by:

- ☐ new rail line construction
- ☐ new roadway construction
- ☐ conversion of private to public highway-rail grade crossing

B. CROSSING LOCATION

FDOT/AAR Crossing Number: ____________________

Jurisdiction for Street or Roadway by Authority of: ☐ City ☐ County ☐ State

Local Popular Name of Street or Roadway: ____________________

Railroad Company: ____________________

Railroad Mile Post: ____________________

Submitted for the Applicant by: ____________________ DATE: __________
Name and Title

Application FDOT Review by: ____________________ DATE: __________
Central Rail Office

REFERENCES:
(Specific Legal Authority) 334.044 F.S.
(Law Implemented) 335.141 F.S.
(Administrative Rule) 14-57.012 F.A.C.

OPENING APPLICATION QUESTIONNAIRE

Design plans, maps, aerials, and supporting documentation must be provided with the application.

If all parties, Applicant, Railroad, and Department, fail to agree to the rail crossing opening through a Stipulation of Parties, the Applicant must establish the crossing meets the criteria found in Rule 14-57.012, Florida Administrative Code. This questionnaire will assist the Department in evaluating the criteria and is not intended to be an exclusive list of factors. If the information is not available or unknown, please mark N/A.

Florida Administrative Code criteria:

A) <u>Safety</u>

a-1. How will the proposed crossing affect safety to drivers, pedestrians, cyclists, and rail personnel?
a-2. Has grade separation been considered in planning the crossing? If not, why?
a-3. What crossings will be submitted for closure to offset the safety impacts of a new crossing opening?
a-4. What safety measures are designed for the proposed crossing?
a-5. What is the distance from the proposed crossing to the nearest intersection? Identify the street.
a-6. Are there plans for any structures to be built near the crossing intersection?
a-7. Identify all major traffic generators (i.e., businesses, shopping malls, recreational areas, special events, etc.) in this area. Specify type, location, and distance to proposed crossing.
a-8. Provide a traffic operations and safety analysis, with traffic issues evaluated for the railroad crossing, train traffic movements, and railroad preemption. This analysis should include all proposed developments in the immediate vicinity and the increase in traffic predicted from the developments.

B) <u>Necessity for rail and vehicle traffic</u>

b-1. Why is the crossing necessary?
b-2. Provide excerpts from the Comprehensive Plan or any other transportation plans relative to the proposed crossing.
b-3. Provide description of land use on each side of the rail crossing.
b-4. Provide predicted Annual Average Daily Traffic (AADT) at the crossing.
b-5. Provide level of service at the crossing.
b-6. Provide anticipated AADT and level of service in 5 years.
b-7. Provide predicted percentage of truck traffic and anticipated truck traffic 5 years out.
b-8. Will trucks carry hazardous materials? If so, approximately how many trips per day or week?
b-9. Will school buses use the crossing? If so, how many school buses will use the crossing per day or week?
b-10. Will emergency rescue vehicles use the crossing? If so, approximately how many trips per day or week?
b-11. What is the predicted number of pedestrians and bike riders that will use the proposed crossing? What is the predicted number of users 5 years out?
b-12. Please provide any corridor studies or other preliminary traffic engineering studies that pertain to this crossing.

C) <u>Alternate Routes</u>

c-1. Are there access roads available to property owners if the crossing is not there?
c-2. Name routes currently used or intended for use if the crossing is not approved?
c-3. Are there traffic signals on these routes?
c-4. How does the proposed crossing, if built, affect the AADT at nearby public crossings? Provide estimated traffic count changes, if any.

D) <u>Effect on rail operations and expenses</u>

d-1. Provide current number and type of rail tracks.
d-2. Are there rail sidings or switches in the location of the proposed crossing?
d-3. Is there a nearby rail yard? If so, what is the distance of the yard to the proposed crossing.
d-4. Provide the current number of daily train movements (number of switching or thru trains; number of passenger or freight trains).
d-5. Provide the approximate times during the day and evening that the crossing will be blocked.
d-6. Provide the approximate length of time (i.e., minutes) that the crossing is blocked.
d-7. Provide minimum and maximum train speeds at the proposed crossing.
d-8. What is the anticipated expansion of tracks and/or train movements?

d-9. What is the distance from the proposed crossing to adjacent public crossings? (Identify adjacent crossings by road name and crossing number.)

d-10. What are the estimated costs of the crossing installation and annual maintenance? Who will be responsible for the costs of installation and maintenance?

E) <u>Closure of one or more public crossings to offset opening a new crossing</u>

e-1. Provide the names and crossing numbers of any crossing closure candidates that may offset the opening of the proposed crossing.

F) <u>Design of the grade crossing and road approaches</u>

f-1. Submit design plans, inclusive of location of sidewalks, bike lanes, and traffic control devices, including pavement markings, signs, and highway traffic signals.

f-2. What future changes are proposed (ex: phase one is a 2-lane roadway, left turn lane to be added in phase two)?

f-3. What is the vehicular design speed at the proposed crossing?

f-4. How many thru or turn lanes? Divided or undivided?

G) <u>Presence of multiple tracks and their effect upon railroad and highway operations</u>

g-1. Please confirm the number of tracks at the location and identify each track.

g-2. How many train movements occur on each track and the types of trains that run on each track (passenger, thru freight or switching freight, and the number of cars)?