Evaluation of Grade Crossing Hazard Ranking Models

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16. Abstract

Public agencies involved with highway-railroad grade crossing safety must allocate available funding to projects which are considered the most in need for improvements. Mathematical models provide a ranking of hazard risk at crossings and support the project selection process. The goal of this research study was to provide ODOT, the ORDC, the PUCO, and other stakeholders with a better understanding of the grade crossing hazard ranking formulas and other methods used by States to evaluate grade crossing hazards and select locations for hazard elimination projects. A comprehensive literature review, along with interviews of state DOT personnel from eight states yielded best practices for hazard ranking and project selection. Detailed evaluation of several different hazard ranking models determined that the existing hazard ranking model used in Ohio, the U.S. DOT Accident Prediction Model, should continue to be used. The research team also recommends greater use of sight distance information at crossings and expanding the preliminary list of crossings to be considered in the annual program as enhancements to the existing project selection process used by the ORDC and ODOT.

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Evaluation of Grade Crossing Hazard Ranking Models

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EXECUTIVE SUMMARY

Research Problem

The intersection of a highway and one or more railroad tracks at grade level is known as a highway-railroad grade crossing. Railroads and highway agencies will install traffic control devices such as crossbuck signs, flashing lights, and/or highway gate arms to promote safety and provide adequate warning of an oncoming train to motorists approaching a grade crossing. Highway-railroad grade crossing safety is a national priority, as safe and effective operation of grade crossings is essential to providing safe highways for the motoring public as well as for the safe transport of freight and passengers via railroads. As of October 2015, there were approximately 5,760 at-grade highway-railroad crossings in Ohio, of which approximately one-third are controlled by passive devices (i.e., crossbucks only). During the most recent five-year period, an average of 67 crashes occurred annually at Ohio's grade crossings.

In Ohio, two public agencies are jointly responsible for highway-railroad grade crossing safety programs. The Ohio Rail Development Commission (ORDC), an independent commission within the Ohio Department of Transportation (ODOT), administers Federal funds for grade crossing improvements on behalf of ODOT. Regulatory oversight and annual inspection of grade crossings fall under the authority of the Public Utilities Commission of Ohio (PUCO). The ORDC and the PUCO administer several programs to provide Ohio's railroads and local communities with funding for improvements to the warning devices and/or other projects to enhance safety at highway-railroad grade crossings. The funding programs for grade crossing improvements managed by the ORDC and the PUCO have been effective at reducing crashes, injuries, and fatalities at Ohio's highway-railroad grade crossings.

State-level safety and regulatory agencies involved with highway-railroad grade crossings must allocate available funding to grade crossing projects within the state which are considered the most in need for improvements. Mathematical models provide an objective ranking of grade crossings and support transparency in the project selection process; however, the practical difference in the crash risk at a set of crossings being considered for improvement may be negligible. Moving forward, grade crossing improvement projects will be selected from a list of crossings for which the model shows little difference in the crash risk. Consequently, identifying the most hazardous grade crossings from a large list of crossing locations with very similar characteristics presents a significant challenge for warning device project selection. The final decision to implement a grade crossing warning device project is based on input from a multi-disciplinary diagnostic review team and professional judgement on the part of agency staff. Nevertheless, a better understanding of grade crossing hazard ranking models currently in use would enhance the project selection process used by the ORDC and PUCO, either by affirming the adequacy of current hazard ranking practices or improving the existing process to better account for the minor differences in grade crossing locations.

Research Approach

Researchers from Ohio University, with assistance from the Texas A&M Transportation Institute, approached the research problem with three key activities. First, the research team conducted a literature review to identify methods used for modeling grade crossing hazard ranking and warning device project prioritization. Second, researchers conducted interviews of state DOT personnel in eight states to obtain details about the performance of certain grade crossing hazard ranking models with respect to ease of use, reliability, data needs, and other

relevant factors. Finally, researchers conducted a detailed evaluation of certain hazard ranking models, including an analysis comparing the model output as well as a functional evaluation of how the models could be accommodated within existing practices of ORDC and PUCO.

Research Findings

The literature review found that 39 out of 50 states, or 78 percent, utilize some type of hazard ranking formula or other systematic method for project prioritization. Approximately half of the states identified the use of the U.S. DOT Accident Prediction Model as the primary hazard ranking method, including Ohio. Other models, such as the New Hampshire Hazard Index, the NCHRP 50 expected crash frequency model, and the Peabody-Dimmick formula are less common. State-specific formulas or methods are currently in use in 11 states. Of these 11 states, detailed information about the formulas used by these states were obtained for five states – Connecticut, Florida, Missouri, North Carolina, and Texas.

The most common factors considered by the states in grade crossing hazard ranking include the volume of highway traffic, the volume of trains at a crossing and their speed, existing warning devices at the crossing, and crash history at the crossing. Table 1 shows a detailed matrix comparing the existing grade crossing hazard ranking model used in Ohio, the U.S. DOT Accident Prediction Model, with the New Hampshire Hazard Index and four state-specific hazard ranking models. The matrix compares each hazard ranking model on factors including compatibility with Ohio practices, applicability to Ohio grade crossings, and model functionality.

Based on the analyses performed as part of this research project, there is no evidence to suggest that a different hazard ranking model than the U.S. DOT Accident Prediction Model would provide a more superior hazard ranking of highway-railroad grade crossings in Ohio.

Recommendations

Based on the findings and conclusions of this research project, the Ohio University research team presents the following recommendations:

- Recommendation #1: The ORDC and the PUCO should continue use of U.S. DOT Accident Prediction Model for grade crossing hazard ranking to assist with warning device project prioritization in the state.
- Recommendation #2: Hazard index models such as the Missouri DOT Exposure Index or the North Carolina DOT Investigative Index should be considered to provide a secondary ranking for passive crossing locations after the initial ranking and diagnostic review process has been completed for the annual program.
- Recommendation #3: The existing field diagnostic review process should be updated to obtain better information about the available sight distance at a grade crossing.
- Recommendation #4: The ORDC should consider revising its warning device project development process to include a larger number of crossings on the preliminary list of project locations.
- Recommendation #5: The ORDC and the PUCO should consider developing a formal written protocol or framework to ensure that key variables in the Ohio highway-railroad grade crossing inventory database are updated and maintained.

Additional details on these recommendations and a detailed implementation plan can be found in the main body of this report.

Table 1: Comparison Matrix of Grade Crossing Hazard Ranking Models

	U.S. DOT Accident Prediction Model (*Model currently used in Ohio*)	**New Hampshire Hazard Index**	**Florida DOT Safety Hazard Index**	**Missouri DOT Exposure Index**	**North Carolina DOT Investigative Index**	**Texas DOT Priority Index**
Type of Hazard Ranking Model	Crash Prediction	Hazard Index	Hybrid	Hazard Index	Hazard Index	Hybrid
Number of States using Model	19	5	1	1	1	1
Number of Variables	9	3	9	8	9	13
Additional Variables Needed in Database	None	None	HS SB	HS SD	SB SD	HS SD
Compatibility with Existing Practice						
• Use of Crash Prediction Metric	✓✓	No	✓	No	No	✓
• All Data Available in Inventory	✓✓	✓✓	✓	No	No	No
• Includes Crash History	✓✓	No	✓✓	No	✓✓	✓✓
Applicability to Ohio Grade Crossings						
• Additional Variables Relevant (Based on Crash Analysis)	N/A	N/A	??	No	??	No
• Accuracy of Model (Based on Expert Panel Analysis)	✓	Limited	Limited	Limited	✓	Limited
Model Functionality						
• Model Complexity	Very	✓✓	✓	✓✓	✓	✓
• Ease of Operation	Not	✓✓	✓	✓✓	✓	✓
• Differentiate Among Passive Crossings	No	No	✓	✓✓	✓	✓✓
• Compatible with Economic Analysis	✓✓	Not	✓	Not	Not	✓
Key – Performance of model with respect to criteria: (✓✓) Strong; (✓) Satisfactory; (??) Unknown; Others Noted.						
Variables – HS: Highway Traffic Speed; SB: Volume of School Bus; SD: Sight Distance						

PROJECT BACKGROUND

Research Problem

The intersection of a highway and one or more railroad tracks at grade level is known as a highway-railroad grade crossing. Railroads and highway agencies will install traffic control devices such as crossbuck signs, flashing lights, and/or highway gate arms to promote safety and provide adequate warning of an oncoming train to motorists approaching a grade crossing. Highway-railroad grade crossing safety is a national priority, as safe and effective operation of grade crossings is essential to providing safe highways for the motoring public as well as for the safe transport of freight and passengers via the national railroad system. The U.S. Federal Highway Administration (FHWA) acknowledges this national priority by allocating funds to states for hazard elimination at highway-railroad grade crossings via the "Section 130" program, a Federal-aid program implemented as an element of the Highway Safety Improvement Program (HSIP). The purpose of the Section 130 program is to fund safety improvements to reduce the number of fatalities, injuries, and crashes at public highway-railroad grade crossings. At least 50 percent of a state's Section 130 funds must be set aside for the installation of protective devices at grade crossings. Investments made under the Section 130 program have been effective at significantly reducing crashes, injuries, and fatalities at highway-railroad grade crossings nationwide since the mid-1970s [Ogden, 2007].

In Ohio, two public agencies are jointly responsible for highway-railroad grade crossing safety programs. The Ohio Rail Development Commission (ORDC), an independent commission within the Ohio Department of Transportation (ODOT), administers FHWA Section 130 funds for highway-railroad grade crossing improvements on behalf of ODOT, as well as other funds made available through state legislative appropriations. Regulatory oversight and annual inspection of highway-railroad grade crossings fall under the authority of the Public Utilities Commission of Ohio (PUCO). Together, the ORDC and the PUCO administer several programs to provide Ohio's railroads and local communities with funding for improvements to the warning devices and/or other projects to enhance safety at highway-railroad grade crossings.

The railroad network of Ohio is vast, including more than 5,300 miles of active mainline rail lines with 36 freight railroads operating in the state. As of October 31, 2015, there were approximately 5,760 public, at-grade highway-railroad crossings in Ohio, of which around 1,950 (33.8 percent) are controlled by passive warning devices (i.e., crossbucks only). A highway-railroad grade crossing crash occurs when a highway vehicle and train collide in the vicinity of the grade crossing. The risk of a collision increases as the volume of highway vehicles and the volume of trains at a crossing location increases. One measure of risk, known as exposure, is the product of the highway traffic volume and the train volume. On an average day, there are an estimated 13.9 million highway vehicle interactions and 77,300 train interactions with Ohio's highway-railroad grade crossings. More than 95 percent of the collision risk (based on the total exposure at all crossings) is at grade crossing locations with active warning devices – highway gate arms and flashing lights. However, crash data indicate that approximately one-third of grade crossing crashes occur at locations with passive warning devices. Nevertheless, targeted investments have improved grade crossing safety in Ohio during the past decade. During the five-year period ending July 31, 2015, there were 333 unique crashes that occurred at 307 grade crossings in the state, or an average of approximately 67 per year. In the five-year period prior to the most recent one (ending July 31, 2010), there were a total of 551 grade crossing crashes or an average of approximately 110 per year.

State Departments of Transportation and other public agencies involved with highway-railroad grade crossings must allocate available funding to grade crossing projects within the state which are considered the most in need for improvements. These agencies utilize statistical models or priority ranking techniques to identify the crossings that would benefit the most from improvements to support decision-making for resource allocation. A systematic method for identifying and ranking crossings that have the most need for safety and/or operational improvement is essential to an informed and transparent decision-making process for project selection for highway-railroad grade crossing improvements. Mathematical models provide an objective approach for ranking and supports transparency in the process.

The funding programs for grade crossing improvements managed by the ORDC and the PUCO have been effective at reducing crashes, injuries, and fatalities at Ohio's highway-railroad grade crossings. As more improvement projects are implemented, the project selection process has become more nuanced. The ORDC and the PUCO currently use the U.S. DOT Accident Prediction Model to assist with project prioritization. Potential grade crossing locations are ranked based on the annual crash frequency as predicted by the model as the measure of hazard risk. Based on the initial ranking generated by the hazard risk model, the final decision to implement a warning device project at a crossing location is based on professional judgement and input from a multi-disciplinary diagnostic review team. Mathematical models provide an objective ranking of grade crossings but the practical difference in the crash risk at a set of crossings being considered for improvement may be negligible. Moving forward, grade crossing improvement projects will be selected from a list of crossings for which the model shows little difference in the crash risk. Other states and institutions have developed new methods for hazard ranking to support project selection for grade crossing improvements which acknowledges this issue. The ORDC and the PUCO are tasked with distributing limited funding resources on the projects which are most effective at improving grade crossing safety. A better understanding of other grade crossing hazard ranking models currently in use would enhance the project selection process used by the ORDC and PUCO, either by affirming the adequacy of current hazard ranking practices or improving the existing process to better account for the minor differences in grade crossing locations.

Research Approach

The general approach for this research project consisted of three parts, as follows:

- A comprehensive literature review to identify methods used by state Departments of Transportation (DOT) and other organizations for modeling grade crossing hazard ranking and warning device project prioritization;
- Interviews of state DOT personnel to obtain details about the performance of certain grade crossing hazard ranking models with respect to ease of use, reliability, data needs, and other relevant factors; and
- Detailed evaluation of certain grade crossing hazard ranking models, including an analytical evaluation comparing the model output as well as a functional evaluation of how the models could be accommodated within existing practices of ORDC and PUCO.

Additional details of the research approach are discussed in later sections of this report.

RESEARCH CONTEXT

Research Objectives and Tasks

The goal of this research study was to provide ODOT, the ORDC, the PUCO, and other interested stakeholders with a better understanding of the grade crossing hazard ranking formulas and other methods used by State DOTs and other organizations to evaluate grade crossing hazards and select grade crossing locations for hazard elimination projects. The specific objectives of this research study were as follows:

1) Conduct a preliminary review of grade crossing hazard ranking formulas currently in use;
2) Investigate the current practices for grade crossing hazard ranking in Ohio;
3) Interview practitioners of selected grade crossing hazard ranking formulas to determine strengths, weaknesses, and functional effectiveness of the formulas;
4) Conduct a detailed evaluation of selected grade crossing hazard ranking formulas; and
5) Develop recommendations for ODOT, the ORDC, and the PUCO on potential improvements that could be made to current hazard ranking practices in Ohio.

To accomplish the research objectives, the Ohio University research team completed the following eight tasks:

- Task 1, Review of Grade Crossing Hazard Ranking Formulas;
- Task 2, Investigate Current Hazard Ranking Practices in Ohio;
- Task 3, Develop Protocol for Practitioner Interviews;
- Task 4, Conduct Practitioner Interviews;
- Task 5, Detailed Evaluation of Selected Hazard Ranking Formulas;
- Task 6, Develop Recommendations to Improve Hazard Ranking Practices in Ohio;
- Task 7, Develop Final Report; and
- Task 8, Project Management.

Grade Crossing Hazard Ranking Practices Summary

The literature review examined current state practices for grade crossing hazard ranking and project prioritization. The review found that 39 out of 50 states, or 78 percent, utilize some type of hazard ranking formula or other systematic method for project prioritization. Approximately half of the states identified the use of the U.S. DOT Accident Prediction Model as the primary hazard ranking method, including Ohio. Other formulas, such as the New Hampshire Hazard Index, the NCHRP 50 expected crash frequency model, and the Peabody-Dimmick formula are in limited use. The most common factors considered by the states in grade crossing hazard ranking include the volume of highway traffic, the volume of trains at a crossing and their speed, existing warning devices at the crossing, and crash history at the crossing (between 3 and 5 years). State-specific formulas or methods are currently in use in 11 states. Of these 11 states, detailed information about the formulas used by these states were obtained for

five states – Connecticut, Florida, Missouri, North Carolina, and Texas. Researchers were unable to identify the grade crossing hazard ranking method or formula for 11 states.

Table 2 reports the factors included in four commonly-used grade crossing hazard ranking formulas plus the five state-specific formulas for which details on the model could be obtained by the research team. Collectively, these formulas account for the grade crossing hazard ranking practices of 31 of the 39 states for which a formula or method could be identified.

Table 2: Variables Included in Selected Grade Crossing Hazard Ranking Models

Variables	**U.S. DOT Accident Prediction Model**	**New Hampshire Hazard Index**	**NCHRP 50 Accident Prediction Model**	**Peabody-Dimmick Formula**	**Connecticut DOT Hazard Ranking Index**	**Florida DOT Safety Hazard Index**	**Missouri DOT Exposure Index**	**North Carolina DOT Investigative Index**	**Texas DOT Priority Index**
Hazard Ranking Model Type	AP	HI	AP	AP	HI	HB	HI	HI	HB
Number of States Using	19	5	1	1	1	1	1	1	1
Traffic Volume (AADT)	✓	✓	✓	✓	✓	✓	✓	✓	✓
Train Volume	✓	✓	✓	✓	✓	✓	✓	✓	✓
Existing Warning Device	✓	✓	✓	✓	✓	✓	✓	✓	✓
Crash History	✓			✓	✓	✓		✓	✓
Train Speed	✓					✓	✓	✓	✓
Number of Tracks	✓					✓		✓	✓
Highway Lanes	✓					✓			✓
Highway Surface	✓								✓
Highway Type/Context			✓						✓
Sight Distance							✓	✓	✓
School Bus/Special Vehicles						✓		✓	
Highway Traffic Speed						✓	✓		✓
Nearby Intersection									✓
Train Type							✓	✓	
Note: ✓ Indicates factor included with selected formula. Formula Type – AP: Accident Prediction Model; HI: Hazard Index; HB: Hybrid Accident Prediction Model/Hazard Index.									
Source: Ohio University research team literature review of grade crossing hazard ranking practices.									

Table 2 also reports the type of formula for each hazard ranking method and the number of states using each method. An accident prediction model is a formula that will predict the number of crashes annually at a grade crossing based on the various factors included in the model. Some accident prediction models, including the U.S. DOT Accident Prediction Model, will also predict the severity of a crash. A hazard index type model calculates a generic value which describes the hazard level of the crossing relative to other crossings in the database. Some hazard ranking models are a "hybrid" type utilizing an accident prediction model as an input to a hazard index calculation. Variables that are not included in the U.S. DOT Accident Prediction Model but are considered in other models include the following: Highway Type/Context, Sight Distance, School Bus/Special Vehicle Volume, Highway Traffic Speed, Nearby Highway Intersections, and Train Type.

Ohio Grade Crossing Improvement Programs Summary

The ORDC and the PUCO jointly administer multiple funding programs to implement warning device upgrades at highway-railroad grade crossings around the state. Funding for these programs is provided through the FHWA Section 130 program as well as state appropriations. The largest program, the Formula-Based Upgrade Program, is the main program used by ORDC and PUCO to implement warning device upgrades with Section 130 funding. The project selection process for the Formula-Based Upgrade Program is a rational process involving both a hazard ranking as well as professional judgment on the part of agency staff. Grade crossings are reviewed twice annually based on hazard ranking and a determination of project feasibility is made. An initial pool of approximately 40 grade crossing locations is developed and a comprehensive field diagnostic review is performed at each location. The diagnostic review team consists of representatives for the ORDC, the PUCO, the railroad, the local highway authority, and other individuals as appropriate. Based on the results of the diagnostic review, a recommendation on implementing a warning device upgrade project at that location is made. During a typical program year, approximately 20-40 projects are initiated, a majority of which are upgrades from passive warning devices (crossbucks) to active warning devices (highway gates and flashing lights). Based on the most recent available data, the average cost of a typical warning device upgrade project is approximately $255,000.

Currently, the ORDC and the PUCO utilize the U.S. DOT Accident Prediction Model to develop a hazard ranking of grade crossings for project prioritization. The U.S. DOT Accident Prediction Model is a multi-stage model that predicts the number of crashes per year at a crossing as well as the probability of a crash being a fatal or injury crash given that the crash has occurred. The basic structure of the U.S. DOT Accident Prediction Model consists of an initial estimate of the number of collisions per year at a crossing location, an adjustment to the initial estimate to reflect crash history at the crossing location, and an adjustment known as the "normalizing constant" to update the crash prediction for current trends. The normalizing constants are routinely updated based on national trends in highway-railroad grade crossing safety. Although the basic structure of the U.S. DOT Accident Prediction Model has not changed since 1986, it represents the state of the practice for predicting crashes at highway-railroad grade crossings and is based on national data.

RESEARCH APPROACH

The research approach for this project consisted of three main elements: a comprehensive literature review, interviews of state DOT personnel to obtain more insight on grade crossing hazard ranking models, and a detailed evaluation of certain models. More details on each component of the research approach for this project are summarized in this section.

Literature Review

The objective of the literature review task was to identify methods used by State DOTs and other organizations for modeling grade crossing hazard ranking and warning device improvement project prioritization. The subjects reviewed as part of this task included:

- Existing models available for highway-railroad grade crossing hazard ranking;
- Existing State DOT practices related to grade crossing hazard ranking and warning device improvement project prioritization;
- Methods for evaluating the effectiveness of hazard ranking models; and
- General literature related to highway-railroad grade crossing safety.

The research team reviewed literature from existing U.S. DOT and state policies related to highway-railroad grade crossing safety and hazard modeling, as well as literature searches through web-based search tools such as the Transportation Research Board TRID database. One major reference source is the comprehensive *Railroad-Highway Grade Crossing Handbook – Revised Second Edition* [Ogden, 2007], which provided insight on grade crossing safety, physical characteristics of grade crossings, and general hazard modeling practices. A number of states, including Florida [Niu, et al., 2014], Illinois [Elzohairy and Benekohal, 2000], Kansas [Burns & McDonnell Engineering Company and Kraft, 2001], Missouri [Qureshi, et al., 2003], and Texas [Weissmann, et al., 2013] have undertaken specific research studies in recent years to examine grade crossing hazard ranking practices in those states. Independent research studies have examined innovative approaches to modeling hazard risk at grade crossings (e.g., McCollister and Pflaum [2007] or Medina and Benekohal [2015]). Finally, there has been recent interest in incorporating economic analysis principles to the evaluation of grade crossing hazards for project prioritization (e.g., Brod, et al. [2013] or Cruz, et al., [2015]).

Additionally, the research team was provided access to reports describing state-level progress and key outcomes related to the FHWA Section 130 Railway-Highway Crossing Program for 2014. These reports were made available to the research team with the approval of the FHWA. These reports included details of grade crossing improvement projects implemented in states during the reporting year, details of the organization and management of the programs, and project selection procedures. These reports provided significant insight on state-level practices and proved to be especially valuable to the research team in identifying existing hazard ranking models and prioritization practices among the states. The amount of detail provided did vary among the states; but, for a majority of states, sufficient detail was provided to allow the research team to determine if the state utilized a mathematical formula or model for grade crossing hazard ranking and/or what factors were considered in the prioritization process.

Complete details of the literature review are discussed in Appendix A of this report.

Practitioner Interviews

The objective of the practitioner interviews task was to conduct personal interviews with state DOT personnel to obtain insight about the performance of certain grade crossing hazard ranking models with respect to ease of use, reliability, data needs, and other relevant factors. The practitioner interviews were structured as telephone interviews designed to last approximately one hour with questions that focused on the following topics:

- Structure and organization of the state DOT grade crossing safety program(s);
- Grade crossing warning device project identification and prioritization approaches;
- Accounting for fatalities as well as “near-miss” incidents at grade crossings;
- Agency experience with particular grade crossing hazard ranking models;
- Factors and variables included in local hazard ranking models;
- Consideration of factors such as school buses, hazardous materials, multiple crossings along a single corridor, or nearby traffic signals; and
- General challenges or limitations faced by the state DOT with respect to project prioritization and/or grade crossing hazard ranking models.

Researchers developed a detailed e-mail request for participation as well as a list of specific questions to be asked during the interview. This preliminary interview framework was submitted to ORDC liaisons for review and comment. After the ORDC feedback was addressed, researchers developed a preliminary list of states that would be targeted for interviews. Because this task involved the use of human subjects in research, researchers obtained approval from the Ohio University Institutional Review Board (IRB) prior to proceeding.

Researchers from Ohio University conducted interviews with staff from the following agencies (dates of the interview also listed):

- California Public Utilities Commission (11/30/2015);
- Illinois Department of Transportation (12/7/2015);
- Kansas Department of Transportation (11/25/2015);
- Michigan Department of Transportation (2/1/2016);
- Missouri Department of Transportation (11/17/2015); and
- New Mexico Department of Transportation (12/11/2015).

The Florida Department of Transportation was included on the initial list of agencies for interview as part of this study. However, no interview could be scheduled with agency representatives after multiple requests from researchers. Additionally, research team partner Texas A&M Transportation Institute coordinated interviews with the North Carolina Department of Transportation (via e-mail) as well as the Texas Department of Transportation (in-person meeting in late December 2015).

Additional details of the practitioner interviews are discussed in Appendix B.

Evaluation of Selected Hazard Ranking Models

The objective of the model evaluation task was to analyze the performance of selected grade crossing hazard ranking formulas with respect to the rankings obtained using each model as well as the functionality of the model within existing data available in Ohio. Researchers analyzed the following grade crossing hazard ranking models as part of this task:

- U.S. DOT Accident Prediction Model;
- New Hampshire Hazard Index;
- NCHRP 50 Expected Crash Frequency Model;
- Florida DOT Safety Hazard Index;
- Michigan DOT Hazard Index;
- Missouri DOT Exposure Index;
- North Carolina DOT Investigative Index; and
- Texas DOT Priority Index.

Researchers selected these models for detailed analysis because they are most commonly used by states for grade crossing hazard ranking (see Table 2). Additionally, three versions of the U.S. DOT Accident Prediction Model were analyzed as a result of variations of that model's application in Ohio and other states. Finally, researchers included a hazard ranking based solely on exposure (product of daily highway traffic and daily train volumes) for comparison.

The first element of the detailed evaluation was an analytical evaluation of the selected grade crossing hazard ranking models. The analytical evaluation proceeded as follows. Researchers obtained a copy of the PUCO highway-railroad grade crossing database, known as the Ohio Railroad Information System (RRIS). Data supplied to the research team included the complete inventory data table as well as the crash records data table. As of October 31, 2015, the Ohio RRIS database included 5,761 highway-railroad crossings that were 1) at-grade, 2) on public roadways, and 3) open for travel. The research team utilized the JMP 11.0 statistical analysis software throughout the evaluation task. Significant data review and checking was necessary to prepare the database for detailed analysis. Some subjective judgement on the part of the research team was necessary in the quality control review. Specifically, some data items with a value of "NULL" or blank entries needed to be reviewed to determine if the values should be zero, remain blank, or some other assumed value. Instances of "NULL" or blank values for AADT were removed from the analysis while similar instances for train volume count, school bus volume, and percent trucks in AADT were assumed to be zero. Missing values for highway traffic speed were completed using the state statutory speed limit as appropriate for the roadway type. For data items required by certain formulas but not currently available or have limited availability in the Ohio inventory database (e.g., sight distance), the research team was only able to analyze the formulas including those variables for a sub-set of the data. For these variables, a "desk review" of crossings via aerial imagery provided additional details. The quality control necessary to prepare the database for detailed analysis provided the research team with substantial insight on potential limitations and issues with the existing RRIS inventory data.

With a complete prepared data set, the research team was able to replicate the exact accident frequency prediction values that had been provided to the research team by the ORDC,

allowing for comparisons to be made with the most current ranking information. For each hazard ranking model, researchers calculated the corresponding metric (either a hazard index value or an estimated crash frequency) and established a ranking value based on the metric. In the event of ties on the value of the model's ranking metric, researchers used the exposure at each crossing to rank the tied values. Researchers compared the rankings obtained using each hazard ranking model with the ranking obtained using the existing model used in Ohio, the U.S. DOT Accident Prediction Model. Comparisons were made using the Spearman's Rank Correlation Coefficient, the 5% and 1% Power Factor, and a simple difference in ranking value. Grade crossings for which the hazard ranking metric could not be calculated due to incomplete data were removed from the pairwise analysis. The analytical evaluation included the complete data set consisting of 5,761 grade crossings as well as a subset consisting of only the grade crossings with passive warning devices (1,947 crossings).

An additional component of the analytical evaluation consisted of a more detailed analysis of a randomly-chosen sample of 20 grade crossings which included the selected hazard ranking models well as an "Expert Panel" ranking of the 20 grade crossings. In the absence of a "standard" ranking to which the different grade crossing hazard ranking methods could be compared, it would be difficult to conclude which method is better or worse. Therefore, the purpose of the Expert Panel ranking was to attempt to establish an "actual" hazard ranking of a random sample of grade crossings and compare this ranking to the ranking obtained using the different hazard ranking formulas. This approach overcomes one of the limitations of this type of analysis in that the "true" or "actual" hazard ranking of grade crossings is unknown. Hazard ranking formulas are used to establish a priority ranking of hazardous crossings based on a formula modeling hazard risk at a crossing; however, not all factors encompassing the risk at a crossing are included in formulas or even able to be measured at all. The Expert Panel ranking for the 20-crossing sample was established by the ORDC technical liaisons based on the grade crossing inventory data for each crossing without reference to the accident prediction value calculated using the existing hazard ranking model used in Ohio.

The second element of the detailed evaluation was a functional evaluation of the selected grade crossing hazard ranking models. The functional evaluation focused on the completeness of variables in the existing Ohio highway-railroad grade crossing inventory database as well as the accuracy of selected variables against other data sources. Researchers examined all variables in use in the current Ohio hazard ranking model as well as additional variables considered by other state models in this task. Researchers measured the completeness by examining the number of valid records in the database for each variable considered and the corresponding percentage of valid entries. Blank or "NULL" records for each variable were assumed to be incomplete. The accuracy of the annual average daily traffic (AADT) data in the grade crossing inventory was examined by comparing the AADT values from the inventory with AADT values from ODOT traffic data for a group of crossings on the state highway system. Additionally, researchers used a desk review of the expert panel sample as well as a second randomly-drawn sample of 40 passive crossings to investigate data issues with the physical layout of the crossing such as the number of tracks and the number of highway lanes.

Additional details of the statistical analysis can be found in Appendix C of this report while the functional evaluation details can be found in Appendix A.

RESEARCH FINDINGS AND CONCLUSIONS

Grade Crossing Hazard Ranking Models

The U.S. DOT Accident Prediction Model is the most commonly-used grade crossing hazard ranking model in practice, with 19 states (including Ohio) using this model. Some states utilize a variation of the New Hampshire Hazard Index while other states use state-specific models. Variables that are not considered in the U.S. DOT Accident Prediction Model but are considered in state-specific models include the highway functional classification/context, available sight distance, highway traffic speed, the presence of a nearby intersection, and train type. Based on the analyses performed as part of this research project, there is no evidence to suggest that a different hazard ranking model than the U.S. DOT model would provide a more superior hazard ranking of highway-railroad grade crossings.

Table 3 displays a matrix comparing the existing grade crossing hazard ranking model used in Ohio, the U.S. DOT Accident Prediction Model, with the New Hampshire Hazard Index and four state-specific hazard ranking models. For each hazard ranking model compared in Table 3, the type of model, the number of states using each model, the number of variables in each model, and the additional variable needs for the inventory database are noted. Each model is compared on the following factors:

- Compatibility with Existing Practice – Assessment of each hazard ranking model with respect to current Ohio practices, including the use of a crash prediction metric as the primary hazard ranking metric, availability of data in the grade crossing inventory database, and the inclusion of crash history in the model calculations.
- Applicability to Ohio Grade Crossings – Assessment of each hazard ranking model with respect to the applicability of the model to Ohio highway-railroad grade crossing concerns. The applicability is defined in terms of the relevance of additional variables in each model (beyond the existing U.S. DOT model) and the model accuracy (as measured by the results of the Expert Panel analysis).
- Model Functionality – Assessment of each hazard ranking model with respect to the model's functionality as a mathematical model as well as the model's ability to be used for specific analyses. The general complexity of the model is examined as is the ease of operation for each model. A model's ability to differentiate between passive crossings that are otherwise very similar is noted based on the inclusion of highway speed and sight distance, two factors that could reasonably differentiate between similar locations. A model's compatibility with an economic analysis approach is also noted based on the crash frequency and severity prediction capabilities.

The strengths of the U.S. DOT Accident Prediction Model is that it uses a crash frequency prediction as the hazard ranking metric, which is explainable and understandable as an approach to grade crossing hazard ranking. Additionally, the U.S. DOT model and other crash prediction models can be extended to an economic analysis, such as a benefit-cost analysis, if desired. The key limitations of the U.S. DOT model are the complexity of the model and the model's inability to differentiate between very similar passive crossing locations. The use of a hazard index model, such as the Missouri or North Carolina models, as a secondary ranking model for passive crossings only would overcome these limitations. However, these hazard indices require information about sight distance, which is currently not available in the Ohio

highway-railroad grade crossing inventory data. Detailed sight distance information obtained as part of the field diagnostic review process could be utilized for this secondary ranking process if it was included in the grade crossing inventory database. The performance of any model including the school bus volume is difficult to assess given the high percentage of incomplete data for that variable.

Table 3: Comparison Matrix of Grade Crossing Hazard Ranking Models

	U.S. DOT Accident Prediction Model ***(Model currently used in Ohio)***	**New Hampshire Hazard Index**	**Florida DOT Safety Hazard Index**	**Missouri DOT Exposure Index**	**North Carolina DOT Investigative Index**	**Texas DOT Priority Index**
Type of Hazard Ranking Model	Crash Prediction	Hazard Index	Hybrid	Hazard Index	Hazard Index	Hybrid
Number of States using Model	19	5	1	1	1	1
Number of Variables	9	3	9	8	9	13
Additional Variables Needed in Database	None	None	HS SB	HS SD	SB SD	HS SD
Compatibility with Existing Practice						
• Use of Crash Prediction Metric	✓✓	No	✓	No	No	✓
• All Data Available in Inventory	✓✓	✓✓	✓	No	No	No
• Includes Crash History	✓✓	No	✓✓	No	✓✓	✓✓
Applicability to Ohio Grade Crossings						
• Additional Variables Relevant (Based on Crash Analysis)	N/A	N/A	??	No	??	No
• Accuracy of Model (Based on Expert Panel Analysis)	✓	Limited	Limited	Limited	✓	Limited
Model Functionality						
• Model Complexity	Very	✓✓	✓	✓✓	✓	✓
• Ease of Operation	Not	✓✓	✓	✓✓	✓	✓
• Differentiate Among Passive Crossings	No	No	✓	✓✓	✓	✓✓
• Compatible with Economic Analysis	✓✓	Not	✓	Not	Not	✓
Key – Performance of model with respect to criteria: (✓✓) Strong; (✓) Satisfactory; (??) Unknown; Others Noted.						
Variables – HS: Highway Traffic Speed; SB: Volume of School Bus; SD: Sight Distance						

Grade Crossing Project Development Process

The typical project development process for a grade crossing warning device improvement project includes identification of a preliminary list of locations, screening for Section 130 program eligibility, field diagnostic review, developing the final project list, and implementation. In all states interviewed for this project, the state-adopted hazard ranking model is used as a starting point for the process and professional judgement is applied in the final project selection. The process used by the ORDC and the PUCO in Ohio is similar to the process used in other states. Some states, including Ohio, develop the preliminary list primarily based on the next available highest ranked passive crossings as identified through the hazard ranking formula. Other approaches used by states to develop the preliminary list include local highway authorities submitting applications, other public agency requests, FRA WBAPS, near-miss locations, locations where a crash has occurred in the past year, and recommendations from the state grade crossing inspector team. The use of near-miss data in the project development process is limited to states where the major railroads provide such data to the states in a uniform manner; other states noted that railroads had expressed concern about the consistency of such data, particularly in the eastern U.S. No states formally incorporate the near-miss data in the hazard risk evaluation process.

Grade Crossing Data Issues

The usefulness of any grade crossing hazard ranking model is only as good as the data that are used to operate the model. Data for grade crossing hazard ranking models are obtained from state-level highway-railroad grade crossing inventory databases or a similar database managed by the FRA. States interviewed as part of this research project expressed varying degrees of confidence in the inventory data but generally agreed that the inventory was the best available information about the characteristics of a grade crossing. States typically confirm inventory data with the appropriate organization (highway agency or railroad) as a part of the diagnostic review process, allowing for the most accurate data to be used for project development. A preliminary assessment of the Ohio highway-railroad grade crossing inventory data conducted as part of this research project indicated the following concerns:

- Comparison of the annual average daily traffic (AADT) between the data in the grade crossing inventory database and corresponding data from other ODOT sources indicated an average error of approximately 32 percent between the two sources. This comparison focused primarily on grade crossings found on the state highway system. It is unclear if similar errors are present on local roadway system grade crossings.
- A review of two separate random samples of grade crossings from the inventory database found that approximately 20 percent of database entries contained inaccurate information about the number of train tracks (main tracks plus other tracks) at a grade crossing.
- Factors included in state-specific grade crossing hazard ranking models such as the highway traffic speed at a crossing, the volume of school buses at a crossing, and the available sight distance at a crossing, are relatively incomplete or not included in the Ohio highway-railroad grade crossing database.

RECOMMENDATIONS AND IMPLEMENTATION PLAN

Recommendations

Based on the findings and conclusions of this research project, the Ohio University research team presents the following recommendations:

- Recommendation #1: The ORDC and the PUCO should continue use of U.S. DOT Accident Prediction Model for grade crossing hazard ranking to assist with warning device project prioritization in the state. The U.S. DOT model represents the state of practice for grade crossing hazard ranking and is based on national trends in grade crossing safety. Absent a state-specific grade crossing crash prediction model, the analysis performed for this research project indicates that no other models currently available provide a more superior ranking of grade crossings than the U.S. DOT model. Additionally, the PUCO should engage its database contractor to update the normalizing constants included with the U.S. DOT model. While the rankings are not changed with the updated normalizing constants, a model that is using the most updated model details will provide the best information for decision-making.
- Recommendation #2: Hazard index models such as the Missouri DOT Exposure Index or the North Carolina DOT Investigative Index should be considered to provide a secondary ranking for passive crossing locations after the initial ranking and diagnostic review process has been completed for the annual program. The only factors in the U.S. DOT model that are relevant for passive crossing locations are the AADT, train volume, and train speed. Establishing a secondary ranking with a hazard index formula that includes factors such as highway traffic speed or sight distance may be helpful to the ORDC and PUCO in hazard ranking. These data could be obtained as part of the field diagnostic review process as described in Recommendation #3 below. Having a secondary ranking would provide ORDC with additional tools to make decisions regarding warning device project selection, particularly if the annual program can only fund a portion of the crossings that were included in the diagnostic review process.
- Recommendation #3: The existing field diagnostic review process should be updated to obtain better information about the available sight distance at a grade crossing. Although the crash data do not bear out the relationship between grade crossing safety and sight distance, the amount of sight distance provided at a passive crossing location is essential to motorists making an informed decision about proceeding over a passive crossing. Measurements of the available sight distance along the highway in all four quadrants of the crossing should be recorded during the field diagnostic review and sight obstructions such as structures or seasonal foliage should also be noted. The highway speed limit should also be recorded to allow for calculations of the required sight distance based on highway and train speed. Once collected, these data should be entered into the grade crossing inventory database. While states have noted difficulty with maintaining data on sight distance for the complete inventory, having this information available in a quantitative way for the crossings being considered for warning device upgrade projects provides a starting point to allow for sight distance to be considered in the future.

- Recommendation #4: The ORDC should consider revising its warning device project development process to include a larger number of crossings on the preliminary list of project locations. Some states that were interviewed as part of this research project reported that their preliminary list has many more crossings than the list used in Ohio. Best practices from states interviewed as part of this research project provide several options for "casting a wider net" to identify potential locations for upgrades. The primary purpose of this recommendation is to identify hazardous grade crossing locations that are not detected by the hazard ranking process (for example, if development near the crossing has occurred and the AADT has increased significantly on the highway). For example, the Michigan "inspector's choice" provision allows for up to two locations each year per inspector to be nominated for a field diagnostic review regardless of where the crossing ranks on the hazard ranking. Including the viewpoints of other stakeholders may help identify hazardous locations that would not have otherwise been considered. The structure of the ORDC to include representatives from railroad labor as well as county engineers also provides an avenue for identifying potential hazardous locations, particularly locations where "near-miss" incidents are thought to be occurring. The existing ORDC policy of automatically convening a field diagnostic review at a crossing where a fatal crash has occurred should be retained. Finally, in lieu of requesting details on school bus volumes at railroad crossings from school districts, the ORDC could instead consider asking school districts if their bus drivers have noticed any particularly hazardous grade crossings along their routes. This option may be more effective at identifying hazardous grade crossings than relying on inconsistent bus volume data.
- Recommendation #5: The ORDC and the PUCO should consider developing a formal written protocol or framework to ensure that key variables in the Ohio highway-railroad grade crossing inventory database are updated and maintained. It is unclear if such a protocol currently exists; however, based on the investigations performed in this research study, there are several issues with key variables in the database. Notably, inventory database values for AADT were found to be inconsistent with ODOT technical services AADT data at some locations and approximately 20 percent of crossings have incorrect data for the total number of tracks. At a minimum, the highway traffic volumes at grade crossing locations where ODOT technical services has established an AADT value should be consistent.

Addressing the issues surrounding Recommendation #5 provides the ORDC with an avenue for the future development of more advanced decision-support systems for grade crossing warning device project selection. In the long term, a state-specific crash prediction model based on Ohio data could be developed for hazard ranking analysis needs as an alternative to the U.S. DOT accident prediction model. The use of local data for crash prediction modeling would be superior to the U.S. DOT model because the state-specific crash trends and relevant variables would be accounted for in such a model. A state-specific crash prediction model could also be used as input to an economic analysis if desired [e.g., Brod, et al., 2013]. However, development of a state-specific crash prediction model is not appropriate or recommended at this time, given the database issues noted in Recommendation #5 and on-going efforts by the ORDC and the PUCO to improve the inventory database.

Implementation Plan

The Ohio University research team presents the following plan for ODOT and ORDC implementation of the research recommendations described in the previous section.

Recommendations for Implementation

- Recommendation #1: To implement Recommendation #1, the PUCO should engage its database contractor to update the normalizing constants included with the U.S. DOT Accident Prediction Model. .
- Recommendation #2: To implement Recommendation #2, the ORDC staff should develop a spreadsheet-based tool to provide an independent calculation of the U.S. DOT model crash frequency as well as the value of the adopted secondary hazard ranking model based on data obtained during the field diagnostic review.
- Recommendation #3: To implement Recommendation #3, the ORDC should revise its Diagnostic Review Team Survey Form to provide additional space for designating the amount of sight distance available on each quadrant of a grade crossing. The form should provide space for the diagnostic team to record the available sight distance along the roadway in all four quadrants of the crossing as well as the nature of any obstructions (e.g., permanent structures, seasonal crops or foliage, or open space). A pilot test of the revised form should be conducted during the next round of funding.
- Recommendation #4: To implement Recommendation #4, the ORDC staff should review its existing warning device project development process and identify potential avenues for identifying more grade crossings to be included on the preliminary review list. A pilot test of an "inspector's choice" program similar to what is used in Michigan should also be considered for the next round of funding. Outreach to groups such as railroad labor, the County Engineers' Association of Ohio, and local school districts may also be helpful in identifying hazardous grade crossing locations not otherwise considered in the hazard ranking process.
- Recommendation #5: To implement Recommendation #5, the ORDC and the PUCO should jointly develop a framework for updating the grade crossing inventory database. At a minimum, the protocol should consider the sources of data, update frequency, uniformity in reporting, and assign roles and responsibilities for updating.

Analysis of Benefits and Risks

- Recommendation #1: The expected benefit of implementing Recommendation #1 is that the hazard rankings based on the U.S. DOT model will be based on the most current version of the model. Even though the rankings do not change with the updated details, it is still beneficial to all agencies involved that the most updated information be used in this process. The risk of implementing Recommendation #1 is low.
- Recommendation #2: The expected benefit of implementing Recommendation #2 is that the ORDC will have additional insight on the relative hazard risk of a subset of grade crossings being considered in the annual warning device upgrade program. An additional benefit is that updated data from the field diagnostic review would be used in this process. The risk of implementing Recommendation #2 is low.

- Recommendation #3: The expected benefit of implementing Recommendation #3 is that the field diagnostic review process would obtain information about sight distance available at a crossing, which in turn would assist ORDC with hazard ranking at locations that are otherwise very similar. One risk in implementing Recommendation #3 is that the field diagnostic review process might take longer at each crossing, but the benefits of additional information outweigh these risks.
- Recommendation #4: The expected benefit of implementing Recommendation #4 is that some locations that are not high-ranking would still be considered for warning device upgrades. Not all factors that make grade crossings hazardous are included (or can be included) in hazard ranking models. Consequently, any additional insight on hazardous locations that are otherwise not detected by the hazard ranking process would be beneficial. There is potential risk in that the project development process would expand significantly outside the existing capacity of ORDC staff to manage the annual program. This risk can be managed by clearly defining the framework for how recommendations can be submitted and by gradually expanding number of new sources to collect recommendations from each year.
- Recommendation #5: The expected benefit of implementing Recommendation #5 is that a detailed protocol with clearly-defined responsibilities for updating data in the inventory database will be agreed-upon and adopted. As a result, future hazard risk assessments will be based on data that is consistent across all organizations involved. The risk of implementing Recommendation #5 is low.

Agency Coordination

Implementing Ohio's highway-railroad grade crossing safety programs is a joint responsibility of the ORDC and the PUCO, with support from ODOT, the railroads, and local highway agencies who participate in the field diagnostic reviews. ODOT and ORDC implementation of the recommendations of this research study will require significant coordination and cooperation with the PUCO, particularly those recommendations related to the Ohio highway-railroad grade crossing inventory database. The ODOT Office of Technical Services and other offices within ODOT, as appropriate, will be involved with implementation of Recommendation #5 to ensure greater consistency in the inventory data.

Estimated Costs and Time Frame

- Recommendation #1: The estimated cost of implementing Recommendation #1 is unknown and is based on the PUCO contractor charges. Recommendation #1 should be implemented immediately upon final approval of this project. The time frame for completion is unknown but the new normalizing constants should be in place prior to the next project cycle for warning device upgrade projects.
- Recommendation #2: The estimated cost of implementing Recommendation #2 is unknown and is based on the cost of ORDC staff time to determine what secondary hazard ranking index, if any, should be used. A final decision on implementing Recommendation #2 should be made prior to the next project cycle for warning device upgrade projects.
- Recommendation #3: The estimated cost of implementing Recommendation #3 is unknown and is based on the cost of ORDC staff time to determine if Recommendation

#3 should be adopted and the time for updating the diagnostic review form. The time burden required for a field diagnostic review would increase although it is unknown how much more time would be added. A final decision on implementing Recommendation #3 should be made prior to the next project cycle for warning device upgrade projects.

- Recommendation #4: The estimated cost of implementing Recommendation #4, is unknown and is based on the cost of ORDC staff time to determine if Recommendation #4 should be adopted. The time frame for implementing Recommendation #4 is unknown and will be based on how the ORDC chooses to proceed with new methods for identifying project locations. If the preliminary list is to be expanded, there will be additional costs to the ORDC staff for project management of additional locations.
- Recommendation #5: The estimated cost of implementing Recommendation #5 is unknown and is based on the cost of ORDC and PUCO staff time to develop a database update framework. FHWA regulations allow for up to 2 percent of a state's Section 130 program allocations to be used for the purpose of grade crossing inventory updates. The time frame for implementation of Recommendation #5 will be based on how the ORDC and the PUCO choose to proceed with updating the inventory database.

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APPENDIX A: LITERATURE REVIEW

Appendix A presents a portion of the findings of the literature review undertaken for this project. The subjects discussed in this literature review include the following:

- Grade Crossing Hazard Ranking Practices in Ohio;
- Ohio Highway-Railroad Grade Crossing Safety Analysis; and
- Evaluating the Effectiveness of Grade Crossing Hazard Ranking Formulas.

As part the literature review task, the research team reviewed literature from the following sources:

- Existing U.S. DOT policy and guidance regarding grade crossing hazard ranking;
- Reports describing state-level progress and key outcomes for 2014 related to the "Section 130 Railway-Highway Crossing Program" made available by the FHWA;
- State DOT research studies undertaken to improve grade crossing hazard ranking;
- State DOT websites, manuals, and regulations; and
- Additional literature as identified through web-based searches.

Details of specific grade crossing hazard ranking formulas and the various methods used by State DOTs and other organizations to evaluate grade crossing hazards and select locations for hazard elimination projects were also studied in the literature review task of this project. However, because these details represent a significant portion of the project's findings and conclusions, they are presented separately in Appendix B.

Grade Crossing Hazard Ranking Practices in Ohio

In Ohio, two public agencies are jointly responsible for highway-railroad grade crossing safety programs. The Ohio Rail Development Commission (ORDC), an independent commission within the Ohio Department of Transportation (ODOT), administers FHWA Section 130 funds for highway-railroad grade crossing improvements on behalf of ODOT, as well as other funds for grade crossing safety made available through state legislative appropriations. Regulatory oversight and annual inspection of highway-railroad grade crossings fall under the authority of the Public Utilities Commission of Ohio (PUCO). Together, the ORDC and the PUCO administer several programs to provide Ohio's railroads and local communities with funding for improvements to the warning devices and/or other projects to enhance safety at highway-railroad grade crossings.

In Task 2 of this project, researchers investigated Ohio's grade crossing funding programs and practices used for grade crossing hazard ranking in support of these funding programs. As part of Task 2, the research team reviewed several documents describing the grade crossing funding programs of the ORDC and the PUCO. Additionally, the research team met with staff members from the ORDC the PUCO to obtain additional details regarding funding programs, hazard ranking models, and project selection practices of the agencies.

Ohio Hazard Ranking Model

The ORDC and the PUCO utilize the U.S. DOT Accident Prediction Model to derive hazard ranking of grade crossings to support the evaluation and project selection process. Detailed computational procedures for the U.S. DOT Accident Prediction Model are described elsewhere (see Table 10 and Table 11) and referenced in the FRA *GradeDec.Net Crossing Evaluation Tool Reference Manual* [FRA, 2014]. The GradeDec.Net reference manual contains the most updated formulas and computational procedures for the U.S. DOT Accident Prediction Model. The "normalizing constants" portion of the U.S. DOT Accident Prediction Model are updated on a periodic basis by the FRA based on historical crash data. Updated normalizing constants are published on the GradeDec.Net website (https://gradedec.fra.dot.gov/). The most recent update to the normalizing constants took place on May 13, 2014. However, research team investigation of the hazard ranking of Ohio crossings based on data provided by the PUCO showed that the normalizing constants used by the PUCO (as of July 29, 2015) were based on the previous update of the normalizing constants, which took place on October 1, 2010. Using the normalizing constants from October 2010 and the other data supplied by the PUCO, the research team was able to replicate the exact value for the predicted annual crash frequency at a grade crossing used by the ORDC and the PUCO to rank grade crossings for project selection.

Ohio Highway-Rail Grade Crossing Database

Data to operate the hazard ranking formula is drawn from the Ohio highway-railroad crossing inventory database, which is jointly maintained by the ORDC and the PUCO (http://gradecrossings.puco.ohio.gov/). Each entry in the database includes details of the physical characteristics of the crossing, characteristics of the railroad and vehicular traffic, and traffic control devices present at the crossing. The PUCO is responsible for updating the information contained in the database primarily through field inspections, although database updates can also be initiated by the ORDC. Crash history data are also maintained by the PUCO. All crashes and fatalities at grade crossings are recorded in the database with the exception of fatal crashes for which a coroner's report concluded that the individual committed suicide. As of October 31, 2015, the database included information on 5,761 highway-railroad at-grade crossings that are open to travel and located on public roadways.

Table 4 presents a more detailed examination of the data availability within the PUCO database. All of the variables included in the existing U.S. DOT Accident Prediction Model used in Ohio are relatively complete, with more than 99 percent of records listing a valid entry for the variables included in this model. Other factors with more than 90 percent valid data include the highway type (i.e., functional classification), the presence of a nearby highway intersection, and the percentage of trucks in the AADT volume.

The analysis presented in Table 4 provides a starting point for a discussion about the completeness of the Ohio highway-railroad grade crossing database if new variables were to be incorporated into the grade crossing hazard ranking process. Data related to sight distance, highway traffic speed, and school bus volume are incomplete or not included in the existing database. The amount of sight distance available at a crossing is not included at all in the database. The highway traffic speed at the crossing is included as a field in the database but only 21 percent of records have a valid entry. One potential solution to this issue would be to utilize the state statutory speed limit for analysis in lieu of the posted speed limit for records with incomplete data.

Table 4: Analysis of Ohio Grade Crossing Inventory Data Availability

Variable	Number of Valid Records	Percent of Records Valid
Existing Warning Device	5,747	99.8%
Highway Lanes	5,756	99.9%
Highway Surface	5,716	99.2%
Highway Traffic Speed	1,210	21.0%
Highway Type/Context	5,699	98.9%
Nearby Highway Intersection	5,240	91.0%
Number of Train Tracks	5,754	99.9%
Sight Distance	Not Included	N/A
Traffic Volume (AADT)	5,741	99.7%
Traffic Volume (Percent Trucks)	5,538	96.1%
Traffic Volume (School Bus)	1,982	34.4%
Train Speed	5,732	99.5%
Train Volume	5,756	99.9%
Source: Ohio University research team analysis of data from the Ohio Railroad Information System (RRIS) provided by the Public Utilities Commission of Ohio (PUCO) as of October 31, 2015.		

The daily volume of school buses passing over a grade crossing is also of interest in evaluating the hazard risk at a crossing location. The current inventory has a field for the school bus volume; however, only 34 percent of records contain a valid entry for this field. The PUCO reported to the research team that a letter is sent to Ohio school districts annually requesting school bus information to assist with grade crossing safety evaluation. However, PUCO noted that state law does not require that school districts respond to the request for school bus traffic data. Therefore, response to these letters is relatively low and thus it is difficult to incorporate the school bus volume on a widespread basis.

In addition to the completeness of the highway-railroad grade crossing inventory database, the accuracy of the data contained in the database is also essential to accurate hazard evaluation and informed decision-making. A wide variety of data sources are used to feed the inventory database, including reports from field inspections, railroad data, and updates following a diagnostic review or the completion of a warning device project. To investigate potential accuracy issues within the inventory database, researchers examined one key data element of the current Ohio hazard ranking formula – the volume of highway traffic at a crossing, as expressed by the annual average daily traffic, or AADT. Detailed statewide data on AADT are available from the ODOT Office of Technical Services, accessible through the ODOT Transportation Information Management System (TIMS) database. Researchers used a Geographic Information System (GIS)-based analysis to spatially relate the location of grade crossings with underlying roadway data from the ODOT TIMS data. Researchers analyzed a sample of 489 grade crossings primarily located on the state highway system (U.S. and State highways) comparing the AADT from the grade crossing inventory with the AADT for the roadway from the ODOT TIMS database. This analysis indicated that the percent difference between the grade crossing inventory data and the ODOT TIMS data ranged between -93.9 percent and +1,095.0 percent, with the average of the absolute value of the percent difference (i.e., direction of the error not

considered) calculated to be 32.1 percent. This discrepancy is not ideal and leaves open the possibility of inaccurate assessment of hazard risk at a crossing based on AADT.

The accuracy of the information related to railroad operations at a grade crossing within the inventory is also a concern. For example, obtaining accurate information on train volumes is difficult because railroads are not required to provide this information to the inventory and, in many locations, trains do not operate on a fixed schedule and volumes are not consistent on a day-to-day basis. Locations with significant agricultural activity, for instance, will see an increase in train activity during certain seasons of the year with very little activity during other times. For this project, researchers did not investigate any issues related to train volume (unlike the AADT investigation described in the previous paragraph).

Ohio Rail Development Commission (ORDC) Grade Crossing Programs

A detailed description of the grade crossing programs managed by the ORDC can be found in the ORDC's "Project Development Process" document [ORDC, 2013]. The ORDC manages four separate funding programs for grade crossing improvements:

- Formula-Based Upgrade Program (warning device);
- Corridor-Based Upgrade Program (warning device);
- Constituent-Identified Program (warning device); and
- Preemption Program (warning devices with nearby traffic signals).

Of the four programs managed by the ORDC, the Formula-Based Upgrade Program for warning devices is the program which most directly utilizes the FRA/Ohio formula. The Formula-Based Upgrade Program is an annual program in which approximately 20-40 crossings in Ohio are upgraded from passive warning device (crossbucks only) to active warning devices (flashing lights and gates). Application of the grade crossing hazard ranking formula for project selection as part of the Formula-Based Upgrade Program proceeds as follows:

- The PUCO will generate an initial list of crossings which are to be considered for the program. This initial list presently includes approximately 1,500 crossings ranked in descending order based on the number of collisions per year predicted at the crossing (calculated using the U.S. DOT Accident Prediction Model formula discussed previously). The number of crossings on the initial list grows slightly each year as more crossings are upgraded. The scope of the list includes only public, at-grade crossings. Regulation of private crossings is outside the jurisdiction of the PUCO.
- PUCO staff will review the initial list and identify grade crossing locations without highway gates that are candidates for a warning device improvement project. Train volumes for these locations are confirmed with the operating railroads and the grade crossings are re-ranked, if necessary. Some higher-ranked crossings will not be identified for improvement if an improvement project, grade separation, or closure/consolidation has already been initiated at that crossing, but not yet completed or a previous field diagnostic review indicated that active devices were not feasible at that location.
- The initial list is provided to the ORDC staff for further evaluation. The initial list will typically contain approximately 40 grade crossings. A "desk review" conducted by ORDC staff will confirm rail conditions, train speed, train volume, and vehicular volume

data for these locations. The ORDC will administer a field diagnostic review for each crossing which has advanced past the desk review stage.

- Field diagnostic reviews are conducted by a multi-agency review team per FHWA guidelines. In practice, any crossing location where a fatal crash has occurred since the last round of funding is automatically included in the field diagnostic review even if that crossing was not on the initial list generated by the PUCO. If the field diagnostic review indicates that an active warning device should be installed at that location, the project will proceed through the standard ORDC project development process. In some cases, the field diagnostic review will identify that a crossing is a potential candidate for closure or that there are physical limitations of the site that prevent flashing lights or gates from being installed at that location.

The project selection process described above is initiated on an annual basis shortly after the start of the new state fiscal year on July 1. If funds are available, a second round of crossing review and project selection is initiated during the fiscal year. During the most recent reporting period (FY 2015), a total of 65 grade crossing projects were funded by the ORDC, including 59 warning device upgrade projects, two roadway geometry improvement projects, two crossing elimination projects, and two planning studies. The total amount spent on these 65 projects was $15,955,815, of which $14,656,113 (approximately 92 percent) was Section 130 program funds. The average cost of a warning device upgrade project in FY 2015 was $253,770.

Public Utilities Commission of Ohio (PUCO) Grade Crossing Programs

The PUCO also administers a grade crossing improvement funding program separate from the ORDC programs. Details of the PUCO funding programs are available from the PUCO website (http://www.puco.ohio.gov/puco/). Funding applications for this project are primarily initiated by local communities seeking grade crossing improvements. The PUCO funding share for local projects is between 25 and 65 percent of the total project costs based on an objective scoring process which includes criteria such as the predicted number of accidents, AADT, train volume, train speed, and number of tracks. Additional information about area development, roadway geometry, and sight obstructions are also included. The number of points scored by the crossing during the evaluation will determine the percentage of PUCO assistance for the project.

Ohio Highway-Railroad Grade Crossing Safety Analysis

To provide additional context for this research study analyzing different methods of hazard ranking for highway-railroad grade crossings, researchers analyzed the characteristics of grade crossings and grade crossing related crashes in Ohio. The primary purpose of this analysis is to determine the factors associated with grade crossing crashes in Ohio and how hazard ranking practices in Ohio can be improved with this information. As of October 31, 2015, the Ohio highway-railroad grade crossing inventory contained 5,761 public at-grade crossings, 307 of which have experienced a crash during the five-year period between August 1, 2010, and July 31, 2015. These 307 locations accounted for 333 unique crashes during this time period.

The results of this analysis are presented in three separate tables on the following pages of this report. Table 5 reports the railroad-related characteristics of Ohio's highway-railroad grade crossings comparing the complete set of grade crossings against the 307 crossings that have experienced a crash during the last five years. Table 6 reports similar information focused on the roadway-related characteristics. The data in Table 6 and Table 7 are based analysis of the

Ohio highway-railroad grade crossing inventory database. Finally, Table 7 focuses on the characteristics of grade crossing-related crashes that have occurred in Ohio over the last 10 years and is based on the data from the PUCO crash database. Table 7 also examines the distribution of grade crossing crashes by crash severity (fatal, injury, and property damage only (PDO)). Crash history of 10 years is examined to provide a larger sample for identifying trends.

Table 5: Ohio Highway-Railroad Grade Crossings: Railroad Characteristics

	All Crossings	Crossings with Crash in Last 5 Years
Number of Crossings	**5,761**	**307**
Type of Warning Device		
• Gates and Flashing Lights (%)	54.5	80.5
• Flashing Lights Only (%)	11.7	5.2
• Passive Warning Devices (%)	33.8	14.3
Location of Crossing		
• Urban Areas (%)	45.0	52.0
• Rural Areas (%)	55.0	48.0
Development Type		
• Open Space (%)	31.6	26.7
• Residential (%)	36.7	28.7
• Commercial (%)	20.0	30.0
• Industrial (%)	10.8	12.0
• Institutional (%)	0.9	0.7
Daily Train Volume		
• None (%)	15.3	4.6
• 1 to 10 (%)	49.0	25.1
• 11 to 20 (%)	12.0	15.3
• 21 to 30 (%)	14.5	22.5
• 31 or More (%)	9.3	32.6
Number of Main Tracks		
• None (%)	3.5	3.6
• One (%)	69.0	42.0
• Two (%)	22.5	43.3
• Three or More (%)	5.0	11.1
Maximum Train Speed		
• Less than 15 MPH (%)	19.1	9.5
• 15 to 25 MPH (%)	20.3	11.1
• 26 to 40 MPH (%)	25.8	22.6
• 41 to 55 MPH (%)	15.8	22.2
• 56 MPH or Higher (%)	19.0	34.6
Source: Ohio University research team analysis of data from the Ohio Railroad Information System (RRIS) provided by the Public Utilities Commission of Ohio (PUCO) as of October 31, 2015. Crash data analyzed for five-year period between August 1, 2010 and July 31, 2015.		
Note: Columns may not sum to 100 percent due to rounding.		

Table 6: Ohio Highway-Railroad Grade Crossings: Highway Characteristics

	All Crossings	Crossings with Crash in Last 5 Years
Number of Crossings	**5,761**	**307**
Annual Average Daily Traffic (AADT)		
• Less than 250 (%)	24.5	17.6
• 250 to 499 (%)	13.6	7.5
• 500 to 999 (%)	14.0	12.1
• 1,000 to 2,499 (%)	19.9	21.5
• 2,500 to 9,999 (%)	22.8	34.5
• 10,000 or Higher (%)	5.2	6.8
Number of Highway Lanes		
• One Lane (%)	3.0	1.3
• Two Lanes (%)	92.3	92.8
• Three Lanes (%)	1.1	2.3
• Four or More Lanes (%)	3.6	3.6
Highway Functional Classification		
• Arterial (%)	5.6	8.2
• Collector (%)	26.9	35.5
• Local (%)	67.5	56.3
Highway Speed Limit		
• 25 MPH or Lower (%)	41.5	39.4
• 26 to 40 MPH (%)	8.0	10.8
• 41 to 54 MPH (%)	3.8	4.9
• 55 MPH or Higher (%)	46.7	45.0
Percent Trucks in AADT		
• 4 Percent or Less (%)	39.3	42.5
• 5 to 9 Percent (%)	56.0	50.7
• 10 to 19 Percent (%)	3.1	3.6
• 20 Percent or More (%)	1.6	3.3
Distance to Nearby Intersection		
• Less than 75 Feet (%)	27.8	30.0
• 75 to 150 Feet (%)	63.0	64.8
• More than 150 Feet (%)	9.1	5.2
Source: Ohio University research team analysis of data from the Ohio Railroad Information System (RRIS) provided by the Public Utilities Commission of Ohio (PUCO) as of October 31, 2015. Crash data analyzed for five-year period between August 1, 2010 and July 31, 2015.		
Note: Columns may not sum to 100 percent due to rounding.		

Table 7: Ohio Highway-Railroad Grade Crossings: 10-Year Crash Analysis

	All Crashes	**Fatal Crashes**	**Injury Crashes**	**PDO Crashes**
Total Number of Crashes	**884 (100%)**	**89 (10.1%)**	**209 (23.6%)**	**586 (66.3%)**
Type of Warning Device at Crossing				
• Gates and Flashing Lights (%)	52.3	42.7	53.6	53.2
• Flashing Lights Only (%)	9.8	10.1	8.6	10.2
• Passive Warning Devices (%)	31.5	38.2	32.5	30.0
• Other Devices (%)	6.5	9.0	5.3	6.5
Type of Vehicle Involved				
• Auto or Van (%)	60.8	48.3	61.7	62.3
• Truck (%)	6.7	7.9	7.2	6.3
• Truck-Trailer (%)	10.4	3.4	7.2	12.6
• Pickup Truck (%)	11.1	11.2	11.0	11.1
• Pedestrian (%)	4.6	20.2	7.7	1.2
• Other/Unknown (%)	6.5	9.0	5.3	6.5
Driver Action				
• Drove Around/Through Gate (%)	17.7	21.4	27.3	13.6
• Stopped and Proceeded (%)	4.4	5.6	4.3	4.3
• Did Not Stop (%)	37.4	43.8	42.1	34.8
• Stopped on Tracks (%)	29.2	12.4	13.9	37.2
• Other/Unknown (%)	11.3	16.9	12.4	10.1
Train Speed				
• Less than 15 MPH (%)	25.8	8.0	15.0	32.2
• 15 to 25 MPH (%)	18.3	6.8	20.0	19.4
• 26 to 40 MPH (%)	29.1	38.6	34.5	25.8
• 41 to 55 MPH (%)	21.6	37.5	25.5	17.9
• 56 MPH or Higher (%)	5.2	9.1	5.0	4.7
Source: Ohio University research team analysis of data from the Ohio Railroad Information System (RRIS) provided by the Public Utilities Commission of Ohio (PUCO) as of October 31, 2015. Crash data analyzed for ten-year period between August 1, 2005 and July 31, 2015.				
Note: Columns may not sum to 100 percent due to rounding.				

While crashes at highway-railroad grade crossings are typically the result of many interrelated factors, some trends and patterns emerged from this analysis:

- Approximately two-thirds of Ohio highway-railroad grade crossings have active warning devices while one-third have passive warning devices (Table 5). However, 85 percent of the 307 crossing locations with a crash in the last 5 years currently have active warning devices (Table 5). This is partially the result of the ORDC warning device project development process, which emphasizes crossing locations that have experienced recent crashes – both as an element of the hazard ranking formula as well as the standing policy of automatically convening a diagnostic review at locations where a fatal crash has

occurred. The distribution of warning devices at the crossing at the time of the crash (Table 7) has a similar distribution as the statewide crossing inventory.

- Crossings that have experienced a crash in the last five years have higher train volumes, higher maximum train speeds, and a larger number of main tracks (Table 5) as well as higher AADT (Table 6) than the statewide average. These trends indicate that the inclusion of these variables in models to assist with establishing a ranking of hazardous crossings is appropriate. The current formula used in Ohio, the U.S. DOT Accident Prediction Model, includes these factors.

- The number of highway lanes traversing a crossing or the highway speed limit at the crossing do not appear to have an impact on the probability that a crash will occur at a grade crossing. Crossings located on higher-classification roadways such as arterials and collectors do experience a greater proportion of crashes; however, this is likely associated with the AADT volumes on the roadway and not the functional classification itself.

- Heavy trucks with trailers merit special consideration in the safe design and operation of highway-railroad grade crossings. The length, weight, and requirements for stopping at the crossing for some types of trucks are all potential factors that need to be addressed. The percentage of trucks in the AADT (Table 6) is higher at grade crossings where a crash has taken place during the last five years. Trucks are involved with approximately 10 percent of all crashes but a relatively lower percentage of fatal crashes (Table 7).

- Similar to some types of trucks, school buses are also required to stop at grade crossings before proceeding across. The Ohio highway-railroad grade crossing inventory data on school bus volumes at a crossing is not sufficiently complete (only 34% of records have valid data, see Table 4) to be included in this analysis. However, it should be noted that the crash history indicates that only 1 crash out of 884 in the last 10 years has involved a "bus" and it is unknown what type of bus was involved in that crash. Until better data on school bus traffic can be obtained, conclusions on the relationship between the volume of school bus traffic and the risk of a crash at a grade crossing cannot be drawn.

- Analysis of driver action before the crash (Table 7) indicates that in a majority of grade crossing crashes, the driver either did not stop or had been stopped on the tracks prior to the crash. A slightly higher percentage of fatal and injury crashes were the result of vehicles driving around or through an activated highway gate. A more detailed analysis of this and other driver-related factors (outside the scope of the current project) may indicate possible countermeasures to reduce hazard at crossing locations such as increasing the visibility or conspicuity of existing warning devices.

- Analysis of the train speed at the time of the crash (Table 7) indicates that the train speeds at the time of fatal crashes are generally higher while train speeds at the time of injury or PDO crashes are generally lower. This relationship suggests that if crash severity is to be considered in the hazard ranking analysis, locations with higher train speeds should be given priority.

Evaluating the Effectiveness of Hazard Ranking Models

In addition to identifying grade crossing hazard ranking formulas currently in use by states for project prioritization, the literature review also identified strategies and methods for evaluating the effectiveness of hazard ranking formulas. It is difficult to evaluate the effectiveness of ranking methods against each other because the analyst is comparing models for predicting the relative hazard of different grade crossings when the actual hazards are difficult or impossible to quantify. The Missouri DOT hazard ranking research study [Qureshi, et al., 2003] identified the following eight key characteristics of a "good" grade crossing model:

- Accuracy of the Model;
- Number of "Difficult" Variables in the Model;
- Explainability of the Model;
- Number of Key Variables;
- Inclusion of Crossing Control Type;
- Number of Variables for which Data are Not Available;
- Number of Total Variables; and
- Inclusion of Weighting Factors.

For each of these characteristics, a grade crossing hazard ranking model can be assessed in a quantitative or qualitative manner. For example, a useful model includes variables which are significant in predicting crash risk at grade crossings as well as variables for which data are easily obtained. However, significant missing or outdated information in grade crossing inventory databases can restrict the usefulness of grade crossing hazard ranking models. If new variables are to be added to existing formulas, the inventory data must be reasonably complete, reasonably accurate, or able to be collected easily. As noted by Weissmann, et al. [2013], it is essential that hazard ranking formulas be compatible with existing agency practices. A quantitative measure for this attribute would be the percentage of crossings in the inventory for which data are complete and/or current.

The development of statistical models for predicting outcomes such as crashes, injuries, or fatalities at highway-railroad grade crossings requires the analyst to choose how many variables must be included in the model. While a model with a larger number of variables is more powerful in terms of explaining the variance in the model outcomes (crash prediction or hazard ranking for grade crossings), it may be difficult to utilize a larger model from a functional perspective as some data may be difficult to collect in certain cases. On the other hand, a model with fewer variables for which data are readily-available may not be satisfactory for discerning between a set of grade crossings which are very similar in terms of the model output. Developing a model for grade crossing hazard ranking which accommodates the predictive needs of the model users while also being compatible with the existing practices for field inspection and inventory data updates is desirable to maximize the usefulness of the model.

From an accuracy perspective, numerical analysis of different hazard ranking methods can be undertaken using statistical methods such as the Spearman's Rank Correlation coefficient or other rank-based statistical metrics. This type of analysis was utilized in several research studies reviewed for this project. A higher value for the Spearman's Rank Correlation

coefficient indicates greater agreement between two independent methods ranking the same data set. A study in Virginia [Faghri and Demetsky, 1986] utilized a Chi-Squared test comparing the actual and predicted number of crashes at each crossing in their comparisons, although the sample size was substantially smaller than the current number of crossings in Ohio. They also utilized a "power factor" approach which calculated the percentage of accidents which occur at the 10 percent most hazardous crossings divided by 10 percent. Therefore, the percentage of crashes expected from the most hazardous 10 percent of a group of crossings would be equal to 10 percent times the power factor. The higher the power factor, the more effective a particular hazard ranking method is in capturing the most hazardous crossings. A similar approach was used in the Texas DOT study [Weissmann, et al., 2013], which used the actual number of crashes at a certain percentage of crossings as a comparison metric.

Other Related Research Studies

Independent (i.e., non-DOT) scholarly research modeling crash risk at highway-railroad grade crossings provides additional insight as to which variables are most significant in predicting crashes at railroad grade crossings. Variables such as the exposure index (cross product of highway traffic and train volume) appear frequently in the literature as significant in crash prediction. Austin and Carson [2002] developed a crash prediction model using data from six large states and found that certain variables not included in the U.S. DOT Accident Prediction Model such as the volume of trains during nighttime hours, crossing surface type, and the presence of pavement markings were significant in crash prediction. They also commented about the difficultly in using the U.S. DOT Accident Prediction Model and noted that the model is problematic to interpret and understand which factors have a greater influence on crash probability. Saccomanno, et al. [2003] modeled grade crossing crashes in Canada and identified grade crossing surface width as a significant factor influencing crashes. Saccomanno and Lai [2005] found that the crossing intersection angle and the prohibition of train whistles at a crossing were significant contributors to crashes at grade crossings. Oh, et al. [2006] examined grade crossing safety in Korea and found that daily train volumes, proximity to commercial area, daily highway traffic volumes, the amount of warning time provided, and the presence of speed humps were significant factors in crash prediction using a gamma model structure. Miranda-Moreno and Fu [2006] compared negative binomial (NB), heterogeneous negative binomial (HNB), and zero inflated negative binomial (ZINB) as alternative models for ranking criteria and identification of hazard locations. Based on a sample of grade crossings in the Canadian railway network they found that the HNB model proved to be more flexible than NB, which was nearly equivalent to ZINB. Significant variables in the recommended HNB model included the exposure, train speed, and road speed. McCollister and Pflaum [2007] developed logit models for predicting grade crossing crash severity and found several significant variables not included in existing models, including the nighttime train volume, percentage of heavy vehicles, crossing angle, and area development type. Hu, et al. [2010] used a logit model with stepwise variable selection to identify what variables significantly predicted the likelihood of crashes using a sample of grade crossings from Taiwan. Their model found that number of daily trains, number of daily vehicles, approach markings, and highway type significantly affected the levels of accident severity. Medina and Benekohal [2015] used a zero inflated negative binomial (ZINB) model to estimate grade crossing collisions based on five years of data from Illinois. The ZINB model more accurately predicted accidents for top 50 ranking crossing and after that was nearly equal to the ranking from the U.S. DOT model.

APPENDIX B: REVIEW OF HAZARD RANKING PRACTICES

Appendix B presents a comprehensive review of common grade crossing hazard ranking formulas and the various methods used by State DOTs and other organizations to evaluate grade crossing hazards and select locations for hazard elimination projects. Also included in Appendix B is a summary and key lessons learned from each of the practitioner interviews conducted as part of Task 4 of the research study.

Review of Grade Crossing Hazard Ranking Practices

The Task 1 literature review examined current state DOT practices for grade crossing hazard ranking and project prioritization. The most common approaches to grade crossing hazard ranking are the hazard index technique and the collision prediction formula technique. A hazard index calculates a value that ranks crossings in relative terms with a higher index indicating a more hazardous crossing whereas a collision prediction formula is intended to calculate the expected annual crash frequency (and the severity of crashes, for some models). While both approaches provide the user with the same output (i.e., a ranking of the most hazardous grade crossing as defined by the model), the collision prediction formulas can be extended to analyze crash frequency or as an input to economic analysis models.

To glean insight on the most current grade crossing hazard ranking practices among states, researchers obtained and reviewed copies of the 2014 *Railway-Highway Crossing Program* annual progress reports for each state. These reports describe the projects funded in each state using Federal-aid funds (the Section 130 program) and the process used by each state to select grade crossing projects. A majority of the state reports provided a useful description of the project selection and hazard ranking practices of the states. For the most part, if a state utilized some type of formula or hazard index to support project selection, that approach was clearly noted in the state Section 130 program report. In some cases, follow-up research on individual State DOT websites was necessary to verify information or obtain information that was referenced in the state report.

Table 8 reports the current grade crossing hazard ranking practices used by states as identified by researcher review of the state Section 130 program reports and follow-up research. Additional details of specific formulas are discussed in a later section of this Appendix.

Table 8: Grade Crossing Hazard Ranking Formulas

Formula/Method	Number of States	Percent of States
U.S. DOT Accident Prediction Model	19	38%
State-Specific Formula or Method	11	22%
None/No Formula Mentioned	11	22%
New Hampshire Hazard Index	5	10%
Multiple Formulas	2	4%
NCHRP 50 Accident Prediction Model	1	2%
Peabody-Dimmick Formula	1	2%
Total All States	**50**	**100%**

Source: Ohio University research team review of state 2014 *Railway-Highway Crossing Program* annual progress reports and follow-up research.

The U.S. DOT Accident Prediction Model was reported by 19 states (38%) as the primary methodology for hazard ranking of grade crossings for project selection. Eleven states (22%) used a state-specific formula or hazard ranking method. For most of these states, the factors considered in the formula or hazard ranking method were listed in the report. A few states described the formula in sufficient detail to be replicated in this project, while other states referenced outside work or specific sections of the state's policies and procedures manuals. Eleven states (22%) reported no details of the hazard ranking methodology or used a method other than a formula-based ranking process (such as an open call for projects). Five states (10%) utilize the New Hampshire Hazard Index while one state each uses the NCHRP 50 accident prediction model and the Peabody-Dimmick Formula. It should be noted that some states reported the use of a modified version of a particular formula (i.e., adjusted coefficients or excluding a particular variable). Some states reported that multiple hazard ranking formulas were used for project selection. Specifically, Mississippi uses a state-specific weighting formula which includes the U.S. DOT Accident Prediction Model as input and Nebraska uses the U.S. DOT Accident Prediction Model and the NCHRP 50 accident prediction model.

A total of 39 out of 50 states (78%) reported the use of one or more hazard ranking formulas or provided a list of the factors considered when evaluating grade crossings for project selection. Table 9 reports the factors considered by states in their grade crossing hazard ranking formulas or other methods and the percentage of states reporting the use of each factor. The factors listed in Table 9 are based on the variables included in the formulas reported by each state or from the factors reported in the state Section 130 program report.

Based on this review of state-level practices in 39 states for which information was provided, the three most common factors considered in the hazard ranking and evaluation process for grade crossing improvement projects are highway traffic volume (AADT), train volume, and the existing warning device at the crossing – all used by more than 90 percent of states. Other key variables considered include the crash history at the crossing, train speed, and the number of railroad tracks at the crossing. Characteristics of the highway including the number of lanes and the road surface (paved or unpaved) are considered by approximately 60 percent of states. The amount of sight distance provided at a grade crossing is considered by 9 of 39 states (23%) but is not included in the U.S. DOT Accident Prediction Model. The U.S. DOT Accident Prediction Model also does not consider the highway traffic speed or the volume of school buses or other special vehicles at the crossing, but both of these factors are considered by 5 states and 4 states, respectively. Eight additional variables are considered by less than 10 percent of the states.

The factors reported in Table 9 reflect all factors considered in hazard ranking calculations or qualitative evaluation method to rank grade crossings for project selection as reported by the states. The preliminary review of the state Section 130 reports identified 11 states for which a state-specific hazard ranking formula or method was used. Of these 11 states, the exact functional form and model coefficients for the hazard ranking formula were able to be obtained for five states – Connecticut, Florida, Missouri, North Carolina, and Texas. The remaining six states – Arkansas, Colorado, Maine, Montana, Oregon, and South Dakota – provided a list of the factors considered but the model details were not described in the state Section 130 report or identified through follow-up research.

Table 9: Factors Considered by States in Grade Crossing Hazard Ranking

Factor	Number of States	Percent of States
Highway Traffic Volume (AADT)*	39	100%
Train Volume*	39	100%
Warning Device Type*	36	92%
Crash History*	29	74%
Train Speed*	29	74%
Number of Tracks*	28	72%
Highway Lanes*	24	62%
Road Surface*	23	59%
Sight Distance	9	23%
Highway Speed	5	13%
Bus/Special Vehicle Presence	4	10%
Highway Type/Functional Class	4	10%
Nearby Intersection/Driveways	3	8%
Train Type	3	8%
Approach Grade	1	3%
Crash Severity	1	3%
Crossing Angle	1	3%
Crossing Condition	1	3%
Number of Train Cars	1	3%
Pedestrian Volume	1	3%
Note: Percentage reported out of 39 states for which information was available.		
* Denotes factor included in U.S. DOT Accident Prediction Model		
Source: Ohio University research team review of state 2014 *Railway-Highway Crossing Program* annual progress reports and follow-up research.		

U.S. Department of Transportation Accident Prediction Model

The U.S. DOT Accident Prediction Model is an accident prediction model that was developed in the mid-1970s to support a comprehensive grade crossing project selection process known as the *Rail-Highway Crossing Resource Allocation Procedure* [Farr, 1987]. The purpose of the resource allocation procedure was to assist State DOTs and railroads in determining effective allocations of Federal funds for rail-highway grade crossing improvements. The U.S. DOT Accident Prediction Model is used by 19 states, including Ohio, to support hazard ranking for project selection. The basic structure of the U.S. DOT Accident Prediction Model includes the following components:

- A mathematical formula which generates a preliminary estimate of the annual frequency of crashes at a grade crossing based on the characteristics of the roadway, highway traffic, and railroad traffic at the crossing;
- Adjustment to the preliminary estimate based on the crash history at the crossing; and
- Additional mathematical formulas to predict the probability of a crash resulting in an injury or a fatality, given that a crash has occurred at the crossing.

Table 10 shows the basic structure of the U.S. DOT Accident Prediction Model formula. A normalizing constant is included in the model to calibrate the model output based on national trends in grade crossing crashes. This constant is updated on a regular basis, with the last update occurring in May 2014. Table 11 describes the calculation procedures for the various factors contributing to the initial estimate of the prediction of the number of collisions per year as well as the normalizing constants for May 2014 and the previous update, October 2010.

The FRA has developed additional tools and resources to make the U.S. DOT Accident Prediction Model more accessible to users by way of its GradeDec.net evaluation tool (https://gradedec.fra.dot.gov/) and the Web Accident Prediction System (WBAPS; http://safetydata.fra.dot.gov/webaps/). Many states utilize the WBAPS as a resource to assist with grade crossing hazard ranking and project selection.

The model structure of the U.S. DOT Accident Prediction Model has not changed substantially since its initial development in the mid-1970s. However, the variables included in the model as well as the model coefficients have undergone some revisions since the initial model development. Specifically, the last update of the model [Farr, 1987] removed a variable for the functional classification of the highway at the crossing (the "Highway Type" variable) from the initial collision prediction estimate. However, a previous version of the U.S. DOT Accident Prediction Model, with the Highway Type variable included, was published in the *Railroad-Highway Grade Crossing Handbook, Second Edition* [FHWA, 1986]. The 2007 update to this publication, the *Railroad-Highway Grade Crossing Handbook – Revised Second Edition 2007* [Ogden, 2007] included the U.S. DOT Accident Prediction Model formula verbatim from the 1986 edition of the *Handbook*, even though the formula was updated sometime around 1986 to remove the Highway Type variable as a component of the initial collision prediction estimate. It is unclear why the 2007 update of the *Railroad-Highway Grade Crossing Handbook* did not include the most updated version of the U.S. DOT Accident Prediction Model.

Table 10: U.S. DOT Accident Prediction Model Formula

Type:	Accident Prediction Model
Formula:	$a = K * EI * MT * DT * HP * MS * HL$ $B = \frac{T_0}{T_0+T}(a) + \frac{T_0}{T_0+T}\left(\frac{N}{T}\right)$ $A = B * C$
Variables:	
a:	Initial Prediction, Collisions per Year at the Crossing
K:	Formula Constant (see Table 11)
EI:	Factor for Exposure Index (see Table 11)
MT:	Factor for Number of Main Tracks (see Table 11)
DT:	Factor for Number of Daytime Trains (see Table 11)
HP:	Factor for Highway Paved (see Table 11)
MS:	Factor for Maximum Timetable Speed (see Table 11)
HL:	Factor for Number of Highway Lanes (see Table 11)
B:	Collisions per Year at the Crossing, Adjusted for Crash History
T_0:	Formula Weighting Factor = $\frac{1.0}{(0.05+a)}$
T:	Number of Years of Crash History
N:	Number of Crashes in T Years at Crossing
A:	Final Prediction, Collisions per Year at the Crossing
C:	Normalizing Constant (see Table 11)
Source: Federal Railroad Administration [2014]	

Table 11: U.S. DOT Accident Prediction Model Factors

Crossing Type:	Passive	Flashing Lights	Gates
K:	0.0006938	0.0003351	0.0005745
EI:	$\left[\frac{(EI)+0.2}{0.2}\right]^{0.37}$	$\left[\frac{(EI)+0.2}{0.2}\right]^{0.4106}$	$\left[\frac{(EI)+0.2}{0.2}\right]^{0.2942}$
MT:	1.00	$e^{0.1917*MT}$	$e^{0.1512*MT}$
DT:	$\left[\frac{(DT)+0.2}{0.2}\right]^{0.1781}$	$\left[\frac{(DT)+0.2}{0.2}\right]^{0.1131}$	$\left[\frac{(DT)+0.2}{0.2}\right]^{0.1781}$
HP:	$e^{-0.5966*(PAVED-1)}$	1.00	1.00
MS:	$e^{0.0077*MS}$	1.00	1.00
HL:	1.00	$e^{0.1826*(LANES-1)}$	$e^{0.142*(LANES-1)}$
C (2014):	0.5086	0.3106	0.4846
C (2010):	0.6768	0.4605	0.6039
EI:	Exposure = AADT * Total Trains per Day		
DT:	Number of Daylight Thru Trains per Day at Crossing		
MT:	Number of Main Tracks at Crossing		
PAVED:	Dummy Variable = 1 if Highway Paved, 2 Otherwise		
MS:	Maximum Train Speed at Crossing		
LANES:	Number of Highway Lanes at Crossing		
C:	Normalizing Constants for May 2014 and October 2010		
Source: Federal Railroad Administration [2014]			

Even though the basic structure of the U.S. DOT Accident Prediction Model has not changed since 1986, the formula still represents the state of the practice and is in extensive use by state and local agencies, including agencies in Ohio, for hazard ranking of grade crossing improvements. The popularity of the U.S. DOT Accident Prediction Model appears to be related to its defensibility as a basis for prioritization and the ease of use of the FRA WBAPS application. Additional details on the current application of the U.S. DOT Accident Prediction Model in Ohio are discussed in Appendix A.

The U.S. DOT Accident Prediction Model formula has been the subject of several studies evaluating its adequacy for grade crossing hazard ranking. Faghri and Demetsky [1986] examined highway-railroad grade crossing hazard ranking in Virginia and found that the U.S. DOT model was superior to other models available at the time of the study based on analysis of crash data from 1,536 grade crossings. Austin and Carson [2002] commented that the general structure of the U.S. DOT Accident Prediction Model is problematic to interpret and understand which factors have a greater influence on crash probability. Qureshi, et al. [2003] included the U.S. DOT model in their comparison of hazard ranking formulas in Missouri, ultimately concluding that a hazard index-type formula was preferred for use in that state. More recently, Medina and Benekohal [2015] concluded that the U.S. DOT model was more likely to under-predict the accident frequency at high-crash locations. The U.S. DOT model was also used in a recent National Cooperative Highway Research Program (NCHRP) project examining the comprehensive costs of highway-rail grade crossing crashes. The NCHRP study developed an analysis framework that use the U.S. DOT model as the basis for crash frequency and crash severity prediction at a crossing, then applies economic factors for the cost of crashes as well as the costs of equipment damage and delay to highway users and the railroad [Brod, et al., 2013].

Historical Formulas

Prior to the development of the U.S. DOT Accident Prediction Model in the mid-1970s, a variety of grade crossing hazard ranking models were used by states and other local highway agencies. A review of some of the models used in the past can be found elsewhere [Faghri and Demetsky, 1986; Elzohairy and Benekohal, 2000]. Three such models – the New Hampshire Hazard Index, the NCHRP 50 accident prediction model, and the Peabody-Dimmick Formula - have been used prominently for many decades to support grade crossing hazard ranking and are still in use today by some states. This section briefly describes these three "historical" formulas and the current status of their usage.

New Hampshire Hazard Index

The New Hampshire Hazard Index is a commonly-used hazard index type formula used for hazard ranking of grade crossings. The New Hampshire Hazard Index, described in Table 12, is currently used by five states (Kansas, Louisiana, Massachusetts, Michigan, and Nevada) as the primary method for ranking grade crossings for improvement. It is unclear from the research team review of current hazard ranking practices if the New Hampshire Hazard Index is currently in use in the state for which it is named. The New Hampshire Hazard Index is the most basic form of the hazard index model type consisting of the exposure index (cross product of the AADT and train volume) with a "protection factor" adjustment for the type of warning device provided at the crossing.

The New Hampshire Hazard Index, or local modifications thereof, appears to be the most common hazard ranking formula used by states historically [Faghri and Demetsky, 1986; FHWA, 1986; Elzohairy and Benekohal, 2000; Qureshi, et al., 2003] and many modifications of the basic formula shown in Table 12 appear in the literature. However, based on the research team review of current practices described in a previous section of this report, many states that previously utilized a hazard index similar to the New Hampshire Hazard Index are now using the U.S. DOT Accident Prediction Model.

Table 12: New Hampshire Hazard Index Formula

Type:	Hazard Index
Formula:	$HI = (V) * (T) * (PF)$
Variables:	
HI:	Calculated Hazard Index
V:	Annual Average Daily Traffic
T:	Train Movements per Day
PF:	Protection Factor: • 0.1 – Automatic Gates • 0.6 – Flashing Lights • 1.0 – Signs Only
Source: Ogden [2007], Appendix F	

NCHRP 50 Accident Prediction Model

Published in 1968, NCHRP Report 50 [Shoppert and Hoyt, 1967] investigated factors influencing safety at highway-rail grade crossings. NCHRP 50 included the development of a mathematical model for predicting train-vehicle collisions at grade crossings as well as non-train-involved crashes in the vicinity of crossings. The NCHRP 50 accident prediction model, described in Table 13, is currently used by one state (Illinois) as the primary method for grade crossing hazard ranking and used by one other state (Nebraska) jointly with another method. The NCHRP 50 model is a simple multiplicative model which predicts the expected annual crash frequency at a crossing based on the AADT, train volume, and the type of warning device at the crossing. The AADT enters the prediction model as a "traffic factor" which increases in value with increasing AADT. In practice, a grade crossing which has an expected accident frequency (EAF) of 0.02 or higher (i.e., one crash every 50 years) would indicate the need for a warning device upgrade.

Table 13: NCHRP 50 Accident Prediction Model Formula

Type:	Accident Prediction Model
Formula:	$EAF = A * B * T$
Variables:	
EAF:	Expected Accident Frequency
A:	Traffic Factor: Based on AADT Approximated as follows: 0.0000012 (AADT) + 0.0006239
B:	Protection Factor: • 3.89 – Crossbucks, AADT < 500 • 3.06 – Crossbucks, Urban • 3.08 – Crossbucks, Rural • 4.51 – Stop Signs, AADT < 500 • 1.15 – Stop Signs • 0.61 – Wigwags • 0.23 – Flashing Lights, Urban • 0.93 – Flashing Lights, Rural • 0.08 – Gates, Urban • 0.19 – Gates, Rural
T:	Current Number of Trains per Day
Source: Ogden [2007], Appendix F	

Peabody-Dimmick Formula

The Peabody-Dimmick formula was developed by L.E. Peabody and T.B. Dimmick of the U.S. Bureau of Public Roads (BPR) in 1941. The Peabody-Dimmick formula is an accident prediction model type formula based on crash data and grade crossing characteristics of over 3,500 grade crossings in rural areas of 29 states. Table 14 describes the Peabody-Dimmick formula. The Peabody-Dimmick formula is currently in use in one state (Georgia) for grade crossing hazard ranking. The state Section 130 report for Georgia indicates that they use a modified version of the Peabody-Dimmick formula although the modifications are not reported. Calculations for the Peabody Dimmick formula are based on a series of curves relating the various factors considered in the model which include the AADT, daily train volumes, the type of warning device at the crossing, and an adjustment factor.

Table 14: Peabody-Dimmick Formula

Type:	Accident Prediction Model
Formula:	$A_5 = 1.28\frac{(V^{0.170})(T^{0.151})}{P^{0.151}} + K$
Variables:	
A_5:	Expected Number of Accidents in Five Years
V:	Annual Average Daily Traffic
T:	Average Daily Train Traffic
P:	Protection Coefficient; See chart below.
K:	Additional Parameter; See chart below.

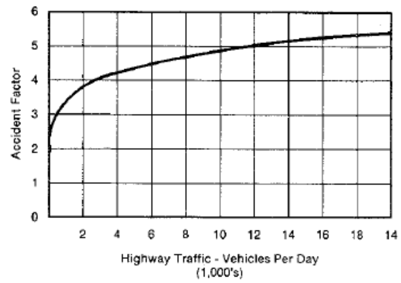

Figure 13a. Relation Between Highway Traffic and Accident Factor, V^a

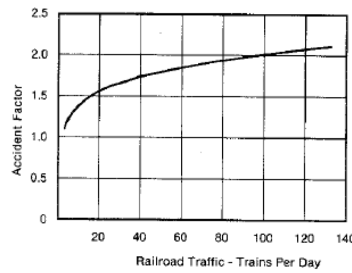

Figure 13b. Relation Between Railroad Traffic and Accident Factor, T^b

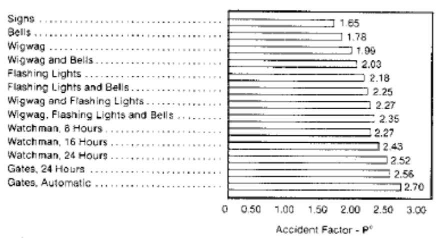

Figure 13c. Relation Between Warning Device and Accident Factor, P^c

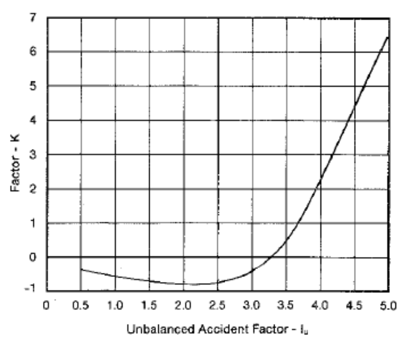

Figure 13d. Relation Between Unbalanced Accident Factor and Additional Parameter, K

The basic form of the equation for use with these curves is:

$$1.28 \frac{V^a \times T^b}{P^c} + K$$

EXAMPLE: Assume a crossing has an AADT of 3,442 vehicles, an average train traffic of 22 trains per day, and is equipped with wigwags. From Figure 13a, the factor due to highway traffic of 3,442 vehicles per day is found to be 3.99. From Figure 13b, the factor due to train traffic of 22 trains per day is found to be 1.59, and from Figure 13c, the factor for wigwags is found to be 1.99. Substituting these factors into the equation, it is found that the hazard index is equal to:

$$1.28 \frac{3.99 \times 1.59}{1.99} + K \quad \text{or,} \quad 4.08 + K.$$

From Figure 13d, K is determined to be + 2.58 for a value of I_u of 4.08 and, with this value for the parameter, the expected number of accidents in 5 years is 6.66.

Source: Ogden [2007], Appendix F

State-Level Hazard Ranking Practices

This section discusses the results of the Task 1 literature review pertaining to grade crossing hazard ranking practices of certain individual states. Detailed information about state-specific hazard ranking formulas was obtained for the states of Connecticut, Florida, Missouri, North Carolina, and Texas. Additionally, the research team identified innovative or noteworthy grade crossing hazard ranking and/or project selection practices in the states of California, Illinois, Michigan, and New Mexico. The key lessons learned from interviews with state DOT personnel conducted as part of Task 4 of this research project are also included in this section.

California

The California Public Utilities Commission (CPUC) is responsible for hazard ranking and project selection for highway-railroad grade crossing improvement projects in the state of California. A summary of the CPUC project development process is provided in a document titled *CPUC Guidelines for the Federal Aid At-Grade Highway-Rail Crossing Program* available from the CPUC website. Researchers conducted a telephone interview with a CPUC representative on November 20, 2015, to obtain more details about the CPUC's project selection and grade crossing hazard ranking practices.

The annual CPUC project selection process is a multi-stage process. First, a preliminary list of 100 to 300 grade crossings are identified as potential candidates for improvement projects. This preliminary list includes crossings that are "flagged" throughout the year due to a fatality occurring at the location, locations that are frequent for "near miss" incidents as reported by some railroads operating in the state, and local highway authority requests. Additionally, the Top 100 most hazardous crossings in California as reported by the FRA WBAPS are also included in the preliminary list. CPUC staff will screen the preliminary list for Section 130 program eligibility and other factors to arrive at a final list of 10 to 30 crossings that will be examined in greater detail by a field diagnostic review team.

The CPUC utilizes the U.S. DOT Accident Prediction Model, as described in the 2007 version of the *Railroad-Highway Grade Crossing Handbook – Revised Second Edition*, for hazard ranking of grade crossing locations. The CPUC also uses the crash severity formulas which accompany the U.S. DOT Accident Prediction Model. The final project prioritization is established using a matrix that consists of six factors, including the expected crash frequency as well as the frequency of fatal and injury crashes. The other factors considered in the matrix include an economic analysis and the potential danger posed by regular use of the crossing by pedestrians, bicyclists, school buses, transit buses, and hazmat vehicles, and other state-specific factors. In the past, the CPUC utilized a state-specific hazard index-type formula for the purpose of developing a grade crossing hazard ranking. The CPUC staff reported that the old hazard index formula was set aside approximately 10 years ago and the current formula was adopted for use. The rationale for adopting the U.S. DOT Accident Prediction Model was that the use of the accident prediction model was more transparent and more defensible for use in project selection, and it better-aligned with the broader goals of the FHWA safety programs. The CPUC staff also reported that the data inputs to the hazard ranking formula are updated after the preliminary list of crossings is developed, allowing for more accurate outputs to be used in the screening and final evaluation.

Connecticut

The Connecticut Department of Transportation (CTDOT) is responsible for hazard ranking and project selection for highway-railroad grade crossing improvement projects in the state of Connecticut. The CTDOT uses a modified version of the New Hampshire Hazard Index to prioritize grade crossings for project selection. The CTDOT hazard ranking index formula, outlined in Table 15, is described in its *Railway-Highway Crossing Program 2014 Annual Report*. The CTDOT hazard ranking index is a more advanced version of the New Hampshire Hazard Index because it includes more protection factors for different types of warning devices at grade crossings as well as an adjustment for crash history. No interviews with staff of the CTDOT were conducted for this research study.

Table 15: CTDOT Hazard Ranking Index Formula

Type:	Hazard Index
Formula:	$HI = \frac{(T+1)*(A+1)*AADT*PF}{100}$
Variables:	
HI:	Calculated Hazard Index
T:	Train Movements per Day
A:	Number of Vehicle/Train Accidents in the Last 5 Years
AADT:	Annual Average Daily Traffic
PF:	Protection Factor: • 1.250 – No Active or Passive Warning Devices • 1.000 – Stop Sign Control • 0.750 – Stop and Protect Control • 0.750 – Manually-Activated Traffic Signal • 0.250 – Railroad Flashing Lights • 0.250 – Traffic Signal Control with Preemption • 0.010 – Gates with Railroad Flashing Lights • 0.001 – Inactive Rail Line • 0.000 – Closed Crossing
Source: CTDOT *Railway-Highway Crossing Program 2014 Annual Report*	

Florida

The Florida Department of Transportation (FDOT) is responsible for hazard ranking and project selection for highway-railroad grade crossing improvement projects in the state of Florida. FDOT uses a hybrid accident prediction model/hazard index developed by researchers at Florida State University (FSU) to prioritize grade crossings for project selection [Niu, et al., 2014]. The FDOT Safety Hazard Index formula, outlined in Table 16, is based on a logistic regression model for crash prediction with adjustments for crash history, warning device type, and the presence of school buses at a crossing. Variables included in the FDOT model but not currently used in the U.S. DOT model include the highway vehicle speed, the total number of tracks, and the number of school buses at a crossing. Researchers requested an interview with FDOT personnel to obtain more information about the FDOT Safety Hazard Index formula and other details of grade crossing project selection in Florida for this research study. FDOT provided an initial response in which the research report describing the development of the most recent Safety Hazard Index was provided to the research team. Researchers made multiple requests for a detailed follow-up interview with FDOT personnel but no reply was received.

Table 16: FDOT Safety Hazard Index Formula

Type:	Hybrid Accident Prediction Model/Hazard Index
Formula:	$t = -8.896 + 0.780Risk + 0.020MTS + 0.014HWSPD + 1.023Track + 0.965Lane - 0.540Flash$
Final Prediction:	$P = exp(t)/[1 + exp(t)]$
Adjustment for Accident History:	$P^* = P\sqrt{H/(P * Y)}$
Safety Index:	$I = 90 + \left(1 - \sqrt{\frac{P^*}{MAXP}}\right) - 5 \times \left(log_{10}(B + 1)\right) \times F$
Variables:	
Risk:	Log(Train)*AADT
Train:	Yearly Average of the Number of Trains per Day
AADT:	Annual Average Daily Traffic
MTS:	Maximum Timetable Speed
HWSPD:	Posted Vehicle Speed Limit or State Statutory Speed Limit
Track:	Log(Main Tracks + Other Tracks)
Lane:	Number of Highway Lanes
Flash:	Dummy Variable = 1 if Any Flashers Present, 0 Otherwise
Y:	Predicted Number of Accidents per Year at Crossing Adjusted for History
H:	Number of Accidents at Crossing during History Period
P:	Number of Years of Accident History Period
I:	Safety Index Value
MAXP:	Maximum Value of Incident Prediction
B:	Number of School Buses at Crossing
F:	Variable = 1 if Active Warning Devices, 2 if Passive Warning Devices
Source: Niu, et al. [2014]	

Illinois

The Illinois Department of Transportation (IDOT) and the Illinois Commerce Commission (ICC) are responsible for hazard ranking and project selection for highway-railroad grade crossing improvement projects in the state of Illinois. IDOT is responsible for managing the federally-funded the Section 130 program while the ICC manages a similar program for local highways funded exclusively with state funds. The ICC program is funded by a portion of the state motor fuel tax that is directed toward railroad safety improvements.

In September 2000, IDOT published a comprehensive research study conducted by the Illinois Transportation Research Center (ITRC) at the University of Illinois at Urbana-Champaign (UIUC) focused on improving grade crossing hazard ranking models for use in Illinois [Elzohairy and Benekohal, 2000]. This report evaluated grade crossing hazard ranking formulas in use at the time of the study and developed a new hazard ranking index formula for use in Illinois calibrated to Illinois-specific grade crossing data. This report also conducted a comprehensive review of grade crossing hazard ranking formulas in use at the time of the study. The results of both tasks are informative for the current research project. First, the new hazard index that was developed was shown to be superior to the existing model used by IDOT (NCHRP 50) but the data required to operate the formula was deemed to be incomplete within the existing inventory of grade crossing data in the state. However, the Illinois Section 130 program annual report did not indicate that the new formula was adopted by IDOT. Second, the review of state formulas in use at the time of the study revealed that several states – California, Kansas, and New Mexico – reported the use of fairly complex hazard index-type ranking models. However, these same states reported the use of different methods in their 2014 state Section 130 program annual reports. These issues were discussed during practitioner interviews with state DOT personnel of these three states as described elsewhere in this appendix.

In light of the inconsistency between the UIUC research study and the hazard ranking practices reported in the IDOT Section 130 program report, researchers contacted IDOT representatives to obtain more details about IDOT's project selection process and grade crossing hazard ranking practices. Researchers conducted a telephone interview with an IDOT representative on December 7, 2015. The IDOT representative confirmed that the agency still utilizes the NCHRP 50 Accident Prediction Model formula for grade crossing hazard ranking and noted that the use of this formula was described in the IDOT *Bureau of Design and Environment Manual*.

The IDOT grade crossing project development process consists of an annual letter distributed to local highway authorities (counties, townships, and municipalities) describing the grade crossing program and soliciting applications for grade crossing warning device improvement projects. Information provided on the two-page application includes the grade crossing location, physical characteristics of the grade crossing, highway traffic information, and railroad traffic information. The application also includes a section calculating the Expected Crash Frequency (ECF) as calculated by the NCHRP 50 Accident Prediction Model formula. IDOT received approximately 90 applications during the most recent program year with approximately 30 projects funded. IDOT staff emphasized that the project application process should only focus on the data required to make a decision about funding a project; for example, the volume of school buses at a crossing is requested on the application form but is not used in a formal way to evaluate crossing hazard or prioritize projects.

The IDOT staff interviewed for this project expressed no concerns about the use of the NCHRP 50 Accident Prediction Model formula to support the project prioritization process. They noted that the "B" factors included in the formula (see Table 13) are easy to understand. IDOT staff also noted that the local highway authorities provided input data for highway traffic volume (AADT) but that there was limited consultation with the railroads on the part of the local highway authorities regarding train volumes. With respect to data sources, IDOT staff stated that the AADT information provided by the local highway authority was cross-checked with IDOT traffic services data as well as existing data in the grade crossing inventory database. Train volume data are addressed in a similar manner. Additionally, IDOT staff noted that local highway authorities generally had limited communication with the railroads at all during the project development phase and that project development would be improved if this communication would take place. Finally, IDOT staff suggested that evaluation of grade crossing locations would be improved if a map could be developed showing the grade crossing along with locations of schools, hospitals, fire stations, other special services, and hazmat concerns such as fertilizer plants within a certain distance of a crossing. This map would serve to inform prioritization with consideration for these circumstances on a qualitative basis instead of using a formula that analytically evaluated these factors.

Based on current IDOT practice, it appears that IDOT did not re-address the issues preventing it from using the more advanced model developed through the research project. Follow-up discussion with IDOT staff on this issue indicates that the staff did not adopt the hazard index developed through the research project because the staff was not convinced that the proposed hazard index did any better at predicting crashes than the existing NCHRP 50 model and that the NCHRP 50 model was simple and practical to use.

Kansas

The Kansas Department of Transportation (KDOT) is responsible for hazard ranking and project selection for highway-railroad grade crossing improvement projects in the state of Kansas. KDOT utilizes the New Hampshire Hazard Index (see Table 12) for grade crossing hazard ranking. Researchers conducted a telephone interview with KDOT staff on November 25, 2015, to obtain more details about KDOT's project selection and grade crossing hazard ranking practices. KDOT's project development process includes an annual ranking of all crossings based on the hazard index value and field diagnostic review at approximately 40 to 50 crossings per year. KDOT also uses a list of crossings provided by certain railroads where "near-miss" or other "unsafe behavior" is observed by some train engineers to assist with the development of the annual program. However, KDOT staff noted that most of these grade crossings already have gates and lights so little more can be done at these locations. KDOT also noted that all crossings with preemption are reviewed annually to ensure that the elements of these control systems are working correctly with updated traffic information.

KDOT staff interviewed for this project expressed satisfaction with the performance of the New Hampshire Hazard Index formula for grade crossing hazard ranking. KDOT staff noted that the New Hampshire Index is simple to use and focuses on the key variables – exposure and the existing warning device. The fact that crash history is not included was not a concern to KDOT staff as the exposure is more of a measure of crash potential or risk than the crash history at a particular location. KDOT adopted the New Hampshire Index in the mid-2000s following a complete update of the statewide grade crossing inventory. Following this update, a KDOT-funded research study concluded that the "Design Hazard Rating Formula" previously used by

KDOT was not suitable for use with the updated database due to a lack of information about sight distance at the crossing and that the New Hampshire formula was superior in identifying crash locations [Burns & McDonnell Engineering Company and Kraft, 2001].

Michigan

The Michigan Department of Transportation (MDOT) is responsible for hazard ranking and project selection for highway-railroad grade crossing improvement projects in the state of Michigan. MDOT utilizes a modified version of the New Hampshire Hazard Index (as shown in Table 17) for grade crossing hazard ranking.

Table 17: Michigan DOT Hazard Ranking Index Formula

Type:	Hazard Index
Formula:	$HI = (V) * (T) * (PF)$
Variables:	
HI:	Calculated Hazard Index
V:	Annual Average Daily Traffic
T:	Train Movements per Day
PF:	Protection Factor: • 1.00 – Crossbuck Sign with or Without Yield Sign • 0.80 – Crossbuck Sign with a Stop Sign • 0.75 – Stop and Flag Procedures • 0.33 – Flashing Light Signals with any 8" Lenses • 0.30 – Flashing Light Signals with all 12" Lenses • 0.27 – Flashing Light Signals with Cantilever Arms and any 8" Lenses • 0.24 – Flashing Light Signals with Cantilever Arms and all 12" Lenses • 0.11 – Flashing Light Signals with Roadway Gates and any 8" Lenses • 0.10 – Flashing Light Signals with Roadway Gates and all 12" Lenses • 0.09 – Flashing Light Signals with Cantilever Arms and Roadway Gates and any 8" Lenses • 0.08 – Flashing Light Signals with Cantilever Arms and Roadway Gates and all 12" Lenses • 0.10 – Any Passive Warning Device with Traffic Signal Interconnection • 0.10 – Any Active Warning Device with Traffic Signal Interconnection
Source: Unpublished correspondence with Michigan DOT	

Researchers conducted a telephone interview with an MDOT staff member on February 1, 2016, to obtain more details about MDOT's project selection and grade crossing hazard ranking practices. The MDOT project development process is handled through the MDOT central office and is an annual, multi-stage process. A preliminary list of approximately 250 crossings is developed, from which approximately 50 to 60 field diagnostic reviews are scheduled. State law requires that a field diagnostic review be convened for any grade crossing location with more than one crash in the past five years. Additionally, MDOT allows for each of the state's four grade crossing inspectors to nominate up to two locations as "inspector's choice" grade crossing location for diagnostic review. MDOT staff noted that the inspector's choice option allows for crossings that would otherwise not be included in the annual program to be considered based on the inspector's knowledge of local conditions and other factors. A total of approximately 35 to 45 projects are funded each year through the MDOT Section 130 program. MDOT reported that a wide range of project types are funded that still meet the criteria for

hazard reduction under the Section 130 program. One example provided was a location where a crash analysis found that all recent crashes happened during nighttime hours. Based on this analysis, Section 130 funds were used to provide illumination at this crossing location.

Several aspects of MDOT's application of the New Hampshire Hazard Index are worth additional discussion. The MDOT modifications include more protection factors than typical applications of the New Hampshire Hazard Index. The protection factors used by MDOT were developed by a multi-disciplinary team of experts within the agency and consider variables such as the presence of cantilever arms as well as the size of the flashing light lens. The differences in the protection factors are based on the anticipated reduction in risk at a crossing if cantilever arms or larger flashing light lenses are used. In addition to using the hazard index calculations for prioritizing grade crossing locations, the hazard index values are used to identify the distribution of relative risk on a statewide basis as well as to calculate an average hazard index value for grade crossings that have had a crash during the previous five-year period. These calculations are used by MDOT as a point of reference to analyze grade crossing safety in the state and to assist with the distribution of funds at different locations.

Missouri

The Missouri Department of Transportation (MoDOT) is responsible for hazard ranking and project selection for highway-railroad grade crossing improvement projects in the state of Missouri. MoDOT utilizes a state-specific hazard index for grade crossing hazard ranking. Table 18 describes the Missouri DOT Exposure Index formula.

Table 18: Missouri DOT Exposure Index Formula

Type:	Hazard Index
Formula: (Passive Crossings)	$EI = TI + SDO(TI)$
Formula: (Active Crossings)	$EI = TI$
Variables:	
TI:	Traffic Index = $\frac{(VM*VS)[(FM*FS)+(PM*PS)+(SM*10)]}{10000}$
SDO:	Sight Distance Obstruction Factor = $\frac{Required\ Sight\ Distance - Actual\ Sight\ Distance}{Required\ Sight\ Distance}$
VM:	Annual Average Daily Traffic
VS:	Vehicle Speed
FM:	Daily Freight Train Movements at Crossing
FS:	Freight Train Speed
PM:	Daily Passenger Train Movements at Crossing
PS:	Passenger Train Speed
SM:	Daily Switching Movements at Crossing
Source: Qureshi, et al. [2003]	

The MoDOT Exposure Index formula is an advanced hazard index-type formula which requires detailed data on specific train types at a crossing (freight, passenger, or switching

movements) and the corresponding speeds of those movements. The MoDOT Exposure Index formula also incorporates available sight distance at the crossing. In December 2003, MoDOT published a research study investigating its current practices for highway/rail crossing project selection [Qureshi, et al., 2003]. This study compared several grade crossing hazard ranking formulas with the MoDOT Exposure Index formula and found sufficient cause to replace the existing formula with a new formula to prioritize crossings. The researchers suggested that the formula used in Kansas would be a suitable alternative and recommended further study on the possible implementation of this recommendation. However, the MoDOT study utilized the formulas and coefficients for other state formulas that were previously identified in the Illinois DOT study [Elzohairy and Benekohal, 2000]. Evidence from the review of current hazard ranking practices conducted for the present study indicates that Missouri is still using the MoDOT Exposure Index formula for hazard ranking and furthermore, the Kansas model which was recommended for adoption in Missouri is no longer used in Kansas. This discrepancy was explored in greater detail with both Missouri and Kansas.

Researchers conducted a telephone interview with MoDOT staff on November 17, 2015, to obtain more details about MoDOT's project selection and grade crossing hazard ranking practices. MoDOT staff confirmed that the exposure index equation described in Table 18 was still in use for grade crossing hazard ranking in Missouri. MoDOT staff also noted that the results of the research study [Qureshi, et al., 2003] recommending that MoDOT adopt a hazard index model similar to Kansas was ultimately not adopted because Kansas was changing its hazard ranking model during the same time period (see previous discussion of Kansas DOT). The FRA WBAPS tool as well as "near-miss" data from some railroads are also used in the MoDOT project development process. The MoDOT project development process is managed by the central office and does not include any formal solicitation to local highway authorities, nor are crossing locations with a fatality automatically included in the annual program.

MoDOT staff did not express any concerns about the use of the exposure index formula. Although the formula does include sight distance as a factor for passive crossings only, MoDOT staff noted that the sight distance factor does not have much influence on the rankings. Additionally, MoDOT staff raised the issue of crops having an impact on sight distance and the difficulty in evaluating sight distance. With respect to data reliability issues, MoDOT staff noted that the railroads are required by Missouri law to provide updated train volume counts annually and that there are no issues with these data. Regarding AADT data, MoDOT staff expressed concern about the accuracy of AADT data as well as issues with AADT values for crossing locations in fast-growing areas where inventory data had not yet been updated. MoDOT staff provided another example where Section 130 funds were applied to upgrade a crossing in an industrial park where a significant amount of truck traffic was expected in the near future but the traffic volume was not recorded in the inventory database.

The MoDOT research study is also informative to the current research study because of the innovative approach that was used to evaluate the hazard ranking formulas. Researchers assembled an expert panel consisting of MoDOT employees who were asked to provide input on the key characteristics of a "good" grade crossing model and the variables that would be included in a "good" grade crossing model. The desired qualities agreed upon by the expert panel in the MoDOT research study included [Qureshi, et al., 2003]:

- Accuracy of the Model;

- Number of Difficult Variables in the Model;
- Explainability of the Model;
- Number of Key Variables;
- Inclusion of Crossing Control Type;
- Number of Variables for which Data are Not Available;
- Number of Total Variables; and
- Inclusion of Weighting Factors.

These eight factors are likely to be relevant to the ORDC and the PUCO and are therefore applicable to this research study as well. To assess the accuracy of the models compared in the study, the expert panel ranked 12 randomly-selected crossings in Missouri based on their judgment of which were the most hazardous. This ranking formed the basis for the detailed analysis and comparison of the formulas evaluated in the study.

New Mexico

The New Mexico Department of Transportation (NMDOT) is responsible for hazard ranking and project selection for highway-railroad grade crossing improvement projects in the state of New Mexico. Researchers conducted a telephone interview with NMDOT staff on December 11, 2015, to obtain more details about NMDOT's project selection and grade crossing hazard ranking practices. New Mexico had been selected for more detailed study in this project because a previous research study [Elzohairy and Benekohal, 2000] had reported the use of a state-specific hazard index in New Mexico but the state Section 130 program had indicated the use of the U.S. DOT Accident Prediction Model. NMDOT staff confirmed that the U.S. DOT Accident Prediction Model is used for hazard ranking in New Mexico through the FRA WBAPS tool. NMDOT receives "near-miss" data from some railroads operating in the state and uses that information along with feedback from railroads, local highway authorities, and citizens to develop its annual program. NMDOT staff noted that the AADT data in the grade crossing inventory database was an issue particularly for low-volume local roads. One potential solution to this issue mentioned by NMDOT was to use a countywide average AADT by functional classification; however, one challenge with this approach is that it is difficult to distinguish between the levels of hazard risk at different crossings if the AADT values are assumed to be the same. Additionally, NMDOT staff mentioned that the U.S. DOT formula did not account for certain factors that may affect safety at grade crossings, including sight distance, nearby highway intersections, preempted traffic signals, observed and posted highway speeds, and the condition of the crossing surface.

North Carolina

The North Carolina Department of Transportation (NCDOT) is responsible for hazard ranking and project selection for highway-railroad grade crossing improvement projects in the state of North Carolina. NCDOT utilizes a state-specific hazard index known as the NCDOT Investigative Index model for grade crossing hazard ranking. The NCDOT Investigative Index model, outlined in Table 19, is described in the North Carolina *Railway-Highway Crossing Program 2014 Annual Report*. The NCDOT Investigative Index model was initially developed in the 1970s and has been updated as issues with the model were identified in the 1980s.

The NCDOT Investigative Index incorporates variables not included in the U.S. DOT Accident Prediction Model such as available sight distances at the crossing, total number of tracks, and AADT adjustments for school bus passenger counts and passenger trains. The NCDOT Investigative Index also includes protection factor adjustments to account for traffic signal preemption at a nearby signalized intersection. Researchers contacted staff from NCDOT to clarify additional details of the NCDOT Investigative Index. A full interview was not conducted as some information was already available about the NCDOT grade crossing project selection and hazard ranking process from another recent research study being led by the Texas A&M Transportation Institute, a partner on the current research study.

Table 19: North Carolina DOT Investigative Index Formula

<table>
<tr><td>Type:</td><td>Hazard Index</td></tr>
<tr><td>Formula:</td><td>$II = \frac{PF*ADT*TV*TSF*TF}{160} + \left(70 * \frac{A}{Y}\right)^2 + SDF$</td></tr>
<tr><td>Variables:</td><td></td></tr>
<tr><td>II:</td><td>Investigative Index Value</td></tr>
<tr><td>PF:</td><td>Protection Factor:
• 1.0 – No Warning Devices
• 1.0 – Crossbuck Signs
• 0.5 – Traffic Signal Preemption Only
• 0.2 – Flashing Light Signals
• 0.1 –Flashing Lights with Gates</td></tr>
<tr><td>ADT:</td><td>Average Daily Traffic
• If school buses use crossing, add (Number of Bus Passengers/1.2) to ADT
• If passenger trains use crossing, ADT * 1.2</td></tr>
<tr><td>TV:</td><td>Daily Train Volume</td></tr>
<tr><td>TSF:</td><td>Train Speed Factor = $\frac{Maximum\ Train\ Speed}{50} + 0.8$</td></tr>
<tr><td>TF:</td><td>Track Factor
<table>
<tr><th>No. of</th><th colspan="5">No. of Through Tracks</th></tr>
<tr><th>Tracks</th><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th></tr>
<tr><td>1</td><td>1.00</td><td>1.00</td><td>--</td><td>--</td><td>--</td></tr>
<tr><td>2</td><td>1.50</td><td>1.75</td><td>2.00</td><td>--</td><td>--</td></tr>
<tr><td>3</td><td>1.60</td><td>1.85</td><td>2.25</td><td>2.50</td><td>--</td></tr>
<tr><td>4</td><td>1.75</td><td>2.00</td><td>2.50</td><td>2.75</td><td>3.00</td></tr>
</table></td></tr>
<tr><td>A:</td><td>Number of Crashes over History Period</td></tr>
<tr><td>Y:</td><td>Number of Years in Crash History</td></tr>
<tr><td>SDF:</td><td>Sight Distance Factor = $\frac{sum(SDF_n)}{4} * 16$
Where SDF_n = Sight Distance Factor for Quadrant n:
• SDF = 0 for Sight Distance Open/Clear
• SDF = 2 for Sight Distance Average
• SDF = 4 for Sight Distance Poor</td></tr>
<tr><td colspan="2">Source: NCDOT Railway-Highway Crossing Program 2014 Annual Report</td></tr>
</table>

NCDOT provided additional details regarding the NCDOT Investigative Index and its project selection practices to researchers via e-mail correspondence. As previously stated, the NCDOT Investigative Index includes a component for sight distance as well as for passenger trains in a crossing and school bus passengers using a crossing. NCDOT noted that the sight

distance component is subjective and that there are concerns about how the data are reported. NCDOT staff also expressed concern regarding the reliability of school bus passenger data. NCDOT does not use any "near-miss" data from railroads and noted that railroads operating in North Carolina are hesitant to provide such data due to inconsistency in what constitutes a "near-miss" incident. While NCDOT did not express any issues or concerns with using the Investigative Index model, staff did note that the agency plans to move toward a decision system based on an economic analysis and has already developed a method for doing so that utilizes the U.S. DOT Accident Prediction Model for the safety analysis component. A report describing the proposed method, based on the method developed for *NCHRP Report 755* [Brod, et al., 2013], was published by NCDOT in 2015 [Cruz, et al., 2015]. NCDOT staff believes that an economic analysis provides for flexibility to incorporate additional items not previously considered as part of a grade crossing analysis.

Texas

The Texas Department of Transportation (TxDOT) is responsible for hazard ranking and project selection for highway-railroad grade crossing improvement projects in the state of Texas. TxDOT utilizes the Texas Priority Index, a state-specific hybrid accident prediction model and hazard index formula developed as part of a 2013 research study [Weissmann, et al., 2013]. The primary purpose of the TxDOT research study was to develop a comprehensive method for addressing warning device project prioritization at low-volume crossings with passive warning devices. The final product of the research study included a crash prediction model, a system of warrants to identify passive crossings for warning device upgrade consideration, and a prioritization index for ranking passive crossings. The TxDOT research study evaluated the proposed model against the previous model used in Texas and demonstrated how the proposed model improved the prioritization process. As a result, TxDOT has implemented the revised Texas Priority Index as well as the passive crossing warrant system in its project development process.

The revised Texas Priority Index, shown in Table 20, includes a detailed accident prediction model and an equation to convert the predicted number of accidents into a priority index which also considers the accident history at the crossing. The Texas Priority Index was estimated using negative binomial regression models based on data from Texas grade crossings and crash history. Notable variables that were significant in the model include area type (urban or rural), sight distance, the presence of a nearby intersection, and the roadway speed limit. Other variables tested but not significant in the final model included the volume of school buses, the intersection angle of the crossing, and the existence of a hump or dip at the crossing location.

Staff from the TxDOT rail division were interviewed as part of this research project by the Texas A&M Transportation Institute on December 28, 2015. The interview discussed project selection, prioritization, and TxDOT's experiences with the revised Texas Priority Index formula. The annual TxDOT project selection process starts with a data integrity review to verify traffic counts, train volumes, crash data, and other data inputs. A preliminary project list of approximately 150 locations is developed. Some locations are eliminated from consideration if a railroad is not willing to assume the cost of maintaining the warning device equipment. A diagnostic review team visits the remaining locations. Other data sources used in the project development process include FRA crash data, broken gate reports, and state crash records. Data on "near-miss" incidents are not actively used in the project development process unless the railroads provide the information. The FRA WBAPS tool is not used by TxDOT for any

prioritization. TxDOT staff did not express any major concerns about the revised Texas Priority Index Formula. The primary concern is related to the integrity of the data, some of which is approaching several years old. TxDOT staff did note that the revised priority index formula is complex enough that it is difficult prior to a diagnostic review to understand why some crossings are higher ranked than others. With the previous Texas Priority Index, the primary driver for selection was auto and/or train traffic levels, so the complexity of the revised index was viewed as a positive since it better identifies possible safety hazards.

Table 20: Texas Priority Index Formula

Type:	Hybrid Accident Prediction Model/Hazard Index
Formula:	$\mu = exp\left[-6.9240 + PF + (0.2587 * HwyPaved) - (0.3722 * UrbanRural) + (0.0706 * TrafLane) + (0.0656 * TotalTrack) + (0.0022 * ActualSD) + (0.0143 * MaxSpeed) + (0.0126 * MinSpeed) + \left(1.0024 * log_{10}(TotalTrn + 0.5)\right) + \left(0.4653 * log_{10}(AADT)\right) - (0.2160 * NearbyInt) + (0.0092 * SpeedLmt)\right]$ $TPI_{Revised} = 1000 * \mu * (A_5 + 0.1)$
Variables:	
μ:	Predicted Number of Crashes per Year
PF:	Protection Factor: • 0.5061 – Flashing Lights • -0.2006 – Gates • 0 – Crossbucks
HwyPaved:	Dummy Variable = 1 if Highway Paved; 2 Otherwise
UrbanRural:	Dummy Variable = 1 if Urban, 2 if Rural
TrafLane:	Number of Roadway Lanes
TotalTrack:	Total Number of Tracks at Crossing
ActualSD:	Actual Stopping Sight Distance for Approach
MaxSpeed:	Maximum Typical Train Speeds
MinSpeed:	Minimum Typical Train Speeds for Switching
TotalTrn:	Total Daily Trains
AADT:	Annual Average Daily Traffic
NearbyInt:	Dummy Variable = 1 if Intersection Nearby; 2 Otherwise
SpeedLmt:	Roadway Speed Limit on Approach
$TPI_{Revised}$:	Revised Texas Priority Index
A_5:	Number of Crashes in Last Five Years at Crossing
Source: Weissmann, et al. [2013]	

Synthesis: Current Grade Crossing Hazard Ranking Practices

Grade Crossing Hazard Ranking Models

The U.S. DOT Accident Prediction Model is the most widely-used hazard ranking model, currently used in 19 states (including Ohio) for grade crossing hazard ranking. The accessibility of the U.S. DOT model has increased with the development of tools such as the FRA WBAPS and GradeDec.net to assist with grade crossing resource allocation. States that were interviewed as part of this research project were generally satisfied with the performance of the hazard ranking models used by the respective states. States such as Florida, Kansas, and Texas have undertaken research studies to assess the adequacy of existing grade crossing hazard ranking models and/or to develop new statistical models for hazard ranking. Other states, including Illinois and Missouri, have undertaken similar research studies but DOT staff reported that the results of the studies could not be practically applied and therefore were not adopted. Recent models developed for Florida and Texas utilize more modern statistical analysis for predicting crash frequency at a grade crossing. One key feature of such models is that they are easier to interpret than the U.S DOT model, allowing for the most important factors that contribute to hazard risk at a crossing to be easily identified. States such as North Carolina are moving toward an economic analysis model of hazard ranking to incorporate the U.S. DOT model in a more comprehensive economic analysis of the grade crossing.

Grade Crossing Project Development

The project development process for warning device improvement projects was similar among the states interviewed as part of this research project. A preliminary list of grade crossing locations is developed and field diagnostic reviews confirm the eligibility of a location for improvements funded by Section 130. The hazard ranking model is used to prioritize locations for improvement; however, in all states interviewed, professional judgement is applied to the final list of projects to be funded.

The number of crossing locations on the preliminary list varies from state to state as does the factors considered in the development of the list. For example, California uses multiple data sources to develop its preliminary list, including output from WBAPS, near-miss reports, and crash locations. Michigan has an “inspector’s choice” option whereby the state’s grade crossing inspectors can suggest up to two locations to be included on the annual program that would otherwise not be included based on the hazard ranking model. Illinois uses a two-page application which is completed by local highway authorities to assist with developing its preliminary list. Near miss reports are used by states if the information is provided to the DOT by the railroads. Some states noted that near-miss data was not reported by the railroads due to concerns about an inconsistent definition of what constitutes a “near-miss” incident.

The treatment of grade crossing locations that have experienced a crash during the previous year is also inconsistent across the states interviewed for this project. In Ohio, any grade crossing location that experiences a fatality during the previous year is automatically scheduled for a field diagnostic review. California includes recent crash locations on its preliminary list. Michigan automatically convenes a diagnostic review for any location with two crashes during a five-year period. States that use the U.S. DOT Accident Prediction Model noted that the crash history is included in the model and that the ranking of that location would be higher after accounting for the crash and thus that location was essentially automatically included on the next round of funding. Some states felt that since highway-railroad grade

crossing crashes are essentially random events, including crash history in the hazard ranking process would not reflect the general risk at crossing locations. However, all the states interviewed for this project noted that the state had some type of special funding account, funded by state appropriations only, that allows for warning device upgrades at high-profile crash locations that do not rank high on the priority list if constituent demand warrants action.

Database Issues

All of the various state DOT staff interviewed as part of Task 4 of this project expressed some hesitation with respect to the accuracy of the data contained with the state-level or FRA highway-railroad grade crossing inventory database. The general feeling among those interviewed was that the inventory data represent the best available data for grade crossing hazard evaluation but there are concerns about the vintage and completeness of data. Most states noted that multiple data sources are consulted to confirm the data supplied with the crossings on the preliminary crossing list. Train counts are typically confirmed with the railroads and/or the state grade crossing inspectors. Missouri DOT staff noted that railroads are required to provide train counts annually and did not express any concerns about these data. AADT data are also of concern. One state noted that using a countywide average AADT for low-volume locations did not help address the concerns about AADT accuracy but did provide a measure of comparison for the data in the inventory database. One state mentioned that the DOT railroad safety group was able to coordinate with the technical services group to align the routine traffic count locations to provide better AADT data for grade crossing evaluation.

Synthesis: Factors Not Currently Considered in U.S. DOT Model

Detailed analysis of the formulas available provide insight into certain factors that are considered by those states to be relevant for hazard ranking but are not included in the U.S. DOT Accident Prediction Model, the model currently used in Ohio for grade crossing hazard ranking. These specific factors, and their potential applicability to grade crossing hazard ranking practices in Ohio, are discussed as follows:

- Highway Functional Classification or Urban/Rural Context – Collectively, these variables consider either the type of highway as defined by the highway functional classification or more broadly, the urban or rural context of a highway location. This variable is considered in at least four states and used in two hazard ranking models – the NCHRP 50 model and the Texas Priority Index model. The highway functional classification variable also used to be considered in the U.S. DOT model; however, due to the inclusion of older information in the recent *Railroad-Highway Grade Crossing Handbook – Revised Second Edition 2007* [Ogden, 2007], it is possible that some states are still considering the variable in their models. In the Texas Priority Index, an urban crossing location is estimated to have more crashes than a rural location. Ohio grade crossing crash data indicate that urban crossing locations have a proportionally higher percentage of crashes compared to the statewide distribution of urban and rural crossings. Higher classification roadways in Ohio also have more crashes than local roadways but that is likely due to the higher traffic volumes and greater activity at those locations.

- Stopping Sight Distance – Stopping sight distance is currently considered by nine states and is included in three of the detailed formulas analyzed in this report. Stopping sight distance enters these formulas in a variety of ways. In North Carolina, the sight distance factor is based on a qualitative assessment of sight distance on each of the four quadrants

of the crossing. Missouri and Texas use the actual measured sight distance in the calculations. All three states noted that while the sight distance is considered, it is difficult to measure with consistency and does not contribute much to the overall ranking calculations. Crash data from Ohio indicate that sight distance obstructions were not noted in any crash over the past 10 years. Sight distance is currently not considered in formulas used by Ohio although it is considered qualitatively by the ORDC and PUCO in its site assessments for projects it is considering funding. Desired sight distance could easily be calculated using the train speed information provided in the Ohio grade crossing inventory if the highway speed were also available (see discussion below). However, determining if this sight distance is available in the field requires additional significant investigation on the part of the grade crossing inspection process.

- School Bus/Special Vehicle Volume – The volume of school bus or other type of special vehicle traffic is considered by four states and is included in two of the formulas analyzed in this report. In both cases, the school bus volume is not included directly in the accident prediction calculations. In Florida, the volume of school bus traffic is used to calculate an adjusted "Safety Index" based on the accident prediction model calculations. In North Carolina, the AADT volume is adjusted based on the number of school bus passengers traversing the crossing. Crash analysis from Ohio indicated that only 1 out of 884 crashes in the past 10 years involved a bus as the vehicle and it is unknown if it was a school bus. Only one-third of crossing locations in the Ohio inventory database had valid information for school bus volumes. Based on the PUCO experience in collecting data on school bus traffic at crossings, it is not likely that a variable accounting for school bus traffic volume could be added without significant effort to update the inventory data.
- Highway Traffic Speed – Highway traffic speed is considered by five states and is included in three of the formulas analyzed in this report. In all three formulas, the highway speed variable enters the calculations directly into the accident prediction or hazard index. The highway traffic speed is included in the existing Ohio grade crossing inventory database although only 21 percent of records have valid data for this variable. Florida overcomes this issue by using the state statutory speed limit in lieu of the actual speed limit. Using the state statutory speed limit to fill in for missing data, crash analysis suggests that grade crossing locations with a recent crash do not have a different highway speed limit distribution than the statewide average.
- Proximity of Rail Crossing to Nearby Intersection – The presence of a highway intersection nearby the grade crossing is considered by three states and is included in one of the formulas analyzed in this report. The Texas Priority Index considers the presence of a nearby intersection as a dummy variable in its crash prediction model. Nearby traffic signal preemption is also considered in the "protection factor" used in the Connecticut, Michigan, and Missouri hazard index calculations. Data on nearby highway intersections and preemption are included in the Ohio inventory. Crash analysis indicates that grade crossings with a recent crash are slightly more likely to have a nearby intersection within 150 feet but there were limited differences in these locations compared to statewide data.

APPENDIX C: STATISTICAL ANALYSIS

Description of Statistical Analysis Methods

In Task 5 of the research study, the Ohio University research team conducted a detailed analytical and functional evaluation of certain grade crossing hazard ranking formulas identified in the literature review task. The purpose of the analytical evaluation was to determine how the existing hazard ranking method used in Ohio compared to other hazard ranking formulas used in other states. The analytical evaluation of the grade crossing hazard ranking formulas consisted of two components. First, researchers performed an analysis of the hazard ranking outcomes based on the complete Ohio highway-railroad grade crossing inventory database, which consisted of 5,761 public, at-grade crossings as of October 31, 2015, as well as a parallel analysis of the complete set of 1,947 public, at-grade crossings with passive warning devices. Analysis of the complete grade crossing inventory database included the following hazard ranking formulas:

- **PUCO Model** (Ranking established based on the U.S. DOT Accident Prediction Model with the normalizing constants as of October 1, 2010);
- **DOT Model** Ranking established based on the (U.S. DOT Accident Prediction Model with the most updated normalizing constants as of May 13, 2014);
- **Handbook Model** (Ranking established based solely on the U.S. DOT Accident Prediction Model as described in the *Railroad-Highway Grade Crossing Handbook – Revised Second Edition 2007*);
- **Exposure Model** (Ranking established based on the product of daily highway traffic volume and daily train volume);
- **New Hampshire Hazard Index** (see Table 12);
- **NCHRP 50 Expected Crash Frequency Model** (see Table 13);
- **Florida DOT Safety Hazard Index** (see Table 16); and
- **Michigan DOT Hazard Index** (see Table 17).

Three hazard ranking formulas identified in this research required information about sight distance available at the grade crossing, information that is currently not available in the Ohio highway-railroad crossing inventory database. These three formulas are as follows:

- **Missouri DOT Exposure Index** (see Table 18);
- **North Carolina DOT Investigative Index** (see Table 19); and
- **Texas DOT Priority Index** (see Table 20).

The second component of the analytical evaluation consisted of a more detailed analysis of a randomly-chosen sample of 20 grade crossings. Using a smaller sample of crossings allowed for analysis which included the three additional formulas listed above as sight distance could be assessed at these locations via aerial imagery. Additionally, an “Expert Panel” hazard ranking of the 20 grade crossings was established. In the absence of a “standard” ranking to which the different grade crossing hazard ranking methods could be compared, it would be difficult to conclude which is better or worse. Therefore, the purpose of the Expert Panel ranking was to attempt to establish an “actual” hazard ranking of a random sample of grade

crossings and compare this ranking to the ranking obtained using the different hazard ranking formulas. This approach overcomes one of the limitations of this type of analysis in that the "true" or "actual" hazard ranking of grade crossings is unknown. Hazard ranking formulas are used to establish a priority ranking of hazardous crossings based on a formula modeling hazard risk at a crossing; however, not all factors encompassing the risk at a crossing are included in formulas or even able to be measured at all. The Expert Panel ranking for the 20-crossing sample was established by the ORDC technical liaisons based on the grade crossing inventory data for each crossing without reference to the accident prediction value calculated using the existing PUCO Model. Because sight distance information is currently not included in the Ohio highway-railroad grade crossing inventory database, researchers obtained this information through "desk review" of aerial imagery of the 20 crossings.

For accident prediction models, researchers calculated the hazard ranking by sorting the data set in descending order from the highest value of accident prediction to the lowest. Hazard index type models were sorted from highest index value to lowest index value. The following statistical metrics were used in this analysis:

- Spearman's Rank Correlation Coefficient, also known as Spearman's Rho (ρ), a measure of the correlation between two independent methods of ranking the same set of data. The value of Spearman's Rank Correlation Coefficient is between 0 and 1, with values closer to 1 indicating a higher level of agreement between the ranking methods. For this analysis, researchers calculated the Spearman's Rank Correlation Coefficient comparing the PUCO Model with the other hazard ranking formulas evaluated (comparison among different models was not examined).
- Power Factor, a measure calculated based on the percentage of crashes occurring at a specified top percentage of crossings as ranked by different methods. For example, a "5% Power Factor" is calculated by dividing the percentage of crashes occurring among the highest-ranked 5% of crossings (as determined by a particular ranking method) by 5%. Hazard ranking methods with higher Power Factor values are desired as these methods are more effective at identifying the most hazardous crossings. Any percentage can be specified for a Power Factor analysis. A more detailed explanation of the Power Factor for hazard ranking analysis is described in Faghri and Demetsky [1986]. Researchers calculated a 5% Power Factor and a 1% Power Factor for each hazard ranking model examined in this analysis.
- For the Expert Panel analysis, researchers calculated the difference in the ranks between the expert panel ranking for a particular crossing and the ranking obtained using the different hazard ranking methods. Researchers also calculated the Spearman's Rank Correlation Coefficient comparing the expert panel ranking with each of the 11 hazard ranking formulas evaluated in this study.

Ranking Correlation Analysis

Table 21 shows the results of the ranking correlation analysis comparing the current grade crossing hazard ranking method used in Ohio (the "PUCO Model") with seven other grade crossing hazard ranking formulas as identified in the literature review. The metric for this comparison is the Spearman's Rank Correlation Coefficient, or Spearman's Rho (ρ). Table 21 shows the analysis results for the complete set of grade crossings in the inventory database (5,761 crossings) as well as for the complete set of grade crossings with passive warning devices

(1,947 crossings). The comparison sample size is also shown in Table 21. The sample size for the ranking comparison was lower than the total number of crossings in each analysis because of incomplete data items for some formulas in the inventory database. The ranking correlation analysis provides a measure to compare the consistency of the rankings obtained using the PUCO model with rankings obtained using different hazard ranking models. A higher Spearman's Rank Correlation Coefficient indicates higher level of agreement between the PUCO model and the specified hazard ranking method.

Table 21: Spearman's Rank Correlation Coefficient Analysis

Hazard Ranking Method	Full Sample (n=5,761)		Passive Only (n=1,947)	
	Sample Size	Rank Correlation	Sample Size	Rank Correlation
DOT Model	5,700	0.999	1,902	1.000
Handbook Model	5,693	0.928	1,895	0.991
Exposure Model	5,700	0.877	1,902	0.937
New Hampshire Hazard Index	5,700	0.869	1,902	0.937
NCHRP 50 Model	5,533	0.735	1,754	0.888
Florida DOT Safety Hazard Index	5,679	0.885	1,899	0.823
Michigan DOT Hazard Index	5,700	0.888	1,902	0.937

Note: Spearman's Rank Correlation Coefficient shown for each hazard ranking method with respect to the hazard ranking derived by the current PUCO Model hazard ranking method.

The analysis reported in Table 21 indicates a strong level of agreement between the rankings derived from the PUCO model and the rankings derived from other methods. The "DOT Model" rankings is the most comparable to the current method; this result is not surprising given that the "DOT Model" is simply an updated version of the model currently used in Ohio. The strength of the ranking correlation improved when just the passive crossings were analyzed for all models except for the Florida DOT Safety Hazard Index. The strength of the correlation values reported in Table 21 suggests that the probability of obtaining a significantly different hazard ranking of grade crossings if a different method was used to derive the ranking is low.

Power Factor Analysis

The "Power Factor" metric has been used in previous research studies comparing grade crossing hazard ranking methods [Faghri and Demetsky, 1986]. As previously explained, the power factor is calculated by taking the percentage of actual crashes that occur at a specified top percentage of most hazardous crossings (for any time period as derived by a particular method) divided by whatever percentage is specified. The results of the power factor analysis are shown in Table 22 for the complete set of grade crossings in the inventory database (5,761 crossings) and Table 23 for the complete set of grade crossings with passive warning devices (1,947 crossings). For this analysis, the total number of actual crashes was based on a five-year average of the number of crashes per year. Thus, if a crossing had experienced one crash during the past five years, it was assumed to have 0.2 actual crashes per year. Based on the five-year average, a total of 66.6 crashes per year occur at Ohio grade crossings, of which 8.8 crashes per year occur at locations that currently have passive warning devices.

To aid in the interpretation of the power factor analysis, a sample calculation of the 5% Power Factor for the PUCO Model using the complete inventory database is given as follows:

Total Number of Crashes per Year: 66.6

Total Number of Crashes per Year in Top 5% of Ranked Crossings: 52.4

Percent of Crashes per Year in Top 5% of Ranked Crossings: 52.4/66.6 = 78.7%

5% Power Factor: 78.7%/5% = 15.7

Interpretation of these calculations are as follows. The Top 5% of crossings as ranked by the PUCO model includes the crossings that account for 78.7 percent of the annual crashes at Ohio grade crossings. By extension, if an analyst was to use the PUCO model to develop a hazard ranking for grade crossing improvement project selection, and the most hazardous 5% of crossings are to be selected for this purpose, then 78.7 percent of the hazard would be at these locations. As such, a higher power factor value is desired. Based on the results of the Power Factor analysis, the three models based on the U.S. DOT Accident Prediction Model and the state-specific Florida DOT Safety Hazard Index provide the best results. This is not surprising as these models include adjustments for recent crash history in their rankings, resulting in locations with recent crashes to be ranked higher.

Table 22: Power Factor Analysis – Complete Inventory Database

Hazard Ranking Method	Top 5% (n=288)		Top 1% (n=58)	
	Number of Crashes	5% Power Factor	Number of Crashes	1% Power Factor
PUCO Model	52.4	15.7	15.8	23.7
DOT Model	52.6	15.8	15.8	23.7
Handbook Model	52.2	15.7	15.8	23.7
Exposure Model	13.8	4.1	3.0	4.5
New Hampshire Hazard Index	12.8	3.8	3.4	5.1
NCHRP 50 Model	10.8	3.2	2.8	4.2
Florida DOT Safety Hazard Index	39.6	11.9	11.0	16.5
Michigan DOT Hazard Index	13.0	3.9	3.2	4.8

Source: Ohio University research team analysis of data from the Ohio Railroad Information System (RRIS) provided by the Public Utilities Commission of Ohio (PUCO) as of October 31, 2015.
Total number of crashes = 66.6 crashes per year based on annual average for five-year period between August 1, 2010 and July 31, 2015.

Table 23: Power Factor Analysis – Passive Crossings Only

Hazard Ranking Method	Top 5% (n=97)		Top 1% (n=20)	
	Number of Crashes	5% Power Factor	Number of Crashes	1% Power Factor
PUCO Model	6.6	15.0	3.8	43.2
DOT Model	6.6	15.0	3.8	43.2
Handbook Model	6.2	14.1	4.0	45.5
Exposure Model	1.6	3.6	0.4	4.5
New Hampshire Hazard Index	1.6	3.6	0.4	4.5
NCHRP 50 Model	2.2	5.0	1.0	11.4
Florida DOT Safety Hazard Index	6.4	14.5	3.4	38.6
Michigan DOT Hazard Index	1.4	3.2	0.2	2.3

Source: Ohio University research team analysis of data from the Ohio Railroad Information System (RRIS) provided by the Public Utilities Commission of Ohio (PUCO) as of October 31, 2015.
Total number of crashes at passive crossings = 8.8 crashes per year based on annual average for five-year period between August 1, 2010 and July 31, 2015.

Expert Panel Ranking Analysis

Table 24 shows the results of the expert panel ranking analysis. The expert panel ranking analysis compares the ranking of 20 randomly-selected crossings as determined by a panel of experts consisting of ORDC technical liaisons and other ORDC staff with the rankings of the same 20 crossings obtained using different ranking methods. The 20 randomly-selected crossings are noted with letters A through T (letters assigned based on ORDC staff ranking after ranking process) to protect the confidentiality of the expert panel ranking results. Also shown in Table 24 is the type of warning device present at each crossing, the average of the absolute value of the difference between the expert ranking and the ranking obtained using each method, and the Spearman's Rank Correlation Coefficient comparing the expert panel ranking with the different methods. The Average Deviation provides a measure of the difficulty in ranking a particular crossing in the expert panel sample across all methods, with a higher value indicating greater difference between the expert panel and the formula ranks.

Table 24: Expert Panel Ranking Analysis

Crossing	Warning Device Type	Expert Ranking	PUCO Model	DOT Model	Handbook Model	Exposure Model	New Hampshire HI	NCHRP 50 Model	Florida DOT SHI	Michigan DOT H.I.	Missouri DOT E.I.	North Carolina DOT I.I.	Texas DOT Priority Index	Average Deviation
A	F	1	2	2	1	3	1	3	7	2	4	2	4	2.2
B	G	2	4	4	3	2	4	7	8	4	3	4	10	2.8
C	G	3	5	5	7	11	13	15	4	11	9	9	6	5.2
D	G	4	6	6	13	12	16	6	10	14	11	8	8	5.8
E	X	5	7	7	6	8	3	1	6	3	12	5	16	3.6
F	X	6	13	13	15	17	14	14	15	13	15	11	18	8.3
G	G	7	20	20	20	20	20	20	20	20	20	14	20	12.5
H	G	8	15	15	17	13	17	17	12	17	13	20	5	6.8
I	G	9	3	3	5	4	6	4	1	5	2	3	1	5.8
J	X	10	18	18	18	18	18	8	17	18	16	13	17	6.7
K	G	11	8	8	9	5	7	12	9	7	7	6	11	2.9
L	G	12	1	1	2	1	2	2	2	1	1	1	3	10.4
M	G	13	10	10	14	6	8	10	5	8	5	18	2	5.5
N	F	14	17	17	11	16	15	18	18	16	18	17	15	2.8
O	F	15	12	12	4	7	5	5	13	6	8	10	7	6.6
P	G	16	11	11	16	9	11	16	11	9	10	7	13	4.9
Q	F	17	16	16	8	14	10	9	14	15	14	16	12	3.8
R	G	18	9	9	10	10	12	13	3	10	6	12	9	9.1
S	X	19	19	19	19	19	19	19	19	19	19	19	14	0.4
T	X	20	14	14	12	15	9	11	16	12	17	15	19	5.8
Correlation:			0.49	0.49	0.28	0.27	0.16	0.30	0.28	0.26	0.27	0.50	0.20	
Warning Device Type: G = Gates and Flashing Lights; F = Flashing Lights Only; X = Passive														

The distribution of warning device type among the 20 randomly-selected crossings was as follows: 11 crossings with gates and flashing lights (55%), 4 crossings with flashing lights only (20%), and 5 crossings with passive warning devices (25%). Compared with the statewide distribution of warning device type (see Table 5), grade crossings with flashing lights only were slightly over-represented in the expert panel sample while passive grade crossings were slightly under-represented. The following conclusions can be drawn from the expert panel analysis as presented in Table 24:

- The hazard ranking formulas that demonstrated the greatest consistency with the expert panel ranking, as measured by the Spearman's Rank Correlation Coefficient, were the current PUCO Model ($\rho = 0.49$), the DOT Model ($\rho = 0.49$), and the North Carolina DOT Investigative Index ($\rho = 0.50$). While a Spearman's Rank Correlation Coefficient of approximately 0.50 indicates a moderate relationship between the different ranking methods, it is evident that these three methods are superior for this analysis given that no other ranking method had a Spearman's Rank Correlation Coefficient greater than 0.30.
- Three crossings – labeled as crossings G, L, and R – had a relatively high average deviation across all hazard ranking formulas as compared to the expert panel ranking. The specific circumstances of these crossings provide some insight into the large deviation and are instructive for the current study on grade crossing hazard ranking.
- Crossing G was ranked as the #7 most hazardous by the expert panel but was the lowest ranked (#20) by all the ranking methods except the North Carolina DOT Investigative Index, which ranked the crossing #14. By itself, Crossing G demonstrates very little hazard with an AADT of approximately 4,900 vehicles per day, zero trains per day, and a maximum train speed of 25 miles per hour. However, this crossing is immediately adjacent to another grade crossing (with a separate database record) less than 100 feet away which has 38 trains per day with a maximum speed of 55 miles per hour. Additionally, the adjacent crossing AADT is listed as 7,900 vehicles per day for the exact same roadway. Although Crossing G has gates and flashing lights, the expert panel noted that the presence of the adjacent grade crossing as well as the presence of a nearby highway intersection as justification for the #7 hazard ranking.
- Crossing L was ranked as the #12 most hazardous by the expert panel but was ranked among the top 3 of all 11 hazard ranking formulas analyzed. Crossing L has an AADT of 13,600 vehicles per day, 44 trains per day, and a maximum train speed of 50 miles per hour. However, Crossing L is located in one of Ohio's ten designated "quiet zone" corridors. In quiet zone areas, locomotive horns are not used at grade crossings and communities are required to install supplemental safety measures to mitigate the increased risk from the absence of a horn. The expert panel noted that the presence of supplemental safety measures at Crossing L as justification for the #12 hazard ranking. However, since none of the ranking methods examined here account for these supplemental safety measures, Crossing L was consistently ranked much higher by the formulas than the expert panel's ranking.
- Crossing R was ranked as the #18 most hazardous by the expert panel but was ranked anywhere between #3 and #13 by the 11 hazard ranking formulas analyzed. Crossing R has an AADT of 1,500 vehicles per day, 6 trains per day, and a maximum train speed of

50 miles per hour. In its review of Crossing R, the expert panel noted that the grade crossing inventory data indicated that the crossing had 3 tracks but a review of aerial imagery indicated that the crossing currently had only 1 main track. Inconsistency between the number of tracks at a crossing as indicated by the grade crossing inventory data and the number of tracks as noted by the expert panel review was noted in three additional locations that were included in the 20-crossing expert panel sample.

In light of the findings discussed in the last bullet point regarding the inconsistency between the numbers of tracks at a crossing in the inventory data compared with the actual number of tracks, researchers conducted a more detailed investigation of this issue. Researchers selected a random sample of 40 crossings with passive warning devices only and conducted a desk review of these crossing locations. Researcher analysis of the aerial imagery indicated that the actual number of train tracks (main plus other) at 9 locations out of the 40 crossings selected (23 percent) was inconsistent with the corresponding number in the inventory data. Therefore, based on two independent random samples obtained from the Ohio highway-railroad grade crossing inventory database, approximately 20 to 23 percent of the records are inaccurate for the total number of tracks at a location. It is very unlikely that these are the only records in the grade crossing inventory that have inconsistent information on the number of tracks. This is an interesting issue because the current hazard ranking model in Ohio, the U.S. DOT Accident Prediction Model, only considers the number of main tracks at a crossing in the crash frequency calculations. Additionally, for passive crossings, the number of main tracks is not applicable to the initial crash prediction (see Table 11). Nevertheless, this finding is concerning for several reasons. First, to the extent possible, it is desirable to use the most accurate information available to assess hazard risk at grade crossings to assist with project prioritization. Second, inaccurate information about the number of tracks (main or other) at a crossing makes it difficult to precisely ascertain the relationship between the number of tracks at a crossing and the hazard risk at a crossing. Finally, the finding that approximately 1 out of every 5 crossings may have inaccurate information about the number of tracks raises concern about the accuracy of other variables in the inventory database.