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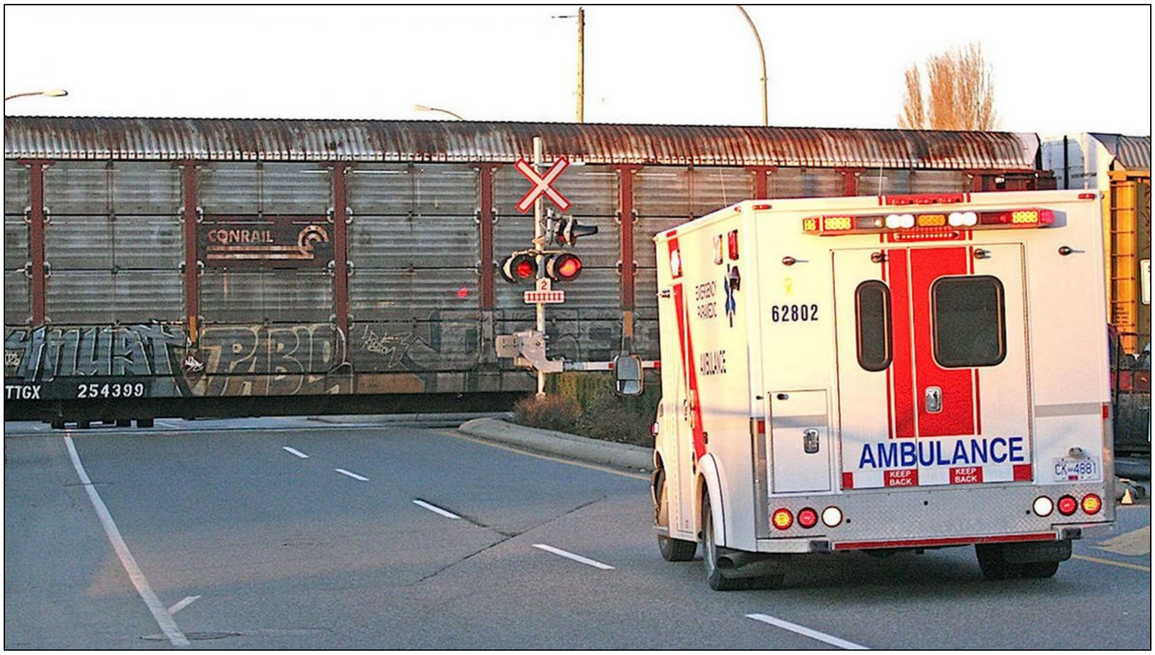
Washington, DC 20590

Assessing the Safety Benefits of a Real-Time Railroad Crossing Information System for Emergency Responders



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14. ABSTRACT

This report assesses the safety benefits of a real-time railroad crossing information system for emergency responders. The study focuses on reducing first responder delays at rail crossings, which have become increasingly critical due to the rise in average train lengths in the United States. The research, funded by the Federal Railroad Administration (FRA), was conducted by TRAINFO between October 2018 and June 2023 in Winnipeg, MB (Canada), Houston, TX, and Charleston County, SC. The primary objectives were to quantify the risk of responders being exposed to active crossings, evaluate the effectiveness of in-vehicle systems, and assess dispatcher tactical maps in reducing these risks.

The study involved the installation of TRAINFO sensors to collect real-time rail crossing data, which was then integrated into in-vehicle systems and dispatcher tactical maps. The findings indicate that more than 90 percent of responder delays at rail crossings can be eliminated using real-time and predictive rail crossing information. However, the effectiveness of these systems is limited by human factors such as available responder attention and the complexity of dispatcher workflows. The report concludes that integrating rail crossing information into Computer-Aided-Dispatch (CAD) software could provide a more consistent and effective solution to mitigate responder delays.

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ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gm)
1 pound (lb) = 0.45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] °F = y °C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
10,000 square meters (m^2) = 1 hectare (ha) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gm) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg)
= 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

TEMPERATURE (EXACT)

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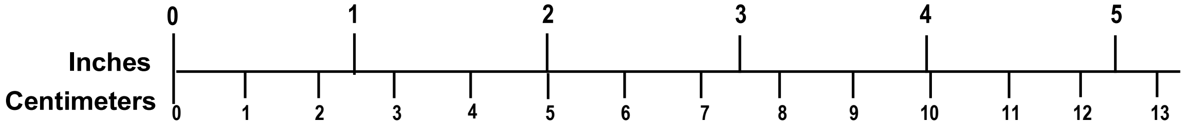
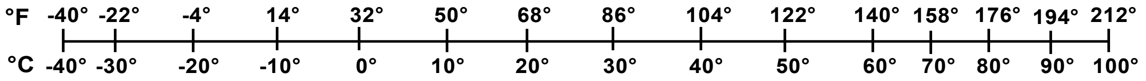
QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

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Executive Summary

The need for more research on the topic of emergency responder delays at rail crossings increases as the average train length in the United States increases. The National Fire Protection Association's (NFPA) Standard 1710 establishes a maximum of four minutes travel time to arrive on scene. Train lengths increased by 25 percent between 2008 and 2018 (US Government Accountability Office, 2018), increasing the chances that a response takes longer than the prescribed four minutes.

In 2018, the Federal Railroad Administration (FRA) sponsored TRAINFO to conduct research to reduce first responder delays at rail crossings. The research focused on three primary objectives:

1. Quantify the risk of responders needing to cross active grade crossings.
2. Evaluate the effectiveness of in-vehicle systems to reduce the risk of responders interacting with active rail crossings.
3. Evaluate the effectiveness of dispatcher tactical maps to reduce the risk of responders interacting with active crossings.

The TRAINFO team conducted the research using sensors installed in Winnipeg, MB (Canada), Houston, TX, and Charleston County, SC. The local municipalities installed the sensors. The project team used the data produced to develop models to quantify the risk of a responder interacting with active rail crossings and integrated the data into in-vehicle systems and dispatch tactical maps to test the ability to reduce responder exposure with active crossings.

The research team also asked the municipal agencies to provide historical responder call log data (with anonymized responder trip origins, destinations, start times, and end times), access to response and dispatch teams to survey and interview, and integration support to test the use of rail crossing information in the dispatch and response processes.

The research showed that the number of responder trips delayed in each city ranged from 2.15 to 8.83 trips delayed per crossing per year. To put this in practical context, the number of responder trips delayed at rail crossings per year in Houston is expected to exceed 6,000. In addition, the research showed that more than 90 percent of responder delays at rail crossings could be eliminated using real-time and predictive rail crossing information. While in-vehicle systems and dispatcher tactical maps can help reduce responder delays, the following factors limit the benefits of in-vehicle systems:

- Limited consideration of broader 911 operations: Providing in-vehicle information to on-route responders is relatively responsive when compared to providing information at the dispatch level. Providing information at the dispatch level allows for consideration of railroad crossing activity and for dispatchers to identify responders who may be impacted. When a dispatcher identifies a responder who is likely to be impacted, they can proactively provide communication on alternate routes or dispatch addition units.
- Available responder attention: Responders must actively focus on navigating traffic at intersections safely, gather information for the call to which they are responding, and perform many other critical elements. This leaves little available attention for on-route responders to focus on additional information systems.

- Unstable vehicle dynamics: Due to uncertain road conditions and dynamic vehicle operations, using visual information systems is a significant challenge for on-route responders. Vehicle instability creates challenges in keystroke precision on Toughbooks and the inability to maintain a focal point on monitors.
- Technology management consistency: Because 911 response agencies typically manage various models of vehicles (i.e., multiple models of ambulances and fire trucks) with various models of onboard technology, they may have difficulty delivering a compatible solution consistently.

The limited automation of this information into dispatcher workflow limits the benefits of its integration into dispatcher tactical maps. Dispatchers must manage multiple calls at any given time and share large amounts of information with responders, which can make it difficult for them to consider rail crossings in the dispatch of every responder. During periods where dispatchers were actively asked to monitor rail crossings, responder delay was decreased by more than 90 percent. However, when dispatchers were not reminded to consider rail crossings, responder delay was reduced by an estimated 50 percent.

While there are benefits to providing rail-crossing information to responders in-vehicle and to dispatchers through tactical maps, the benefits do not consistently address responder delays. These findings suggest that the most effective strategy to address first responder delays is to integrate rail crossing information into the unit recommendation models of computer-aided-dispatch (CAD) software. In theory, this integration would influence unit recommendation algorithms to eliminate the human effort and consistently consider rail crossings in unit routes. Further research could evaluate the benefits and challenges of integrating rail crossing information into CAD software.

1. Introduction

Between October of 2018 and June of 2023, the Federal Railroad Administration (FRA) sponsored TRAINFO to conduct research to reduce first responder delays at rail crossings. The project uses data from sensors installed in Winnipeg, MB (Canada), Houston, TX, and Charleston County, SC.

1.1 Background

The severe effect of blocked crossings on emergency response time and the lack of effective approaches to avoid these delays necessitate the need for research to determine a solution. The National Fire Protection Association (NFPA) Standard 1710 establishes performance objectives for first responders, including a maximum of four minutes travel time to arrive on scene. Data provided to the Government Accountability Office suggests that the average US freight train length in 2017 was 1.4 miles, an increase of 25 percent since 2008 (US Government Accountability Office, 2018). Urban train speed limits are around 25 miles per hour, resulting in an average rail crossing blockage duration of around four minutes. First responders encountering blocked crossings will usually fail to meet their performance objective and these delays can have severe consequences. For instance, the survival rate of a cardiac arrest victim decreases by 10 percent for every minute of defibrillator delay (Heart & Stroke Foundation, 2012). Although public safety professionals recognize this risk, they do not have adequate train information to determine where and when these delays occur and develop strategies to select and route units around blocked rail crossings.

Standard operating practice for first responders encountering a blocked rail crossing is to radio the railroad to cut the train and allow the emergency vehicle to pass. Although railroads are highly responsive, the time to cut the train typically exceeds the amount of time it takes to re-route or dispatch an alternate unit. In some cases, the railroad industry and communities have cooperated to reduce the impact of blocked crossings on emergency response. However, these efforts have not involved the provision of real-time blockage data by the railroad industry on a scalable, repeatable basis. First responders are increasingly using real-time routing tools such as Waze to help improve response time, but these sources do not provide railroad crossing blockage information. Grade separation eliminates delays at rail crossings but often cost between $5 million and $40 million, with complicated projects exceeding $100 million. Communities may not even undertake planning or other pre-development actions to address grade crossing separations because the cost to complete the project is prohibitive (US Senate Committee on Commerce, Science, and Transportation, 2021).

1.2 Objectives

This research evaluates the effectiveness and feasibility of using real-time and predictive rail crossing blockage information to better understand and mitigate the risks of blockages on emergency response times. The research objectives are to:

- Quantify the risk of responders encountering active crossings.
- Evaluate the effectiveness of in-vehicle systems to reduce the risk of responders interacting with active rail crossings.

- Evaluate the effectiveness of dispatcher tactical maps to reduce the risk of responders interacting with active crossings.

1.3 Overall Approach

The overall approach of this research involves a multi-phase methodology designed to comprehensively evaluate the impact of real-time and predictive rail crossing information on emergency response times. The phases include:

1. Data Collection: Gather historical responder call log data, rail crossing blockage data, and traffic count data from the selected cities (Winnipeg, MB, Houston, TX, and Charleston County, SC).
2. Model Development: Create risk and benefit models to estimate the frequency and severity of responder delays at rail crossings and the potential travel time savings from using rail crossing information.
3. System Development: Design and develop in-vehicle and dispatcher-integrated rail crossing information systems.
4. System Testing and Evaluation: Conduct field tests and virtual demonstrations to assess the effectiveness and user acceptance of the developed systems.
5. Analysis and Reporting: Analyze the collected data and test results to draw conclusions and provide recommendations for future research and implementation.

1.4 Scope

The scope of this research focuses on evaluating the feasibility and effectiveness of using real-time and predictive rail crossing information to mitigate the impact of rail crossing blockages on emergency response times. The research scope is:

- Geographical: The study is conducted in three cities: Winnipeg, MB (Canada), Houston, TX, and Charleston County, SC.
- Data: The research uses historical responder call log data, rail crossing blockage data, and traffic count data.
- System: The system includes the development and evaluation of both in-vehicle and dispatcher-integrated rail crossing information systems.
- Outcome: The primary outcomes include the quantification of responder delays, the effectiveness of the developed systems in reducing these delays, and recommendations for integrating rail crossing information into emergency response processes.

1.5 Organization of the Report

The remainder of this report is organized into the following sections. Section 2 is a review of previous work related to rail crossing information systems and their impact on emergency response times. Section 3 includes a detailed description of the risk and benefit models, including their design, testing, and observations. Section 4 covers the process of designing, developing, and testing the in-vehicle system, along with user feedback and observations. Section 5 details the development and testing of dispatcher-integrated systems and their effectiveness in reducing responder delays. Section 6 summarizes the project’s findings, outlines conclusions drawn from the research, and makes recommendations for future work.

2. Literature Review

The research team conducted an extensive, but not exhaustive, literature review to identify previous work related to quantifying the risk of first responder delays due to blocked rail crossings and rail crossing information systems to support emergency service applications.

2.1 Rail Crossing Information Systems for Emergency Service Applications

Goolsby et al. (2003) provided the earliest example of this research in a project by Texas Transportation Institute in Sugar Land, Texas. Their research developed a prototype rail crossing information system using Doppler radar to detect trains and send blocked crossing information to dispatcher kiosks. The research found it viable to develop technologies to detect rail crossing information, but with some limitations (i.e., slow trains providing erratic data and trains stopping and temporarily disappearing). City fire, police, and public works personnel found the system to be useful in making emergency decisions.

2.2 Quantifying First Responder Delays at Rail Crossings

In 2004, the Volpe National Transportation Systems Center (Volpe) conducted a benefit-cost evaluation of a theoretical crossing blockage information system that extrapolated travel time savings using average daily distributions of train and vehicle traffic (Lee et al., 2004). The Volpe team designed the system for a sub-urban commuter station on the Long Island Rail Road to control train and vehicle traffic, including an emergency vehicle pre-emption system in which the train slows down to allow first responders to cross. However, the research does not specifically quantify first responder delays at rail crossings or the benefits of an information system. This project identified opportunities to reduce responder delays; however, the opportunities were limited as a result of the limited availability of reliable real-time train information.

In 2006, FRA published a report regarding the impacts of blocked highway-railroad grade crossings on emergency response providers (Federal Railroad Administration, 2006). The report acknowledges that blocked rail crossings can have serious impacts on first responders and that these impacts are likely to intensify with growth in both rail and highway traffic. The report also identifies principal causes of blocked crossings and provides examples of remediation actions, including grade separation, monitoring rail crossings with radars and cameras, and obtaining train location information from the railroads. The report finds that it is impossible to quantify the delays emergency responders experience at blocked rail crossings but that the extent of the problem can be gauged from contacts with emergency responders, states, railroads, and FRA safety personnel. FRA concludes that there is no single solution that works in all cases and that the best solutions involve addressing all the crossing issues in a corridor at the same time, such as noise, traffic congestion, economic development, and safety.

In 2016, Park et al. (2016) published research at the University of Saskatchewan in which they used a probabilistic geographic information system analysis to estimate how a fire station service area and fire truck response time changes with real-time crossing blockage information in Saskatoon, Saskatchewan. The researchers developed simulation models with input from the Saskatoon Fire Department that determined the shortest travel routes between fire stations and emergency incidents in Saskatoon based on blocked crossings. The models determined the area around a fire station that can be reached within 4, 6, and 10 minutes with and without blocked rail crossings. The researchers conducted analyses for two fire stations. They found that blocked rail crossings reduce the 4-minute response area around a fire station by 90 to 100 percent, indicating that blocked crossings are likely to prevent first responders from achieving NFPA's 4-minute standard travel time objective. The research also found that blocked rail crossings increase response time by up to 5.6 minutes and that predictive rail crossing information can reduce response times by up to 62 percent.

In 2018, Wu et al. (2018) conducted research at AECOM and the University of Nebraska-Lincoln to illustrate a methodology to evaluate travel-time reliability for the routes and networks affected by trains traveling through highway-rail grade crossings. This research developed a simulation model calibrated to local traffic conditions and signal preemption strategies using field data to generate travel time data for analysis. The researchers calculated the reliability of travel time estimates between origin-destination pairs impacted by blocked crossings. This research found it reasonable to calculate travel time reliability for origin-destination pairs, but the research is limited to general vehicle travel and does not take into consideration the changes in vehicle behavior by mode (i.e., first responders).

2.3 Observations

The literature review yielded few examples of research or previous work related to quantifying first responder delays at rail crossings and systems to help emergency service providers avoid these delays. Generally, the literature confirms that blocked rail crossings are a serious risk for first responders, reveals a need for a novel approach to quantify the risk of first responders being delayed at rail crossings, and suggests that a real-time rail crossing information system can help avoid these delays. Overall, the literature review validated the need for the research conducted by TRAINFO and described in this report.

3. Development and Validation of Risk and Benefit Models

The project team developed risk and benefit models to estimate the frequency of first responders being delayed at blocked rail crossings, the severity of these delays in terms of additional travel time compared to expected, and the amount of travel time savings that could be achieved if first responders had predictive rail crossing blockage information to re-route. Before building these models, the team needed to understand the emergency response process, including the sequence of events and composition of trips. This section describes the emergency response process and the purpose, overall approach, data limitations and assumptions, design, outputs, and testing results for each model.

3.1 Emergency Response Process

The emergency response-time process involves call processing time (the time from receiving a 911 call to alerting emergency response stations or units), turnout time (the time from receiving an emergency alert to boarding the response vehicle), and travel time (the time that the vehicle begins traveling to the call location to arrival time; National Fire Protection Association, 2021). For the risk model, the research team focused on the impacts of blocked rail crossings on the travel time, which NFPA Standard 1710 recommends being completed in 240 seconds or less.

This model considers two types of first responder units (firefighters and paramedics) and three types of origins and destinations (emergency response stations, previous call locations, or medical facilities). The model calculates travel time and delays caused by blocked crossings for trips from any origin traveling to a call location or medical facility; return trips to the station are excluded from the risk analysis.

3.2 Risk Model Design

For the model, the team considers risk to be the product of probability and severity. The purpose of the risk model is to estimate the frequency of a crossing being occupied by a train and the demand for a responder to interact with the crossing (i.e., the severity).

The overall design of the risk model involves importing sample emergency call log data (including vehicle origin and destination coordinates and time of departure and arrival for individual trips) and sample rail crossing blockage data (including the start and end time for individual blockage events at specific crossings) into TRAINFO's Emergency Responder Risk Model. The model summarizes risks by crossing, station, and response area. For instance, the model shows which crossings produce the highest risk of a responder being delayed, which stations have the highest risk of being impacted by blocked rail crossings, and which areas of a city/region have the highest risk of receiving delayed care due to first responder delays at rail crossings.

The model uses sample crossing blockage data to produce occupancy distributions, which are defined as the proportion of a given hour-of-day for a given day-of-week that a rail crossing is blocked. This distribution provides the likelihood that a crossing will be blocked for any hour and day. Figure 1 shows the occupancy distribution for a specific crossing on Mondays. As an example, this distribution indicates that during the 11:00 am hour on Mondays (i.e., between 11:00 am and 12:00 pm) the crossing is blocked for about 27 percent of the hour (approximately 16 minutes).

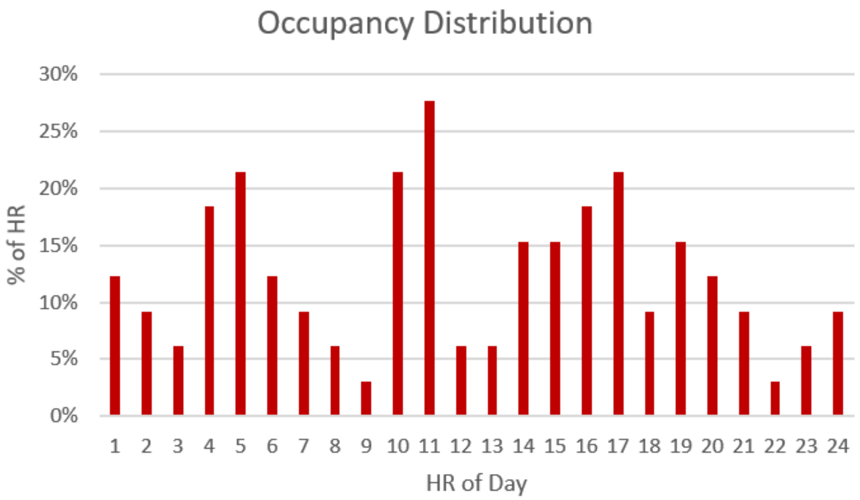


Figure 1. Occupancy Distribution Example

The model uses sample call log data to produce responder/crossing interaction distributions, which is defined as the proportion of responder trips of a given hour-of-day for a given day-of-week that that travel over crossings. This distribution provides the likelihood that a first responder unit's travel route will cross a rail crossing (regardless of whether it is blocked or not). Figure 2 shows the responder/crossing interaction distribution for Mondays. As an example, this distribution indicates that during the 7:00 am hour on Mondays (i.e., between 7:00 am and 8:00 am) there is about a 75 percent likelihood that a responder's travel route will cross a rail crossing.

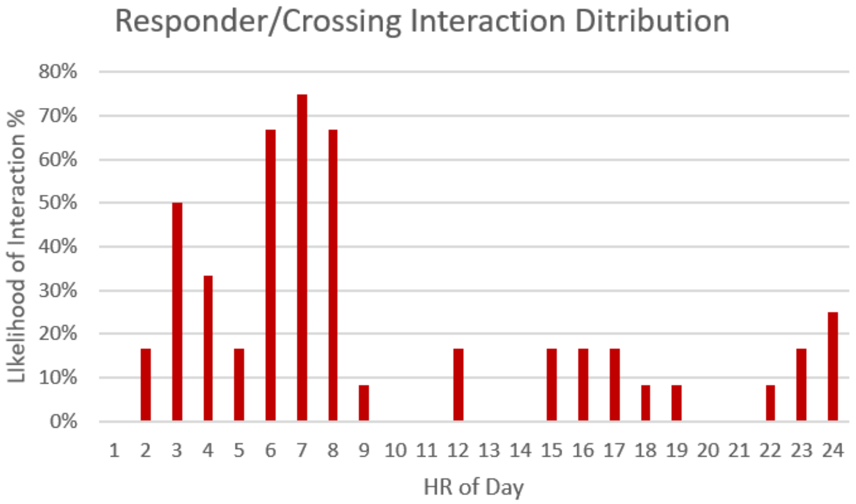


Figure 2. Responder/Crossing Interaction Distribution

3.3 Risk Model Testing

The research team tested and validated the model using Winnipeg data and feedback from Winnipeg Fire Paramedic Service (WFPS) personnel. As Figure 3 shows, there are 156 rail crossings, 30 emergency response stations, and 6 hospital locations in Winnipeg.

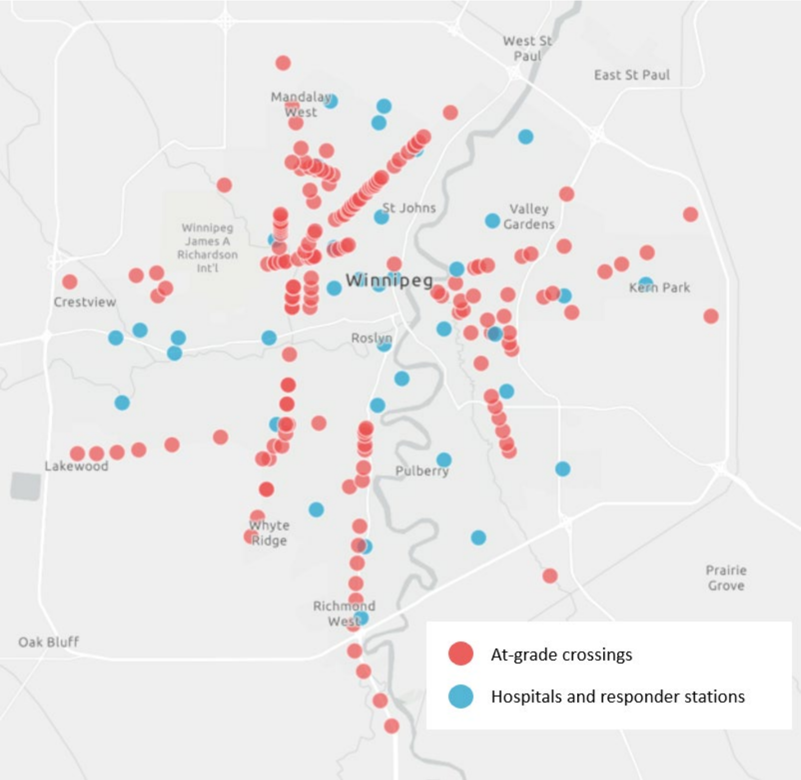


Figure 3. Locations of Winnipeg Rail Crossings, Responder Stations, and Hospitals

TRAINFO's train detection sensors provided rail crossing blockage data and WFPS provided emergency call log data. For this project, the team collected between 5 and 52 weeks of continuous rail crossing blockage data at 68 of 156 rail crossings in Winnipeg. These crossings included all main line crossings, five spur line crossings, and accounted for nearly three-quarters of all rail crossing blockages in Winnipeg. For the remaining 88 crossings, which were all located on spur lines, the researchers used Transport Canada's Grade Crossing Inventory to determine the number of trains per day and three years of TRAINFO data from five spur line crossings in Winnipeg to estimate the average blockage duration. The average blockage duration for these five crossings was 6 minutes 49 seconds; however, they were also known to have exceptionally long blockages. Considering this bias, the project team used the 20th percentile blockage duration from this data (which was two minutes) as the average for the 88 crossings without TRAINFO data.

WFPS provided 52 weeks of firefighter and paramedic call log data. This represented more than 100,000 vehicle trips. Due to privacy restrictions, the City of Winnipeg aggregates responder origin, call location, and waypoint addresses, and coordinates to the postal code level (equivalent with Zip+4 codes in the US). Further, WFPS does not record vehicle route information. Based on feedback with WFPS, the researchers used the fastest path between origins and destinations as calculated by Google Maps application programming interface (API). They ran each path through TRAINFO's digital representation of the North American rail network to determine if the trip interacted with a rail crossing. The team excluded any potential delays due to vehicle queues at blocked crossings because they assumed the vehicles could drive around these vehicles when the crossing cleared.

The researchers verified the model by reviewing the results with WFPS, asking them a series of questions. Their responses are summarized below.

- **Question 1**: How many times per week do you believe responders are exposed to blocked crossings?
    - Responses ranged from 10 to 15 times per week. After receiving the responses, the project team shared the model results, which indicated 6.8 times per week.
    - After reviewing the results and exploring specific issues with WFPS, they agreed that the model results were reasonable.
- **Question 2**: At which crossing do you expect responders to be delayed most frequently?
    - All respondents identified the Marion St. crossing (Transport Canada ID 21521). After responding, the team shared the model results which indicated that Marion St. was the crossing at which responders are most delayed (0.78 responders per week).
    - After reviewing the results and seeing the relative risk differences between all crossings, WFPS agreed that the results were reasonable.
- **Question 3**: How many times per week do you expect responders to be delayed at the crossing causing the most delays?
    - Responses ranged from one to two times per week at the Marion St. crossing. After responding, the researchers shared the model results, which indicated that 0.78 responders were delayed per week at the Marion St. crossing.
    - After reviewing the results in more detail, WFPS agreed this was reasonable.
    - During the review WFPS personnel realized that there were nine other rail crossings within one mile of the Marion St. crossing that influenced their recollection of delays. The model estimated that these 10 crossings delayed 1.3 responders per week, which was similar to the anecdotal feedback from WFPS.

In addition to reviewing the results with WFPS for validation, the research team validated the model by comparing the model output from a specific crossing with the actual data from that crossing. Specifically, they plotted every trip that crossed the Shaftesbury Blvd. crossing using actual WFPS data and estimated the time each responder would have arrived at the crossing. Then, they cross-referenced the responder arrival time with actual rail crossing blockage data collected by TRAINFO sensors. If the arrival time was between the start and end time of the blockage, the trip was identified as impacted by a blocked crossing. The actual trip plot indicated that 0.71 trips were impacted per week (37 trips over a 52-week period) at the Shaftesbury Blvd. crossing. The risk model indicated that 0.72 responder trips were impacted per week, a difference of 1.4 percent, which provided strong validation of the model results.

3.4 Risk Model Observations

Table 1 summarizes the results of the model for each city.

Table 1. Summary of Risk Analysis for Each Location in the Study

Location	No. of Unique Crossings Involved	Responder Interactions with Crossings	Responder Delays at Crossings	Population Served by 911 Responders
Winnipeg, MB (Canada)	159	>20,000	>260	750,000
Houston, TX	373	>1 million	>6,700	2.28 million
Charleston County, SC	46	>3,700	>140	413,000

While the magnitude of the responder delays was considered significant by the 911 agencies, the model showed the concentration of the delays to be focused on a small number of crossings. In Winnipeg, more than 50 percent of the responder delays occurred at only 5 crossings; in Houston 33 percent of the responder delays occurred at 10 crossings, and in Charleston County, 90 percent of the responder delays occurred at 5 crossings. These observations are important as they indicate that if rail crossing information systems can reduce responder delays, a significant amount of the delay can be addressed with minimal cost.

These data also showed that, as expected, hospitals, fire stations, and senior complexes near crossings had an increased risk of responder delay. This observation warrants further research. Anecdotally, the research team posits that social demographic characteristics of a destination and their proximity to a rail crossing will be a strong indicator of locations at high risk of responder delays at crossings.

3.5 Benefit Model Design

Benefit is defined as the reduced response time on a call having used rail crossing information to help re-route a responder. For this research, only re-routing was considered in the benefit analysis model. Alternate unit dispatching is another viable solution, but is beyond the present scope, as the benefit model is intended to show the benefit of in-vehicle systems to reduce responder interactions with rail crossings.

The overall design of the benefit model assumed the traffic queues resulting from an active rail crossing would influence responders in being delayed; this assumption made it necessary to collect traffic count data to develop the benefit model. Additionally, the model used responder call logs, and historical grade crossing activity. For each crossing activation, the model determined what the queue extent (QE) and impact period (IP) were for each crossing activation. QE is defined as the length of the queue resulting from a given crossing activation. The IP is defined as the time the crossing activation started, and the time the queue recovered. In addition, the model ran each responder trip to flag responder trips interacting with a crossing (RI is denoted for responder trips interacting with a crossing).

Once the QE, IP, and RI were determined, the model evaluated if an RI occurred during the IP for any crossing. For all RI occurring during an IP for a crossing activation event, the RI's travel time was evaluated to determine if crossing activation increased the travel time of the responder trip. If the travel time was greater than the expected travel time, the trip was deemed to be delayed by the crossing activation. This approach assumes no other traffic delays impacted the responder trip. With the impacted trips flagged, the research team simulated an alternate route for the responder. The simulated alternate route's travel time was compared against the actual responder travel time to evaluate if there was a response time benefit.

3.6 Benefit Model Testing

Testing was conducted at the Shaftesbury crossing in Winnipeg, shown in Figure 4. The project team reviewed each responder trip interacting with the crossing manually and cross-referenced the interactions with crossing activation history. For each interaction, they manually calculated the queue extent and determined the impact periods. Upon determining the impact periods, they evaluated the responder travel times against the expected and flagged the trips that were delayed. The researchers found that the number of responder trips delayed for the crossing output from the model matched the manual calculation.

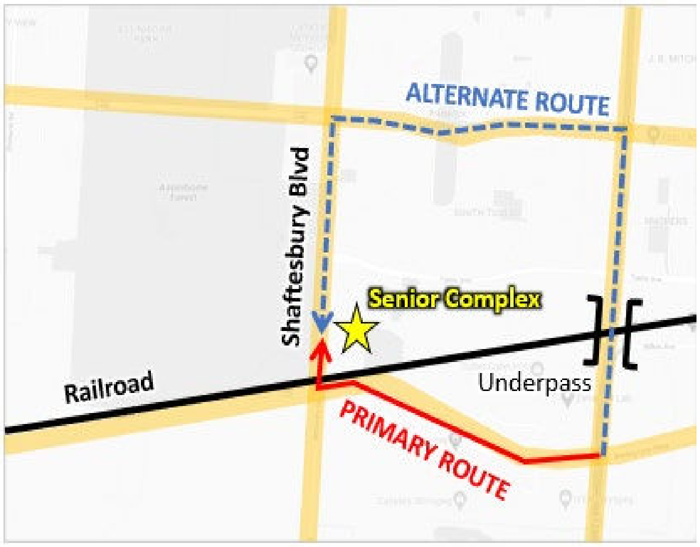


Figure 4. Sample Reroute for the Shaftesbury Crossing

For the responder trips delayed, the researchers estimated the responder travel time to a suitable reroute location and the remaining travel time on the alternate path away from the crossing. They found that the number of trips whose response time would have been improved matched the number output from the model; this provided strong validation for the model's accuracy.

3.7 Benefit Model Observations

The benefit model was run for one crossing (the Shaftesbury crossing shown in Figure 4) due to the constraint on purchasing traffic count data. Table 2 shows the results from the Shaftesbury crossing.

Table 2. Benefit Analysis Results for Shaftesbury Crossing in 2019

Statistic	Results
Responder trip crossing interactions	139
Number of responder trips present in queue during impact period	45
Number of responder trips present during impact period experiencing delay	37
Average delay for delayed responders	184 seconds
Number of responder trips with an improved response time	30
Average response time improvement	182 seconds

The Shaftesbury crossing results show that having the ability to reroute a responder would have provided more than an 80 percent reduction in responder delay at the crossing. The residual queue from a crossing activation has little to no impact on response time. The responder trips impacted were all impacted by the gate down-time and not the residual traffic queue. This observation suggests future studies may not need to consider the queue. Not considering the queue would eliminate the need to purchase traffic count data and make the approach more economically viable.

4. Development and Evaluation of an In-Vehicle Rail Crossing Information System

The research team developed and evaluated an in-vehicle rail crossing information system prototype to determine its effectiveness in reducing first responder delays. This process included significant participation and cooperation from WFPS and involved the following steps:

- System requirements development
- System concept design and review
- Technical merit and user acceptance evaluation
- System testing

This section describes the process for designing, developing, testing, and evaluating the in-vehicle prototype and presents findings about its feasibility and effectiveness.

4.1 System Requirements Development

To develop system requirements, the researchers interviewed WFPS personnel (including station and department chiefs and dispatch supervisors) to understand the emergency response process and determine in-cab technical constraints, shadowed emergency dispatchers and call-takers, and joined first responders on emergency calls to observe their actions and behaviors during live events.

The WFPS emergency response process, as shown in Figure 5, involves:

- Call-takers (individuals who answer 911 calls and route them to the appropriate dispatch group)
- Dispatchers (individuals who triage the call and assign a responder)
- Responders (individuals who address the call; they are typically firefighters, paramedics, or police officers)

The discussions with WFPS personnel indicated that rail crossing information could be used by dispatchers or first responders.

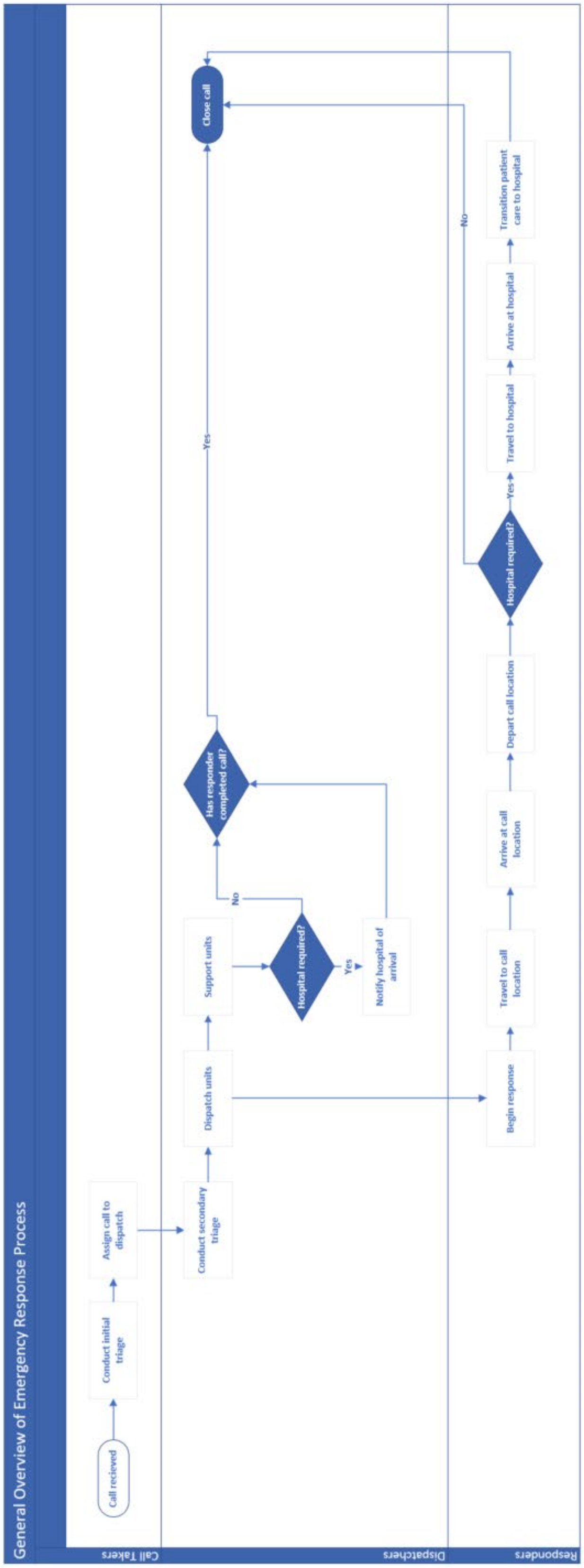


Figure 5. WFPS Emergency Response Process

The team developed the following three types of in-vehicle system requirements:

- Business requirements: the measurable benefits expected from the system
- User requirements: functions of the system that a user needs to achieve business requirements
- Non-functional requirements: architectural and administrative constraints with which the system must comply

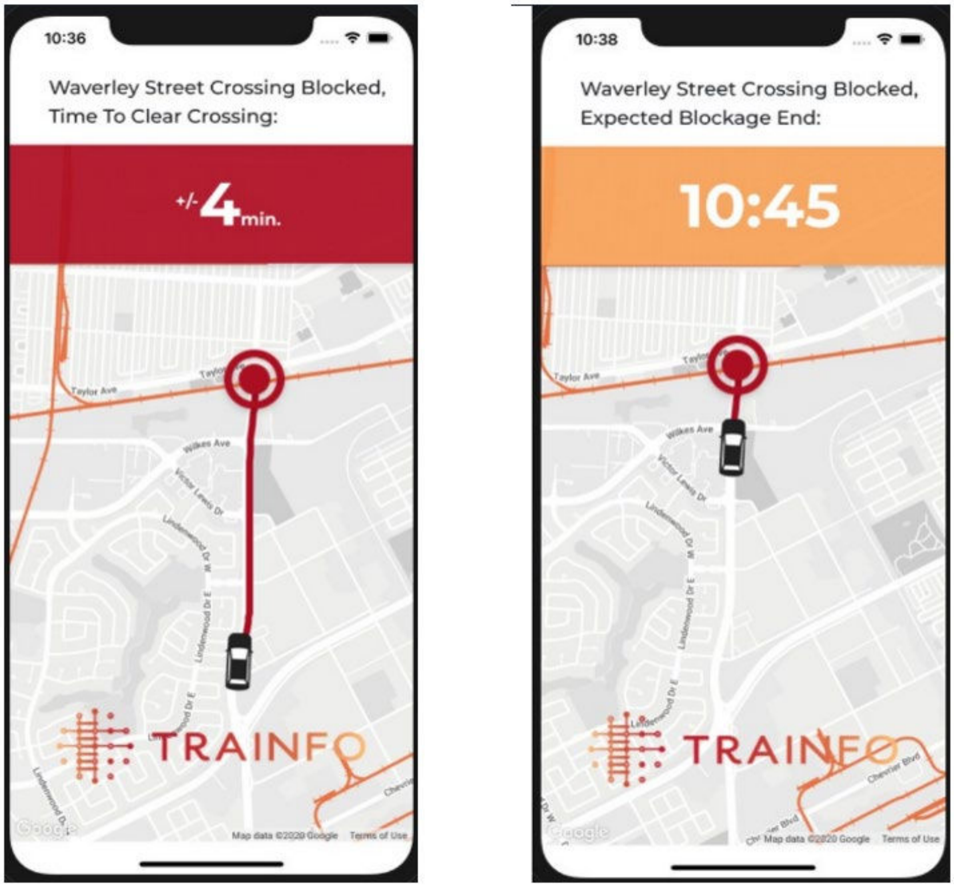
Table 3 outlines 18 requirements that the in-vehicle system was designed to meet.

Table 3. In-Vehicle System Requirements

ID	Requirement Type	Requirement
R1	Business	Reduce response times.
R2	Business	Reduce vehicle miles driven.
R3	Business	Increase fleet capacity.
R4	User	Only provide information when it is relevant to the responder.
R5	User	Show expected vehicle path to call location and what crossings may be encountered.
R6	User	Ensure the system can operate without the use of hands while the vehicle is in operation.
R7	User	Provide audible alerts as well as visual alerts.
R8	User	Provide crossing information before vehicle arrives at a crossing.
R9	User	Ensure the system is activated on vehicle engine start and deactivated on stop.
R10	User	Provide route information in the station before departure.
R11	User	While vehicle is in operation, ensure vehicle location is known.
R12	User	Provide information on the estimated start and duration of an active rail crossing.
R13	User	System must not require an independent browser tab or screen.
R14	Non-Functional	System must not require extra equipment be installed in a vehicle.
R15	Non-Functional	System must comply with National Emergency Number Association (NENA) and NFPA best practices.
R16	Non-Functional	System must comply with the Freedom of Information Policy Act (FIPPA).
R17	Non-Functional	System must be interoperable in the US and Canada.
R18	Non-Functional	System must comply with Open Web Application Security Project (OWASP) guidelines for application security.

4.2 System Concept Design Review

Based on the interviews with WFPS, dispatch shadowing, and participation in first responder calls, the project team designed the system concept shown in Figure 6. TRAINFO sensors detect trains and collect rail crossing blockage data. These data are wirelessly sent to and centralized in TRAINFO's Cloud. TRAINFO's machine-learning models analyze the data to identify current rail crossing blockages and predict future blockages, and a wireless cellular network using HTTPS protocols distributes this information to a Toughbook inside the cab, where drivers receive visual and audible alerts about blocked rail crossings. The system includes numerous security protocols including a firewall. WFPS Toughbooks run a background service that uses an in-vehicle modem to push vehicle GPS data to TRAINFO's Cloud. The Toughbooks also include a browser that calls the in-vehicle web-app from TRAINFO's Cloud.



10:36

Waverley Street Crossing Blocked,
Time To Clear Crossing:

+/-4 min.

10:38

Waverley Street Crossing Blocked,
Expected Blockage End:

10:45

Figure 6. Concept In-Vehicle Rail Crossing Information System

4.3 Technical Merit and User Acceptance Evaluation

WFPS personnel evaluated the system based on its technical merit and user acceptance. WFPS vehicle technicians evaluated technical merit based on the feasibility of installing the system and interfacing with physical components in the vehicle. WFPS IT system analysts evaluated technical merit based on the system's compliance with non-functional requirements and the feasibility of installing the system on existing WFPS technologies. The system passed both technical merit evaluations and feedback from WFPS was generally positive.

WFPS responders evaluated their experience of the web-app against the user requirements listed in Table 3 (requirements R4 to R13). Although the system received positive feedback, drivers indicated that providing in-vehicle rail crossing information is unlikely to be the most effective approach to avoid delays at blocked crossings. This is due to the numerous demands on first responder attention that currently exist while enroute to a call, including spotting traffic at intersections, gathering information and details about the emergency, and many other critical elements. Users did not feel they had sufficient attention capacity to focus on rail crossing information. Further, users indicated that unstable vehicle dynamics experienced during a call makes it difficult to interact with computer screens and process rail crossing information. Despite these challenges, WFPS users approved the design for research purposes.

4.4 System Testing

The system test as originally planned would have involved a live deployment of the in-vehicle system with first responders completing a post-call survey and participating in a focus group discussion to provide feedback. However, the COVID-19 pandemic prevented this approach due to increased call volumes for first responders and protocols to minimize physical interaction which prevented the research team from in-person interactions with responders and vehicle technicians. Instead, the team developed an online virtual demonstration with first responders. Although this limited the in-vehicle experience, the researchers were still able to present the demonstration to other first responder agencies besides WFPS and obtain their feedback.

The team conducted demonstrations with 19 agencies (16 from the US and 3 from Canada) which included participants ranging from Fire Chiefs, Dispatch Supervisors, and Fire and Medical Responders. About 80 percent of participants had over 10 years of experience. General feedback was that rail crossing information was necessary and would reduce response times and operating costs by avoiding dispatching multiple units to an emergency if the primary unit were to interact with a rail crossing and by avoiding longer routes to grade separation. However, most participants indicated that rail crossing information would be more effective if delivered via dispatchers rather than through in-vehicle systems.

4.5 Observations

The development and evaluation of an in-vehicle rail crossing information system revealed three main observations:

1. Rail crossing information is important in reducing response times and reducing the cost to provide 911 services. While real-time crossing blockage information is useful, first responders indicated that predicting the blockage start and end times was critical to minimize responder interaction with active crossings.
2. The use of in-vehicle systems is difficult for responders because of unstable vehicle dynamics and limited available responder attention.

3. Providing predictive rail crossing blockage information to dispatchers is likely the most effective way to reduce responder delays at rail crossings. Providing in-vehicle notifications requires drivers to react to blocked crossings, whereas providing information to dispatchers facilitates a more proactive response. Dispatchers can select units that will not be impacted by trains, know when to dispatch additional units, and potentially provide faster re-route alternatives. Additional research should evaluate the benefits of providing rail crossing information to dispatchers.

Responders and dispatchers use a wide range of information systems, ranging from medical records to structural building information. It is challenging to add new information into their processes and systems. These include the cognitive challenges of absorbing many types of information under stressful conditions and physical challenges of adding another screen to the existing array of screens. While the need for rail crossing status information is valuable, delivering it as an integration into an existing system (i.e., Computer-Aided-Dispatch [CAD] software and situational mapping tools) would help minimize the cognitive and physical challenges.

5. Development and Evaluation of Rail Crossing Information Integrated into Dispatch Tactical Maps

Tactical maps are tools used by dispatchers outside of their CAD systems to provide tactical, geo-referenced information to support the response process. Lane closures, accidents, and location of traffic cameras are a few examples of the geo-referenced information found in a tactical map.

The research team developed integrations into the tactical maps for Charleston County and the City of Houston. Developing and evaluating the integrations involved in the development of APIs and system testing. This section describes the process for developing the APIs, conducting system testing with dispatchers from the City of Houston and Charleston County, and provides a summary of the observations from testing.

5.1 Development of API

To develop the API, the team consulted with the tactical map vendors for Charleston County (Alastar by ATI) and City of Houston (Haystax). A GEO-JSON structured API was requested from both vendors. In both scenarios, two types of API calls were requested; they are the *Get Crossings* call and the *Get Crossing Statuses* call. The *Get Crossings* call provides the tactical map with a reference of all the crossings for which they may receive data and the meta data summarized in Table 4. The *Get Crossings* call is referenced by the tactical maps daily to see if there are new crossings from which it can expect data.

Table 4. API Attributes in the Get Crossings Call

API Attribute	Attribute Description
Crossing Identifier	Crossing identifier as defined by FRA in the US and Transport Canada in Canada
Latitude	Crossing latitude
Longitude	Crossing longitude
Crossing Name	Street name the crossing intersects
City	City in which the crossing is located
State	Province/state in which the city is located
Time zone	Province/state time zone
Country	Country in which the province/state is located

The *Get Crossing Statuses* call provides the tactical map with the status of all monitored crossings. The tactical maps call *Get Crossing Statuses* every 10 seconds for an update. Table 5 summarizes the data attributes provided in the call.

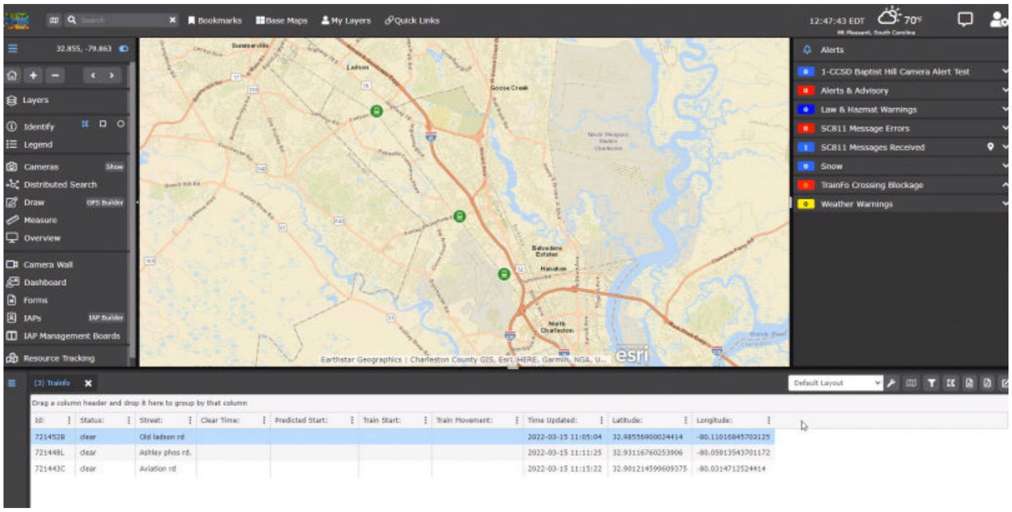
Table 5. API Attributes in the Get Crossing Statuses Call

API Attribute	Attribute Description
Crossing Identifier	Crossing identifier as defined by FRA in the US and Transport Canada in Canada
Crossing Status	The status of the crossing as either blocked or clear
Train Movements	Movement of the train classified as either continuous or non-continuous. Non-continuous movements are those where a train exhibits a stopping, shunting, or switching movement
Train Start	Time crossing became active if the crossing status is *Active*
Predicted Start	Time crossing is expected to become active if crossing status is *Clear* and train is approaching
Clear Time	Time crossing is expected to be clear if crossing is currently active or a train is approaching

Using the developed APIs, the tactical maps for both municipalities were able to access real-time and predictive crossing information. In both instances, the data was translated as crossing icons with the following visual cues depending on the crossing status:

- Solid Green: Crossing is clear.
- Solid Amber: Train is approaching crossing.
- Solid Red: Crossing is active.
- Flashing Red: Train is exhibiting a non-continuous movement at the crossing.

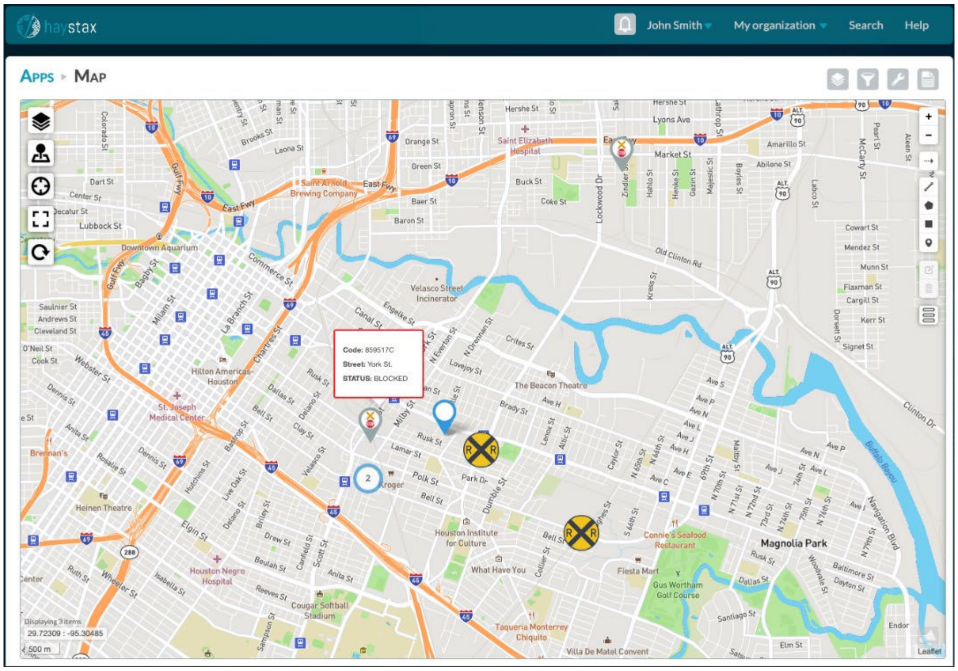
Samples of the tactical maps with integration are shown in Figure 7 (Charleston County) and Figure 8 (City of Houston).



Drag a column header and drop it here to group by that column

Id:	Status:	Street:	Clear Time:	Predicted Start:	Train Start:	Train Movement:	Time Updated:	Latitude:	Longitude:
721452B	clear	Old ladson rd					2022-03-15 11:05:04	32.98556900024414	-80.11016845703125
721448L	clear	Ashley phos rd.					2022-03-15 11:11:25	32.93116760253906	-80.05913543701172
721443C	clear	Aviation rd					2022-03-15 11:15:22	32.901214599609375	-80.0314712524414

Figure 7. Tactical Map with TRAINFO Integration Example for Charleston County



Code: 859517C
Street: York St.
STATUS: BLOCKED

Figure 8. Tactical Map with TRAINFO Integration Example for City of Houston

5.2 System Testing

The project team developed two test criteria to evaluate the effectiveness of tactical map integrations in reducing responder delays at rail crossings:

1. The number of trips impacted by active rail crossings is reduced.
2. The integration is consistently used.

If both criteria are met, the tactical map was deemed to be an effective method to reduce responder delays at crossings.

5.2.1 Test Criteria 1: The Number of Trips Impacted by Active Rail Crossings is Reduced

To test criteria 1, the team ran the responder risk model before and after the integration. The before scenario was run using 1 year of call log data and the after scenario was run after 3 months of the tactical map being released to dispatchers.

In Charleston County, data were collected for seven crossings; however, only three crossings were evaluated as a result of delays in equipment installation with the county. The results (Table 6) demonstrate a 78 percent reduction in responder delays at the crossings.

Table 6. Change in Responder Risk Before and After Tactical Map Integration (Charleston County)

Crossing	Responders Impacted Per Week Before	Responders Impacted Per Week After
Ashley Phosphate Rd. 721448L	0.44	0.1
Aviation Rd. 721443C	0.006	0.003
Old Ladson Rd. 721452B	0.1	0.02

In the City of Houston, data were collected for seven crossings. The before scenario was run using 1 year of call log data and the after scenario was run after 3 months of the tactical map being released to dispatchers. The results, shown in Table 7, demonstrate a 1 percent reduction in responder delays at the crossings.

Table 7. Change in Responder Risk Before and After Tactical Map Integration (City of Houston)

Crossing	Responders Impacted Per Week Before	Responders Impacted Per Week After
Commerce St. 288129A	1.5	1.4
Hirsch Rd. 755640L	0.43	0.4
Leeland St. 288224V	0.54	0.47
Lockwood St. 859523F	0.78	0.62
Market St. 755709E	0.79	0.7
Polk St. 288039B	0.17	0.17
York St. 859517C	0.12	0.12

5.2.2 Test Criteria 2: The Integration is Consistently Used

In both the City of Houston and Charleston County, dispatchers were interviewed after no less than 3 months of the tactical map integrations having gone live. When the integration first went live, dispatchers were asked to use the map and log their feedback. After a few weeks of the initial engagement with the tactical map integration, engagement had reduced. Feedback from dispatchers stated that having to cross-reference between the tactical map and their CAD to dispatch and support units was difficult considering they could be supporting up to 12 calls at a time. This challenge was not isolated to referencing rail crossing status, but any traffic issue present in the tactical map. While it was a challenge cross-referencing multiple systems, dispatchers still found the integration to be useful.

Feedback from dispatchers in the City of Houston showed significant challenges with having the tactical map influence routing. Because of the complexities in the City of Houston's 911 operations and the challenges of big city traffic networks, dispatchers depend heavily on the unit recommendations from their CAD. Rail crossings are one of many traffic issue in the city, and it is a challenge for dispatchers to focus solely on them.

5.3 Observations

While the results in Charleston County showed significant promise, the results in Houston show a deeper need to see rail crossing status (amongst other traffic data) integrated in the CAD systems to reduce responder delays. In addition to the tactical map integration being made available for dispatchers, the City of Houston provided the tactical maps in firehalls for responders to reference as they departed for calls. Feedback from responders on the tactical map in the firehall was generally positive, but described challenges with not getting updates when crossing statuses changing after they left the firehall.

An interesting tactic taken by Charleston County was using risk modeling to set temporary lane closures on road segments during periods where the rail crossing has increased activity. Figure 9 shows the crossing activation frequency and average activation duration for the Ashley Phosphate crossing. The 2:00 pm and 1:00 pm hours are periods during which the number of activations and the duration of activations coincide with periods where responders have an increased demand to cross the crossings. Charleston County has set temporary lane closures on this road segment for the 2:00 pm and 3:00 pm hours in their CAD; this eliminates this road segment as an option for responders during the noted times.

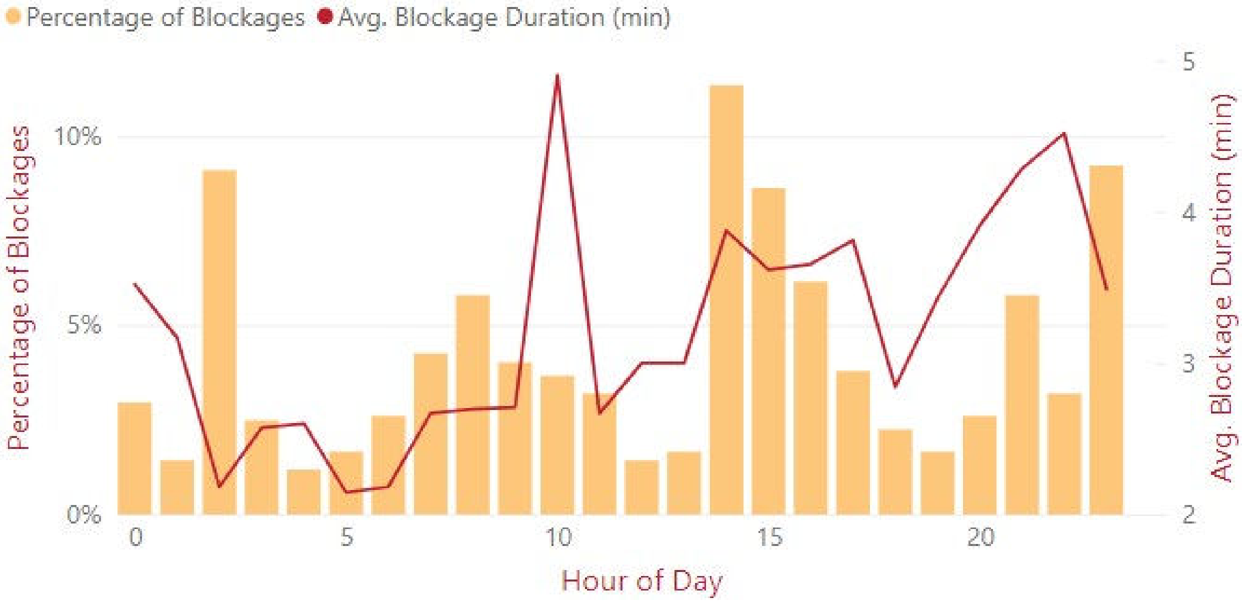


Figure 9. Distribution of Crossing Activity over the Course of a Day (Ashley Phosphate Crossing in Charleston County)

6. Conclusion

This research demonstrated that rail crossing activity has a meaningful impact on first responder delays. There are anywhere from 2 responder delays per crossing per year to 20, on average. A significant proportion of delays occur at a fraction of the crossings. While the impact is significant, the research also demonstrated the ability to eliminate as much as 80 percent of responder delays at rail-crossings using rail crossing information systems.

While the research demonstrated that producing rail crossing information using wayside detection is feasible, identifying where the information should be incorporated in the emergency response process was a challenge. In-vehicle integrations showed challenges with responders having limited available attention to use the information. Tactical map integrations for dispatchers showed significant promise and benefit in Charleston County; however, for agencies serving larger populations, (i.e., City of Houston) using tactical maps was a challenge. For dispatchers with agencies serving large populations, the volume of calls they manage at a time and complexity of the road network create a high dependency on using CAD systems to automate unit recommendations and routing. This dependency limits the capacity of a dispatcher to cross-reference tactical maps to support unit selection and responder routing. Even medium sized agencies (i.e., Charleston County) have a significant dependance on the automation their CAD can provide.

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Abbreviations and Acronyms

ACRONYMS	**EXPLANATION**
API	Application Programming Interface
FIPPA	Freedom of Information Policy Act
IP	Impact Period
NENA	National Emergency Number Association
NFPA	National Fire Protection Association
OWASP	Open Web Application Security Project
QE	Queue Extent
RI	Responder trips interacting with a crossing
WFPS	Winnipeg Fire Paramedic Service