Development of an at-grade rail crossing information system prototype

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Abstract

The success of an emergency response is often measured in minutes or even seconds. Small delays to fire, paramedic, and police en-route to emergencies can be catastrophic and even fatal. Train crossing delays can represent a significant source of delay and can frequently last more than several minutes. Although the number of emergency vehicles being delayed by a train compared to the total number of emergency calls may be perceived as small, anecdotal evidence from dispatchers and prior research indicate that emergency vehicles can be stopped by trains on a weekly and nearly daily basis. Given that real-time data are available to determine the location, speed, and direction of a train, it is concerning that this information is not being used to inform emergency responders and prevent unnecessary delays at rail crossings. Meanwhile, however, dispatchers have insufficient information to make real-time decisions that best support responses to emergencies.

This paper describes the development of an at-grade rail crossing information system (RCIS) prototype that can detect a blockage and communicate the information in real-time. Specifically, this paper provides preliminary data analysis results from the prototype concerning the accuracy of the system, challenges and limitations, lessons learned, key considerations, and feasibility for implementation. The paper describes various applications for the RCIS, including integration with traffic management centres and providing traveler information directly to road users via smartphone apps or media outlets.

INTRODUCTION

Railroads provide essential transportation services and often interface with other modes of transportation. However, blockage delays at at-grade railroad crossings are inevitable. Grade separated railroad crossings are the most effective option for addressing these delays but are also the most expensive and are not always feasible due to other constraints such as insufficient space. Other options are necessary to reduce delays when grade separation is infeasible.

Railroad crossing delays directly impact emergency response time, transit service reliability, commuter travel time, and truck productivity. Potential consequences of these impacts can include:

- loss of life or increased injury severity due to inadequate response time to emergency situations,
- higher property damages due to fires or other disasters,
- higher emergency service costs due to the potential for dispatching additional units when the first responder is blocked at a rail crossing or operating redundant emergency stations to account for potential rail crossing delays,
- negative public image issues when emergency vehicles are stopped at a blocked crossing with their sirens and lights activated,
- reliance on third-party, reactive information (e.g., media traffic reports) for train delay updates,
- elevated road safety risks due to the potential for additional emergency vehicles on the road,
- disrupted transit schedules,
- increased emissions due to congestion,
- pre-mature investment in grade separation construction,
- higher freight transportation costs, and
- general disturbances to the public caused by travel delays (e.g., late for work, family events, meetings, etc.).

This paper describes the development of an at-grade rail crossing information system (RCIS) prototype and pilot test that detects blockages and communicates this information in real-time. Specifically, this paper provides preliminary data analysis results from the prototype concerning the accuracy of the system, challenges and limitations, lessons learned, key considerations, and feasibility for implementation.

BACKGROUND

The Canadian Rail Operating Rule (CROR) 103(c) states that "…no part of a movement may be allowed to stand on any part of a public crossing at grade, for a longer period than five minutes, when vehicular or pedestrian traffic requires passage. Switching operations at such crossing must not obstruct vehicular or pedestrian traffic for a longer period than five minutes at a time…" (1). However, moving trains, regardless of speed, are not considered in violation of CROR 103(c) and can block the crossing for longer than five minutes (2).

Up to 40,000 cardiac arrests occur each year in Canada (3) with approximately 85 percent of these occurring in homes and public places (4). The survival rate of a cardiac arrest victim decreases by 7-10 percent for every one minute delay in defibrillation (5) and after more than 12 minutes the survival rate is less than five percent (6). Therefore every minute of delay has significant consequences and can result in serious injury or death.

Most fire and paramedic services are mandated to respond to incidents within six minutes. This includes one minute for emergency call handling, one minute for preparation time, and four minutes for travel time. An emergency vehicle delayed at a grade crossing could jeopardize the target response time. Due to this potential, fire and paramedic stations are strategically located to mitigate these delays. While the location of the station can sometimes address the problem, emergency vehicles are commonly delayed at rail crossings. In Winnipeg, for example, an emergency vehicle is delayed at a crossing between two and five times per week (7). Strategically locating stations to mitigate rail crossing delays can result in excess stations being operated. A research study in Saskatoon demonstrated that a station's catchment area decreased from 4.7 km^2 to 0.5 km^2 when a rail crossing delay occurred and that an RCIS could reduce travel response time by nearly two minutes (from 6.0 minutes to 4.2 minutes) during this blockage (8).

Although emergency stations are often strategically located to mitigate rail crossing delay within their catchment area, not all stations are equipped to handle certain emergencies. In these cases special emergency responders must be dispatched from outside the catchment area. The ability of strategically located stations to avoid rail crossings becomes much more difficult to achieve in these situations. Further, if an emergency crew is already attending an incident, a crew from another catchment area must be dispatched and could also encounter rail crossing delays.

Grade separation eliminates rail crossing delays at a significant cost. These projects can exceed $250 million and often require land expropriation, especially in urban areas. An RCIS provides an opportunity to consider delaying investments in grade separation or satisfactorily addressing at-grade rail crossing issues altogether. From this perspective, investing in an RCIS can result in millions of dollars of savings for jurisdictions.

The mantra "we cannot build ourselves out of congestion" is commonly recited among transportation officials and practiced in the form of implementing intelligent transportation systems. However, regarding at-grade rail crossings, few alternatives exist to address delays and congestion without constructing grade separated facilities. This paper provides an overview of the design, development, and pilot test of an RCIS in Winnipeg, Manitoba to demonstrate its feasibility and provide an option for jurisdictions to consider to address rail crossing delays without major capital and operating costs.

DESIGN AND DEVELOPMENT OF THE RCIS PROTOTYPE

Creating the RCIS prototype involved designing and developing data collection technologies and methods, communication protocols, data management systems, analytical processes, and reporting capabilities.

We collected data using one of two methods. We applied one method to receive rail pre-emption signals at interconnected traffic signals. For this method we developed technologies to monitor the rail pre-emption signal and transmit occurrences of those signals in coded packets to an off-site application program interface (API) server. We used a second method at key locations where interconnected signals were unavailable. For this method we developed technologies to spatially monitor the rail line for blockages, bundle the monitor data into packets, and transmit the data packets to an off-site API server. For both methods, we used GSM modems operating on 850 MHz to transmit data packets from monitoring equipment to the off-site servers.

We processed data from the GSM modems in the RCIS API server by running a custom program to filter incoming data packets and store them in a MySQL database. We designed the structure of this database to store the incoming monitor data and spatial relationships between multiple at-grade rail crossings and their associated rail lines. We also cross-referenced spatial relationships within a custom developed prediction-processing algorithm (patent pending). These proprietary algorithms accept incoming monitor data to identify the blockage location, determine the cause of the blockage (e.g., full-length train, maintenance, etc.), estimate the duration of the blockage, predict which crossing will be blocked next, and estimate when the next crossing will be blocked.

To develop the proprietary algorithms we established and applied thresholds to define logical movements and situations. We developed initial algorithm rules and logic based on data analyses that revealed historical trends and relationships, statistical analyses to estimate the probabilities of various events, and our extensive industry intelligence regarding rail operations. The algorithms are designed to continually and automatically improve each time new data is received. This capability ensures that algorithms can adapt to changes in rail operations in real-time and can flag unusual events.

Raw data from the RCIS produces three basic metrics: the time, location, and duration of a rail crossing blockage. From these basic metrics we can determine the number of grade crossing activations by time-of-day and day-of-week. We can also develop advanced metrics such as predicting the next location of a grade crossing blockage (including estimating the time it will be blocked and the duration of the blockage), estimating train length, speed, and direction, and inferring train type (e.g., container, commodity, etc.).

PILOT TEST OVERVIEW AND RESULTS

We conducted a pilot test of the prototype RCIS on a portion of the CP Emerson mainline in Winnipeg, Manitoba. The total length of this line within city limits is approximately 11.5 km and the piloted length is approximately 2.5 km. The initial pilot involves two data collection points located at the intersection of Marion St and Archibald St and the intersection of Cottonwood St and Archibald St as shown in Figure 1. Both of these locations provided data through interconnected traffic signals. We conducted the pilot test over a nine week period during the first quarter of 2015. We recorded over 1100 rail crossing blockages - 774 at the Marion St and Archibald St crossing and 348 at the Cottonwood St and Archibald St crossing. A subsequent pilot test is planned to include additional data collection points along the entire 11.5 km length of the rail line using data from other interconnected signals and spatial monitors.

Conditions for the initial pilot test were intentionally selected to provide challenging situations. First, only two data collection points were used, representing the situation with the fewest data collection points possible. Second, there is an industry turn-out approximately half way between the two data collection points, representing a situation where the activation of one crossing does not necessarily result in the subsequent activation of the downstream crossing. For example, a crossing at Cottonwood and Archibald does not necessarily result in a crossing at Marion and Archibald which creates challenges for predicting crossing blockages. Third, portions of this rail line are double-tracked, representing a situation where it is logically possible for trains to travel in opposing directions towards each other. Therefore we expect the initial pilot test to produce among the poorest performing results and predictions. We are planning subsequent pilot tests to determine how additional data collection points improve results and understand how to minimize additional data collection points while achieving high accuracy.

Figure 2, Figure 3, and Figure 4 show some of the preliminary results at the Marion and Archibald rail crossing. On weekends, the longest, shortest, and average blockage duration lasted 27, 0.5, and 6 minutes, respectively (these metrics are also available for individual days of the week). The average blockage duration was 6 minutes which is longer than the targeted travel time for emergency vehicles to respond to an incident.

Tests on our predictive algorithms produced favourable results. Despite the limited number of data collection points and the complex rail operations we were able to correctly predict (plus or minus one minute) when the next crossing would become blocked more than 85% of the time. We were also able to correctly predict the duration of the blockage (plus or minus two minutes) with more than 85% accuracy. We expect this accuracy to improve with additional data collection points and a longer time period to incorporate historical data.

The outputs of the RCIS can feed several different user groups and be provided in many different formats including text, graphics, or maps. Text formats include American Standard Code for Information Interchange (ASCII), graphical formats include spreadsheet charts and illustrations, and map formats include shapefile (.shp), keyhole markup language (.kml), and others. The flexibility in outputs ensures that rail crossing information can be integrated with various dispatch software, traffic management centre systems, transportation engineering and planning reports, and other user needs.

Despite the limited geographic coverage of the pilot RCIS we received significant public demand for this information. To meet this demand, we created a Twitter account to disseminate this information with anyone who followed this account. Figure 5 shows a screenshot of the tweets shared with followers. This dissemination method provided real-time tweets whenever a crossing was blocked at Marion and Archibald or Cottonwood and Archibald. This is a basic notification system that provides tweets for both locations every time there is a blockage. However, most users only want a notification for certain crossings and during certain times of the day. To address this demand, we are currently developing a smartphone app that can provide this capability.

Figure 5 illustrates the type of data being collected (e.g., the time and location of a blockage) and reveals interesting findings from the data. For example, at 6:17 pm there was a blockage at Cottonwood (the south data collection point) and at 6:22 pm there was a blockage at Marion (the north data collection point). This suggests the presence of a northbound train. There are also blockages at Marion at 8:10 pm and 8:17 pm but none at Cottonwood. This suggests movements by short rail vehicles associated with the industry turn-out. At 10:12 pm there was a blockage at Marion and at 10:18 pm there was a blockage at Cottonwood. This suggests the presence of a southbound train. Unlike the raw data collected and stored in our database, the Twitter feed does not show when a crossing is cleared. Using this additional data we are able to calculate blockage duration and, together with our industry intelligence, estimate train length.

CHALLENGES

The design, development, prototyping, and piloting stages revealed several challenges. Short trains and maintenance vehicles were challenging, primarily due to the industry turn-out between the data collection points) since their behaviour is less predictable than unit trains. However, the challenges with their unpredictability is somewhat mitigated due to the short duration of blockages they cause. Often these blockages are less than one minute and are essentially inconsequential for most road users.

Rail operations are another challenge for predicting the location and duration of rail crossing blockages. Mathematical relationships and historical trend analyses are mechanical methods for predicting data patterns and can generally be established for any dataset, irrespective of the subject. We incorporated these methods into the predictive algorithms of the RCIS to provide basic information and predictive capabilities. However, we found that incorporating industry intelligence about how railroads operate (e.g., operational impacts of weather and climate, broad economic influences on freight movement, characteristics of different train types, and many others) is key to overcoming the shortcomings of a purely mechanical system.

The location of data collection points can also introduce challenges. Minimizing data collection points is desirable to help minimize system costs. Therefore, strategically selecting points is important. Junctions and industry turn-outs are areas where complex rail vehicle movements occur and where many data collection technologies could be installed. However, we found that applying industry intelligence and algorithmic logic can minimize the amount of equipment to install and maintain.

CONCLUDING REMARKS

Travel delays caused by rail crossing blockages impact emergency response time, transit service reliability, commuter travel time, and truck productivity. The consequences of these delays can be significant, particularly when considering the delays to emergency services. Grade separation is an effective option for eliminating these delays; however, it is also a very costly option that is not always feasible due to other constraints such as available space. Currently jurisdictions have few options for addressing these options. This paper describes an on-going project to research, prototype, and pilot test a rail crossing information system (RCIS) to help road users and transportation system operators mitigate rail crossing delays without significant investments.

The project demonstrates that an RCIS is feasible, effective, and relatively inexpensive. The RCIS piloted for this project is capable of providing real-time rail crossing delay information in multiple outputs such as text, graphics, and maps and in multiple formats that are compatible with most software applications. The RCIS comprises three levels to meet various user needs and budgets. The lowest level is a notification system that provides real-time information about the location and time of a rail crossing blockage. This level is useful for personal use or for low budget situations. The second level is a semi-predictive system that provides the same information as the notification system, but also predicts the location of the next blockage location. The third level is a fully-predictive system that provides the same information as the semi-predictive system, but also predicts the estimated time until the next location experiences a blockage and the estimated duration of this blockage. This level is useful for emergency and traffic management applications with higher budgets.

Our initial pilot test demonstrated relatively accurate predictive capabilities. We conducted this test under challenging conditions with few data collection locations and complex rail operations. Despite these challenges, the RCIS was capable of predicting the next blockage location with over 85% accuracy (plus or minus one minute) and the duration of the blockage with over 85% accuracy (plus or minus two minutes). We are planning to conduct subsequent pilot tests with additional data collection locations and expect improved results.

Rail crossing blockage information is useful for many users and applications. The RCIS pilot has generated interest from municipal traffic management centres, emergency service providers, transportation planners (both rural and urban), road safety professionals, media, and the general public. Further, the real-time notification RCIS can be transferred to other jurisdictions and become fully operational in less than a month. The semi- and fully-predictive RCIS requires integration of local industry intelligence and time for the algorithms to calibrate to specific operational characteristics; therefore additional time is required to become fully operational. Rail crossing delay impacts are expected to exacerbate as railway and roadway traffic volumes increase, trains become longer, and safety concerns rise. It is infeasible and unsustainable to build ourselves out of these impacts through grade separation investments. An RCIS provides a feasible and cost-effective option to mitigate rail crossing delay impacts.

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Figures and Tables

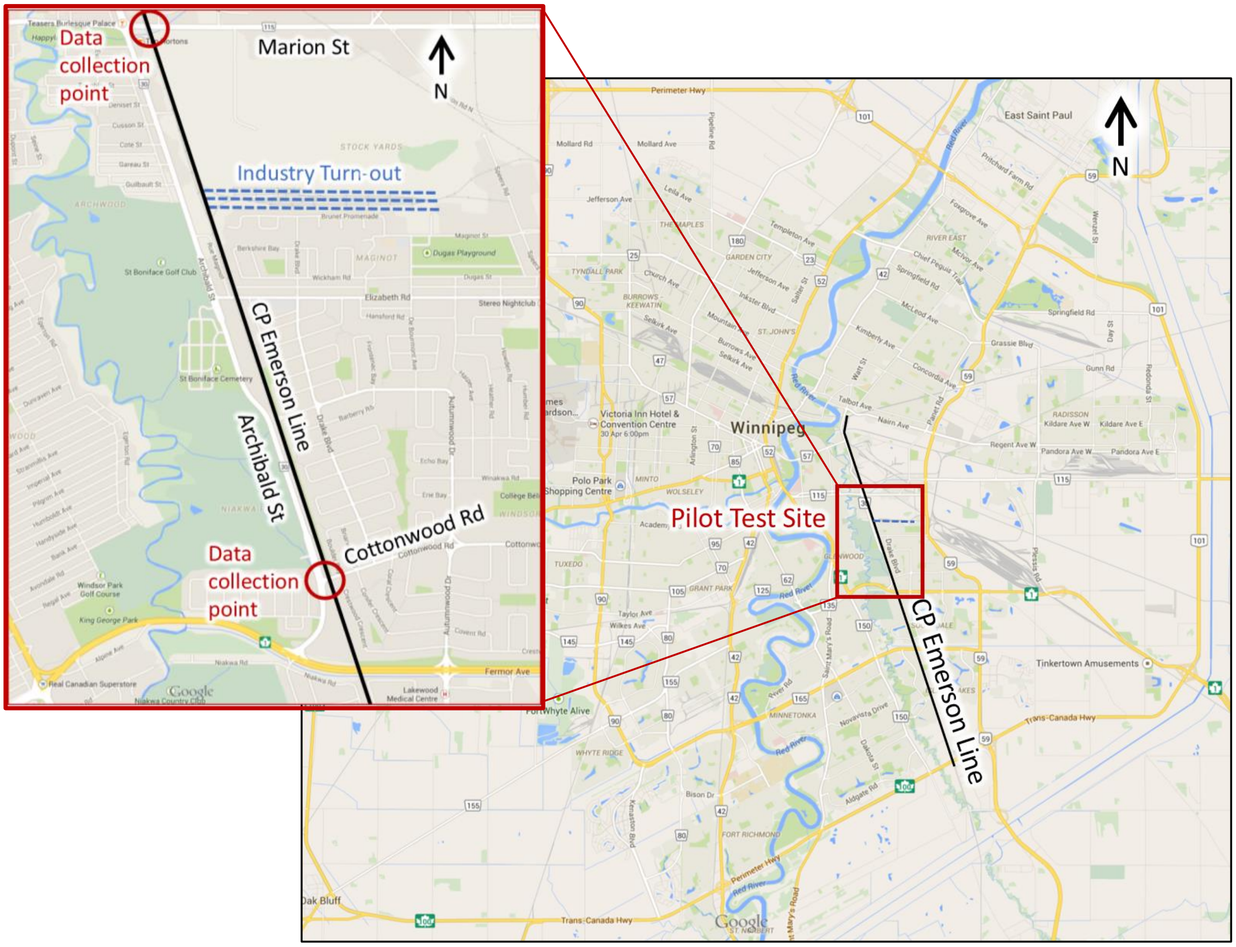

Figure 1: Pilot test site

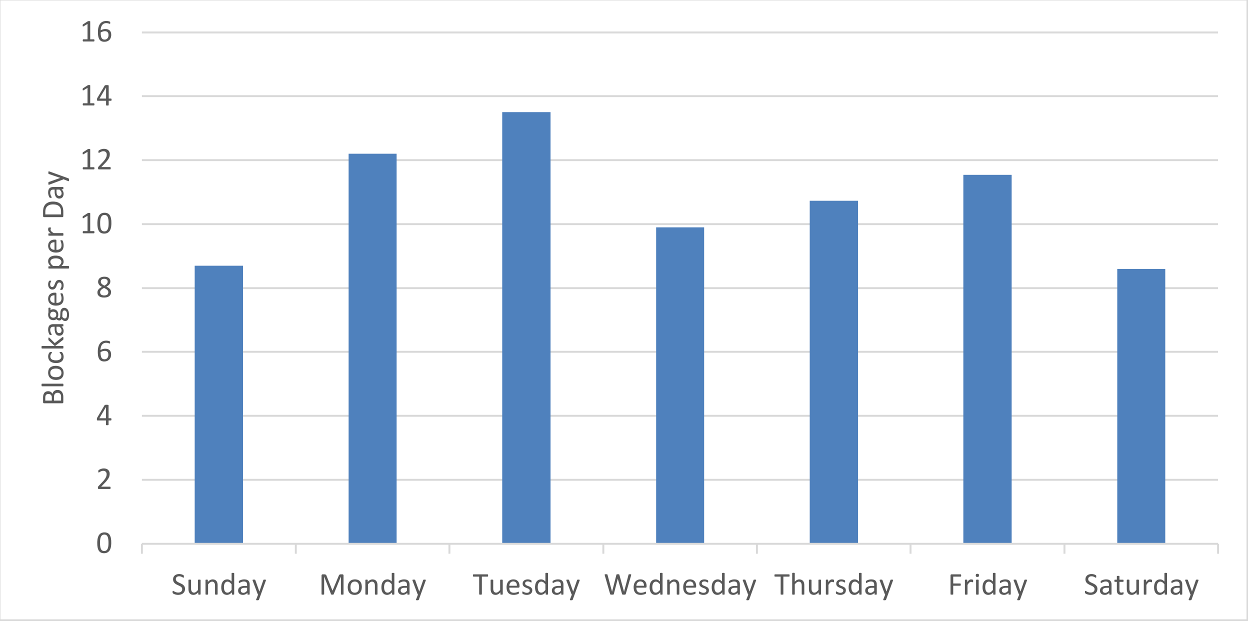

Figure 2: Average number of blockages at Marion St by day-of-week

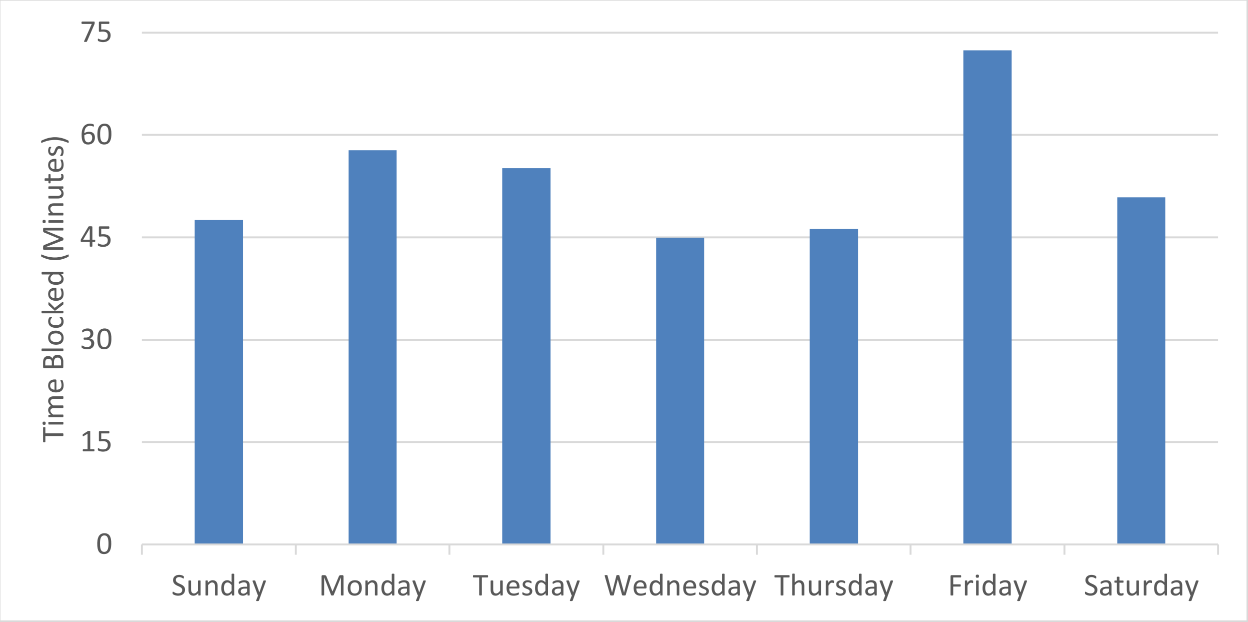

Figure 3: Average cumulative blockage time at Marion St by day-of-week

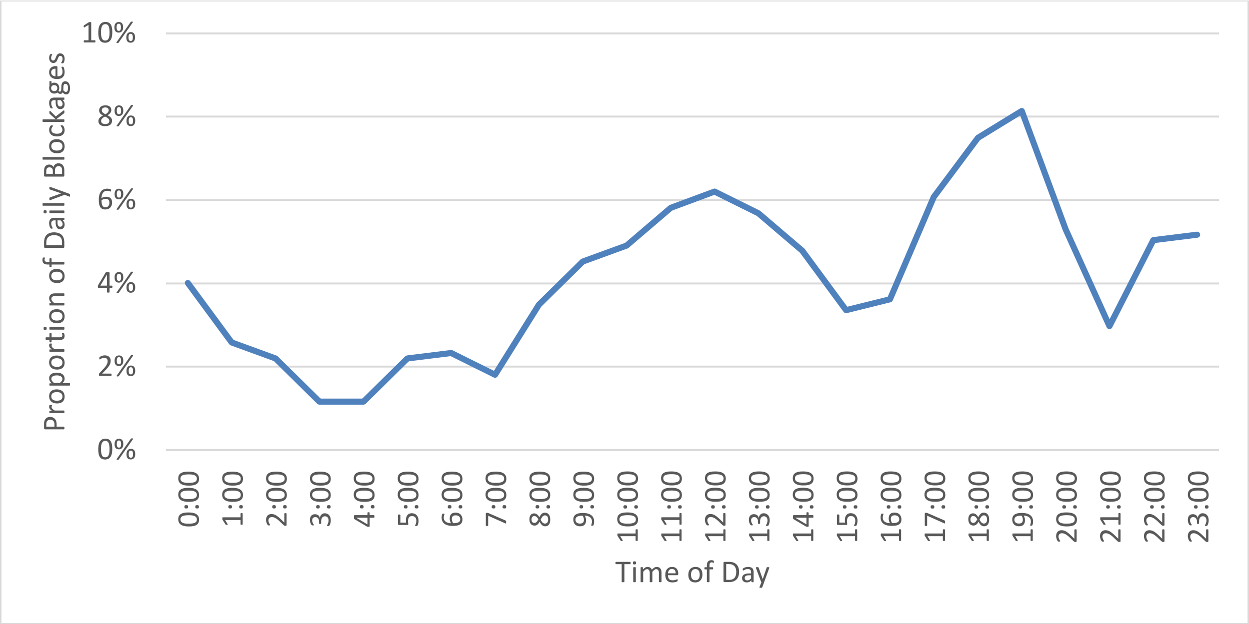

Figure 4: Proportion of Blockages at Marion St by Time-of-Day

TrainfoWPG @TrainfoWPG · 14h
Cottonwood and Archibald 10:18 pm Rail crossing blockage #traffic #winnipeg More locations coming soon.

TrainfoWPG @TrainfoWPG · 14h
Marion and Archibald 10:12 pm Rail crossing blockage #traffic #winnipeg More locations coming soon.

TrainfoWPG @TrainfoWPG · 16h
Marion and Archibald 08:17 pm Rail crossing blockage #traffic #winnipeg More locations coming soon.

TrainfoWPG @TrainfoWPG · 16h
Marion and Archibald 08:10 pm Rail crossing blockage #traffic #winnipeg More locations coming soon.

TrainfoWPG @TrainfoWPG · 18h
Marion and Archibald 06:22 pm Rail crossing blockage #traffic #winnipeg More locations coming soon.

TrainfoWPG @TrainfoWPG · 18h
Cottonwood and Archibald 06:17 pm Rail crossing blockage #traffic #winnipeg More locations coming soon.

Figure 5: Real-time Twitter feed of rail crossing blockages