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Application of Advanced Analytic and Risk Techniques to Railroad Operations Safety and Management

FINAL REPORT
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16. Abstract

Railroads generate large amounts of data. The data collected by railroads are in several different forms including both numeric and textual data. Further, there are numerous external databases that contain information and data relevant to railroad maintenance, operations, and capital investments. The fundamental problem with the amounts of data and varied data sources is that railroads have generally lacked tools and the capability to analyze these data to develop predictive models to improve decisions regarding maintenance, operations, and capital investments that improve safety, service and, ultimately, overall profitability. This is particularly a problem for Class II and III short line railroads that lack significant staff and resources to undertake these analyses. This project specifically addresses these problems with two Class II railroads in terms of grade crossing and trespassing incidents and identifying potential transload customers for specific commodities.

For one railroad partner, high-risk grade crossing and trespassing situations are identified, and potential risk reduction measures are recommended. For the other railroad partner, potential customers for two possible transload commodities are identified and data sources provided for further analyses.

A prototype decision support system (DSS) is proposed, and advanced data visualization tools are demonstrated and applied for both railroads. Recommendations for further research and development are made specifically for grade crossing and trespassing risk metrics and profiles.

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DESCRIPTION OF THE PROBLEM

Railroads generate large amounts of data. Data are collected about operating performance, maintenance work and accidents. The data collected by railroads are in several different forms including both numeric and textual data. Further, there are numerous external databases that contain information and data relevant to railroad maintenance, operations, and capital investments. The fundamental problem with the amounts of data and varied data sources is that railroads have generally lacked tools and the capability to analyze these data to develop predictive models to improve decisions regarding maintenance, operations, and capital investments that improve safety, service and, ultimately, overall profitability. This is particularly a problem for Class II and III short line railroads that lack significant staff and resources to undertake these analyses. Since these railroads originate/terminate 30-40% of all rail freight traffic in the United States, gaining improved operations, safety and service directly impacts the customers and local economies where these railroads operate. This project specifically addresses these problems.

APPROACH

The primary goal of this research project was to extend our prior work beyond the proof of concept and demonstrate it can be introduced and implemented within everyday railroad decision-making. To accomplish the latter, we anticipated a two-phased project: Phase 1) development of a prototype system that complements and improves the current tools and DSS used by the cooperating railroads, and Phase 2) a staged roll-out of the prototype system within cooperating railroads that would become integrated into the railroads' day-to-day operations, maintenance, and decision-making protocols. This report addresses the work undertaken and completed in Phase 1: develop a prototype system that complements and improves the current tools and DSS used by the cooperating railroads.

To accomplish Phase 1, the following activities were completed:

- Collected data from participating railroads and external data sources.
- Fused the collected data into a unified database to allow for integrated displays of the railroads' operational metrics, maintenance and capital expenditure decisions.
- Merged data from different sources together to increase understanding and decision options.
- Developed a risk model for maintenance, operations and investment decisions.
- Developed a prototype DSS with data dashboards for use in supporting maintenance, operations, and investment decisions.

METHODOLOGY

Since the project developed prototype tools to improve decision-making related to various maintenance activities, operational decisions and investment decisions, the impact of these adopted tools on metrics of maintenance, etc. are beyond the time and budget scope of this project. Thus, the impact assessment for the completed project is whether or not the partner railroads choose to adopt and implement the prototype decision tools. In short, a binary yes/no decision is the metric. Thus, the primary metric to determine the impact of this specific project is the adoption of the new tools into the everyday practices of the participating railroads. As is discussed later in this report, one railroad has chosen to move forward with the types of tools and analyses developed in the project and one railroad has chosen to not move forward at this time. The reasoning and decisions are discussed below.

FINDINGS

The initial primary customer/external stakeholder for this work was The Everett Railroad based in Duncansville, PA. The secondary customer/external stakeholder for this work was the Consolidated Rail Corporation (Conrail) based in Philadelphia but operating primarily in New Jersey. Once the project began and the data requirements became clear to The Everett Railroad management, they requested we find another primary customer as upon further investigation into their data sources and records, it was clear the data required for the project could not be readily or easily collected and provided to the team. With that decision, the project team pivoted with the primary customer/stakeholder becoming Conrail and a short line railroad holding company – Carload Express – as the secondary customer/stakeholder. In further conversations with both railroads senior managers – the President and Chief Operating Officer of Conrail and the Vice President Equipment and Technology for Carload Express – interests were expressed in having the project team's expertise and the types of analyses and potential decision tools brought to bear on two sets of pressing problems. For Conrail, – grade crossing (GX) and trespassing incidents were its primary concern. For Carload Express, identifying potential new rail-served customers (either direct served or transload served) was high on its list for exploring the tools and methodologies of the project. Both railroads believed the tools being proposed by the team could potentially complement and improve the current tools and decision support systems (DSS) used by each company. As with all railroads in the U.S., trespassing and GX incidents are respectively the first and second largest cause of railroad-related injuries and fatalities. Unfortunately, following many years of successfully reducing such with various engineering and enforcement initiatives, such accidents have plateaued and have been increasing in recent years. These incidents clearly met all three of our project objectives – improving day-to-day operations, maintenance, and decision-making protocols.

The identification of potential new rail-served customers similarly met all three of our project objectives – improving day-to-day operations, maintenance, and decision-making protocols because identifying and capturing new rail-served customers required changes in day-to-day operations to provide the new customers with competitive service that would shift them from truck to rail and at the same time change how the railroad was maintained and decisions made regarding service practices.

As is well known, shortly after beginning of 2020, the COVID-19 pandemic hit. As is also well known, the pandemic continued much longer and caused much greater economic and personal damage throughout the country. It similarly had significant impacts in the Conrail and Carload Express territories. As was the case throughout the U.S., Rutgers University went into shelter-in-place modality and the railroad industry's personnel were confronting significant operational and revenue issues as customers were suddenly confronting enforced closures, loss of revenue, disrupted supply chains, etc. Nevertheless, over the course of two terms, the project continued as five Rutgers MBS student teams, working remotely, collected data from both companies and conducted extensive online searching of external non-railroad data sources. In addition, a few student team members were able to conduct some on-the-ground observations of NJ GXs and surrounding environs. Since in-person meetings could not occur, online conference calls became the norm with the student teams and with Conrail and Carload Express personnel. However, as the pandemic continued throughout 2020, and continues as this report is written, the online meetings with the railroad management teams essentially came to a halt as they dealt with the day-to-day issues of sustaining operations and maintaining a safe and healthy workforce. By the end of 2020, Carload Express withdrew from the project following receipt of the results of our initial analyses regarding new market opportunities for direct and transload services in the Pittsburgh, PA region. Carload Express' decision is discussed more fully in the results and conclusions section.

Appendix 1 is the Interim Report submitted to CAIT that covers all the work of the initial Rutgers MBS student teams completed for Conrail and Carload Express. As mentioned, Carload Express did not continue the work following receipt of the information contained in Appendix 1, however, Conrail remained engaged in the project and found the preliminary results very informative and subsequently identified a large number of High-Risk Grade Crossings for which it wanted similar and more detailed research to be undertaken. Following further discussions with Conrail, target study GXs were identified along the Vineland Secondary in Southern New Jersey and along the Michigan Line and Sterling Secondary in the Detroit Metro Region. These particular lines and GXs were selected because they represented illustrative examples of two types of railroad operating scenarios and could be potentially used as "models" for other GXs, vehicular traffic (both current and future), land uses and potential uses of SMART technologies for reducing risks in these types of corridors. These situations would also provide a good test of the analytical methodologies and potential uses of risk models to improve railroad decisions and provide more detailed analyses to State DOTs for use in their future GX improvement projects. The necessity for this latter point is highlighted by the recent FRA Final Ruling regarding State Highway-Rail Grade Crossing Action Plans (**Federal Register** / Vol. 85, No. 240 / Monday, December 14, 2020 / Rules and Regulations), which states among other things that railroads, states, communities, etc. "must identify specific strategies for improving safety at grade crossings, including grade crossing closures or grade separations." It is further supported by testimony of Karl Alexy before the House Transportation and Infrastructure Committee, Subcommittee on Railroads Pipelines, and Hazardous Materials in early 2020 (Alexy, K. 2020. Tracking Toward Zero: Improving Grade Crossing Safety and Addressing Community Concerns.)

The following discussion highlights the further research conducted for Conrail on the GXs in Detroit and South Jersey. Appendices 2 and 3 contain more detailed results for these two areas.

Conrail Grade Crossing and Trespassing Risks

For the continued research, Conrail wanted to better understand factors such as surrounding land use patterns, vehicular speed, types of traffic (composition), train speed, demographic characteristics of the surrounding areas, and other factors that could be contributory to GX and trespassing incidents. Further, it wanted insights into current technologies that could be implemented to reduce the risks at the specific GXs as well as possible SMART technologies that could be introduced in the near- to medium-term for the identified GXs. The finding highlights and recommendations from the Detroit lines and Vineland Secondary follow. Details for both of these sets of analyses are presented in full in Appendix 2: Detroit Grade Crossing & Trespass Risk Mitigation – attached and Appendix 3: Conrail Risk Mitigation Project: Gloucester City GX's – attached.

Detroit:

Conrail identified four specific GXs in the Detroit Metro region that have current and expected ongoing problems:

Table 1: Detroit Lines

Name	Line	Milepost	GPS Coordinates	DOT #	Territory
Central Ave	Michigan Line	4.11	42.322294-83.130833	511945J	Detroit
Lonyo Ave	Michigan Line	4.21	42.320988-83.137628	512363H	Detroit
6 Mile Road	Sterling Secondary	9.6	42.419249-83.035588	511087E	Detroit
8 Mile Road	Sterling Secondary	11.79	42.448136-83.037133	511093H	Detroit

The specific risks for each of these GXs are traffic volumes and speeds, vandalism of warning devices and other safety features approaching the GXs, parking close to the GXs, expected increases in traffic and speeds, and injuries to track and signal workers resulting from vehicular incidents. Conrail's interests are to find near-term solutions that could reduce the current risks and address future risks as traffic and other factors change over time. In addition to Conrail on these lines, there are Amtrak, CSX, and Norfolk Southern operations on these lines. However, the primary rail traffic is freight.

Building on the earlier work discussed in the Interim Report, the Detroit team focused on such factors as surrounding land uses, demographics of the immediate areas, relationships between existing GX protections, vehicular traffic, and other factors. In addition, the reviewed literature on SMART technologies, active and passive technologies currently being used – either by Conrail or elsewhere – that could be implemented to achieve reductions in risks associated with GX and trespassing incidents at these specific GXs. Specifically, the team studied the physical, statistical, and engineering characteristics of the four GXs to provide risk assessment and identify potential mitigation strategies for GX and trespassing incidents in Detroit, Michigan. With the information collected from geographical information systems such as Google Earth, the Federal Railway Administration (FRA) database, and the US Department of Transportation (USDOT) database, the team considered surrounding land uses, highway characteristics, distractions, and obstructions (FRA 2020). Together, the team proposed a three-level risk assessment that begins with measures at the municipality level to advanced technological levels with SMART technology.

The following discussion focuses on Lonyo Avenue as a way of illustrating the work done for all four GXs. The detailed results for all the Detroit GXs are found in Appendix 2: Detroit Grade Crossing & Trespass Risk Mitigation, attached.

Lonyo Avenue:

The Lonyo Avenue GX is located very close to the Central Avenue GX thus, the zoning information is very similar for both crossings – the exception is the Central Avenue Crossing is proximate to a railyard. The area is surrounded by intensive industrial districts and special industrial districts – specifically M3: General Industrial District which permits the normal industrial operations of the majority of industries that can be proximate to residential properties; M4: Intensive Industrial District which permits uses that are objectionably hazardous and rarely close to residential areas; and M5: Special Industrial District which are properties located deep in industrial districts that are hazardous.

Further, the Lonyo Avenue crossing has pavement markings and advance warning signs leading up to the crossing. At the crossing, there is a “Stop Here on Red” sign along with the ENS sign. The crossing also has active technologies including, three roadway gate arms, six pairs of flashing lights, and two bells. The highway speed limit is 50 miles per hour (mph) and this crossing is regularly used by school buses and approximately 20% of trucks.

The grade crossing angle for Lonyo Avenue is 72.5°, at this angle, there is a greater chance of drivers being careless and short-sighted. This finding is consistent with the evidence found in an earlier study that depicts the ratio of the percentage of 617 gate-running crashes at a specific crossing at a specific angle with the driver and a sample of 1004 crossing angles (Cooper & Ragland 2015). At the 72.5-degree mark, grade crossing collisions reach the highest probability of occurring on the upper right quadrant. At this angle, there is a greater chance of drivers being careless and short-sighted. Of the four GXs, Lonyo Ave and Central Ave need to be observed more closely in regard to their crossing angles and possible mechanisms to reduce the risks of incidents since changing the angle of the grade crossings is not an option.

Through in-depth analyses and filtration of GX incidents among NS, CSX, and Conrail within Detroit, Wayne County, Michigan over the last decade (2011 - 2020), several factors from the FRA database were considered: collision time intervals, weather conditions, presence of streetlights, and the connection of cross warning signals with highway signals.

The FRA data for the GX collision times over the course of one day are grouped in four-hour intervals. Overall, the GX collisions peaked at four-time intervals: 12 AM - 4 PM, 8 AM - 12 PM, 4 PM - 8 PM, and 8 PM - 12 AM. Several possible conclusions emerged from this analysis. There is an upward trend from 12 PM - 12 AM, where at the 4 PM interval, the number of incidents double from 12 PM, and at the 8 PM interval, the number of incidents triple. The rise in incidents at the 4 PM interval can possibly be attributed to evening rush hour traffic. With many people on the road, the traffic can become backed up and people can become careless and impatient. A similar occurrence can also be noted at the 8 AM interval for the morning rush hour traffic. Following into the 8 PM and 12 AM intervals, there is less visibility and driver vision perception is skewed.

The Detroit weather data for the same ten-year period during GX incidents show the majority of grade crossing incidents occurred on a clear day. One possible explanation for this could be that drivers are more careless on the road during clear weather. Drivers may feel more confident and are more likely to engage in risky driver behaviors, such as speeding. On the other hand, poor weather conditions with decreased visibility force drivers to be cautious on the road. This would explain the significantly fewer cases.

Similar analyses of the FRA data for the presence or absence of streetlights at the GXs show there’s an overall even split between the answers “yes” and “no” for the presence of streetlights during the incident. Because the majority of GX collisions occur at night, sufficient streetlight vision becomes imperative and a significant factor to investigate in the future.

Again, for the same ten-year period, the FRA data for GX warning signals connected with highway signals show there is a clear divide between the “yes” and “no” answers, with the majority of incidents having no cross-warning signals connected with highway signals. Since drivers tend to focus on highway signals when driving, it appears a relatively simple solution for decreasing driver confusion and distraction is to effectuate synchronization of crossing warning signals with highway signals.

Further analysis of the FRA data for GXs in the Detroit area demonstrated the majority of incidents occurred as a result of vehicular driver error – a finding not unique to Detroit. Figure 1 shows three different reports for which a GX incident had occurred. These three reports represent many of the types of cases that occur in the area, all of which are due to human error, negligence, and risky driver behaviors.

Figure 1: FRA Sample Incident Reports

- "Driver attempted to beat the train at the Sibley Road Crossing and was hit by the oncoming train, all signals were operating as intended. No injuries were reported."
- "Vehicle drove around crossing gates in front of train causing impact."
- "Driver of vehicle going wrong way on one way street disregarded railroad signals and was struck by engine NS 9950."

The different problem crossings have a variety of unique characteristics that distinguish each crossing from one another. One of the most important differentiating factors is the Average Annual Daily Traffic counts (AADT). AADT is essentially the average of all traffic on a road divided by 365 days, depicting the average traffic volume on any day of the year. This is not a perfect measurement, as certain times of the year may have more traffic than others. However, this statistic serves its purpose in giving a general overview of traffic on a road, allowing the level of traffic to be determined. Every crossing has different AADT statistics as each crossing has unique characteristics that differentiate it from other crossings. Again, our illustrative grade crossing is Lonyo Avenue, and it is used to illustrate possible protection and detection solutions for reducing risks of GX incidents.

Lonyo Avenue is a lower traffic, smaller, 2-lane road. Although the AADT values are low, they are increasing from around 6,300 in 2017 to around 8,000 in 2019, indicating more levels of traffic ("SEMCOG Traffic Volume Map" 2019). This increase in AADT indicates that action must be taken at this crossing, as more vehicles on this road can lead to more accidents at GXs. Over the course of 10 years, the AADT for this road was 8,898. This road is within city jurisdiction. Lonyo Avenue has an AADT of 8,898, making it a lower traffic volume crossing ("SEMCOG Traffic Volume Map" 2019). A distinguishing feature about this crossing is the number of traffic signals before and after the GX. This makes it an excellent candidate to synchronize traffic signals for vehicles with GX signs. This is a simple fix, pairing the two signals in a way such that both the crossing signal and traffic light reflect the same message. Accomplishing this prevention measure will require cooperation between Conrail and the City.

In addition, because Lonyo Avenue is a lower volume crossing, with many traffic signals potentially confusing vehicular traffic, crossing times information should be made easily understandable for motorists. This can be done through the implementation of Variable Messaging Signs (VMS) and Grade Crossing Integrated Railroad Radar (Khattak & Lee 2018 and Goolsby, Merrell E, et al. 2003). Again, in this case, Conrail and the City would need to collaborate regarding placement of the signs and implementation of the VMS as Conrail would be responsible for installing and maintaining the requisite train detection components of the system.

As noted previously, the Lonyo Avenue GX is an illustrative case for the Detroit GX analyses. Now we turn to South Jersey and the Vineland Secondary GX analyses.

Vineland Secondary – South Jersey

Conrail's concerns regarding GXs on the Vineland Secondary are two-fold: the proposed development of the dedicated light-rail commuter track Glassboro-Camden Line (GCL) in Southern New Jersey (Glassboro-Camden Final EIS 2021) in the Vineland Secondary Right-of-Way, and the track-speed upgrades for existing freight-only operations, which include liquefied natural gas transport as well as other hazardous materials potentially pose increased risks for GXs on this line. These risks are expected to be potentially even greater for GXs in close proximity to proposed new transit stations and platforms for the light-rail commuter operations. It is expected there will be significant risks, both inherent and indirect, adjacent to stations in areas where current patterns of residential and other land uses may be more directly impacted by the combination of hazardous freight products, passenger population, and higher speeds.

Conrail identified the proposed Gloucester City Station as a particular area of concern presenting several factors that require attention in the planning and development of risk mitigation strategies for the expected rail operation changes in the future. Following a high-level overview of the eleven GXs through Gloucester City, the three crossings immediately proximate to the proposed station and parking lot became the focus of this project – Market Street, Cumberland Street, and Monmouth Street.

These locations are primarily residential in nature. It is expected in the future there will be an increase in residents seeking employment outside of the city and making use of the new station. Further, this may induce new businesses to operate in close proximity to the Gloucester City Station. Both of these factors will result in a need for increased safety measures is required for the proposed Gloucester City Station and parking lot as research indicates that GX incidents are expected to increase with the increase in rail traffic (Fleming et al. 2018). With plans for the development of Gloucester City Station, there will be an increased risk for community members. Reasons for this increased risk include a second line as well as parking lots. As the vast majority of GX crashes can be attributed to poor judgement, deployment of existing and new technologies can help to prevent future incidents.

From the site surveys, several risks were identified at each GX. To illustrate, we cite examples of problems at each of the GXs or in the proximate area and potential solutions. Detailed analyses, potential solutions, and full recommendations for the three GXs are contained in Appendix 3: Conrail Risk Mitigation Project: Gloucester City GX's, attached.

Cumberland Street:

The first identified risk is that lack of clear pedestrian safety. Although this is an overarching problem for all three GXs, Cumberland St. will sit in between the parking lot and Gloucester City Station meaning it will likely have the highest amount of foot traffic. One notable problem is sidewalk ends on one side of the cross street and there is no clear sidewalk on the other side. In fact, to get back on the sidewalk a pedestrian has to not only cross the GX, but also cross to the other side of the street. Although implementing sidewalk crossings is not in the domain of Conrail, there are potential technologies Conrail can implement to make the GXs safer overall for pedestrians.

Market Street:

The Market Street GX shares many concerns as Cumberland Street. However, the main concern is directed to a cluster of three gas stations roughly 100 yards from the actual GX. Initially, this may appear trivial. However, an unfortunate sequence of events (consequential of a serious GX incident) quickly defines this observation as non-trivial. More specifically, should an accident at the GX cause a train transporting Liquefied Natural Gas (LNG) to impact the gas line buried in the Right-of-Way (ROW), the potential for a deadly and large explosion is suddenly dangerously high. Such an explosion could engulf this cluster of gas stations, compounding the problem even further and many would likely die within the densely surrounding area. Additionally, the Middle School located roughly 200 yards away is placed at great risk as well. The probability of such an occurrence is low given that many errors would have to occur. However, it is important to consider, because it is possible, thus reinforcing the need for effective risk mitigating solutions.

Monmouth Street:

Monmouth Street also shares many concerns outlined noted above. Unique to Monmouth Street however is the location of a relatively unguarded gas valve station. As noted previously, there is a buried natural gas line buried in the railroad ROW. Further, the intersection of Monmouth Street and South Railroad Avenue is a chokepoint. So, the potential for vehicular accidents is greater here than at the other situations identified. While this gas valve station has a standard highway guard rail and low chain-link fence around it to protect it from potential vehicular incursions and to keep pedestrians from easily accessing it, any rail-related incident – whether from a GX incident or other derailment issue – could lead to a truly explosive and dangerous situation.

The conditions illustrated above that increase the probability of GX related incidents include poor road markings, lack of prevention from crossing the track, dense surrounding neighborhood, and gas lines running parallel to the track. As a consequence of these conditions, risks include trespassing, impact between vehicle and train, and potential explosions resulting from impact with LNG transport. Installation of a second track for commuters, from the GCL plan, increases the probabilities of such risks, demanding solutions to mitigate both current and future risk. Through a literature review and outside research, the proposed solutions to best mitigate risk (based on current and future conditions) fall under two categories: (1) protection, (2) detection, and (3) protection and detection.

In the Gloucester City GX situations quad gates are proposed under the GCL plan. Notwithstanding these proposed protection solutions, there are still risks that can be addressed with further passive and active protection and detection interventions.

- For vehicular traffic, one option is lights, which is a great way to capture attention. This may be especially useful in quiet zones or poorly lit areas. An example of this is the LightGuard Systems which are LED lights embedded into the pavement (*Light Guard Systems*, https://www.lightguardsystems.com/traxalert-grade-crossing-irwl-warning-light-system/. Accessed 27 3 21).
- Another potential solution that was considered are flexible traffic separators to be placed in between the roads (Ko, Byungkon, et al. 2003).

- For pedestrian traffic, a possible solution is LED railroad crossings sign. These variable message systems (VMS) can display messages for pedestrians such as "another train coming" (*Signal-Tech*, https://www.signal-tech.com/products/rail. Accessed 27 3 2021).
- Another type of VMS for pedestrian safety is broadcasting warning messages to individuals' cell phones. With improvements in detection and monitoring as previously discussed, variable warning messages can be displayed within apps (*Signal-Tech*, https://www.signal-tech.com/products/rail. Accessed 27 3 2021).
- Advanced image detection through Artificial Intelligence (AI) helps in a variety of situations, and in many ways outperforms comparable radar-based solutions. Image recognition through deep learning models can both detect and classify as well as track objects and people at grade crossings. Using conventional railroad crossing cameras, real-time analysis can help to identify unauthorized entries to facilities and can also help to detect when a dangerous object is on the track (Sheikh, et al. 14).
- LiDAR, which stands for light detection and ranging technology, can be used as an object detection product to detect trespassers, pedestrians, vehicles, and other objects that pass the crossing (*LBFoster* 2021).
- Another potential for PTC equipped trains and operating territories, which will likely be the case with the Vineland Secondary once commuter and high hazardous materials are carried in the corridor, is communication between the GX protection and the train.
- Finally, currently under development and testing, a radar-based sensor system is an early warning technology that provides an automated protection and detection response at grade crossings (Rosyidi, M. 2019).

Grade Crossing Detection and Protection Technologies

There is an extensive literature on passive and active technologies to detect and protect against GX and trespassing incidents (see **SMART HIGHWAY-RAILROAD GRADE CROSSING LITERATURE** listing prior to the Appendices). Appendices 2 and 3 provide detailed discussions of the technologies identified and investigated in depth in this project. The literature summarized in Appendices 2 and 3 represent those technologies found to be most likely relevant for the two study in this project.

DSS and Visualization Tools

As discussed in the Interim Report, we demonstrated the applicability of the data visualization tools and those tools were applied in the analyses of the Detroit and Vineland Secondary grade crossings. Additional data sources were accessed for these studies and preliminary analyses were completed regarding potential risk mitigation solutions for grade crossing and trespassing incidents. However, due to the delays in developing these further analyses – as described previously – full development of the DSS risk models based on the **Tree Structure for Freight Railroad Decisions** presented in the Interim Report was not possible prior to the project end date. All the analyses and recommendations detailed in Appendices 2 and 3 have been provided to Conrail, as well as a remote online presentation was made on the 5th of May to Conrail's Chief Engineer of Design and Construction. Unfortunately, Conrail's President and COO could not attend the presentation as he was meeting with his successor, who is now the new President and COO. As described later in the **RECOMMENDATIONS**, there are further analyses that would lead to developing risk profiles for grade crossings and possible trespass locations that would be inputs into tree decision model for investment decisions by Conrail and could inform state and local authorities in their decisions regarding grade crossing improvement projects on Conrail as well as for other railroads within their respective jurisdictions.

CONCLUSIONS

In conclusion, the project as proposed in late 2019 envisioned gathering data from the participating railroads, combining those data with data gathered from external, non-railroad data sources, utilizing advanced analytic and data visualization tools to identify opportunities for improving railroad operating, maintenance and investment decisions and developing a protype decision support system (DSS) that could support the railroads' current decision-making processes. It was furthered envisioned the prototype DSS would be tested by the railroad personnel for ease and usefulness in day-to-day decisions, as well as long-term investment decisions.

Covid-19 led to significant delays in data gathering as the participating railroads focused solely on maintaining the health and safety of their crews and serving customers as needed. The railroads were also confronted with significant revenue declines as many customers were forced to cease operations. All of these factors, in conjunction with Rutgers going into virtual class and research mode, created substantial delays and reduced the research teams abilities to gather data, do onsite investigations and engage with the railroad personnel.

Notwithstanding these dramatically altered circumstances, the project continued, data were gathered, models were developed and operationalized and the teams pivoted to accomplishing what could be addressed as proposed and sought to work with the railroads to meet their substantially altered needs and expectations. Initial reports and analyses were delivered to Conrail and Carload Express to determine whether the research efforts were generating data and analyses that were addressing their concerns. As mentioned previously, Carload Express decided to not pursue further work. The VP of Marketing determined he could not devote further resources to obtain the level of granularity he needed for the marketing analyses to determine potential market demand for transload steel and plastic products for delivery in the Pittsburgh Metropolitan area. With that decision, no further work was undertaken for Carload Express.

Conrail, on the other hand, continued to remain interested but still overwhelmed by Covid-19 issues. In the fall of 2020, the Conrail's Vice President – Corporate Development and Chief Legal Officer – and the Primary customer/external project manager for this project retired and that role transitioned to the President and COO. It became clear at this juncture the project could not be completed on the proposed end-date and a non-cost extension was requested and granted. In the meantime, President and COO delved further into the research teams' work done on the all high-risk GXs in the Conrail territory, he asked some of his direct reports to identify from Conrail's perspective the most high-risk GXs because he was impressed with what had been discovered in the initial research on all the railroad's GXs. In late December 2020, Conrail had identified the high-risk GXs on which it wished to have further analyses completed. In January 2021, Conrail had a telcon with team members to discuss in more detailed what it would like investigated and Conrail's Chief Engineer of Design and Construction was brought into the project. The new focus was on two sets of GXs, four in the Detroit territory and GXs in Gloucester City, NJ on the Vineland Secondary. The following remarks focus on those particular GXs.

The Detroit and Vineland Secondary are distinct research initiatives although linked to the same concerns – grade crossing and trespassing incidents. Thus, we frame our conclusions in a similar fashion. First, the Detroit findings are summarized, and then the Vineland Secondary findings follow.

Detroit:

Given the analysis of the physical characteristics, traffic counts, land uses, and existing safety measures of the four high-risk Detroit grade crossings, further research may be needed to determine the most appropriate technological solutions. City and county plans for land usage over the course of twenty to forty years in the future can give insight into how each district will allot its land commercially, as it will indicate potential new businesses and real estate properties that will increase the population and traffic volume in the area. This will inevitably require the implementation of active measures to mitigate risks in case the collision rate disproportionately rises.

Other considerations for research include the population profile, specifically in regards to the homeless population near high-risk grade crossings, and analysis of other metropolitan areas. This will give insight into trespassing incidents and ways to target the demographic, via signage and other passive measures, protect pedestrians from passing trains, and strictly enforce trespassing laws through penalization with fines. Metrics can be used to predict trespassing incidents given the profile of a particular location, and the specific times that incidents are most likely to occur. Similarly, comparing Detroit's characteristics with another city as well as its grade cross and trespass risk mitigation strategies would be a possible study for further research.

Based on the latest and most available research, Detroit grade crossings should follow three main levels of protection. Each level increases in technological scope and capacity: the first at the municipality view with synchronizing traffic signals with the grade crossings; the second on the roadways with active and passive technologies; the third from a computerized view. These steps should be followed and observed gradually until the most effective and cost-efficient solution(s) is determined. The incorporation of existing and SMART technologies into Detroit's safety protocols will be able to reshape its grade cross landscapes and promote a progressive future for its citizens.

Vineland Secondary:

The project team has demonstrated the necessity to mitigate current and future risks associated with Gloucester City grade crossings. Additionally, solutions to mitigate these risks have been proposed. Visual and demographic investigations of Market, Monmouth, and Cumberland Street GX's exposed sources of current and future risk. Conditions that increase the probability of GX related incidents include poor road markings, lack of prevention from crossing the track, parking too close to tracks, dense surrounding neighborhood, and gas lines running parallel to the track. As a consequence of these conditions, risks include trespassing, impact between vehicle and train, and potential explosions resulting from impact with LNG transport. Installation of a second track for commuters, from the GIS plan, increases probabilities of such risks, demanding solutions to mitigate both current and future risk. Through a literature review and outside research, the proposed solutions to best mitigate risk (based on current and future conditions) fall under two categories: (1) protection, (2) protection and detection. Many solutions have been proposed and described in great detail. Ultimately, these solutions have the capacity to effectively mitigate the identified risks of Cumberland, Market, and Monmouth Street grade crossing.

RECOMMENDATIONS

Before we discuss the two geographic areas with specific recommendations, we offer the following specific recommendations that flow from the work done in Detroit and Gloucester City but address the larger issue of developing data visualization dashboards that display the output of potential risk metrics that can be used risk profile models to prioritize GX and trespass mitigation strategies and railroad decisions for investments.

- Due to the compressed timeframe between January 2021 and May 2021, complete identifying existing conditions at each GX.
- Develop view shed analysis (i.e., crossing view angle determination), and preliminary identification of potential trespassing paths within 1,000 feet of each GX.
- Develop detailed risk metrics for both the Detroit and South Jersey situations, including some visuals showing simulated risk enhancers such as vehicles parked in no parking zones close to the tracks or blocking the views of signals, maybe some visuals of vegetation or other visual barriers, etc.
- Develop some simulated risk reducers, e.g., lane separators, SMART warning devices, etc. that could be introduced to reduce risks.
- Develop estimates of risk-enhancers – e.g., population projections by cohorts, AADT estimates for future populations, land use changes, etc.
- Develop estimates of risk reductions that could accrue through use of SMART technologies, as well as other types of interventions that could reduce the risks.
- Use these risk metrics and simulated risk reduction estimates as inputs into the **Tree Structure for Freight Railroad Decisions** model for use in data dashboard displays in a DSS.

Following are specific recommendations for the Detroit and Gloucester City GXs.

Recommendations for Detroit Crossings:

Each crossing covered has specific characteristics that differentiate it from other crossings. With unique challenges presented to each crossing, specific measures must be taken to address these issues. Because of this, generally, a single solution cannot be applied to all crossings, unless it is a measure simple enough to be implemented on a large scale. Out of all of the prospective measures, the first measure that must be implemented, regardless of crossing, is to synchronize traffic signals for vehicles with grade crossing signs. This measure is required, as a majority of railroad crossing signals are not connected with traffic signals. This disconnect can itself lead to grade crossing incidents, causing confusion to motorists, in certain cases where a traffic signal may be green while a train is approaching. This is a simple fix, pairing the two signals in a way such that both the crossing signal and traffic light reflect the same message. This should be done at all crossings looked at in this project as a universal measure, as it should involve no new infrastructure or investment, and only requires the pairing of signals. As for the rest of the mitigation measures, only specific technologies should be implemented at specific crossings due to unique crossing characteristics. This is covered in more detail in the next sections.

8-Mile Road:

The safety of the 8-Mile Road crossing can be greatly improved by implementing certain measures. 8-Mile Road is a major East to West arterial road in Detroit and is part of a series of numbered roads going East to West, serving as major routes in the Detroit and Wayne County area. This specific crossing has an AADT of 30,500 making it the highest volume road out of all of the crossings analyzed ("SEMCOG Traffic Volume Map" 2019). The road is also very wide, ranging from four to five lanes throughout its length.

Because of the width and the high-speed volume of traffic of 8-Mile Road, traffic channelizers are recommended as the first passive technology to be implemented at the grade crossing. Previously, as was mentioned, a majority of crossing incidents occur on clear days and the ability to speed may be a contributing factor in grade crossing incidents. Traffic channelizers would limit the ability of vehicles to speed through the crossing or drive around the barriers as cars would be confined to their lanes and forced to drive more cautiously. As recommended by Ko, Courage, & Wilis (2003), these should be placed in a series between 20 and 40 feet leading up to the crossing. By controlling driver behavior by forcing vehicles to stay within lanes, fewer illegal crossings are expected due to limited movement. After this, more advanced technologies should be implemented. The first of these measures should be the Automated Railroad Infrastructure Security System (DaSilva, Baron & Carroll, 2006). This is due to the fact that this is a high-volume road in close proximity to businesses and restaurants.

The homeless population of Detroit is particularly high, and the age distribution of the homeless population closely matches that of individuals involved in trespassing incidents. Because of this, the Automated Railroad Infrastructure Security System can provide benefit to this crossing through its deterrence systems (DaSilva, Baron & Carroll, 2006). The location of this crossing in a populated region, with businesses on either side, increases the potential of trespassing activity due to the high population of this specific area. The volume of traffic across this crossing also justifies the implementation cost of the security system, as it does have a higher chance of trespassing activity than other, more remote crossings.

As 8-Mile Road is a major, high-traffic road in Detroit, the potential of stalled vehicles on tracks is higher at this crossing location. This can potentially cause grade crossing incidents with the collision of trains with stalled vehicles. For this reason, an ITS-based Stalled Automobile Detection is recommended at this crossing. This smart technology would notify approaching trains of potential collisions, making this grade crossing safer (see for example, Guerrero-Ibáñez, J., Zeadally, S. and Contreras-Castillo, J. 2018).

The final advanced technology that is recommended to be implemented at the 8-Mile Road crossing is Positive Train Control Equipment. As mentioned earlier, this technology is not meant to be specifically installed at crossings, however, it can be mandated to be activated on certain rail lines. The 8-Mile Road crossing would benefit from PTC equipment by allowing it to work with the other advanced technologies being suggested, to make this high volume crossing one of the safest in Detroit. PTC equipment would allow trains to be aware of trespassers detected from the Automated Railroad Infrastructure Security System, preventing potentially fatal accidents. Additionally, PTC equipment would communicate with the stalled vehicle sensor to prevent similar collisions from occurring. PTC equipment would give trains much more information at this particular high-volume crossing, allowing trains to cross 8-Mile Road well aware of any potential incidents or accidents.

Recommendations for Gloucester City Crossings:

At this juncture there remain many unknowns regarding GCL implementation schedule, updating population and economic forecasts, etc. there are several questions left unexplored. Thus, we will suggest work for future groups to tackle. The team recommends five future actions/ considerations for Conrail to consider. In general, these recommendations serve to monitor changes of ongoing risk and further validate SMART tech (or non-SMART tech) recommendations. To monitor risk: (1) demographic trends should be monitored, specifically with the influence of a second commuter track, (2) gather insights on future businesses, and (3) obtain finalized plans for gas line relocation. To further validate solutions: (4) developers of the various technological solutions should be contacted to gain insight on existing usage and cost considerations, and (5) consider educating local residents on the functionality of these solutions to increase awareness. The research has demonstrated that much information regarding demographic, geographic, and possible solutions is readily available. In the effort to maintain full understanding of current and future risks, however, it is necessary to validate whether the information is useful and currently accurate. Completing these five recommendations, over time, may aid in this validation.

In terms of immediate recommendations, the following are suggested:

Cumberland Street:

The first recommendation for Cumberland Street is to work with Gloucester City improve the sidewalk alignments and completion to eliminate the need to for pedestrians cross to the other side of the street and the GX simply to continue their walking on a sidewalk and not in the street.

Second, VMS technology could be installed at pedestrian levels the inform the walking public when a train is approaching.

Third, South Railroad Avenue, which parallels the railroad and "Ts" into Cumberland Street needs improved signage. It is a one-way street that is often used as a two-way street. Should a drive proceed the wrong and make a right-hand turn on to Cumberland the vehicle is immediately in the GX. At a minimum, at least a Stop sign should be placed at the corner of South Railroad Avenue and Cumberland Street.

Fourth, along the South Railroad Avenue median between railroad tracks and the roadway, local residents clearly use is a parking area. There is no barrier between the parked cars and the operating railroad tracks. At a minimum, some form of fencing or barrier should protect the track from an accidental vehicular incursion and casual pedestrian trespass.

Market Street:

As previously mentioned, Market Street GX shares many concerns as Cumberland Street. However, the main concern is directed to a cluster of three gas stations roughly 100 yards from the actual GX. This GX needs heightened detection and protection attention immediately even prior to proposed light rail and LNG operations and heightened freight speeds. This GX shares a similar Natural Gas Access Value Station issue with Monmouth Street. The recommendations are the same for addressing a potential vehicular or derailed train car(s) impacting the access valve station. If the access valve is to be relocated from its current place roughly three to five feet away from the railroad tracks, some of the following recommendations will be easier to implement.

First, install a protective unit for vehicular attacks – these can be custom designed, however, since there are other access valves elsewhere along the pipeline, perhaps identifying and existing design for use at all access valves proximate to roadways and railroad tracks in this corridor.

Second, if the protective units are cost-prohibitive, install a Bollard "array" to deflect vehicles and perhaps reduce the momentum a derailed railroad car.

Third, if sufficient space can be arranged, elevated landscaping may also act to deflect or reduce penetration momentum.

Fourth, combine all of the above with a reinforced concrete enclosure.

In terms of longer-term solutions to be considered for the Gloucester City GX studied in this project, the following are recommended for further research regarding existing usage and life-cycle cost considerations for installations in settings such as those found in Gloucester City.

The first option is lights, which is a great way to capture attention. This may be especially useful in quiet zones or poorly lit areas. LightGuard Systems offers LED lights embedded into the pavement (*Light Guard Systems*, https://www.lightguardsystems.com/traxalert-grade-crossing-irwl-warning-light-system/. Accessed 27 3 21).

A second solution is the installation of flexible traffic separators to be placed in between the roads. Where these have been installed and data gathered before and after installation, a statistically significant result demonstrated the effectiveness in reducing gate drive-around behaviors (Ko, Byungkon, et al. 2003). This solution could be easily implemented now, prior to any changes in current operations.

In anticipation of the proposed development of a parking lot adjacent to the Gloucester City Station and the increased foot traffic across the tracks, the third recommended safety improvement is the installation of VMS at the GX (see for example *Signal-Tech*, https://www.signal-tech.com/products/rail. Accessed 27 3 2021).

A variation of this solution to help pedestrians understand there is a second train coming is switching voices for audio messages between trains. Switching between a masculine and feminine voice for the two pieces of information can help pedestrians to make this distinction (*Progressive Railroading*, Trade Media Press Group, 1 2015).

Another strategy for pedestrian safety is broadcasting warning messages to individuals' cell phones with variable warning messages displayed within the apps (Chen and Hsiao 2017and *TravelSafely* 2020).

LiDARdetection. This is possible because high quality cameras which are low power and low cost are becoming more ubiquitous (Sheikh et al. 2004). For example, real-time analysis can classify a moving object as a pedestrian and track suspicious or risky behavior (Fayyaz and Johnson 2020 and *Nokia* 2020). These may be very accessible and feasible options within the near future and should be further researched as plans solidify for changes in operations and activities along the Vineland Secondary.

Once the two-track configuration is determined, LiDAR becomes a potential solution for reducing GX and trespasser incidents. The system can sit between the two tracks on the side of the GX and can detect trespassers, pedestrians, vehicles, and other objects that pass the crossing (Goolsby, Merrell E, et al. 2003).

Another technology that will be applicable on this line in the future is the utilization of PTC to not only address train operation issues, but to warn the locomotive engineer if the safety apparatus at a crossing malfunctions, such as a gate arm not operating properly (*Progressive Railroading* 2015).

Finally, a radar-based sensor system that provides both protection and detection has been tested in Indonesia in a parallel track environment and has been found to be effective and integrated with existing gates, warning lights, warning speakers, and VMS (Rosyidi, M. 2019). This would appear to be a cost-effective solution as well that bears further research into potential application in Gloucester City prior to installation of a second commuter track.

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APPENDICES

Appendix 1: Interim Report -- Application of Advanced Analytic and Risk Techniques to Railroad Operations Safety and Management

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30 June 2020

Background

The primary goal of this research is to extend our prior work beyond the proof of concept and demonstrate it can be introduced and implemented within everyday railroad decision-making. To accomplish the latter, the project was divided into two phases: Phase 1) development of a prototype system that complements and improves the current tools and DSS used by the cooperating railroads, and Phase 2) a staged roll-out of the prototype system within cooperating railroads that become integrated into the railroads' day-to-day operations, maintenance and decision-making protocols. The focus of this project is on Phase 1: development of a prototype system that complements and improves the current tools and DSS used by the cooperating railroads.

In the first 8 months of Phase 1 the following specific work tasks were to be undertaken:

1. Work with participating railroads to gather additional useful data possibly including Close Call data: Months 1-2 following NTP.
2. Fuse the data from various railroad sources to combine text mining output of maintenance activities, location data, and numeric operation data: Months 2-5 following NTP.
3. Meet with participating railroads to detail the information the railroads seek from the text and data mining: Month 4 following NTP.
4. Create additional data analytic and risk management models from the fused data; including a risk model to prioritize maintenance activities, operational decisions and investment decision: Months 5-8 following NTP.
5. Prepare and deliver interim progress report: Month 8 following NTP.

Work Accomplished To-Date

The primary customer/external stakeholder for this work was The Everett Railroad based in Duncansville, PA. The secondary customer/external stakeholder for this work was the Consolidated Rail Corporation

(Conrail) based in Philadelphia but operating primarily in New Jersey. Once the project began and the data requirements became clear to The Everett Railroad management, they requested we find another primary customer as upon further investigation into their data sources and records, it was clear the data required for the project could not be readily or easily collected and provided to the team. With that decision, the project team pivoted with the primary customer/stakeholder becoming Conrail and a short line railroad holding company – Carload Express – as the secondary customer/stakeholder. In further conversations with both railroads senior managers – the President and Chief Operating Officer of Conrail and the Vice President Equipment and Technology for Carload Express –deep interests were expressed in having the project team's expertise and the types of analyses and potential decision tools brought to bear on two sets of pressing problems – grade crossing accidents/incidents and identifying potential new rail-served customers (either direct served or transload served). Both railroads believed the tools being proposed by the team could potentially complement and improve the current tools and decision support systems (DSS) used by each company. As with all railroads in the U.S., grade crossing accidents are the second largest cause of railroad-related injuries and fatalities trailing trespassing which is the first cause of such incidents. Unfortunately, following many years of successfully reducing grade crossing accidents with various engineering solutions, such accidents plateaued and have been increasing in recent years. These incidents clearly met all three of our project objectives – improving day-to-day operations, maintenance and decision-making protocols.

The identification of potential new rail-served customers similarly met all three of our project objectives – improving day-to-day operations, maintenance, and decision-making protocols by identifying and capturing new rail-served customers required changes in day-to-day operations to provide the new customers with competitive service that would shift them from truck to rail and at the same time change how the railroad was maintained and decisions made regarding service practices.

Basically, Tasks 1, 2 and 3 consumed the first four months following Notice to Proceed (NTP). As is well known, shortly after beginning of the year, the COVID-19 pandemic began to rear its ugly head and ultimately, the University went into shelter-in-place modality and the railroad industry's personnel were confronting significant operational and revenue issues as customers were suddenly confronting enforced closures, loss of revenue, disrupted supply chains, etc. Nevertheless, working remotely with our three Rutgers MBS student teams, data were obtained from both companies and extensive online searching of external, non-railroad, data sources was undertaken. Since in-person meetings could not occur, online conference calls became the norm with the student teams and with Conrail and Carload Express personnel. Initial data cleaning, merging and text mining, along with performing initial analyses of the merged data sets were completed as delineated in Task 4. These efforts led to enhanced data analytic and risk management models from the fused data; including a risk model to prioritize maintenance activities, operational decisions and investment decisions. The results of this work include a paper and presentation submitted for the AREMA annual conference in Dallas, TX, September 13-16, 2020. Accepted papers are to be published in the Conference Proceedings. Further, a poster and two paper abstracts have been prepared and submitted for presentation at the INFORMS Annual Conference in National Harbor, MD, November 8-11, 2020.

As summarized in the following materials, the research results have been shared with Conrail and Carload Express and the management teams of both companies are assessing how these analyses and decision models can help them improve their respective company's day-to-day operations, maintenance, and decision-making. As could be expected given the current curtailed railroad operations for both companies, it has not been possible for the team to schedule further online meetings with the management teams, but we have been assured the materials sent to them are being reviewed internally and further discussions will occur as soon as is practicable.

Example Data, Analyses, Visualizations and Models Developed to Date

In the following materials we provide illustrations of the types of data collected, analyses performed, and models developed as of this writing. The first set of illustrative analyses focus on grade crossing issues and the second set focus on the marketing issues. We have conducted analyses of the grade crossing data for both Conrail and Carload Express. The marketing analyses focus on Carload Express. Finally, we present a risk model to prioritize maintenance activities, operational decisions, and investment decisions as one of the outputs to date.

Grade Crossing Analyses

There were two teams working on the grade crossing analyses. One team focused on Conrail and the other on Carload Express. Because of the COVID-19 situation, all data gathering was remote and largely confined to publicly available data. In particular, the teams utilized the following data sources:

- weather data,
- land movement data,
- AADT,
- land use data,
- angle of grade crossing,
- grade crossing surface material,
- satellite imagery data of grade crossings,
- street view data to the extent they are available,
- traffic and railroad signal, warning sign, etc. data,
- direction of vehicular travel at time of accident data, train direction of travel at time of accident,
- vehicle and train speed data,
- number of highway lanes,
- injury/non-injury data, and other data discovered in the course of research.

The data sources were:

- Federal Railroad Administration (FRA)
    - https://safetydata.fra.dot.gov/officeofsafety/default.aspx
    - https://safetydata.fra.dot.gov/OfficeofSafety/publicsite/DownloadFStructure.aspx
        - Highway Rail Grade Crossing Accidents
            - Highway Rail Accident refer to an accident of the train with a vehicle?
            - Important identified attributes -
            - Vehicle information (VEHSPD, TYPVEH, VEHDIR)
            - Typacc - train hit the vehicle or vehicle hit the train
            - Temp, Visibility, weather
            - Position of vehicles
            - Railroad related information -> typeeq (type of railroad)
            - Train speed (trnspd)
            - Signal, locwarn, lights
            - Motorist reaction (motorist)
            - View was obstructed or not (view)
            - Totkld, Totinj (in rail)
            - totocc (# total occupant in vehicle)
            - Track related details -> Typtrk, trkname, trkclas

                - Total number of people killed, injuries
                - Types of warning device at crossing -> (crossing)
                - Type of crossing -> public or private
                - Hazard materials exploration (hazardness of accidental situation) -> released by who (vehicle or rail), quantity,
                - Whisban (whistle ban in effect)
                - Narrative
                - Demography of drivers involved in accident
            - Rail equipment accidents
                - CASINJRR, CASINJ or TOTINJ
                - CASKLDRR, CASKLD or TOTKLD
                - CAUSE, ACCAUSE
                - Important identified attributes -
                    - Railroad involved and its type, grade crossing, timing, weather, visibility, tons, total loss in $, #injured, #killed, narrative, station nearby (station, subdiv), track details (type, class, density), cars causing accidents, primary and secondary causes
                - Incident no.
            - Railroad casualties
                - Year and month of incident.
                - Type of person whose injury is reported using various codes from A - J.
                - Nature of Injury
                - Location of Injury (indicates location of injury on body)
                - Type of Railroad
                - Time of Incident
                - No of positive alcohol and drug tests
                - Code that describes an event that caused injury
            - Operational Data
                - Type of Railroad
                - Region
                - Railroad worker hours
                - County code
                - State and county code
                - Passenger miles - movement of 1 passenger for 1 mile
                - Narration which gives description
                - General details such as Report year, month, county code.
- FRA NARN GIS Data
    - https://www.arcgis.com/home/item.html?id=96ec03e4fc8546bd8a864e39a2c3fc41
    - https://data-usdot.opendata.arcgis.com/search?tags=Rail
- NJTPA (https://www.njtpa.org/opendata.aspx)
    - https://www.njtpa.org/NJTPA/media/Documents/Planning/Regional-Programs/Studies/Rail%20Freight%20Capacity%20and%20Needs%20Assessment%20to%202040/NJTPAFreightRailCapacityCompleteReport3-6-2013.pdf?ext=.pdf
    - https://countyprofiles.njtpa.org/resources/SourceDocument.pdf
- NJDOT (https://www.state.nj.us/transportation/refdata/)
    - NEW JERSEY'S RAILROAD NETWORK https://www.state.nj.us/transportation/gis/maps/RailRoadlines.pdf

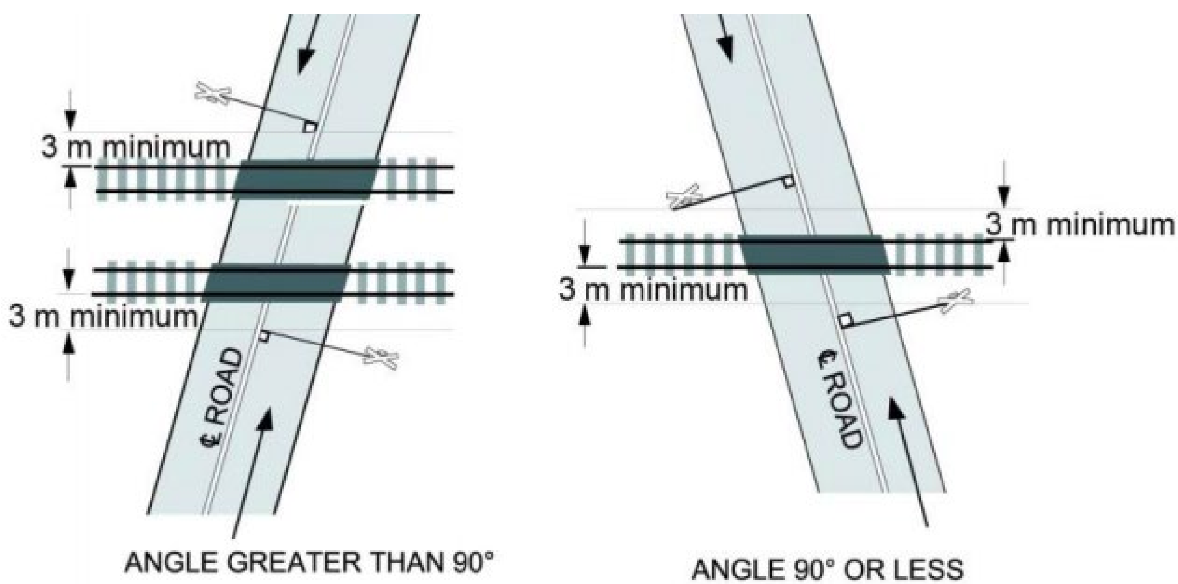
- The New Jersey Railroad System https://www.njtransit.com/pdf/NJStateRailPlan.pdf
- DVRPC (Delaware Valley Regional Planning Commission)- Philadelphia (https://www.dvrpc.org/Data/DVRPC/)
- Penn-DOT (https://data-pennshare.opendata.arcgis.com/)
  - Data on Railroad crossings https://data-pennshare.opendata.arcgis.com/datasets/rmsrrx-railroad-crossings-1
- Municipal and County
  - Land use patterns
  - Crossings
  - Planning department data
  - GIS
  - Building perimeter
  - Population (Town Planning Dept)
  - Population changes
  - county/city population https://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_17_5YR_S0101&prodType=table
  - Transportation departments
- Data from National Climatic Data Centre (https://www.ncdc.noaa.gov/data-access)

The fused data analyses led to many visualizations and conclusions. The following figures and tables are illustrative of the preliminary work undertaken in the first round of data fusing.

Initial Data Scans to Test for Simple Relationships – Illustrative Results – Conrail

File: CICrossingFiltered

Angle at Grade Crossing



File: CICrossingFiltered

XAngle

a. Column - FI
b. Smallest Crossing Angle 1 = 0° – 29°   2 = 30° – 59°   3 = 60° - 90°

4 > 90

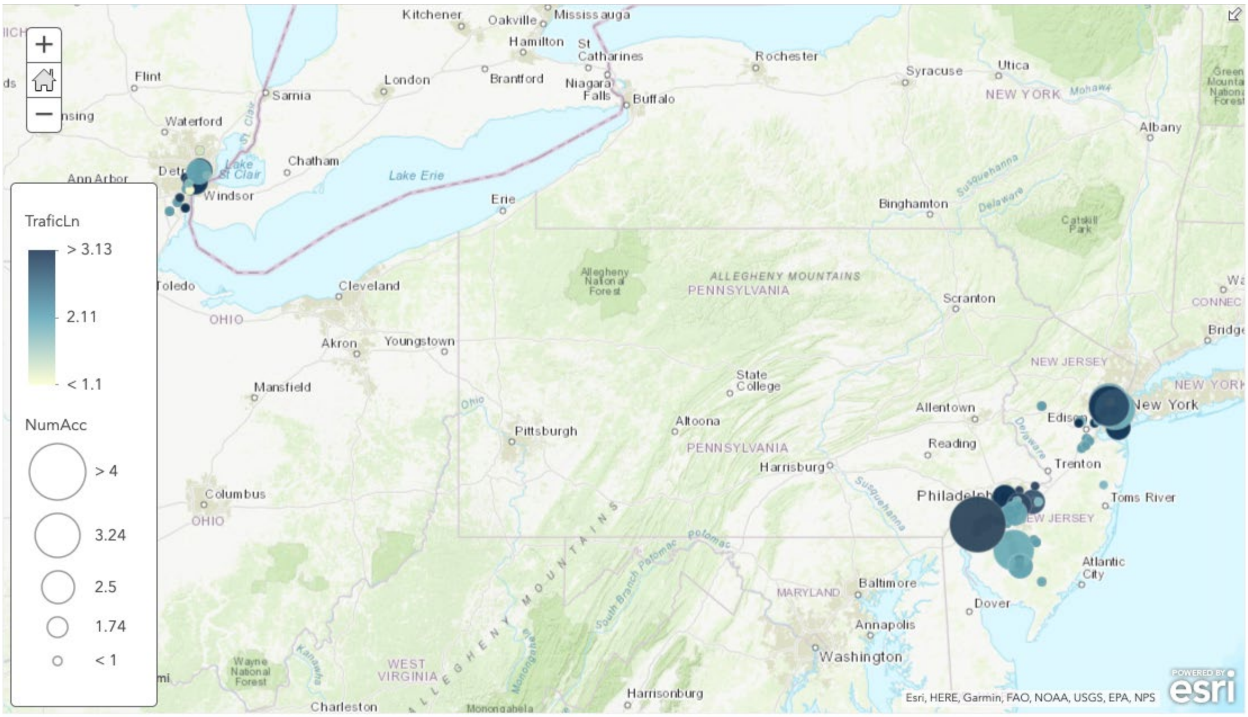
varchar(1)

XAngle	Count
1	8
2	10
3	80
4	6

Observation:

a. The size of the circle represents the number of accidents. The bigger the radius the more accidents.
b. The color difference represents the angle of grade crossings. The lighter the color the smaller the angel.
c. As we can see from the GIS, we can tell that most of the spots with a lot of accidents have light colors. Hence, if the angle of grade crossings is small, there are more accidents.

Traffic Lane and Traffic Type



File: CICrossingFiltered

a. TraficLn (EW) Number of Traffic Lanes Crossing Railroad varchar(2)
b. TraflnType (EX)

TraflnType Traffic Lane Type	Type 1	Type 2	Type 3
Total Number	2	145	1
*1 = One-way Traffic 2 = Two-way Traffic 3 = Divided Traffic			

Observation:

a. The size of the circle represents the number of accidents. The bigger the radius the more accidents there are.
b. The color difference represents the number of traffic lanes. The darker the color, the more there are.
c. As seen from the GIS, mapping, most of the spots with a lot of accidents have dark colors. Clearly, if there are more traffic lanes, there are more accidents. Not a significant finding, but rather confirmatory of what one would expect to find. In short, the analytics are not generating results that do not concord with what would be expected.

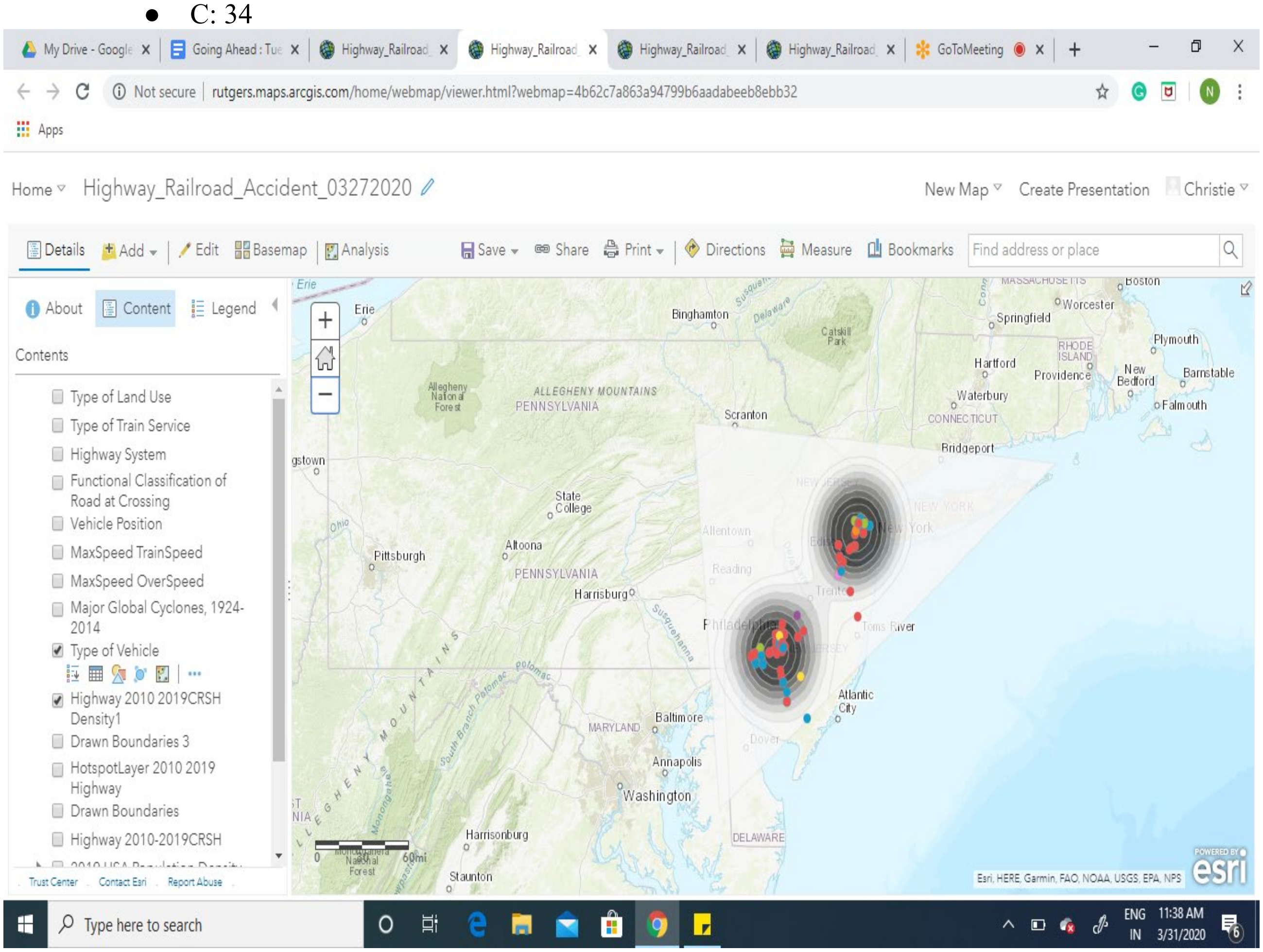
Type of Vehicle

Typveh - (AE - highway data) type of vehicle, e.g., bus, auto, etc.
A= auto
B= truck
C= truck-trailer
D= pick-up truck
E= van
F= bus
G= school bus
H= motorcycle
J= other motor veh.
K=pedestrian
M=other

Observation:

a. A- Auto typed vehicles are major vulnerable vehicles for accidents in accident prone areas (hot spots) especially in South Jersey and North Jersey
b. Detroit - C typed vehicles (Truck-trailers)
c. Distribution of accidents across type of vehicle

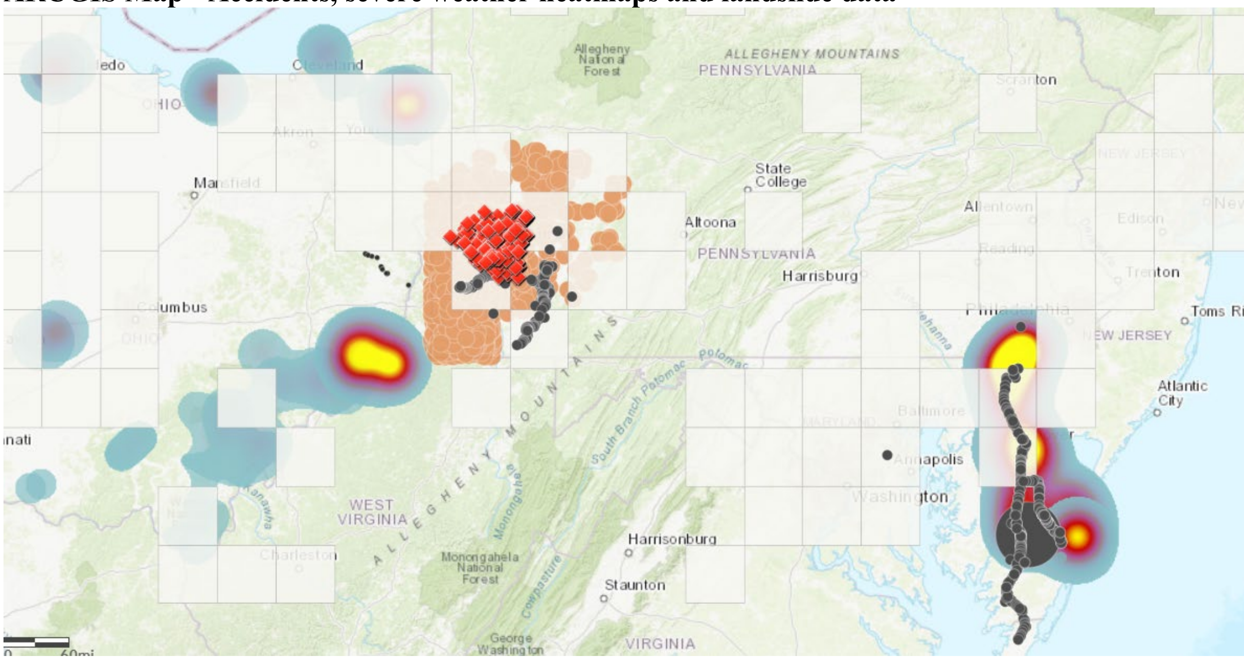
- A: 83
- B: 38
- C: 34



Initial Data Scans to Test for Simple Relationships – Illustrative Results – Carload Express

Carload Express ArcGIS Analysis of Accident Clusters, Severe Weather and Land Movement Data

ARCGIS Map - Accidents, severe weather heatmaps and landslide data



Data Scans to Test for Additional Relationships – Illustrative Results – Conrail

Angle Vs Traffic Analysis

Angle	Traffic Volume	# of Accidents	# of Crossings	% of Accidents per traffic volume
1	15,200	8	5	0.05263%
2	80,604	12	8	0.01489%

3	609,518	83	71	0.01362%
Grand Total	705,322	103	84	0.01460%

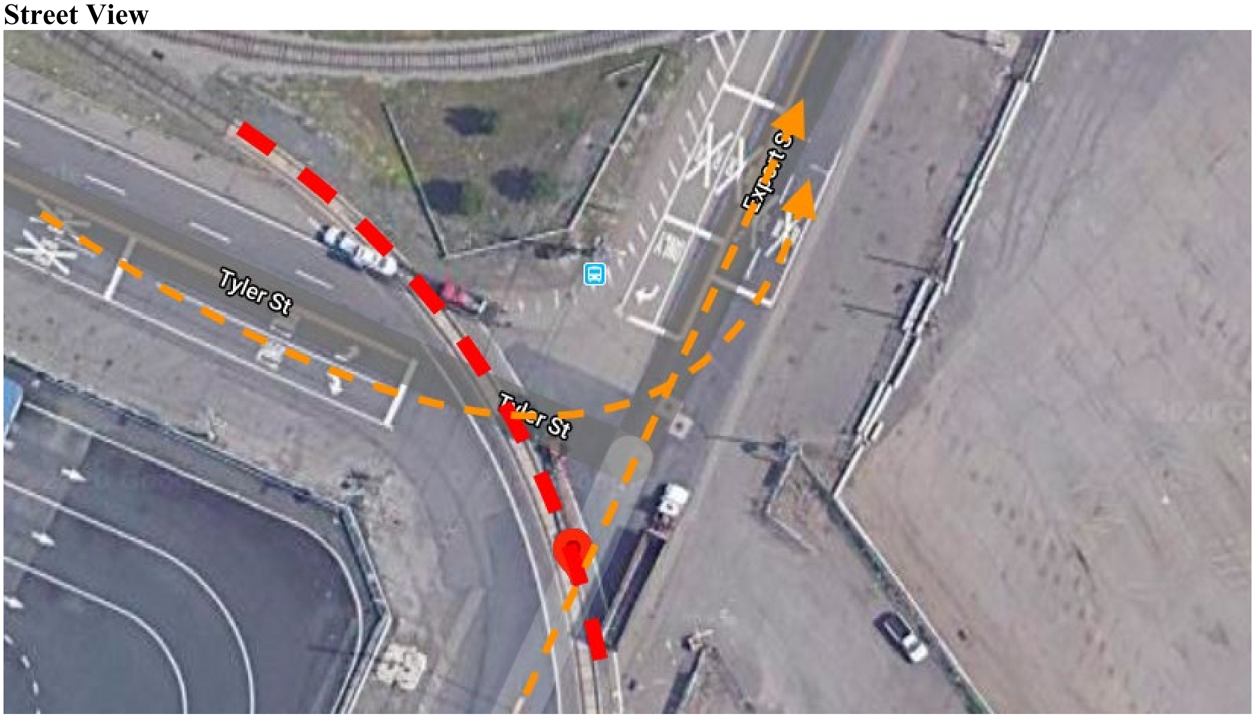
Conclusion: Lower the angle, higher were the % of accidents per traffic volume

Street View

Street View

Street View

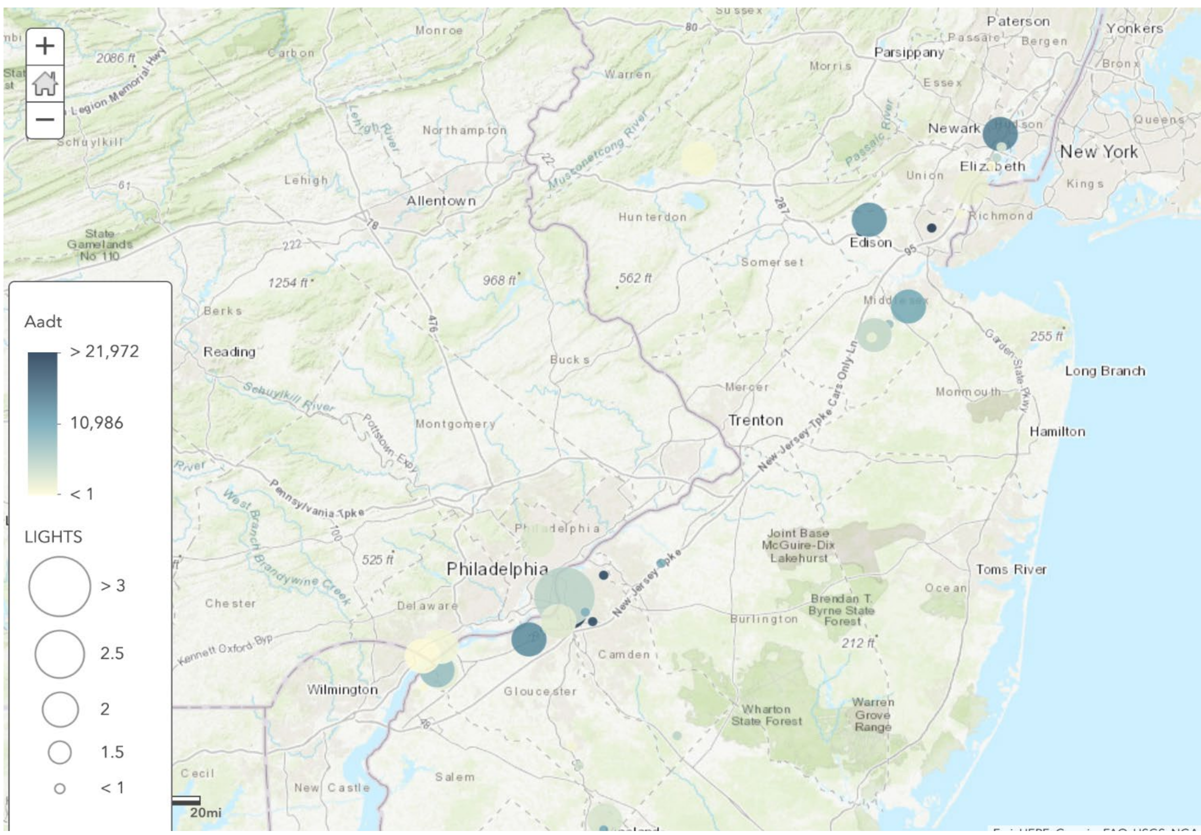
Street View



Lights/Signals vs Traffic Volumes

Lights	Traffic Volume	# of Accidents	# of Accidents per Traffic Volume
Yes	**382851**	**39**	**0.01018673**
No	**139299**	**16**	**0.01148608**

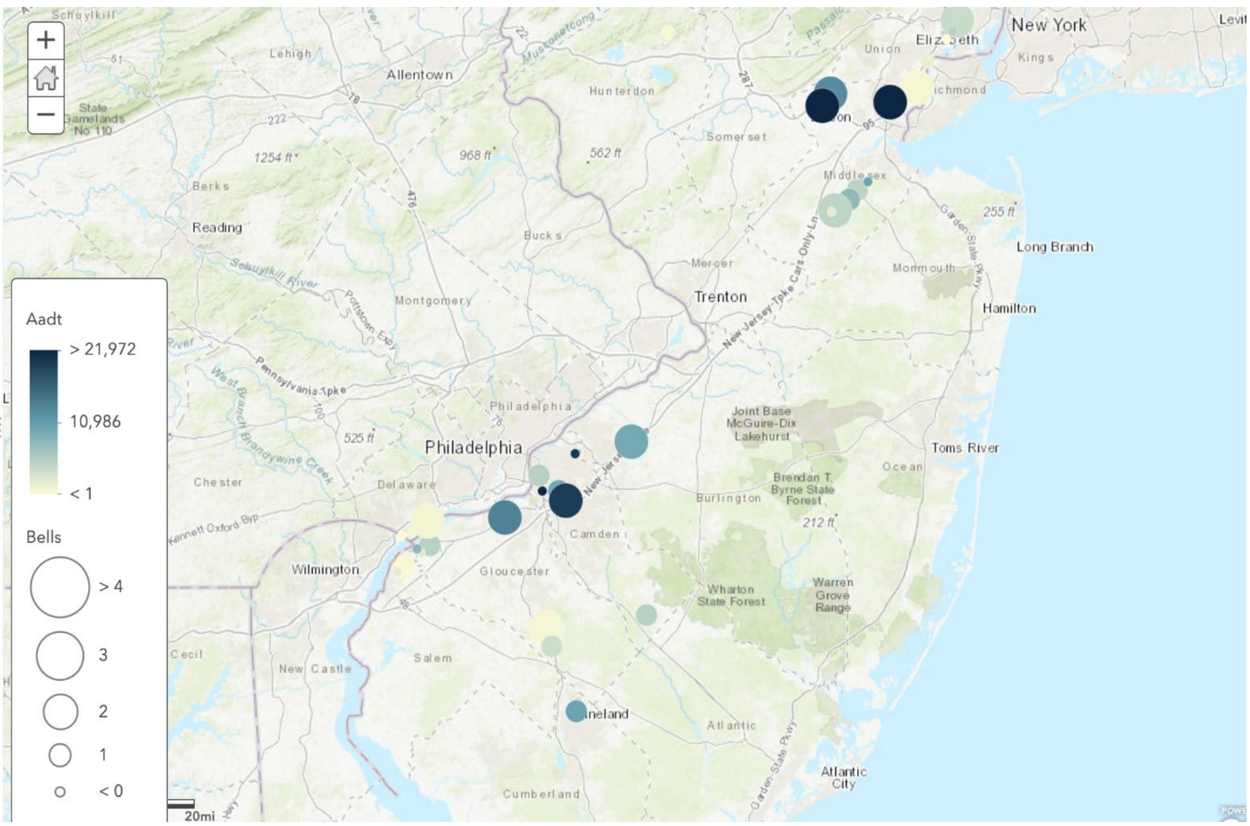
- There is no significant difference between the number of accidents per traffic volumes for crossing with or without lights
- More Traffic areas have lights



Number of Crossing Bells

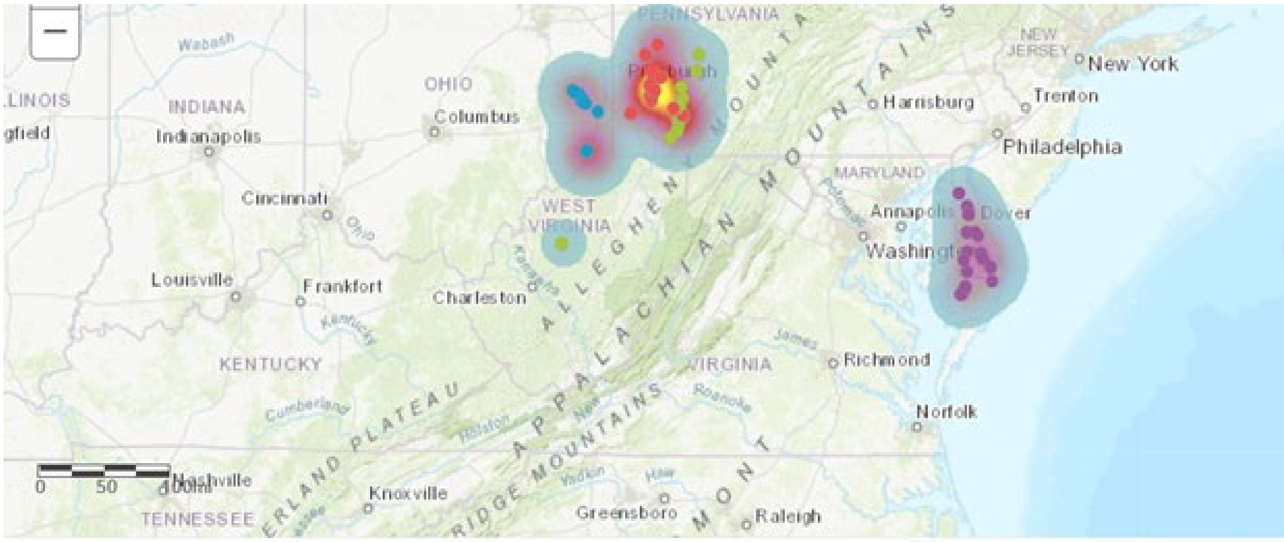
# of Bells	Traffic Volume	# of Accidents	# of Accidents per Traffic Volume
0	137864	20	0.01450705
1	76336	10	0.01309998
2	242270	18	0.00742973
3	0	0	
4	63169	1	0.00158305

- No Significant difference between accidents of 0 and 1 bells but that with more than 2 bells have significantly lower accidents
- No pattern that higher traffic areas have more bells



Data Scans to Test for Additional Relationships – Illustrative Results – Carload Express

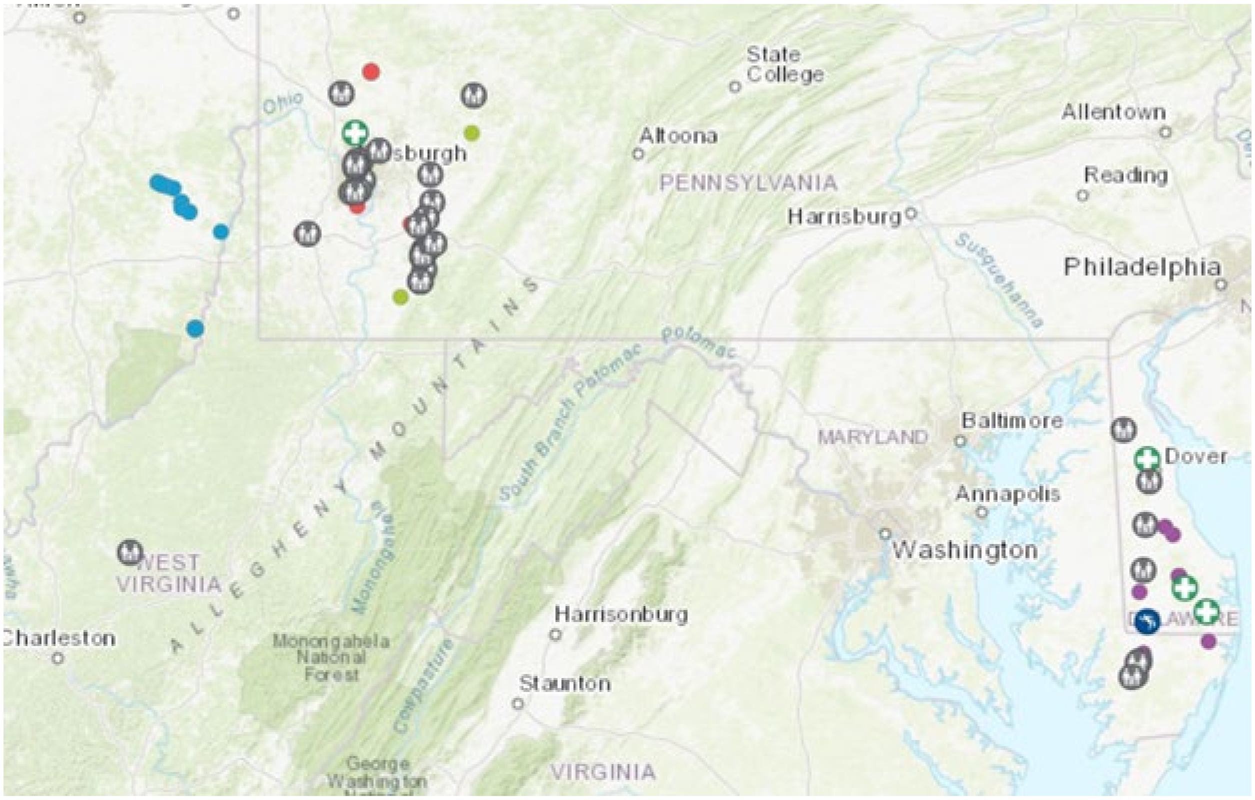
Carload Express Accidents Hotspot Analysis:



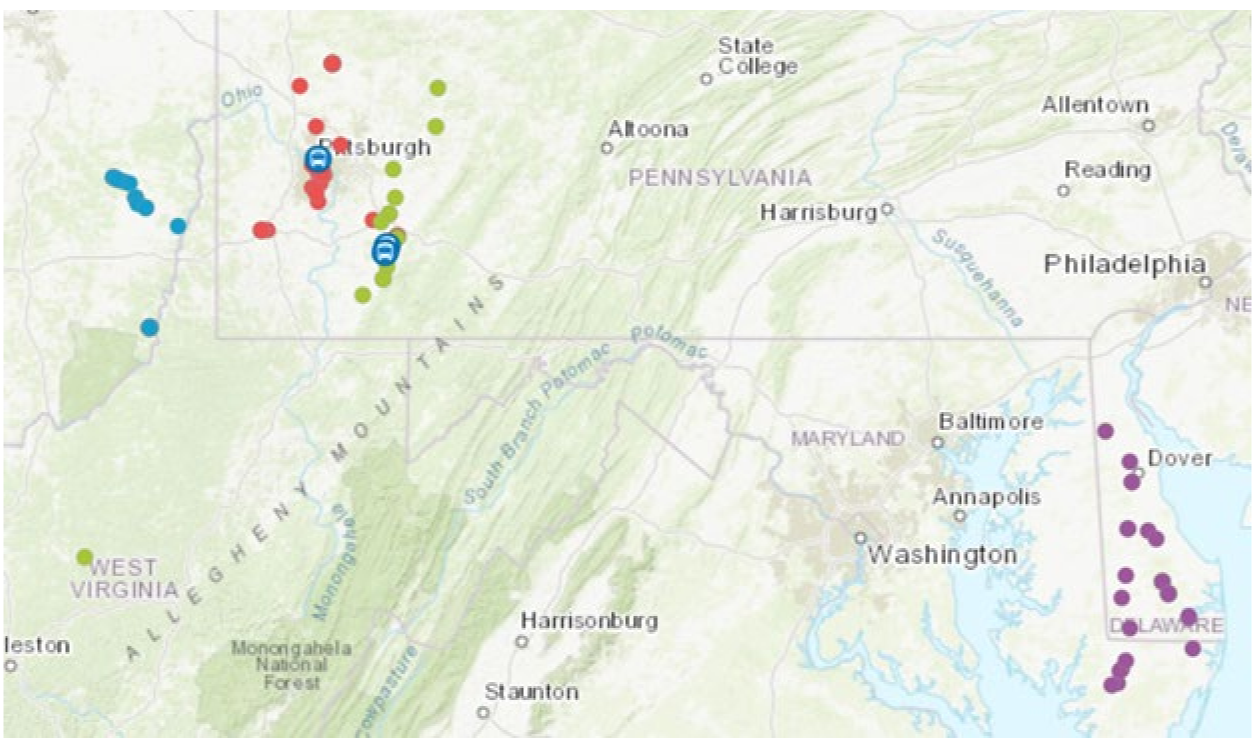
Carload Accidents Hot Spots ID (Features: 140, Selected: 0)

ID	Statistical Significance	ID
14.00	Cold Spot with 95% Confidence	14
24.00	Cold Spot with 95% Confidence	24
113.00	Hot Spot with 95% Confidence	113
115.00	Hot Spot with 95% Confidence	115
118.00	Hot Spot with 95% Confidence	118

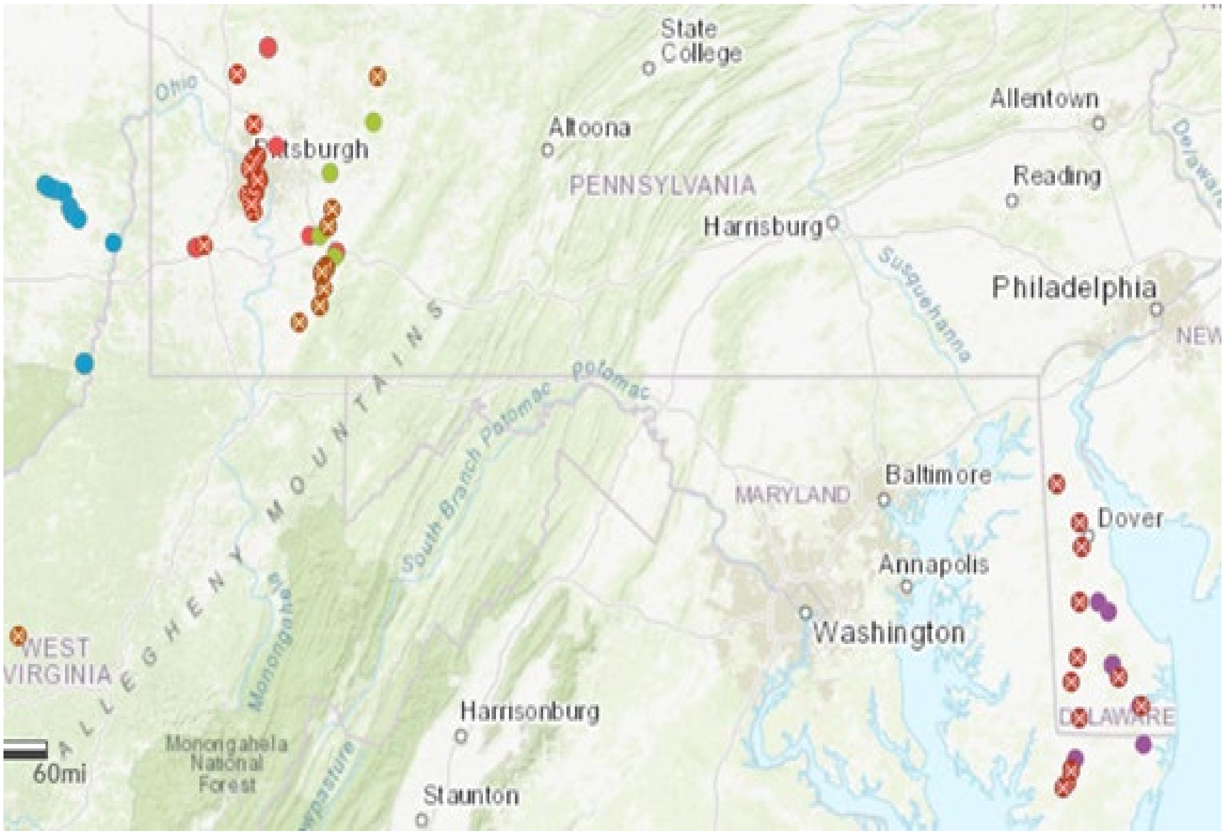
Carload Accident Injuries:



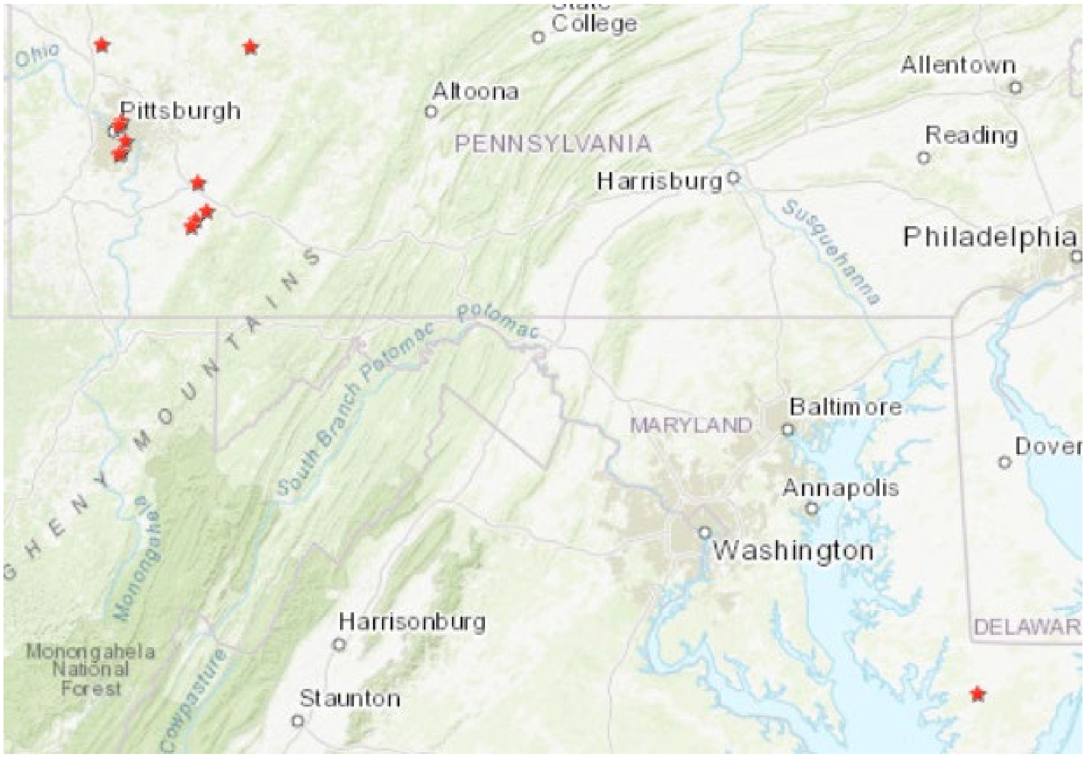
Location of warning:



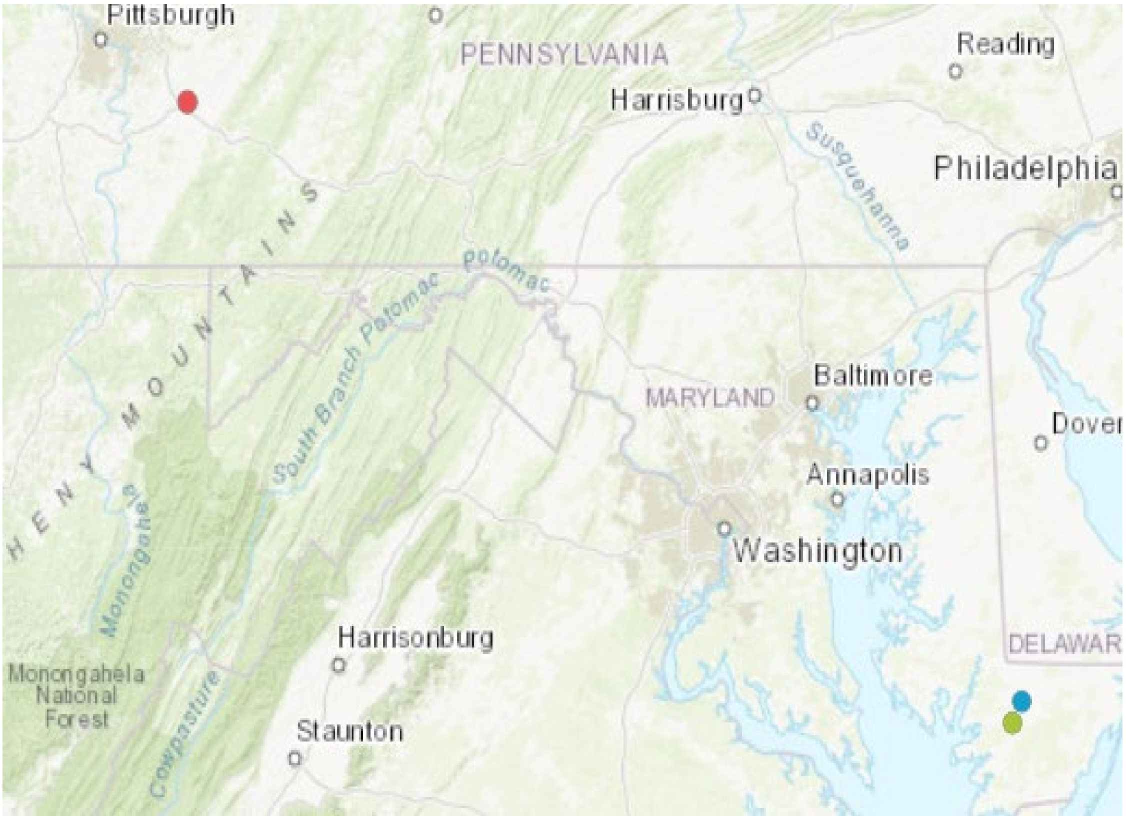
Signals:


State College
Allentown
Ohio
Altoona
Pittsburgh
PENNSYLVANIA
Reading
Harrisburg
Susquehanna
Philadelphia
NEW
Potomac
South Branch Potomac
ALLEGHENY MOUNTAINS
Baltimore
MARYLAND
Dover
Annapolis
Washington
WEST VIRGINIA
Monongahela
Harrisonburg
DELAWARE
60mi
Monongahela National Forest
Staunton

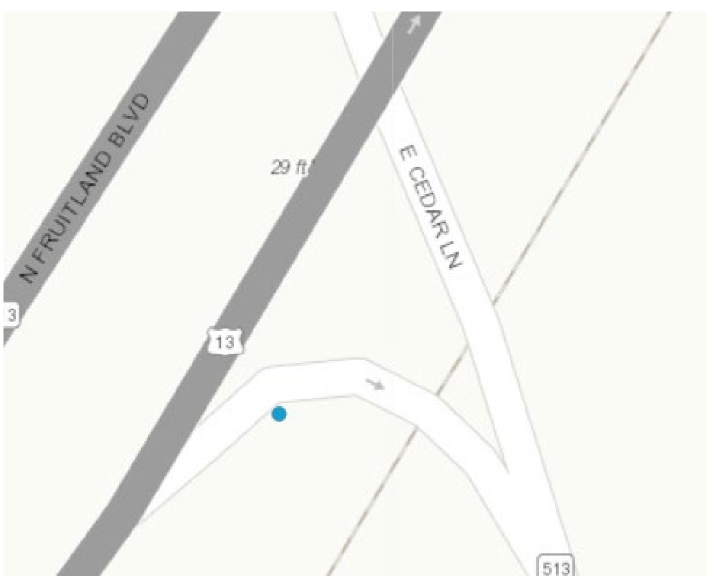
Severe weather:



Carload Express Accidents Coldspot Analysis:



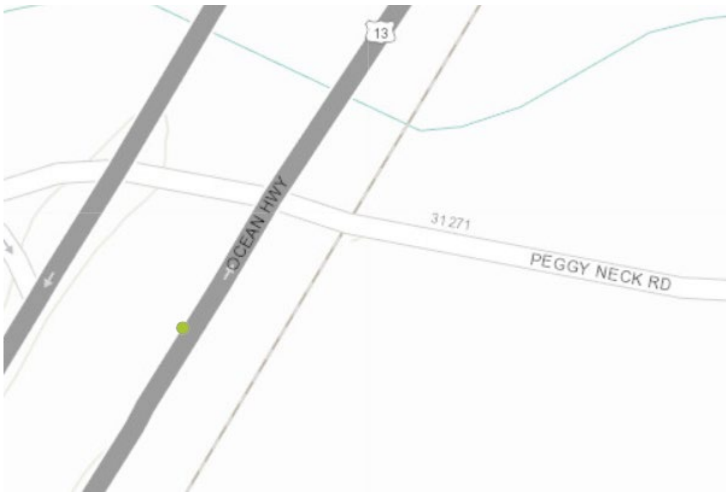
530224K - DCR - Lane St, Fruitland, MD:



- 2 accidents one on 20th Feb, 2017 at 6:20 PM and other on 21st Sep, 2018 at 3 PM

- Both accidents caused due to highway vehicle's failure to stop at the grade crossing but drivers uninjured
- No inclement weather on both days
- Track is not signaled, no highway traffic signals controlling the crossing and no bells present
- Other signs or signals present but no advance warning signs present
- AADT - 1882

- DCR - Peggy neck, Eden, MD:



- 1 accident on 7th November, 2017 at 5:45 PM
- Accident caused due to tractor stuck at the grade crossing but driver uninjured
- Heavy rains and low visibility which could be a possible cause of the accident
- Track is not signaled, no highway traffic signals controlling the crossing and no bells present
- Other signs or signals present but no advance warning signs present
- AADT - 400

544503W - SWP - Foxtown Rd, Scottdale, PA:

- 6 accidents identified but details available for only one on 30th August, 2010 at 12 PM
- Accident caused due to dump truck's failure to stop at the grade crossing. The truck struck the train
- No inclement weather
- Track is not signaled, no highway traffic signals controlling the crossing and no bells present and no advance warning signs present
- Other signs or signals not present for 4 of the 6 accidents
- Average AADT - approx. 2300

Common trends:

- 2-way traffic lanes
- Asphalt crossing surface
- All vehicles under the speed limit
- Train speed <25 MPH
- Vehicles include Auto, Truck and truck-trailer
- Grade crossing angle is 60-90 deg
- Flashing lights present at all the grade crossings

Carload Express Potential New Rail-Served Customers:

The marketing analyses are focused on Carload Express. There was one team working on these analyses. As with the grade crossing analyses, all data gathering occurred remotely. We received inputs from Carload Express as to the markets it wished to understand. Following those conversations, the team proceeded to explore the publicly available date appropriate to identifying potential customers and sourcing areas for two market segments: plastic resins and steel products to be moved through a transload facility in the Pittsburgh, PA market catchment area.

Several databases, both public and private were accessed, these include Census and BTS data, Thomas Publishing Company, World Steel Association and Commodity Flow Survey (CFS) data from 2012. Other data sources consulted include: United States Department of Transportation - Department of Transportation Library, Ohio Railroad Information System and the Pittsburgh GIS Data page. Both, GIS and Tableau platforms have been used to compile and analyze data. Data and commodity flows are based on NAICS (North American Industry Classification System), SCTG (Standard Classification of Transported Goods) codes and Mode of Transport codes.

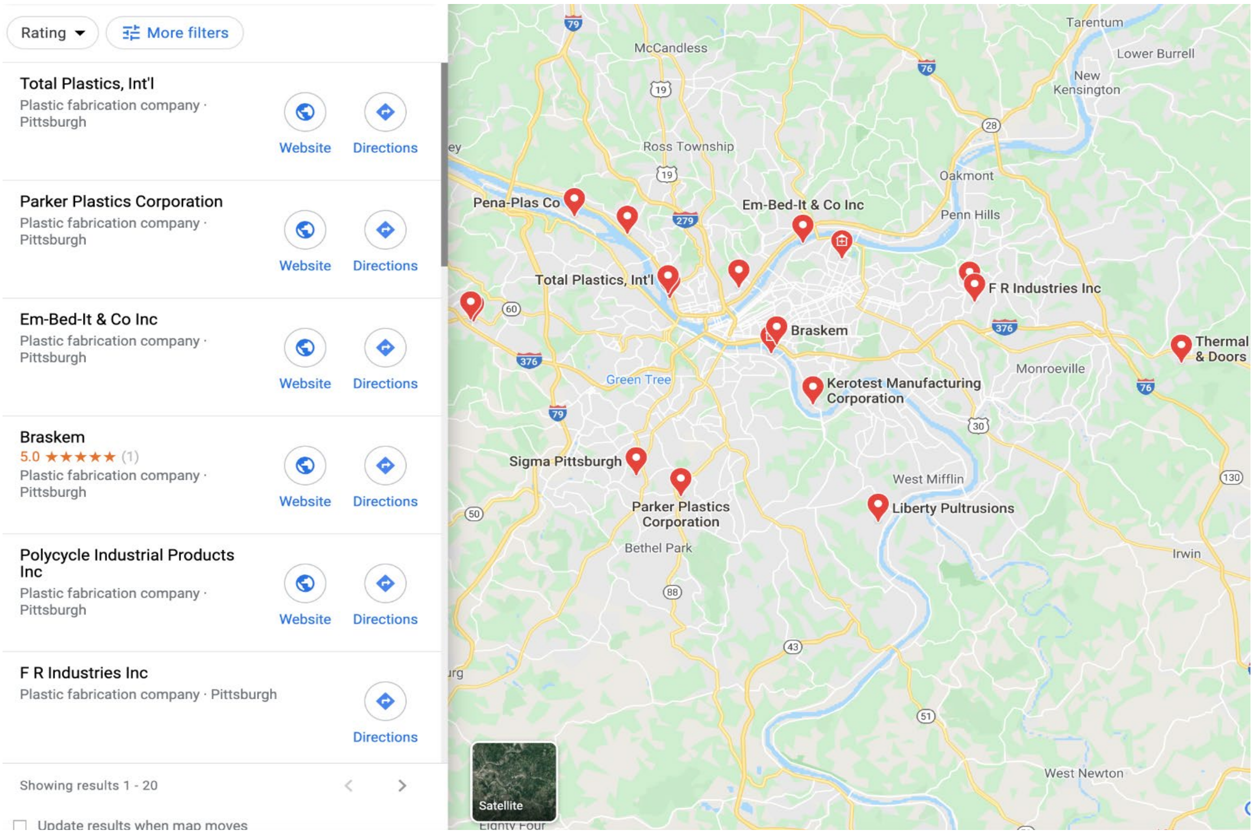
The Census and the BTS datasets typically show the largest industries by state or similar aggregate data which cannot be used to identify specific companies (either manufacturing or consuming) that are relevant to expand Carload's operations. Some private data-sources were explored as well. For example, https://www.thomasnet.com/products/steel-79740205-1.html provides the largest distributors of steel. Additionally, https://www.worldsteel.org/steel-by-topic/statistics/top-producers.html identifies the largest producers – Nucor, US Steel Corporation, Steel Dynamics Inc. Using individual company websites, their various factory locations were compiled. Plotting these data in ArcGIS, specific locations in the Pittsburgh, PA area proximal to railroads are identified. Further, the Commodity Flow Survey data from 2012 available at https://www.census.gov/data/datasets/2012/econ/cfs/2012-pums-files.html provide many insights into the flow of commodities from and to Pennsylvania. The following figures and tables illustrate some of the data developed to date regarding plastic resins and steel products flowing into and out of the Pittsburgh, PA metro area and proximate to a Carload Express served transload facility.

SHIPMT_ID	ORIG_STAT	ORIG_MA	ORIG_CFS_	DEST_STAT	DEST_MA	DEST_CFS_	NAICS	QUARTER	SCTG	MODE	SHIPMT_V	SHIPMT_W	SHIPMT_D	SHIPMT_D	TEMP_CNT	EXPORT_Y	EXPORT_C	HAZMAT	WGT_FACTOR
7694	42	428	42-428	51	99999	51-99999	325	2	24	6	143751	179689	222	288	N	N	N	N	46.8
13826	42	430	42-430	48	29700	48-29700	327	1	32	6	72641	155235	1444	1941	N	N	N	N	56.7
20995	42	428	42-428	6	348	06-348	326	4	24	6	7727	14387	2382	3015	N	N	N	N	36.2
25081	42	428	42-428	42	99999	42-99999	331	4	32	6	60741	156340	108	172	N	N	N	N	113.9
26528	42	99999	42-99999	34	408	34-408	4931	4	43	6	34344	34344	169	200	Y	N	N	N	365.2
29738	42	428	42-428	45	273	45-273	325	2	20	6	42677	68976	546	761	N	N	N	N	74.1
42044	42	99999	42-99999	21	99999	21-99999	331	2	33	6	69202	154758	337	641	N	N	N	N	109.3
52391	42	428	42-428	42	428	42-428	325	4	24	6	142720	178400	1	1	N	N	N	N	30.4
53156	42	99999	42-99999	24	47900	24-47900	212	4	15	6	1208254	24658243	206	390	N	N	N	N	48.9
54073	42	99999	42-99999	21	99999	21-99999	331	1	32	6	82091	166564	337	641	N	N	N	N	101
67096	42	430	42-430	42	430	42-430	4235	2	41	6	207038	207738	35	46	N	N	N	N	39.6
85077	42	430	42-430	42	428	42-428	4239	1	41	6	35143	185221	269	381	N	N	N	N	32.8
85414	42	428	42-428	39	99999	39-99999	331	2	32	6	66875	191071	288	408	N	N	N	N	248.4
90433	42	428	42-428	42	428	42-428	324	3	17	6	503954	1058303	1	1	N	N	N	P	45.9

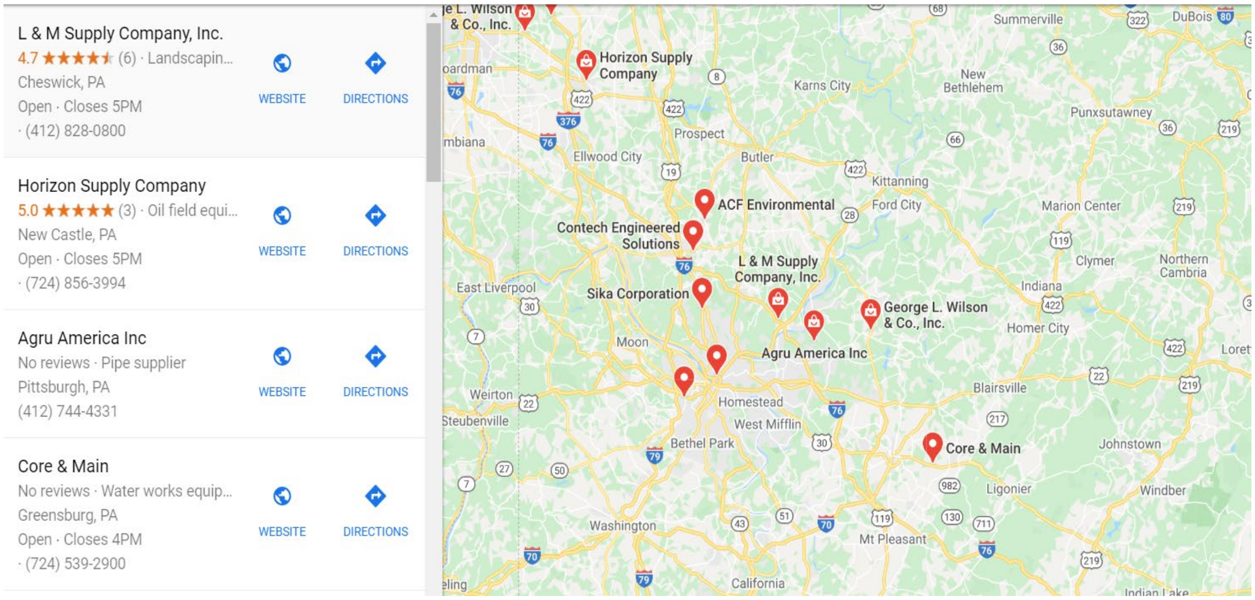
Origin/destination, by commodity

The first row in the Table indicates that there was a shipment of "Chemical Manufacturing" (NAICS=325) related commodities, specifically, "plastics and rubber" (SCTG=24), between "Philadelphia-Reading-Camden" area (CFS_AREA=42-428) and Virginia (CFS_AREA=51-99999) by freight rail (mode=6) in the 2nd quarter of 2012. The
Value of shipment = $143,751, the Weight of shipment = 179,689 lbs and the Routed distance = 288 miles.

PT and PET manufacturers in the Pittsburgh region

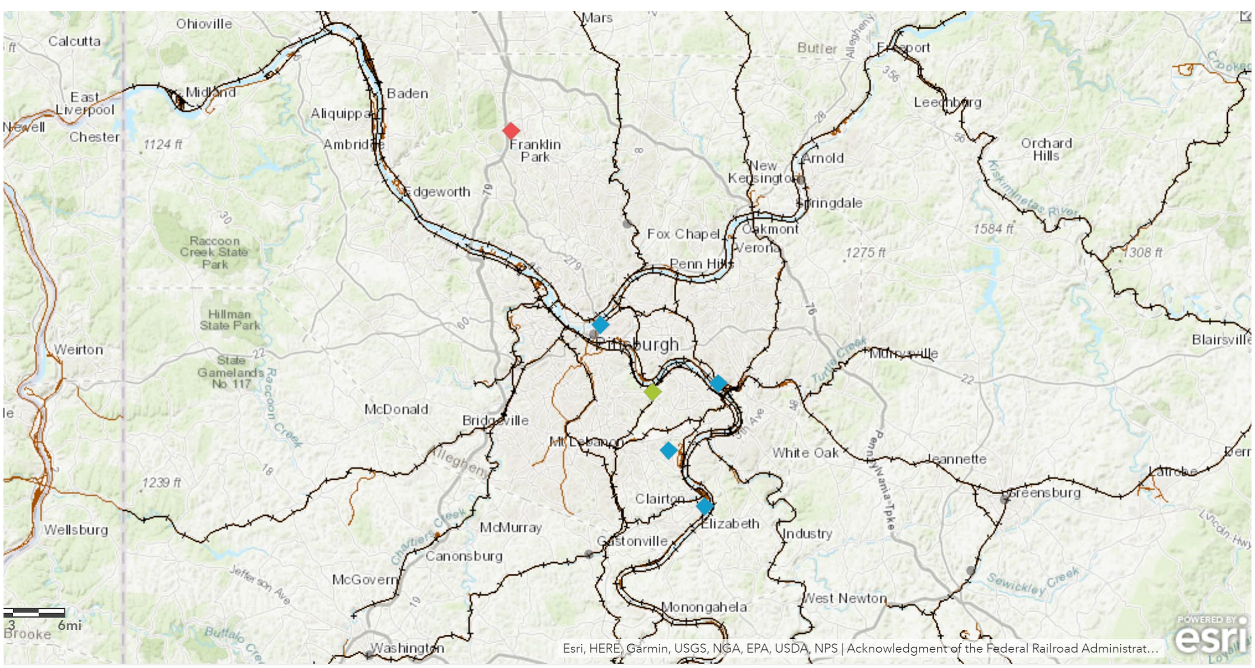


Polystyrene and Polypropylene manufacturers

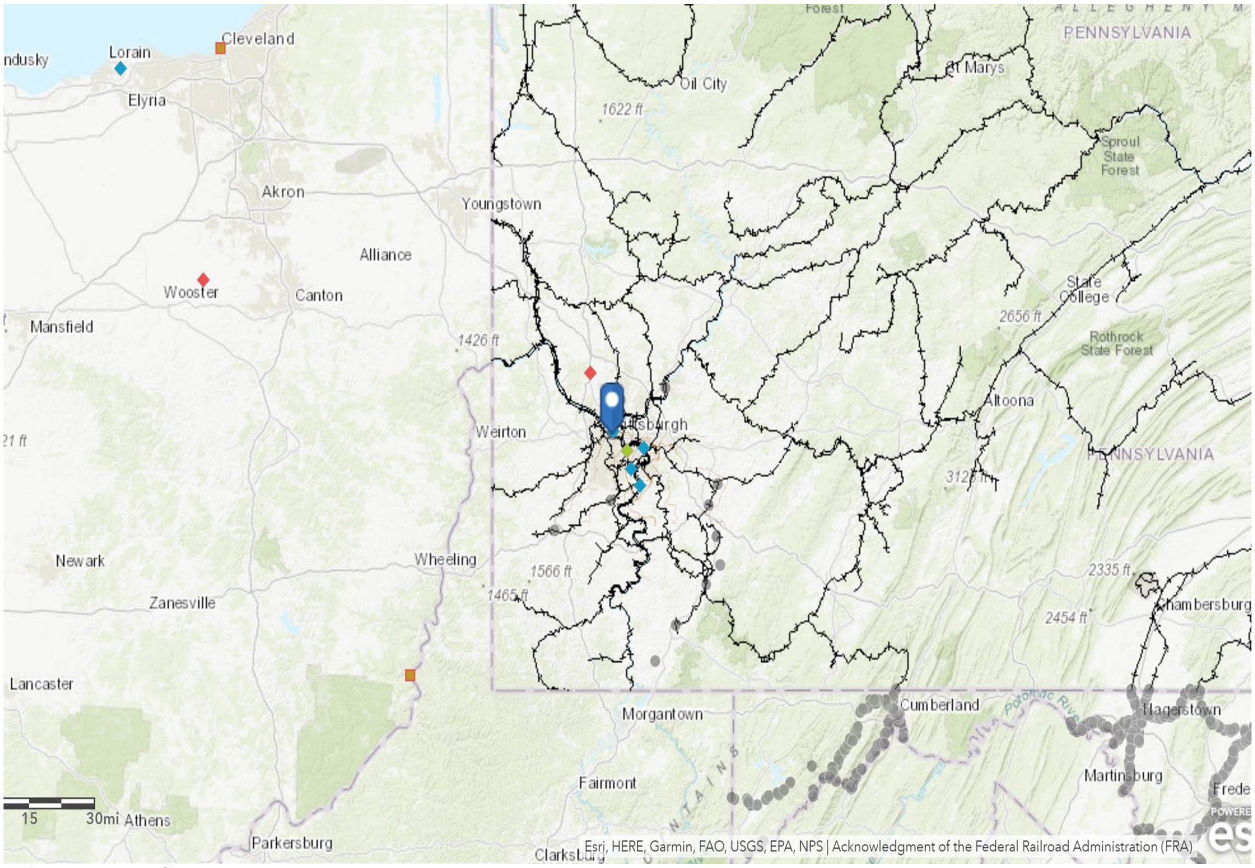


Using data from the World Steel Association, the largest steel producers and distributors in the Pittsburgh area are plotted in ArcGIS proximate to railroads in the Pittsburgh region, as shown the figure below. In addition, the Carload Express handling facilities as depicted on Carload Express' website are plotted as well. The table below lists the commodities handled in these facilities.

Major Steel Commodity Consuming/Producing Facilities in Pittsburgh Area



Steel Producers and Distributors in Pittsburgh Region



Legend

SteelDistributors

- Steel

SteelMfgFacilities

- NUCOR
- US Steel
- Steel Dynamics, Inc

CarloadHandlingFacilities

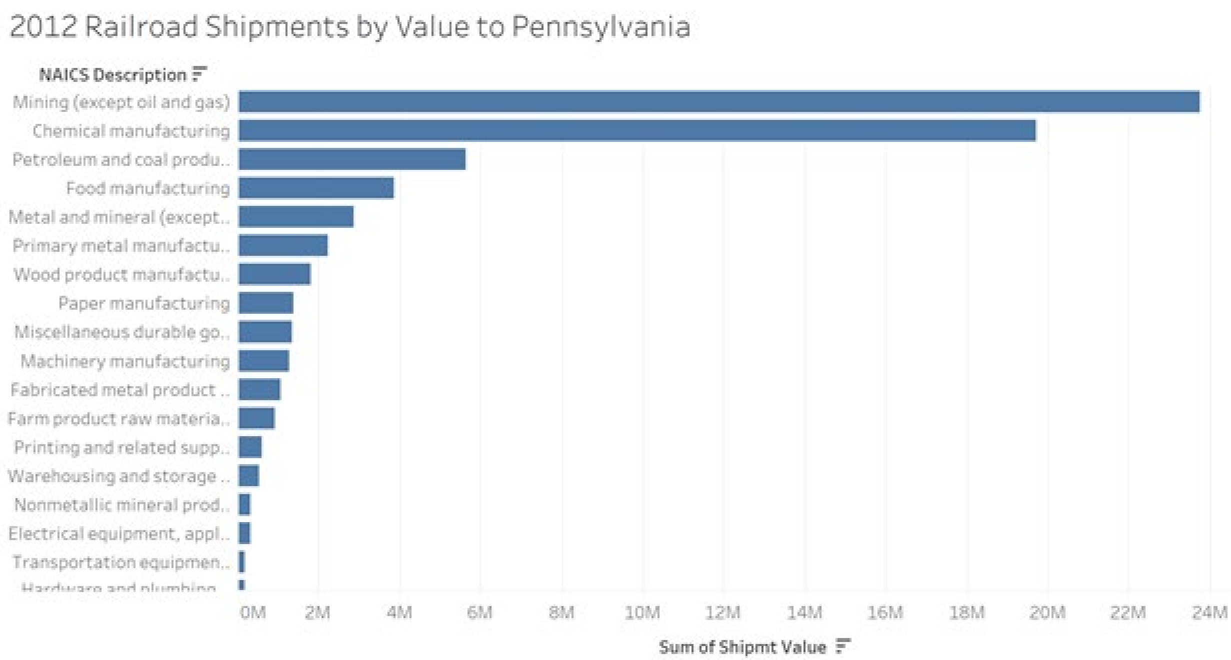
Yes	**No**	**No**	**No**	**No**	**No**	**No**	**Bullskin, PA**	**Bullskin Tipple Co**	**SWP**
Sand, coal and mineral handling	Dry Bulk Chemical & Resin handling	Food handling	Lumber handling	Metal handling	Liquid Chemicals & Ethanol handling	Paper handling	Location	Name of Handling facility	ServingRR
Yes	Yes	Yes	Yes	Yes	Yes	Yes	Mt. Pleasant, PA	Savage Services	SWP
Yes	No	No	No	No	No	No	Smithfield, PA	Hi-Crush Partners	SWP
Yes	No	No	No	No	No	No	Youngwood, PA	Transpac	SWP
Yes	No	No	No	No	No	No	Uniontown, PA	Wildcat Minerals	AVR
Yes	Yes	No	No	No	Yes	No	Pittsburgh, PA	CSX Transflo	AVR
Yes	Yes	Yes	Yes	No	No	No	New Kensington, PA	New Kensington Public Delivery Track	AVR
Yes	No	No	Yes	No	No	Yes	Glenshaw, PA	Kelman Bottles	AVR
Yes	No	No	No	No	No	No	Omal, OH	McKees Rocks Industrial Enterprises	OHIO
Yes	No	No	No	No	No	No	Omal, OH	Wildcat Minerals	OHIO
No	Yes	Yes	Yes	No	No	No	Pittsburgh, PA	Glenwood Public Delivery Track	AVR
No	Yes	Yes	Yes	No	No	No	Washington, PA	Washington Public Delivery Track	AVR
No	Yes	Yes	Yes	No	No	No	Finleyville, PA	Finleyville Public	AVR

								Delivery Track	
No	Yes	Yes	Yes	No	No	No	Pittsburgh, PA	Strip District Public Delivery Track	AVR
No	Yes	No	No	No	No	No	Bullskin, PA	Connellsville Public Delivery Track	SWP
No	Yes	Yes	Yes	No	No	No	Omal, OH	Omal Public Delivery Track	OHIO
No	No	Yes	No	No	No	Yes	Greensburg, PA	Catch Up Logistics	SWP
No	No	Yes	No	No	No	No	Youngwood, PA	AMPCO Distribution	SWP
No	No	Yes	Yes	No	No	No	Connellsville, PA	Connellsville Public Delivery Track	SWP
No	No	No	No	Yes	No	No	Pittsburgh, PA	Transload Express	AVR
No	No	No	No	Yes	No	No	New Kensington, PA	Paul Riggle & Sons, Inc	AVR
No	No	No	No	No	Yes	No	Pittsburgh, PA	Sunoco Logistics	AVR
No	No	No	No	No	No	Yes	Greensburg, PA	Stone & Company	SWP

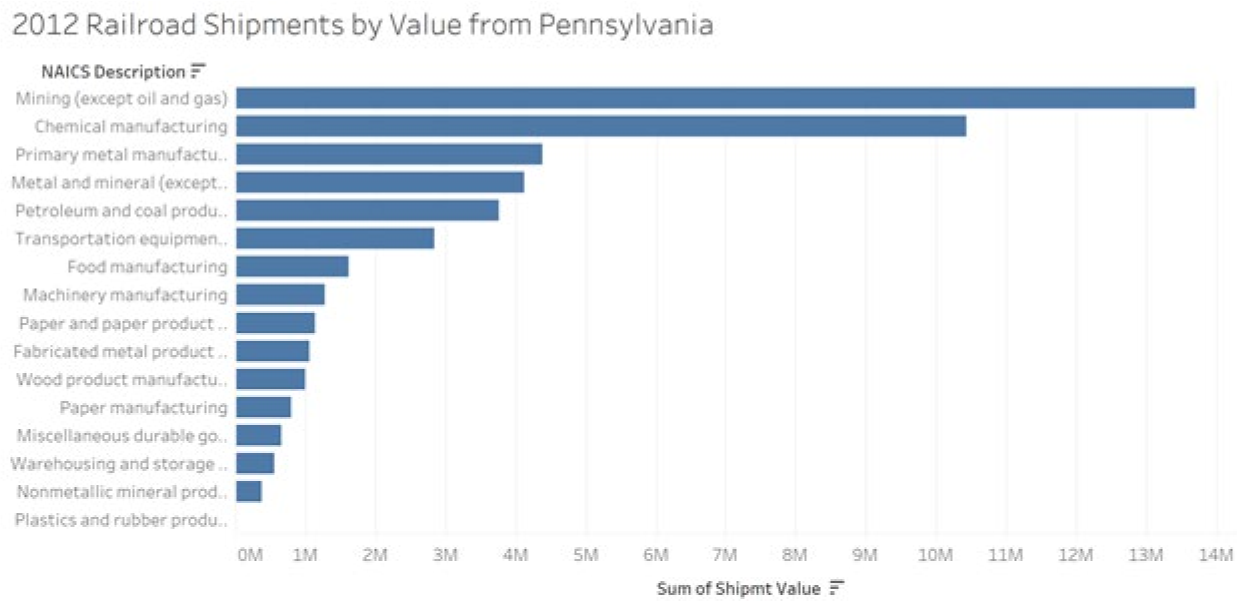
Carload Handling Facilities Commodities

The following figures, based on overall CFS commodity data, are illustrative. The Carload Express Team is currently drilling into specific moves by commodity and location to determine whether lane-specific moves can be identified from this data source.

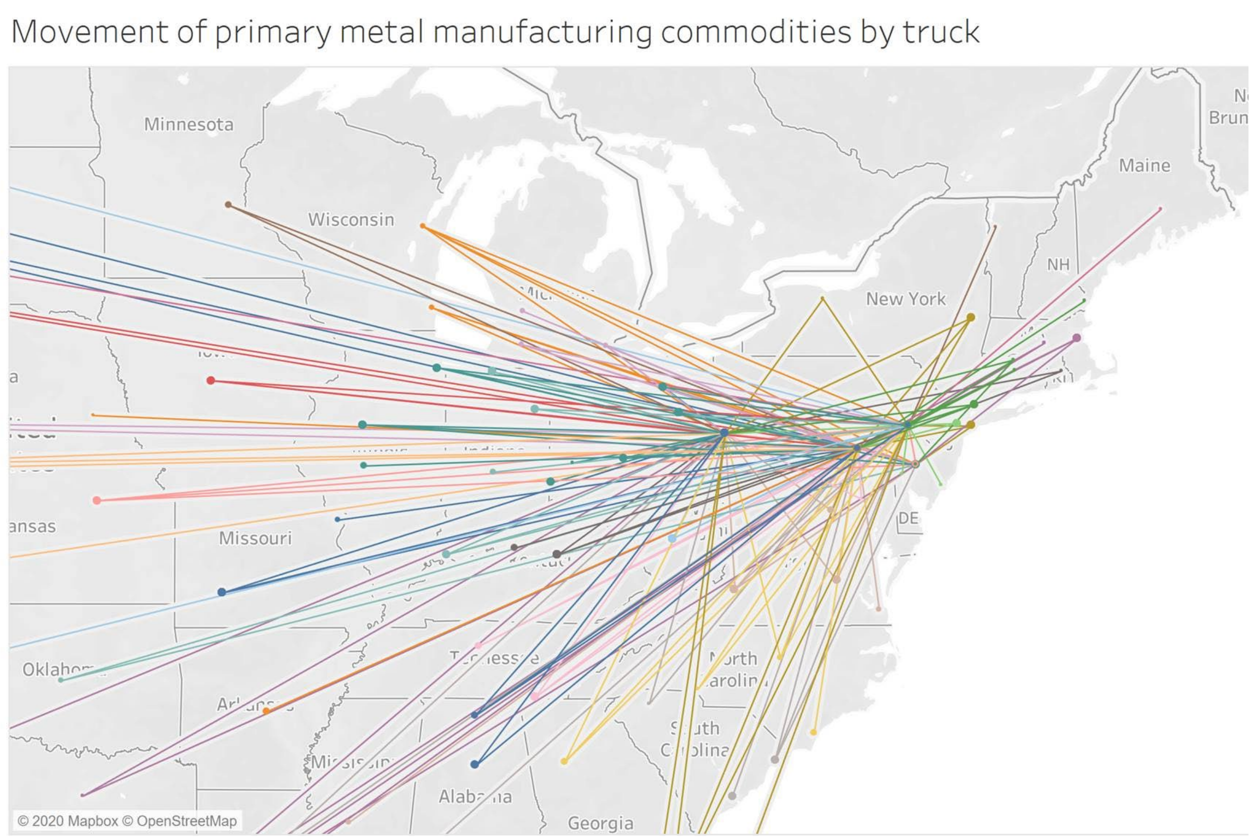
2012 Rail Shipments to Pennsylvania by Value



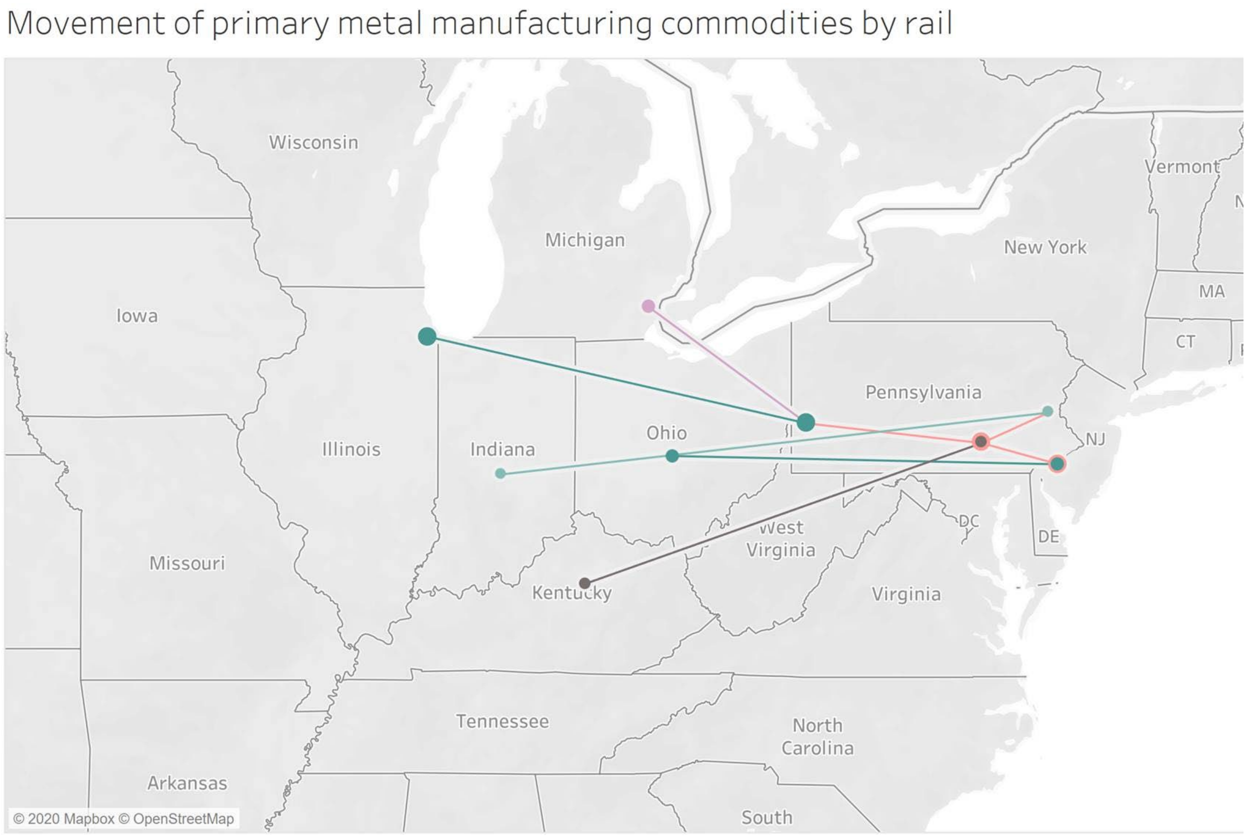
2012 Rail Shipments from Pennsylvania by Value



Primary Metal Manufacturing Truck Shipments



Primary Metal Manufacturing Rail Shipments



Risk Model to Prioritize Maintenance Activities, Operational Decisions and Investment Decisions

Preliminary work has been completed by the team in integrating track inspection optimization models with Enterprise Risk Management (ERM) optimization models. In this work, the fundamental assumption is that railroads are complex and tightly coupled corporate systems with multiple business divisions, e.g., Engineering, Operations, Marketing, HR, IT, etc., as well as multiple departments within those divisions, e.g., Maintenance of Way, Maintenance of Equipment, Communication and Signals, Service Planning, Intermodal, Coal, Automotive, Customer Service, etc. Each Division and its Departments are individually seeking to maximize/minimize whatever their respective objectives are within their individual budgets, etc. In this analysis, we demonstrate how the conditional probabilities derived from LDA and SME Miner can be used in a shared and dependent risk decision-tree analysis to address logical consistency constraints, capital resource constraints and risk constraints.

It has been shown that maintenance decisions impact customer service through delayed deliveries. While there may be unavoidable service impacts to service by maintenance activities, when and how these delays occur can have impacts on such things as service delivery penalties and over the long-term, loss of business. This latter situation illustrates another important factor in these types of decisions – the multiperiod character of decisions, e.g., different time-horizons and different payback periods. Thus, having an automated mechanism that creates the likely impacts of various decisions across a railroad enterprise could be a useful and helpful tool for decision-makers confronted with tradeoffs between different investment scenarios, etc.

The Production Team Scheduling Problem model adopted in this research is shown below.

$$\text{(PTSP)} \qquad \min \sum_{\text{all cost items}} C_{\text{cost item}}(\mathbf{x},\mathbf{y}), \tag{4.1}$$

s.t.

$$\sum_{w \in W_{\text{start},k}} \sum_{v \in V} x_{v_{\text{start},k} vkw} = 1, \qquad \forall k \in K, \tag{4.2}$$

$$\sum_{v' \in V} x_{vv'kw} - \sum_{v' \in V} x_{v'vkw} + \sum_{p \in P_{vk}^{+}} \left(y_{pkw}^{+} - y_{pk(w-t_{pk})}^{-} \right) + \sum_{p \in P_{vk}^{-}} \left(y_{pkw}^{-} - y_{pk(w-t_{pk})}^{+} \right) = 0,$$

$$\forall v \in V \setminus \{v_{\text{start},k}, v_{\text{end},k}\}, k \in K, w \in W, \tag{4.3}$$

$$\sum_{w \in W_{\text{end},k}} \sum_{v \in V} x_{vv_{\text{end},k} kw} = 1, \qquad \forall k \in K, \tag{4.4}$$

$$y_{pkw}^{+} + y_{pkw}^{-} = y_{pkw}, \qquad \forall p \in P_k, k \in K, w \in W, \tag{4.5}$$

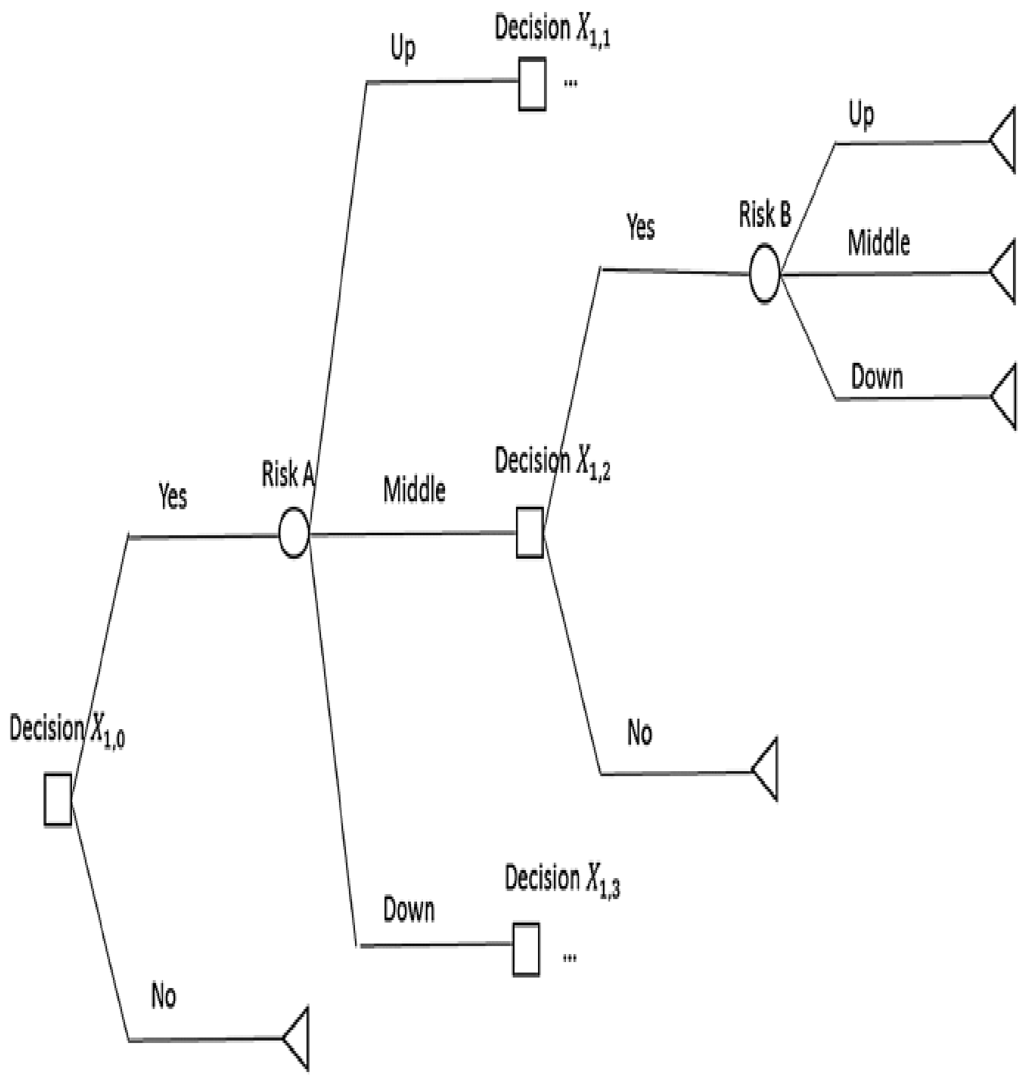
$$\sum_{w \in W} \sum_{k \in K_p} y_{pkw} = 1, \qquad \forall p \in P, \tag{4.6}$$

$$y_{pkw}^{+}, y_{pkw}^{-} \in \{0,1\}, \qquad \forall p \in P_k, k \in K, w \in W. \tag{4.7}$$

Core PTSP (Production Team Scheduling Problem) Model

In the following figure, a simplified decision-tree diagram is illustrated.

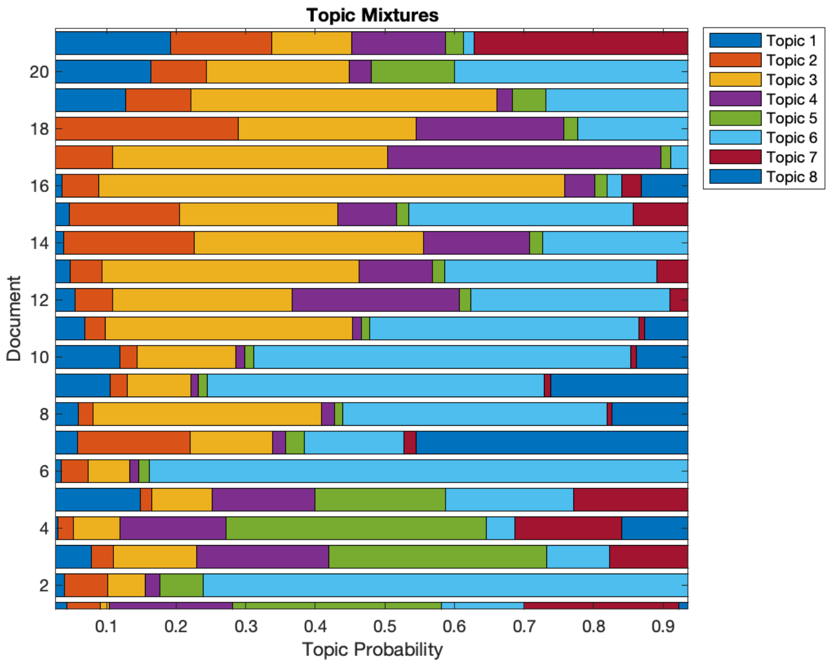
Tree Structure for Freight Railroad Decision Structure



In this example, Decision $X_{1,0}$ is a capital maintenance program for a particular division on a particular line of railroad. To simplify, the decision Yes is based upon surpassing the internal ROI for such projects. The decision No is failure to pass the internal ROI for such projects. For simplification, ignore the risks associated with a No decision. Using the ERM optimization model in *(7)*, and conditional probability data from our LDA and SME Miner analyses for past service impacts of comparable maintenance decisions, we estimate the possible likely impacts for decisions $X_{1,1}$, $X_{1,2}$ and $X_{1,3}$, where the risks go up, are in the middle range, or go down for Risk A. Using these same conditional probabilities, we calculate the upper and lower bounds of each estimate. In this example, with this information provided to both MOW and Service Planning, the agreed most likely case is the middle range of risks. Which then leads to making decisions $X_{1,2}$ and leads to Risk B, with its concomitant high, middle or low risks and for a particular customer impacted by the Maintenance decision made in A. Again, the upper and lower bounds of these risks can be derived from the conditional probabilities of past behavior of the customer. A further set of actions could then be determined by Customer Service to ameliorate the likely customer behavior based upon the expected response with no Customer Service intervention.

To place this in the context of the preceding examples, using LDA analysis, various maintenance activities and service delays are extracted from the railroad's maintenance and service performance logs. In these analyses, surfacing significantly contributes to increased service deliveries – raising the average from 25 for all maintenance activities to an average of 33 for surfacing, an increase of over 30%. These data illustrate that service is most significantly impacted by surfacing on that main line junction with a Class I railroad – one of its major interchange partners. The figure below allows us to obtain the likelihoods of Topic 4 (surfacing) being manifest in the 1519 daily entries over the period from 2014 to 2017. In general, statistically, the more observations one has, the greater the confidence in the probability ranges. In this case, we use the observations from 20+ log entries to derive our upper, lower and middle probability estimates. From the figure, we observe the lower probability estimate of a service impact from surfacing is 0.475 and the upper probability is 0.58 and middle probability estimate is 0.528. So, in Figure 7, Decision $X_{1,1}$ has a risk of 0.58 of negatively impacting service to customers, $\text{Decision}_{1,2}$ has a risk of 0.528 of negatively impacting service to customers and Decision $X_{1,3}$ has a risk of 0.475 of negatively impacting customer service, where the three decisions have to do with surfacing start times. Assuming Management decides that $x_{1,2}$ is the more likely outcome and given historic surfacing data for $\{v_{start, k}, v_{end,k}\}$ in (4.3), we can similarly calculate estimates for $\{v_{start, k}, v_{end,k}\}$ to refine the likely service impacts for Risk B, which is the customer response to the estimated service disruptions.

Probability of Topic Membership for Individual Log Entries



Conclusions

To date, this research demonstrates the feasibility of integrating various methodological tools to improve condition-based management for freight rail service corridors. Further, the research demonstrates that currently available analytic tools can be used to visualize patterns in multiple data sources to discern patterns in highway-rail grade crossing accidents that have not historically been recognized by railroad operators and policy makers. In addition, the research demonstrates that that currently available analytic tools can be used to visualize patterns in multiple data sources to identify potential business development opportunities for railroads to utilize in their marketing decisions.

Specifically, automated LDA text mining, in conjunction with R to develop SME Miner was used to convert daily maintenance log text into conditional probabilities for service delays which were then used as inputs into the production team scheduling problem (PTSP) and married with an ERM optimization model using shared and dependent risk decision-tree analysis to illustrate how such tools could be used by railroad management to make data-driven driven decisions regarding maintenance scheduling to reduce negative customer impacts.

In a similar manner, the research team has demonstrated that readily available visualization tools – Python ggplot and Tableau – can be used to extract patterns from multiple data sources related to grade crossings that are readily interpretable and can potentially improve resource decisions and allocations to reduce these kinds of incidents. The research team is currently analyzing data from sources such as State DOT, MPOs, weather data, geologic data, Street View and Satellite imagery related to both hot and cold spots for grade crossing accidents as well as urban and non-urban settings. These analyses provide much more granular results and greater predictive capability. However, there are significant liability issues for railroads surrounding these types of analyses. The team is trying to address these issues to allow the results of such analyses to be placed in the public domain. Regardless, both sets of results suggest these are fruitful areas for further research and illustrate the need to place greater focus on cold spots as these are the preponderant source of grade crossing accidents.

Finally, the research team has demonstrated that readily available visualization tools – ArcGIS, Python ggplot and Tableau – can be used to extract patterns from multiple data sources to identify potential business development opportunities for railroads to utilize in their marketing decisions.

The remaining months of the project will be devoted to developing a DSS framework for testing and use by the participating railroads. It is hoped the current difficulties encountered by the companies resulting from the Covid-19 pandemic will subside sufficiently in the remaining time of the project that a meaningful test can be conducted of the DSS framework. At a minimum we hope the participating railroads will be able to provide feedback on how they anticipate integrating the framework into their operations going forward.

Appendix 2: Detroit Grade Crossing Analyses

See attached report.

Appendix 3: Conrail Risk Mitigation Project: Gloucester City GX's

See attached report.

GLOBAL
INFORMATION SYSTEMS

MBS EXTERNSHIP
RUTGERS
Professional Science Master's Program
Master of Business and Science
EXCHANGE PROGRAM

DETROIT GRADE CROSSING & TRESPASS RISK MITIGATION

Proposed By:

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PROJECT SUMMARY

In the United States, a train collides with a vehicle/person once every 115 minutes. Each year, nearly 1000 people are killed in train-related accidents. Of the various causes linked to these incidents, one significant trend was the lack of proper warning devices in each of the crossings. Warning devices can be separated into two categories: active and passive. Active devices are those that give either a visual or audible advance notice of the approach of a train. Passive devices do not have lights, sounds, or gates; instead, they include signs and markings. Advance warning signals are necessary to warn motorists and pedestrians and to prepare them for a railroad crossing.

This research paper examines the characteristics and considers surrounding land uses, highway characteristics, distractions, obstructions, and other risk factors of four high-risk grade crossings in Detroit, Michigan. Using these data, research on viable technologies is studied to reduce grade crossing and trespassing incidents. Together, this information was used to recommend possible risk mitigation strategies for Conrail.

Recommendations were categorized into three levels. Level 1 is to implement basic measures such as synchronizing traffic signals with grade crossings; Level 2 includes implementing passive and active technologies; Level 3 is to implement SMART technology. The levels ensure that proper solutions are carried out without wasting resources on expensive devices. These suggestions are to reduce the likelihood of trespassing and grade crossing incidents and potential injuries and fatalities that may result.

Several crossing characteristics and technologies were explored throughout this report. Some limitations include the considerations of future land uses of the city and county, population profiles near the high-risk grade crossings, and influences on certain variables in this report. Further research is required to understand future district plans and reallocations of the land. The proposed recommendations are based on the latest information provided by various sources and databases.

“IN THE UNITED STATES, A TRAIN COLLIDES WITH A VEHICLE/PERSON ONCE EVERY 115 MINUTES.

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COMPANY BACKGROUND & PROBLEM OVERVIEW

Global Information Systems (GIS) LLC is an engineering consulting firm that specializes in Applications & Database Development; GIS & CAD; Materials Verification & Pipeline Data Modeling; Real-time Data Integration, Analysis, Dash-boarding & Reporting of both construction and integrity activities. With the latest research and technology, GIS LLC has provided many people, processes, and industries with the tools for success. Through these operations, customers have been able to optimize time, money, and project efficiency, which has paved the way for powerful solutions.

GIS LLC's supported the project team in its work with Conrail, a Class II freight railroad that operates primarily in New Jersey and in the Detroit Metropolitan area. Conrail provides rail freight service to customers that are receiving or shipping some form of freight through interline connections with NorfolkSouthern (NS) or CSX. This specific project focuses on Detroit. Conrail has identified four grade crossings (GX) in Detroit that it views as being high-risk now and/or in the future: 6 Mile Road, 8 Mile Road, Central Ave, and Lonyo Ave. Detroit is infamous for its high-speed vehicular traffic, frequent vandalism of signals, issues with lighting, GX protection devices, and signage, etc. Likewise, these problems, particularly the frequent high-speed vehicular traffic, have been linked to injuries that railroad maintenance personnel have experienced at these GXs.

Through this report, the team studied the physical, statistical, and engineering characteristics of the four GXs to provide risk assessment and identify potential mitigation strategies for grade crossing and trespassing incidents in Detroit, Michigan. With the information collected from geographical information systems such as Google Earth, the Federal Railway Administration (FRA) database, and the US Department of Transportation (USDOT) database, the team considered surrounding land uses, highway characteristics, distractions, and obstructions. Together, the team proposed a three-level risk assessment that begins with measures at the municipality level to advanced technological levels with SMART technology. The following report walks through the team's overall analysis and recommendations for Conrail.

2. Background Information

The high-risk grade crossings were broken down into three levels of analysis. First, the demographics of the Detroit population were considered. The breakdown of age, race, gender and average household income all served as key factors to understanding the people being served by the proposed solutions. Once the demographics were analyzed, the next step was to study the physical characteristics of each grade crossing. These were analyzed using geographical information systems such as Google Earth and Google Maps. Lastly, numerical data from the FRA database and the USDOT database were researched and interpreted. Further analysis of the numerical data revealed interesting results that detailed the conditions of both GX and trespassing incidents, such as the times, weather conditions, and presence of street lights.

2.1. Demographics of Detroit

Several aspects of Detroit's demographics were studied. Detroit's total population is 664,139, and the majority of the population consists of African Americans and individuals under the age of 18, 25-44, and 45-64.

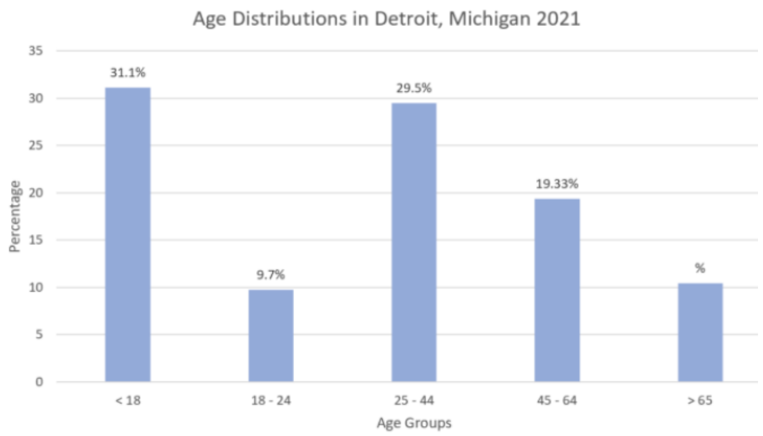

Figure 1: Age Distributions in Detroit

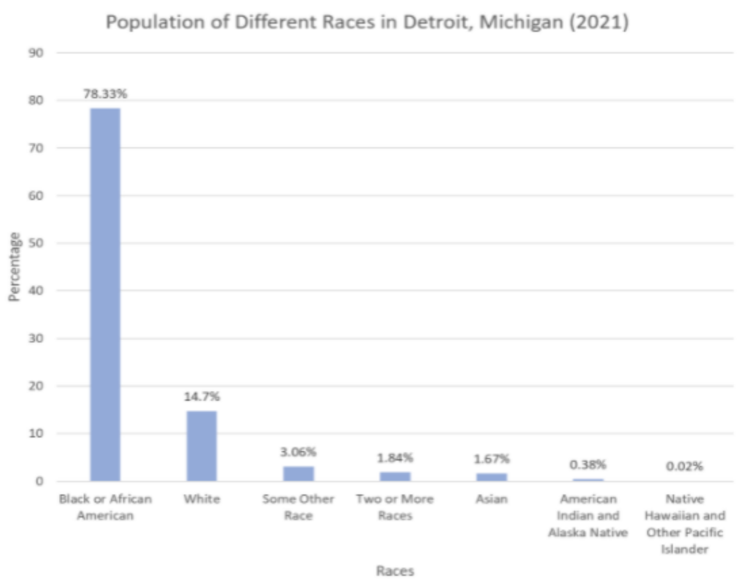

Figure 2.: Population of Different Races in Detroit

Detroit is currently listed as one of the most impoverished cities in the US, with approximately 30% of its residents living below the poverty line. In addition to poverty, the homelessness rate is highest amongst single adults from the ages of 35 to 64, at approximately 70%, and may possibly provide insight into trespassing trends. FRA data suggest that trespassing cases primarily occurred between men in their mid 40's and 50's. This can potentially be linked to the homeless population since the homelessness rate is highest in adults of these ages.

2.2. Geographic Information

Each of the high-risk grade crossings in Detroit has different attributes or factors to consider. Attributes may include the type of crossing, land uses, and existing active and passive technologies. Every crossing that will be observed is of public ownership type, meaning that the roadways are under the jurisdiction of, and maintained by, a public authority. In addition, the crossings are highway-rail grade crossings where a roadway crosses railroad tracks at the same level or grade and the type of train on these crossings are freight trains. The following sections describe the characteristics of each of the four high-risk crossings in Detroit.

2.2.1. 6-Mile Road: 511087E

The areas around the 6-Mile Road crossing are primarily classified as either two-family residential districts or intensive industrial districts.

Figure 3: Zoning Information for 6-Mile Road

Aside from the land use information, it is important to observe passive and active technologies at each grade crossing, as portrayed in Figures 4 and 5. For instance, the 6-Mile Road crossing contains advanced warning signs and pavement markings to alert motorists of a railroad crossing ahead. Furthermore, the crossing contains 2 cantilevered flashing light structures, which are large metal structures to alert motorists from a distance. These structures also hold flashing lights and gateway arms. This specific crossing has a two-quadrant gate configuration to block oncoming traffic on both sides. Located next to the gates are bells to alert pedestrians and drivers nearby when a train is approaching the crossing. In Figure 5, there is an Emergency Notification System (ENS) sign, which contains a phone number to report any problems or emergencies. One thing to note on this ENS sign is that it contains the crossing ID number, which is different for each grade crossing.

Figure 4: Signage for 6-Mile Road

Figure 5: Existing Warning Devices for 6-Mile Road

The highway speed limit is 25 miles per hour (mph) and this crossing is not regularly used by school buses. Moreover, although the crossing has industrial districts nearby, this crossing is only used by approximately 10% of trucks.

2.2.2. 8-Mile Road: 511093H

This specific crossing is surrounded by two-family residential districts and intensive industrial districts.

Figure 6: Zoning Information for 8-Mile Road

Furthermore, this crossing has advanced warning signs and pavement markings to alert motorists and pedestrians, as portrayed in Figure 7.

Figure 7: Signage for 8-Mile Road

In addition to these signs, the 8-Mile Road crossing consists of 4 cantilevered flashing lights structures, 2 on each side. Figure 8 only shows one side of the highway, the same structure is located on the opposite side as well. On each side, there are 2 gateway arms in a two-quadrat configuration. There are 8 pairs of flashing lights and 4 bells at this crossing. Similar to the previous crossing, this one also has a "Stop Here on Red" sign and an ENS sign.

Figure 8: Existing Warning Devices for 8-Mile Road

The highway speed limit is 40 miles per hour (mph) and this crossing is not regularly used by school buses. One last note is that this crossing is used by approximately 25% of trucks.

2.2.3. Central Avenue: 511945J

The Central Avenue grade crossing is primarily surrounded by intensive industrial districts and special industrial districts. One important note is that in the bottom right of Figure 9, there is a freight railyard.

Figure 9: Zoning Information for Central Avenue

As shown in Figure 10, this crossing also has advanced warning signs along with pavement markings to warn motorists. Additionally, the crossing has a low clearance sign right before the crossing, which can be seen in Figure 11. In terms of the active technologies at the crossing, there are 2 roadway gate arms, one in each lane, and there are 4 pairs of flashing lights. The crossing also has 1 bell to warn nearby pedestrians and motorists. An important note is that this specific crossing already has a train detection system in place, the Constant Warning Time system. This detection system measures train speed, direction, distance from the crossing, and the estimated train arrival time. When a predetermined estimated arrival time is reached, the warning displays at the crossing. Similar to other crossings, this crossing also has the ENS sign and the "Stop Here on Red" sign.

Figure 10: Signage for Central Avenue

Figure 11: Existing Warning Devices for Central Ave

The highway speed limit is 40 miles per hour (mph) and this crossing is regularly used by school buses. One last note is that this crossing is used by approximately 10% of trucks.

2.2.4. Lonyo Avenue: 512363H

The Lonyo Avenue grade crossing is located very close to the Central Avenue grade crossing, which is why the zoning information is very similar for both crossings. The area is surrounded by intensive industrial districts and special industrial districts.

Figure 12: Zoning Information for Lonyo Avenue

Aside from the zoning information, this crossing also has pavement markings and advance warning signs leading up to the crossing. At the crossing, there is a "Stop Here on Red" sign along with the ENS sign. The crossing also has active technologies including, 3 roadway gate arms, 6 pairs of flashing lights, and 2 bells.

Figure 13: Signage for Lonyo Avenue

Figure 14: Signage for Lonyo Avenue

Figure 15: Existing Warning Devices for Lonyo Avenue

The highway speed limit is 50 miles per hour (mph) and this crossing is regularly used by school buses. One last note is that this crossing is used by approximately 20% of trucks.

2.2.5. Crossing Angle

The grade crossing angle is another significant factor that requires analysis. The angle in which the train approaches relative to the road affects driver vision perception, which can ultimately lead to GX incidents. This is especially pertinent in non-perpendicular crossings, where the tracks on one side of the driver might be difficult to see. On the other hand, the other side of the tracks will be very easy to see. Depending on the behavior of drivers, the crossing angle can go in one of two directions. The increased visibility in one direction can counteract the poor visibility in the other direction. This would allow drivers to have more control on the road and avoid accidents. In contrast, this could also lead to risky driver behaviors because having better visibility can lead to driver overconfidence about measuring the train’s approaching position and speed. Majority of grade crossing incidents are at the fault of the driver for law breaking and improper actions at the site.

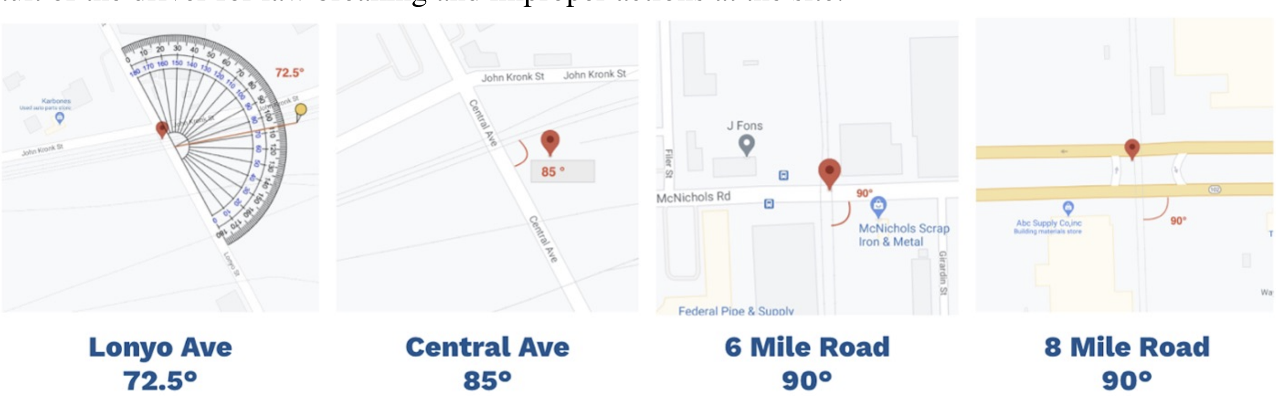

Figure 16: Crossing Angles for Detroit GXs

Figure 16 shows the crossing angles of the four Detroit GXs. The angles at each crossing were measured by using Google Maps and an online protractor. For 6 Mile Road and 8 Mile Road, the crossings are perpendicular, so drivers are able to see both sides of the track at the same level of visibility. For Lonyo Ave and Central Ave, the crossings are slightly less than 90 degrees, so there exists the possibility of judgement error for drivers. This can be further analyzed by Figure 17, which is taken from a study that depicts the ratio of the percentage of 617 gate-running crashes at a specific crossing at a specific angle with the driver and a sample of 1004 crossing angles (Cooper & Ragland, 2015). As seen in the 360-degree point of view, the crash and random sample angles are rounded to the nearest 10 degrees. The dark red ring represents a ratio of 1, and outside of the ring, the ratio steadily increases by 0.2. The blue trends represent where GX collisions have primarily occurred throughout the sample study. These trends illustrate trains that approach from the right as a greater problem than trains that approach from the left, with the lower and upper right quadrants being the highest, respectively. This graphic was utilized to form a possible assumption for the Detroit GXs. At the 90-degree mark, GX collisions occur within the ring at a ratio of 1, so they are less likely to occur since drivers have a better perception of the road and tracks. Thus, in the case of 6 Mile Road and 8 Mile Road, their perpendicular crossing angles will have less of an effect on the overall likelihood of GX incidents than non-perpendicular crossing angles. At the 85-degree mark, GX collisions break out of the ring and have a slightly higher probability of occurring at a ratio of about 1.1. At the 72.5-degree mark, GX collisions reach the highest probability of occurring on the upper right quadrant at a ratio of about 1.3. At this angle, there is a greater chance of drivers being careless and short-sighted. Of the 4 GXs, Lonyo Ave and Central Ave may need to be observed more closely in regard to their crossing angles.

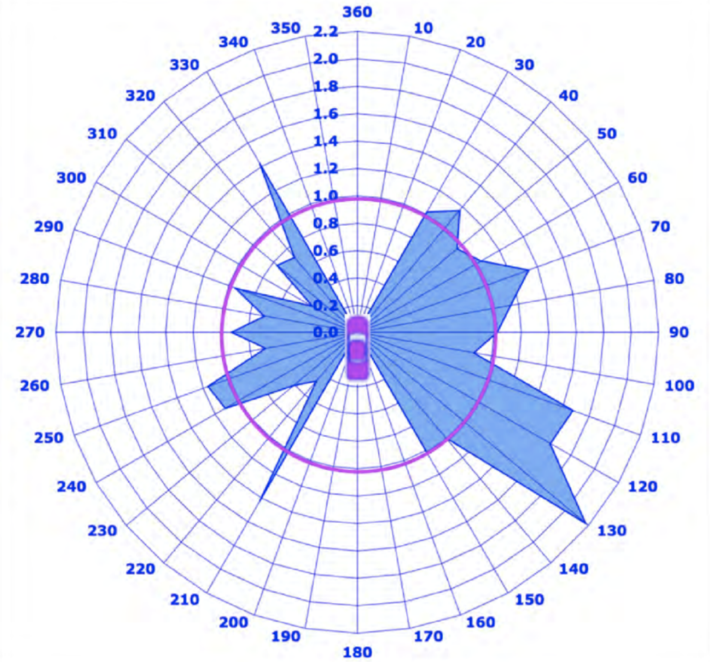

Figure 17: Ratio of Percentage of Crash Crossing Approach Angles to Percentage of Random Sample Crossing Approach Angles (Cooper & Ragland, 2015)

2.3 Federal Railway Administration Data

Through in-depth analysis and filtration of grade crossing incidents among NS, CSX, and Conrail within Detroit, Wayne County, Michigan over the last decade (2011 - 2020), several factors from the FRA database were considered: collision time intervals, weather conditions, presence of street lights, and the connection of cross warning signals with highway signals.

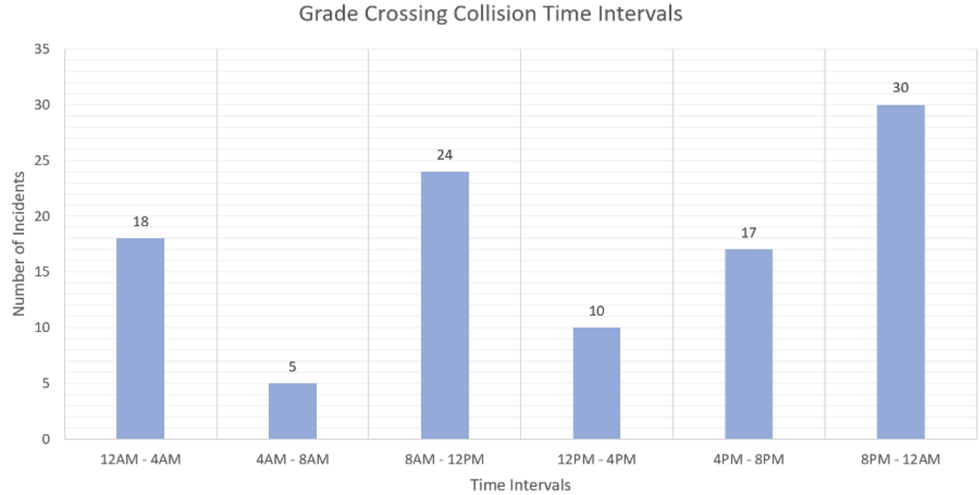

Figure 18: Grade Crossing Collision Time Intervals from 2011-2020

Figure 18 shows the grade crossing collision times over the course of one day in four-hour intervals. Overall, the GX collisions peaked at four-time intervals: 12 AM - 4 PM, 8 AM - 12 PM, 4 PM - 8 PM, and 8 PM - 12 AM. Several possible conclusions emerged from this analysis. There is an upward trend from 12 PM - 12 AM, where at the 4 PM interval, the number of incidents double from 12 PM, and at the 8 PM interval, the number of incidents triple. The rise in incidents at the 4 PM interval can possibly be attributed to evening rush hour traffic. With many people on the road, the traffic can become backed up and people can become careless and impatient. A similar occurrence can also be noted at the 8 AM interval for the morning rush hour traffic. Following into the 8 PM and 12 AM intervals, there is less visibility and driver vision perception is skewed.

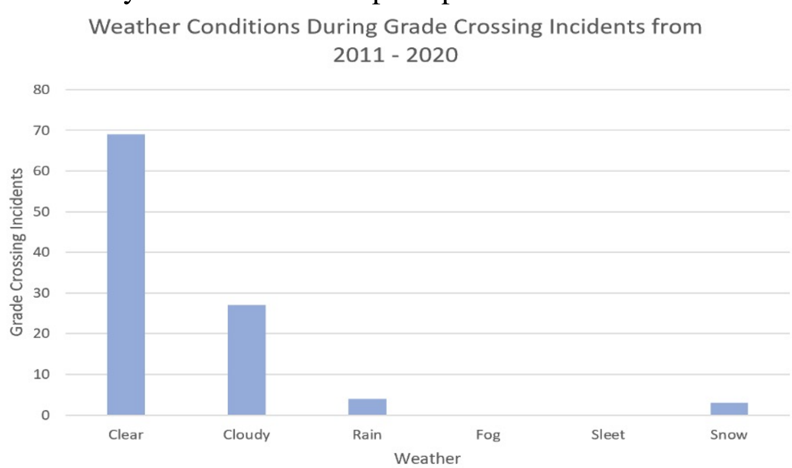

Figure 19: Weather Conditions from 2011-2020

Figure 19 shows the weather conditions during GX incidents. The majority of grade crossing incidents occurred on a clear day. One possible explanation for this could be that drivers are more careless on the road during clear weather. Drivers may feel more confident and are more likely to engage in risky driver behaviors, such as speeding. On the other hand, poor weather conditions with decreased visibility force drivers to be cautious on the road. This would explain the significantly fewer cases.

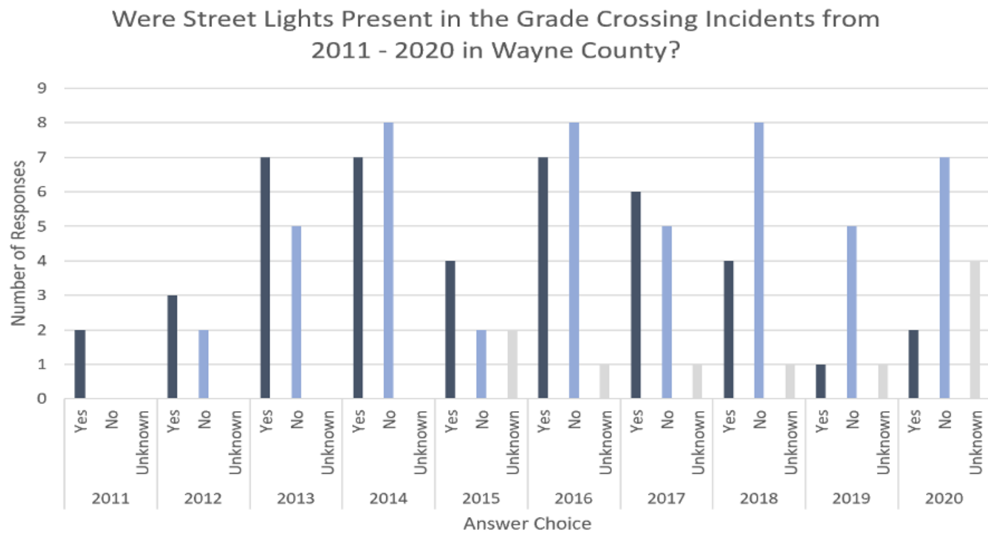

Figure 20: Presence of Street Lights from 2011-2020

Figure 20 shows the reported presence of street lights in GX incidents. There's an overall even split between the answers "yes" and "no" for the presence of street lights during the incident. Because the majority of GX collisions occur at night, sufficient street light vision becomes imperative and a significant factor to investigate in the future.

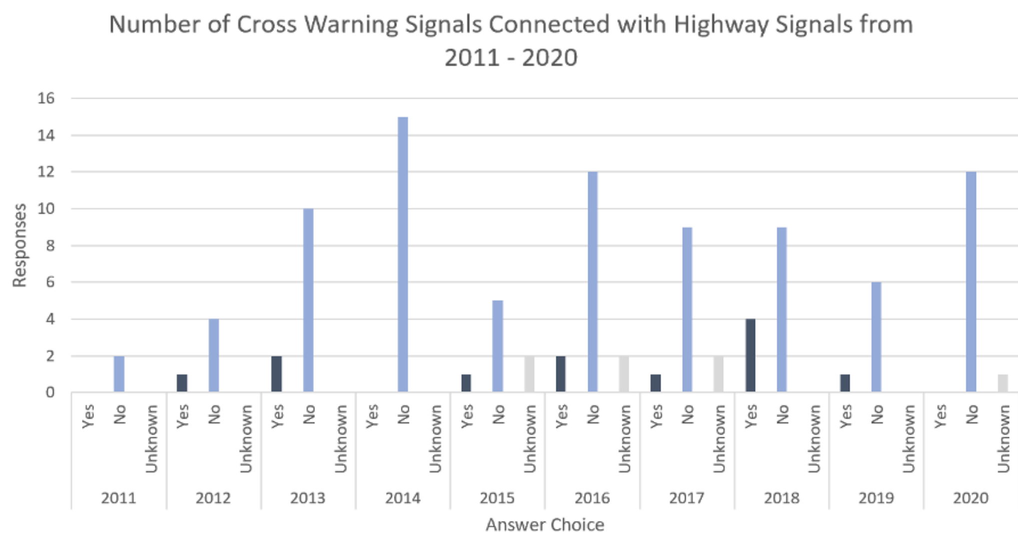

Figure 21: Presence of Cross Warning Signals from 2011-2020

Figure 21 shows the reported presence of cross warning signals being connected to highway signals. As seen in the graph, there is a clear divide between the "yes" and "no" answers, with the majority of incidents having no cross-warning signals connected with highway signals.

Sample Reports

"Driver attempted to beat the train at the Sibley Road Crossing and was hit by the oncoming train. all signals were operating as intended. No injuries were reported."

"Vehicle drove around the crossing gates in front of the train causing impact."

"Driver of vehicle going wrong way on one way street disregarded railroad signals and was struck by engine NS 9950."

Figure 22: FRA Sample Incident Reports

Figure 22 shows three different reports for which a GX incident had occurred. These three reports represent many of the types of cases that occur in the area, all of which are due to human error, negligence, and risky driver behaviors.

2.4. United States Department of Transportation Data

The different problem crossings have a variety of unique characteristics that distinguish each crossing from one another. One of the most important differentiating factors is the Average Annual Daily Traffic counts (AADT). AADT is essentially the average of all traffic on a road divided by 365 days, depicting the average traffic volume on any day of the year. This is not a perfect measurement, as certain times of the year may have more traffic than others. However, this statistic serves its purpose in giving a general overview of traffic on a road, allowing the level of traffic to be determined. Every crossing has different AADT statistics as each crossing has unique characteristics that differentiate it from other crossings.

The first AADT statistics that will be analyzed are for 8-Mile Road. The yearly statistics are visible below in Figure 23.

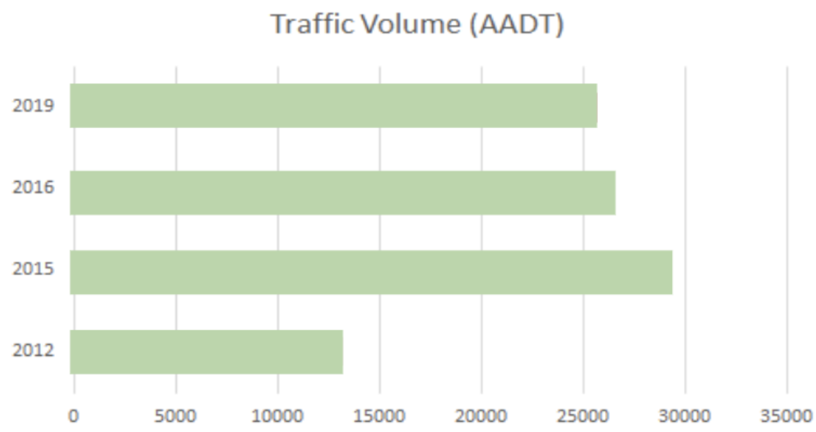

Figure 23: Annual Average Daily Traffic for the 8-Mile Road Crossing
Source: ("SEMCOG Traffic Volume Map" 2019)

8-Mile Road is a high-traffic road, as visible in the statistics above. Although no discernible trend is seen from the time periods of 2012 to 2019, it is apparent that 8-Mile Road sees a large volume of traffic. Over the course of 10 years, the AADT for this road was 30,500. This road is within county jurisdiction.

The next crossing that will be looked at is the Lonyo Avenue crossing. The yearly AADT statistics for Lonyo Ave are seen below in Figure 24.

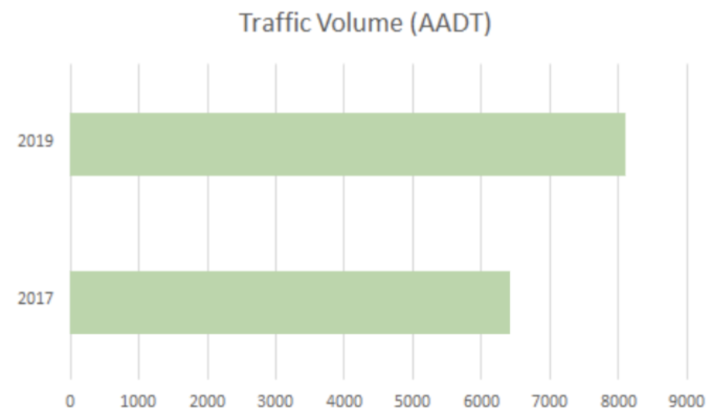

Figure 24: Annual Average Daily Traffic for the Lonyo Avenue Crossing
Source: ("SEMCOG Traffic Volume Map" 2019)

Lonyo Avenue is a lower traffic road, as seen in the low levels of traffic in the statistic above. Although the AADT values are low, they are increasing from around 6,300 in 2017 to around 8,000 in 2019, indicating more levels of traffic. This increase in AADT indicates that action must be taken at this crossing, as more vehicles on this road can lead to more accidents at Grade Crossings. Over the course of 10 years, the AADT for this road was 8,898. This road is within city jurisdiction.

The next crossing that will be looked at is the Central Avenue Crossing. The AADT statistics for this crossing are visible in Figure 25.

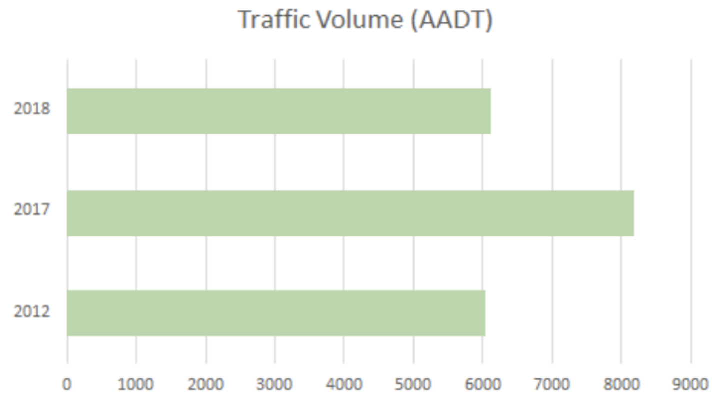

Figure 25: Annual Average Daily Traffic for the Central Avenue Crossing
Source: ("SEMCOG Traffic Volume Map" 2019)

Central Avenue, like Lonyo Avenue, is a lower traffic road, compared to the other crossings. Although there is no discernible trend, over the course of 10 years, the AADT was 11,884, indicating that there is considerable traffic on this road, even though it may seem comparatively less when compared to other crossings.

6-Mile Road is the final crossing that will be analyzed. The AADT statistics for this crossing are visible below in Figure 26.

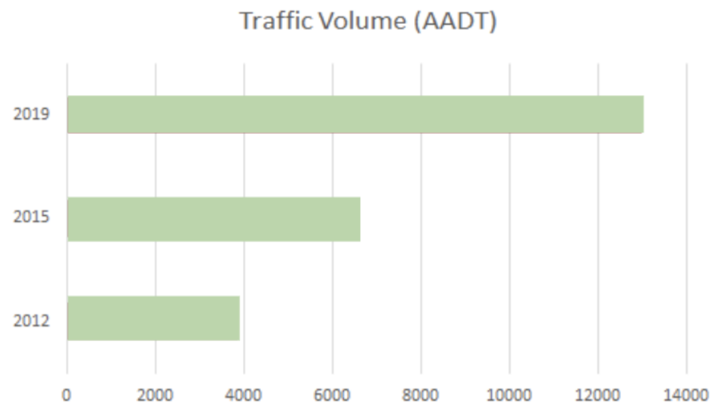

Figure 26: Annual Average Daily Traffic for the Central Avenue Crossing
Source: ("SEMCOG Traffic Volume Map" 2019)

6-Mile Road is a higher traffic road, with traffic volumes substantially increasing in the last 10 years. The average AADT over the 10-year span is 6,830 and is increasing over time. This increases the urgency to come up with solutions as crossing volumes increase.

3.1. Communicating Train Information and Location Data

In certain problems or high-volume crossings, train information systems are implemented to decrease accidents or illegal crossing activity. These systems share train crossing data with drivers or other authorized individuals. In 2016, it was found that there were 2,041 accidents involving these highway-rail crossings (Khattak & Lee, 2). It is apparent that this number of accidents must be lowered, and a clear solution is offered. In a study by the University Transportation Center for Railway Safety (UTCRS) the University of Nebraska-Lincoln, a system to inform drivers of oncoming trains is proposed. This system, the Train Occupancy Time Estimation System (TOTES), was developed to accomplish this. Using multiple forms of detection, it was determined that laser, and video imagery detectors combined with Passive infrared and ultrasonic detectors provided the most accurate automated input, with a 100 percent detection rate. However, the study proposes the implementation of Intelligent Transportation Systems (ITS) as the most favorable option to track train movements, with the communication protocol described in Figure 27.

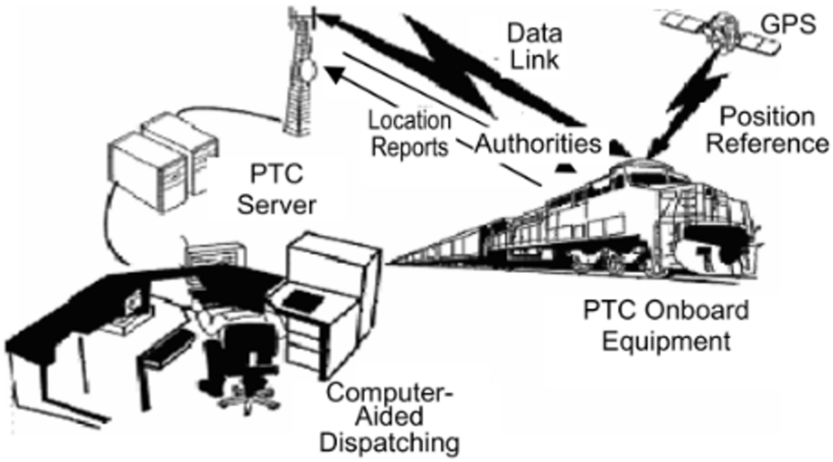

Figure 27: Intelligent Transportation Systems (ITS)
Source: (Khattak & Lee 2018)

This study proposes a unified approach with three sub-systems to accurately convey train information to drivers. The first system is Train detection, the second being detection control, and the final system using Variable Messaging Signs (VMS) to communicate train information with drivers accurately.

Depending on the data from the detection control system, the VMS displays variable information dependent on train length, speed, and distance from crossings, with separate modes for idle crossings, train approach warnings, and imminent train crossing warning. This warning system also allows the manual input of data by employees in certain survey positions, counting variables such as cars in queue, train length, and location and manually inputting these into the VMS to alert drivers. An example of a VMS is shown below in Figure 28.

Figure 28: A Sample VMS System Notifying Drivers of Crossings
Source: (Khattak & Lee 2018)

This study, conducted primarily at FRA Crossing #074406N, concluded that the application of VMS systems in conjunction with the other subsystems led to lower levels of illegal driving activity at these crossings. It was recorded that an average decrease of 24% of cars crossing marked white lines was observed, indicating that the presence of a VMS significantly changed driving patterns.

Another study of the implementation of a similar rail grade crossing monitoring system was conducted in Sugarland, Texas. This implementation primarily used a Doppler Radar-based detection system and differed from the previous source in that its primary use was to alert emergency personnel of trains blocking emergency routes instead of the public. The Doppler Radar detection system was found to be more effective than a transponder-based detection technique, the transponder system only provided location data at a success rate of 38 percent while the Doppler system successfully detected the location, speed, and length at a success rate of 100%. The Doppler system was also cheaper at a cost of between $7,500 and $10,000 per site compared to $30,000 per site for the transponder. The final system used a combination of gate detection, using a sensor to determine when gates are closed, combined with the doppler detection system.

There are three subsystems in this detection system: the field subsystem, communications subsystem, and traveler subsystem. These subsystems overlap with the functions of the previous study, with the communications subsystem including communications infrastructure which links filed detection devices with the computing and processing center. In anecdotal interviews with emergency services, this system is viewed positively. All interviewed services noted that it was useful and easy to understand. It is noted that this system in Sugarland has the potential to be extended to the general public through VMS information or highway advisory radio.

3.2. Prevention Through Vehicle Safety and Passive Measures

Actively tracking and monitoring all movements at grade crossings, of rails and vehicles, is an effective method to decrease accidents and inform both trained personnel and traffic goers as shown in the two sources above. However, it is not the only effective means to decrease accidents and inform drivers of the risks at Grade crossings. In a study by The University of Florida Transportation Research Center, using video cameras to analyze passive measures, it was found that these measures were effective in decreasing crossing incidents. This study was carried out at 3 different roads in Central Florida, Park Road, US 98, and SR 17. Park Road was the most active railroad, with an AADT of 16,100 and 19 trains per day, followed by US 98 with 3,854 AADT and 16 trains per day. The least active crossing was SR 17 an AADT of 2,592 and 10 trains per day. The cameras were equipped with sensors that detected closing gates in order to make data analysis easier. The passive technology used in this study was the QWICK KURB Crossing Channelizer, as depicted below after installation in Figure 29. These crossings were described to have the preventive measures of “Flashing lights, reflectorized gate arms and bells are the existing active warning devices at the sites” (Ko, Courage, & Wilis, 23).

Figure 29: An Installation of traffic channelizers at a crossing.
Source: (Ko, Courage, & Wilis 2003)

The QWICK KURB channelizer essentially forces traffic to stay in the designated lanes, preventing “go-arounds” where vehicles leave their lane to cross Grade crossings at unauthorized times. The QWICK KURB is different from standard traffic channelizers in that it has a raised curb along with more visible channelizers to make switching lanes for standard vehicles more difficult while keeping it accessible for emergency vehicles. It was observed that “26 violations were observed in the period before the installation of the traffic separators and only one violation was observed after the separators were installed.”. (Ko, Courage, & Wilis, 61). This one violation is deemed anecdotal and thus not significant as a gate technical issue caused them to be lowered seven minutes early, leading to a car crossing 35 seconds after realizing no train was near. It was noted that Channelizers did not help in stage 1 crossing incidents, or incidents, where the driver crossed after warning lights, were initiated but before the gates went fully down. Regardless, the implementation of these passive crossing measures has led to decreased crossing drive around crossing incidents, which is the overall purpose of these channelizers.

To decrease grade crossing attempts at unauthorized timings, however, other passive measures beyond channelizers should be considered. Channelizers, while effective at their intended task, do not cover other methods for crossing, which need to be investigated. In a report by the Institute of Transportation Engineers, standard approaches are described to make grade crossings safer. These measures are not restrictive, rather aimed to be informative to the driver and make the crossing safer for different types of vehicles. The report recommends that in tight grade crossings with a distance of 2 meters or less between the stopping point and the track there should be pre-signals to warn motorists at a distance of 50 feet away if low traffic or 75 feet if high traffic or commercial ("Preemption of Traffic Signals Near Railroad Crossings A Recommended Practice of the Institute of Transportation Engineers", 12). The report also recommends limiting the visibility of downstream signals to mitigate confusion for motorists crossing the grade crossing. A study commissioned by the FRA covers other informative measures for drivers to decrease grade crossing accidents. By analyzing grade crossings using LiDAR and drones equipped with sensors, researchers were able to determine the grade of certain crossings to provide motorists with accurate information to prevent grade crossing incidents with low ground clearance vehicles (Baron & Desilva 2019).

Trespassing, similar to grade crossing incidents, is a large category of accidents that occur on railroads that must be deterred to avoid incidents on railroad property. A study by the FRA about Trespassing Detection Systems in Pittsford, NY looks to decrease this through a security system. This system involves a combined system of a Video Camera, Infrared light, Speaker, and Motion Detector in the arrangement seen in Figure 30.

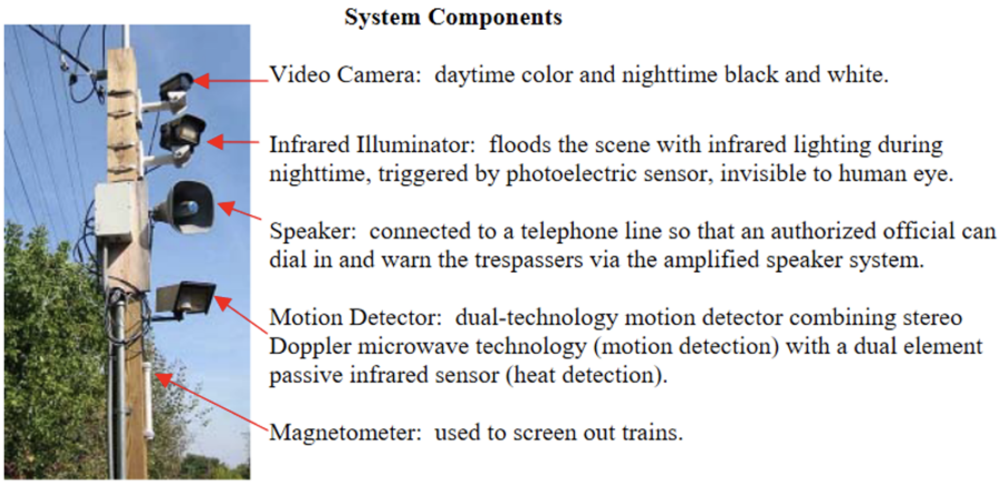

Figure 30: A sample configuration of a Railroad Security System
Source: (DaSilva, Baron & Carroll, 2006)

This system serves to identify trespassers and deter their presence or alarm local law enforcement of their presence. Out of about 3,726 alarms during the study period, about 9% were positive trespasser identification. Railroad operations triggered 28.4% of alarms, animal activity triggered 45.6% of alarms, and approximately 17% of alarms were triggered by unknown reasons not visible on camera (DaSilva, Baron & Carroll, 9). To make this system more accurate, significant efforts were taken in this study to decrease these false alarms and increase accuracy. It was explained that "After many iterations, a configuration was obtained that resulted in reducing animal-triggered alarms from over two per day to about three per month. Similarly, the range of the motion detectors was changed to minimize coverage of the canal. Train events, comprising roughly 22 percent of all events, were almost eliminated by the end of the second year by rewiring the magnetometers." (DaSilva, Baron & Carroll, 12). Through adjusting magnetometers to detect trains more effectively, and fine-tuning the detection zone for humans, false alarms were limited. Over the course of this study, 4 trespassers were saved from being struck by trains due to this system (DaSilva, Baron & Carroll,15). The system also resulted in a 50 percent reduction in trespassing events from the first year to the final year of study (DaSilva, Baron & Carroll,13). This system was estimated as having an installation cost of around $40,000, operating costs of $2,660, and maintenance costs of $5,000 per year. Although potentially costly, this study displayed the effectiveness of the system in deterring trespassers.

3.3. SMART Real-Time Computer Vision System

This is a 'smart' real-time computer vision system, using only COTS (Commercial-off-the shelf) hardware to monitor the motion of pedestrians, animals, bikers, vehicles, etc. This system constantly monitors and detects moving objects, tracks the object, and analyzes its shape and motion at a crossing. After analyzing, an active device is triggered to warn pedestrians. This monitoring system consists of six steps: (1) Object Detection, (2) Shadow Removal, (3) Tracking, (4) Classification, (5) Activity Detection, and (6) Triggering Decision (Sheikh et al., 3).

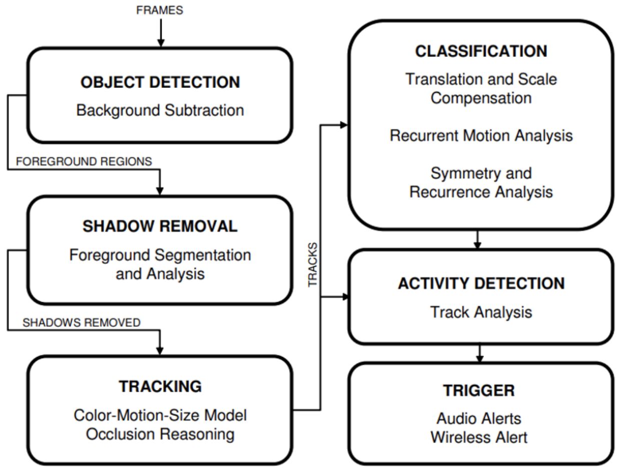

Figure 31: Components of the visual surveillance system
Source: (Sheikh et al., 2004)

Object Detection includes detecting candidate foreground pixels using pixel-wise models of color. Candidate regions are then tested for gradient-based foreground pixels at their boundaries. These two models of gradient and color are then updated based on the classification process. This approach makes it possible to detect objects with quick illumination changes and cloud shadows. Other modeling schemes often experience difficulties in dealing with shadows; however, this system uses a shadow model that makes it possible to observe shadow colors at specific points. The estimate of the shadow is then improved with time by noting that the pixel intensity is a mixture of 3 distributions: the background Gaussian; the shadow Gaussian, which has a lesser mean than the background Gaussian; and the object Gaussian, which has low weight and high variance (Sheikh et al., 3). For each pixel, another class is generated to represent shadow: thus, a pixel may be assigned to the background class, the shadow class, or any of the foreground classes.

Tracking and Classification: From the previous paragraph, it is observed that detection is performed per frame and tracking is essentially establishing correspondence between detected objects across frames. Each object is first modeled by color and spatial PDFs, a Gaussian distribution to represent the spatial position, and the color is represented by a normalized histogram. To establish this correspondence, each pixel detected in the subsequent frame votes for membership to a single model, based on its color and position, and a region corresponds to the object to which more than KP votes go. If KP pixels vote for more than two objects, it is concluded that occlusion is occurring. Using a feature vector called the 'Recurrent Motion Image,' the periodicity of the behavior of objects is observed, providing a means to distinguish between cars (with no periodicity) and humans (periodic motion of arms and legs during walking).

To monitor railroad grade crossings, there are specific surveillance requirements that need to be met. For a situation of 'interest', a specific combination of events needs to occur, the train should be approaching while a pedestrian, vehicle, or animal enters within a certain boundary of the railroad. In the system, a stationary camera is placed for surveillance, and an area can be demarcated at the time the system is set up using the GUI. The yellow boundary represents the so-called 'danger zone'. In the figure, the boxes of objects within the danger zone are red, while the boxes of objects outside the danger zone are green. The system receives two inputs, one from the traffic signal (triggered when a train approaches) along with visual input on the position of pedestrians and vehicles with respect to the danger zone. At the correct combination of events, a rule-based algorithm detects activities based on the object classification, track patterns, and the object model (Sheikh et al., 3). Speed, direction, and orientation of silhouettes, with respect to each other, provide a language in which to express events of interest. A warning setup is attached to the system, to trigger an alarm at the onset of an undesirable event. An audio alert is generated, and since the system is online, an email or message can be sent to an authorized individual. This is shown below.

Figure 32: Detecting Objects in the Danger Zone
Source: (Sheikh et al., 2004)

Testing: To measure system performance, six hours of videos were observed in two locations in Central Florida, with histories of trespasser violations. The results included 5 different videos to portray different conditions (lighting, wind, and traffic density). The table is shown below for reference.

	Duration (minutes)	Number of Interesting Objects
Data Set 1	65	85
Data Set 2	72	171
Data Set 3	80	215
Data Set 4	70	160
Data Set 5	65	94

Figure 33: Test Results to Evaluate System
Source: (Sheikh et al., 2004)

Tests were based on 3 different criteria:

1. Object correctly detected or not.
2. Tracking Performance throughout the duration.
3. Classification of the object (Person, Vehicle, or Group) correctly labeled or not and what was the incorrect label that was assigned to it.

The equations below are used to provide detection, classification and tracking results.

$$\text{Detection Accuracy} = \left(\frac{\text{Number of Correct Detection}}{\text{Total Number of Object}}\right)$$

$$\text{Tracking Accuracy} = \left(\frac{\text{Number of Completely Correct Tracks}}{\text{Number of Correct Detections}}\right)$$

$$\text{Classification Accuracy} = \left(1 - \frac{\text{Number of Correct Classifications}}{\text{Number of Correct Detections}}\right)$$

$$\text{Detection Precision} = \left(\frac{\text{Number of Correct Detections}}{\text{Total Number of Detections}}\right)$$

The figures below illustrate the results of the test study. From these results, it is clear that the system accurately detected, classified, and tracked the object. There were few instances where detection was not entirely accurate; however, that may be due to the specific data set that was tested.

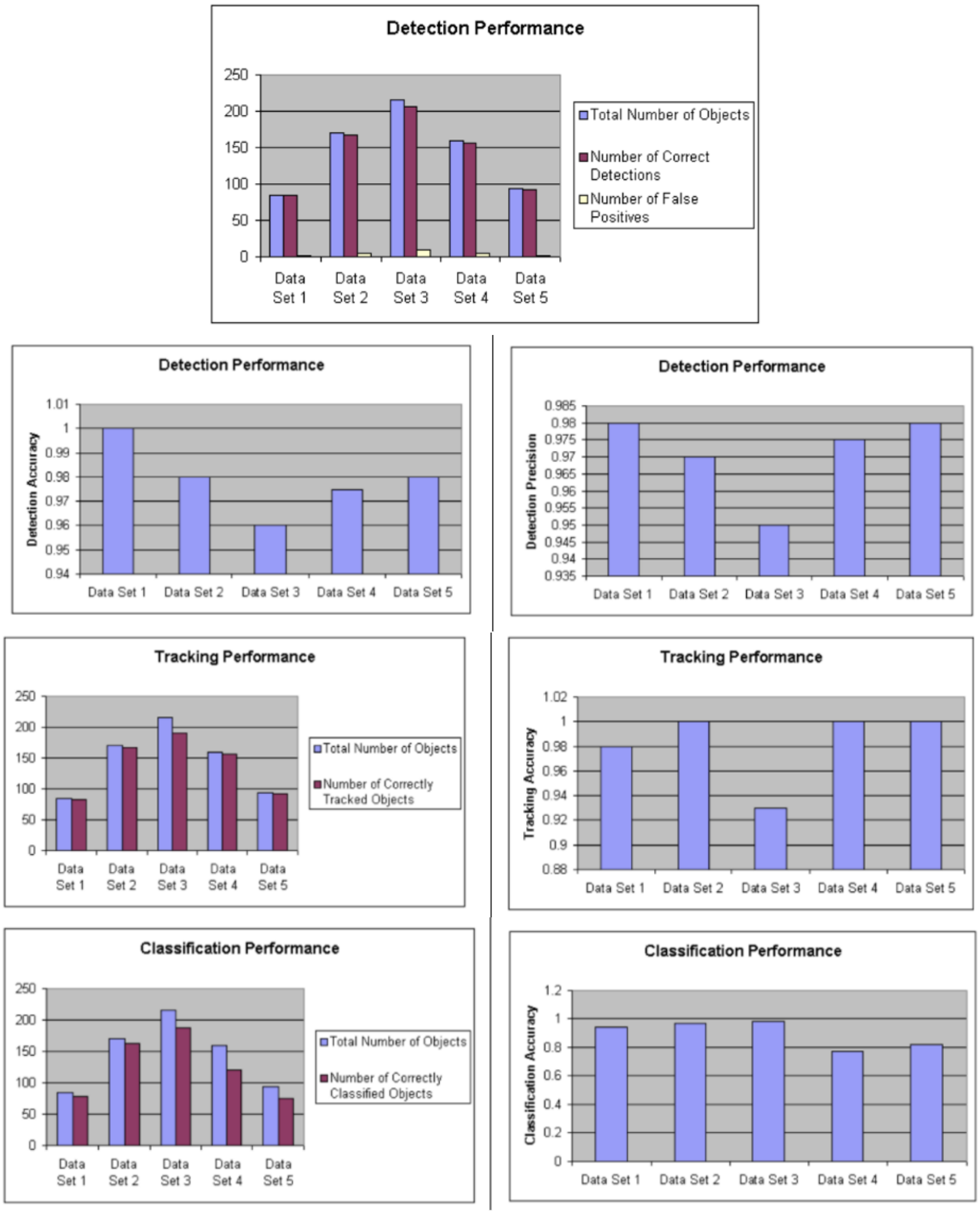

Figure 34: Study Results
Source: (Sheikh et al., 2004)

Conclusions: Video surveillance technologies similar to the one outlined above have the potential to decrease grade crossing incidents. Additionally, the monitoring system can operate 24/7 without any interruption. Aside from railroad monitoring, this specific technology can also be used for monitoring job site security and preventing vandalism. This solution may be a cost-effective solution for monitoring grade crossings because of continued improvement in computer vision algorithms, and availability of low cost, low power, high-quality video cameras, and increased computing power.

3.4. Railway Crossing Collision Avoidance System

This system is currently being implemented in Canada and it alerts vehicles close to the grade crossing as the train approaches the crossing. The train is equipped with a signaling device, which operates with the GPS receiver in the train to emit a signal to the receiver located at the crossing. This signal is sent continuously at predetermined intervals and it provides the rail vehicle's location with respect to the railway crossing (Welk, 29). Multiple emissions ensure that enough data are collected to accurately measure the train's velocity and the estimated time of arrival. Next, the railway processes data/information and transmits a signal to alarm the approaching road vehicles. This system also consists of different levels of alarm depending on how close the rail vehicle is to the crossing. These levels of alarms could also be used for severe weather conditions.

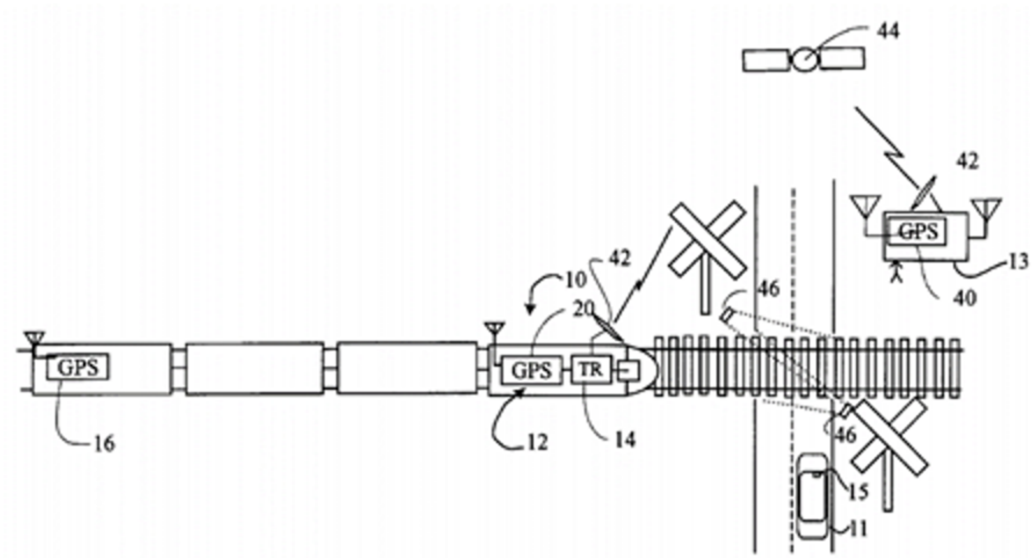

Figure 35: Railway Crossing Collision Avoidance System
Source: (Welk, 1997)

3.5. Prototype Rail Crossing Violation Warning (RCVW)
CV = Connected Vehicle Technologies (can be used to warn highway drivers of a predicted collision with an approaching train)

This system will use CV technologies to increase safety at grade crossings and it alerts equipped road vehicles approaching a highway-rail intersection of approaching railway vehicles. The primary goal of this application is to improve situational awareness of drivers approaching highway-rail intersections and to improve the flow of traffic. The RCVW has two subsystems: vehicle-based subsystems (VBS), which are installed in connected vehicles, and roadside-based subsystem (RBS), which is integrated into crossing infrastructure (David et al., 2).

Components of RCVW System:

1. Computing Platforms (CPs): Control RCVW subsystems that need to be installed in vehicles and roadside.
2. Low-Latency Wireless Communication Radios: To exchange messages between RCVW VBS and RBS subsystems.
3. Global Positioning System (GPS): Resides within VBS and RBS and it will provide accurate, real-time position and time information to each computing platform.
4. Driver Vehicle Interface (DVI): The VBS interface that provides vehicle driver violation warning and alerts

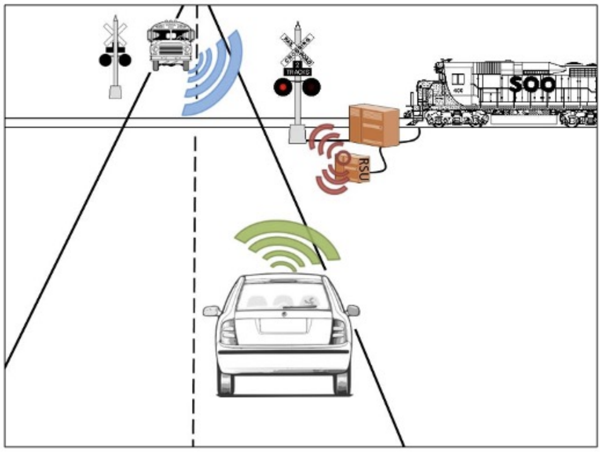

Figure 36: Rail Crossing Violation Warning System
Source: (David et al., 2017)

FRA data suggest that top causes attributed to highway-rail grade crossing crashes include distracted drivers and driver judgment errors. Existing warning devices are limited in effectiveness when a motorist’s situational awareness is compromised; they don't communicate with roadway-vehicle systems. As a solution to this problem, this system increases situational awareness by sending alerts.

3.6. Radar-based Sensor System for Smart Level Crossing Technology

Smart Level Crossing (SLC) is a system developed to increase safety and it is an example of early warning technology at grade crossings. This system can detect the arrival of a train at certain points and inform the next gate of the railroad crossing. To achieve this, the system captures train arrival time using radar sensors and sends the information to the main control, and then passes it to the Variable Messaging Sign and warning. Therefore, the SLC mechanism is very much programming-based.

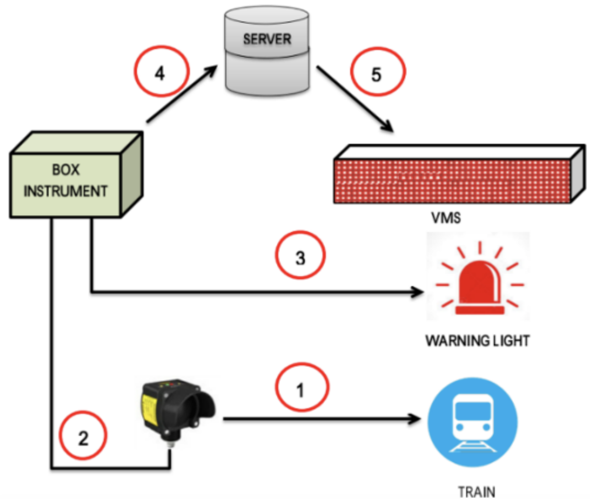

Figure 37: Design of the SLC System: (1) Radar sensors capture the picture of the train from the railway area (2) Detected train information is sent to the instrument box to process (3) The information of train exiting is also sent to the instrument box (4) Information that was processed by instrument box is then sent to warning light (5) Another subsystem sends data to the server (6) Server-side application processes and sends information to the Variable Messaging Sign *Source:* (Rosyidi et al., 2020)

Advantages of Radar Sensors include immunity from weather conditions, such as rain, fog, wind, light, humidity, and air temperature. This makes it possible for radar sensors to detect accurately in outdoor environments. In addition to this advantage, the installation and maintenance of radar sensors are safe and easy since they do not need to be mounted directly on the train track. Thus, radar sensors can be used to warn oncoming traffic at grade crossings of incoming trains.

3.7. Factors Contributing to the Safety of Level Crossings

The geographic location of a level crossing determines its safety in relation to traffic intensity, length and width along the road axis, free height and space, spatial layout, and technical implementations. An analysis in the Czech Republic, a nation in which occurrences of grade crossing accidents are disproportionately high, legislative, technical, and awareness-raising measures to reduce incidents have been proposed. Since the population in the area affects traffic flow, measures will continue to be implemented over time as the population increases. Keeping the "danger zone" a minimum of 10 meters away from general public access is a way to ensure safety, especially in urban settings.

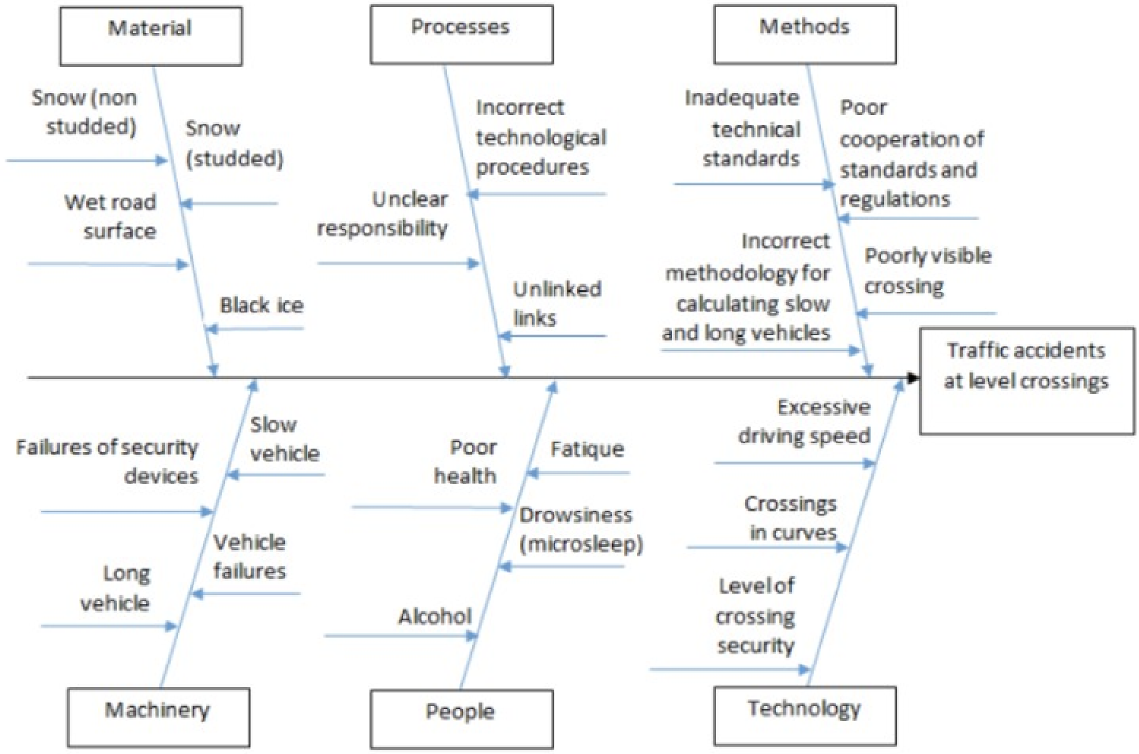

Figure 38: Risk Analysis at Level Crossings Using the Ishikawa Method

In the cause-and-effect diagram above, it was concluded that along with human factors, the number of accidents at the crossings is also caused by a relative lack of coordination in regulations and technical standards, in terms of updating legislation from the European Commission.

3.8. Object Detection

Research of the level crossings throughout Great Britain and Europe have indicated the expansion plans and ongoing projects on the land have led to accidents and fatalities and automating the operational cycle to make intelligent decisions via machine learning is a potential solution. For example, sensors, both installed inside and outside the rail lines (unable to disrupt them during maintenance periods) such as radars and CCTV systems use post-processing algorithms. These models can detect and localize obstacles without the use of a manual operator.

3.9. Intelligent Grade Crossing System

Intelligent Grade Crossing technology, which integrates a detection and railroad wayside system, can be used to mitigate the stalling of vehicles on tracks and abandoned cars that would lead to accidents. It is able to send a dynamic message sign of the speed and location of the particular train so that the driver can stop in a time-effective manner, and train operators can control the stopping of the train as it approaches the crossing. Curbing motorists with CCTVs along with a police presence that penalizes the behavior with fines will apply to the New York state area.

3.10. Active Warning Systems

A field operational test study was performed with the Minnesota Department of Transportation to determine the performance of low-cost, low-volume active systems in comparison to more costly systems. The 80-day study indicated zero failures in the system and its activation, and it was able to track daily train movements to provide efficient warning times. The low-cost system was able to locate locomotives and crossings, via GPS technology, communicate between each component wirelessly, and is powered by batteries and solar panels. As it is active, it is equipped with traffic control devices giving warning of the approach or presence of a train, in conjunction with the standard passive control signs.

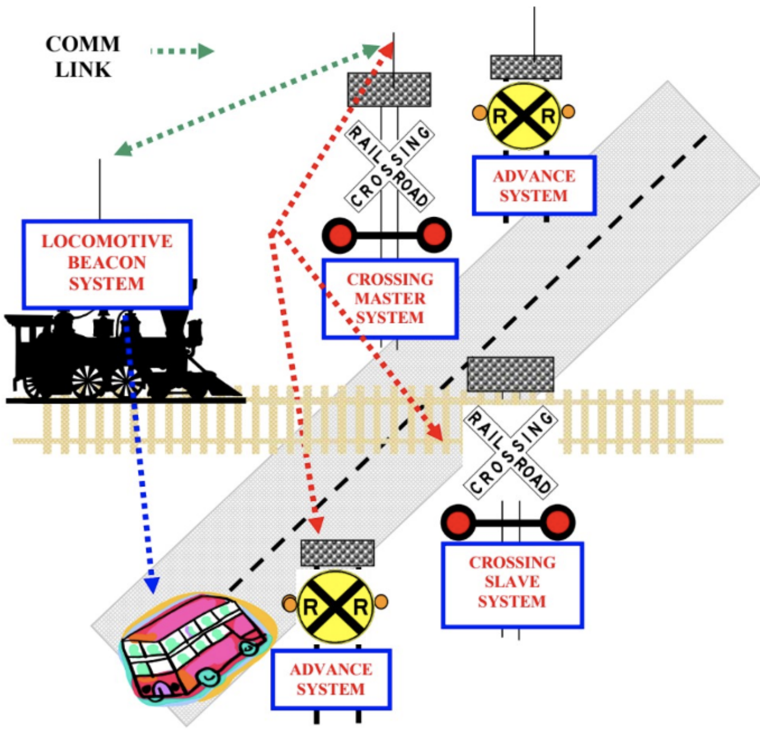

Figure 39: HRI_2000 System Diagram

Trespassing and Grade Crossing incidents are a wide group of accidents with a variety of differentiating variables, depending on crossing location, accident time, and even demographics of populations crossing these Grade Crossings and being involved in accidents. These demographics, patterns, and general data were covered and analyzed in the previous section. Using the results from the data analysis, suggestions can be made for solutions to these incidents and mitigating risk at these crossings. In the following section, specific technologies will be explored further. These technologies include active and passive solutions and Smart solutions. These technologies will then be categorized by characteristics such as implementation complexity and technological level. Finally, these technologies will be assigned to crossings based on crossing characteristics.

4.1. Active and Passive Mechanisms

The first category of technologies to limit grade crossing and trespassing incidents is Active and Passive technologies. This category is less involved and can be implemented with little monitoring, besides simple maintenance.

4.1.1. Traffic Channelizer

This technology, as discussed earlier, is a simple traffic-management system designed to limit the movement of vehicles at the approach of Grade Crossings. This is done through the separation of wider traffic lanes into narrow lanes to allow for two-way traffic or to distinctly mark certain lanes. However, in the case of Grade Crossings, this specific traffic device can be used to limit “Drive-around”, at crossings. A “Drive-around” is a traffic event in which a driver turns into the oncoming lane to drive around grade crossing gates to cross a grade crossing at unauthorized times, such as when a train is approaching.

The installation of these channelizers is simple as they are widely used by a variety of traffic agencies. The cost is minimal, and only simple maintenance such as replacing damaged traffic separators is required. Traffic Channelizers are already in use by the Michigan Department of Transportation and are available in a variety of options for specific use cases. For the purpose of limiting illegal grade crossing attempts, standard tubular markers serve this purpose best. These tubular markers, as described by the Michigan DOT “[M]ay be used effectively to divide opposing lanes of road users, divide vehicular traffic lanes when two or more lanes of moving vehicular traffic are kept open in the same direction, and to delineate the edge of a pavement drop off where space limitations do not allow the use of larger devices" ("Temporary Traffic Control", p. 607). Dividing lanes by using tubular markers, as described by the Michigan DOT, can restrict vehicles to continue in their specific lanes without entering opposing traffic lanes. Lane separators are designed to delineate traffic while being inexpensive and harmless to vehicles in the event of a collision. They are also reflectorized, allowing them to be easily visible at night. Their effectiveness at limiting traffic drive around was analyzed in a study by the University of Florida which was discussed earlier. The number of drives around events decreased at two sites from 1.1 percent of all crossings being drive around violations to .34 percent and 3.9 percent to 0 percent at the respective crossing sites during the study period, displaying their effective decrease of violations (Ko, Courage, & Wilis, 2003, p.p. 71-72). As recommended in the study, these traffic separators should be placed with a 3-foot space between individual separators in a series up to 40 feet away from larger crossings. This spacing would allow for adequate implementation of the system to effectively discourage drive-around incidents. The abundance of traffic separators, a simple installation by DOT crews, and effectiveness at decreasing grade crossing drive around incidents indicates that traffic channelizers can be a low-cost, low maintenance tool as a primary defense to limit traffic violations at these crossings. A sample standard channelizer used by the Michigan Department of Transportation is displayed in Figure 40.

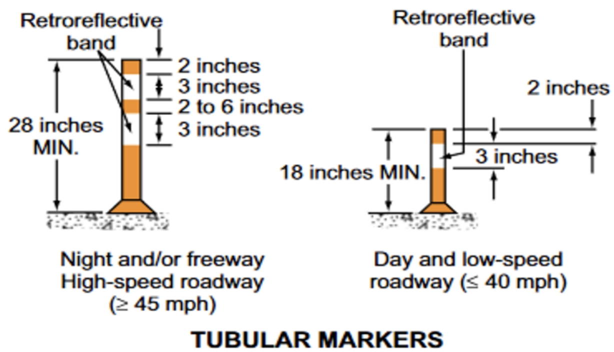

Figure 40: Standard specification tubular markers in use by the Michigan DOT
Source: (Michigan MUTCD., 2011)

4.1.2. 4-Quadrant Gates

There are two types of gate configurations that can be utilized at gated crossings: four-quadrant gates and others. Four-quadrant gates block all entrances and exits when activated and lowered. Other configurations include two-quadrant and three-quadrant gates. These gates only cover lanes in which incoming traffic is approaching, leaving the exits open. This increases the likelihood of cars driving around the gates colliding with an oncoming train. About 97.28% of crashes have occurred at crossings that were unequipped with four-quadrant gates, and only 2.72% of crashes occurred at those that were equipped. While this might be true, there are several other factors that also need to be considered before concluding four-quadrant gates as useful grade crossing technologies. The demographics of the area or amount of traffic volume are a few instances. Some issues that can potentially occur through the use of 4-quadrant gates include vehicles getting trapped and gate damage. If a vehicle is unable to fully pass through all the gates, it has either the choice of remaining within the barriers and colliding with the train or breaking through the plastic gates. Thus, 4-quadrant gates might not always be a viable option.

4.2. Smart Technology

The second and much larger category of technologies to limit grade crossing and trespassing incidents is SMART technologies. These technologies involve systems that connect with one another through new and existing communication protocols to monitor and improve grade crossing safety. This category of technology differs from the previous section in that it involves significantly more investment, monitoring, and maintenance during its installation and throughout its use cycle. Different types of prospective technologies within this category will be explored further in this section.

4.2.1 Automated Railroad Infrastructure Security System

The Automated Railroad Infrastructure Security System can provide an all-in-one solution for the issue of trespassing at or near Grade Crossings. This specific system is made up of five different components which work in conjunction to detect trespassers on railway property. This system, as described earlier, is a proven effective trespasser deterrent. In the study commissioned by the FRA, a 50 percent reduction in trespasser activity was observed during the four-year study period (DaSilva, Baron & Carroll, 2006, p. 13). The system uses cameras, motion sensors, infrared lights, and magnetometers to detect trespassing activity and a loudspeaker connected to a security monitoring service to deter trespassers. If a loudspeaker announcement does not deter the trespasser, the police are called, which is also announced on the loudspeaker. In total, this unit costs around $40,000 for installation, $2,660 annually for operating costs, and $5,000 annually for maintenance in 2006 dollars.

This system does require constant monitoring, with a security officer on standby to warn trespassers through the loudspeaker integrated into the security system. The original study, conducted on a railroad bridge in Pittsford, New York, was examined in a rural, low-population environment, so significant differences are expected should this technology be deployed in Detroit. In a densely populated region such as Detroit, these devices pose a risk of being damaged or stolen, so the value of these devices must be taken into account when determining prospective areas of application. Placing signs, warning of the surveillance and security system, is recommended as a preliminary deterrent, driving potential trespassers away before having to use the other security features. Additionally, the final stage of determent, calling local authorities, may put pressure on the Detroit Police force, keeping them from responding to other calls. To remedy this, a dedicated stand-by police or security team can be prepared to serve as a final line of deterrence for trespassers, to be called when all other options are exhausted. This could potentially increase the cost of application for the security system, and must also be taken into account when determining an effective location for deployment. This will be discussed further in the specific crossing recommendations section.

4.2.2. Grade Crossing Integrated Railroad Radar

An Integrated Railroad Radar placed at Grade Crossings can serve to detect approaching trains and work with other vehicle alerting systems to alert traffic. The main purpose of this system is to provide vehicles with specific, detailed information on approaching trains to deter illegal crossings during these times. Current level crossing signals provide undetailed and inconsistent information to drivers, with actual train distances from crossings varying greatly. The method of detection currently relies on electromagnetic triggers, with no speed, time of arrival, or direction information, the only information provided is that a train is arriving soon. This variation and unreliability of existing infrastructure can contribute to illegal grade crossings by limiting the information given to vehicle drivers. Drivers can become irritated, or unaware of the approaching danger, and attempt to cross in illegal ways. Integrated Railroad Radars can provide all of the required information to drivers, and mitigate these illegal crossings.

Railroad radar works by using radar technology to detect approaching trains. The information it gathers is detailed and specific. This technology can provide information on the speed of the approaching train, direction, and time of arrival information. This helps to communicate detailed information to drivers. This system, when paired with existing current technology, is extremely reliable at providing this information. In a study of a radar-based detection system in Sugarland, Texas, 100 percent of all train movements in the study were accurately detected with the radar system (Goolsby, Vickich, & Voigt, p.4). This accurate detection rate is very high, and although it was recorded in ideal conditions, such a high detection rate translates to high detection rates in the real world as well. As mentioned before, the system costs between $7,500 and $10,000 for initial installation at a site. It has a 25-year operational life, with total lifecycle operating costs being around $255,220 estimated at the time of the study in 2003. This number has likely increased since then. In terms of installation, a distance of at least 50 feet from a grade crossing and around 3,500 feet from another radar is recommended (Goolsby, Vickich, & Voigt, p.9). This limits the application of railroad radar to railroad lines with significant free space on both sides of the crossing. This rules out certain crossings from the application of this radar. Due to the cost of application, it is recommended that such a system is only applied at higher volume crossings which could effectively use the detailed information provided by the radar system. Specific crossing recommendations will be covered in the following sections. A sample component of the radar detection system is depicted below in Figure 41.

Although the radar is an important tool in gathering train data, the data are meaningless if not conveyed to drivers in some way. This can be done through a variety of ways, such as a traveler information station operating on an AM frequency, like many other publicly operated traveler information systems. This would, however, require significant investment and maintenance, making other, less infrastructure-heavy information conveying technologies, which will be covered below.

Figure 41: A Sample of a radar detection system
Source: (Goolsby, Vickich, & Voigt, 2003

4.2.3. Positive Train Control (PTC) Equipment

Positive train control equipment, otherwise abbreviated as PTC equipment is a new technology embedded within train communication systems to provide detailed information as well as certain remote control and safety abilities. PTC equipment reduces trains from overspeeding, running lights, and other safety precautions, making train operations safer. Essentially, this equipment safeguards train operation from human error-related factors. This system, and the data gathered from the computers and communication equipment within it, can also be used to make grade crossings safer, through similar methods as Grade crossing integrated radar. PTC equipment can provide the real-time location, speed, and direction information from directly onboard the train, providing information more accurately than other external systems such as radar. PTC equipment differs from other listed technologies in that PTC communication equipment is installed on individual locomotives instead of externally. However, PTC equipment still requires certain infrastructure to be built to communicate signals from locomotives, such as antennas and communications towers. This provides certain benefits, in that data gathered are significantly more detailed and precise, and that many more crossings can benefit from train information instead of certain crossings with technology installed.

PTC's variety of uses beyond just grade crossing safety makes it a beneficial technology to install on all locomotives. Installation for PTC equipment is expensive, with installation figures being between $70,000 and $100,000 per locomotive (Stagl 2012). This cost is different from the cost to install certain technologies as every train that passes through the crossing must have this equipment equipped. In the Rail Safety Improvement Act of 2008, all freight that involves hazardous cargo which traveled on passenger rail had to have PTC equipment enabled to operate on passenger tracks. A deadline of December 30, 2020, was given to all railways that fell under this category to comply and implement PTC equipment ("Positive Train Control" 2020). Although this law does not cover all rail lines, forcing a large number of locomotives to enable PTC equipment, it opens the ability for PTC to be used on other rail lines as well. Currently, Norfolk Southern Railroad has PTC equipment active on 8,000 miles of track ("Positive Train Control" 2020). CSX has indicated that it will enable Positive train control on 16,000 miles of track (“Programs and Initiatives.”). Although not enabled across the entire network, both railroads have an expansive network of tracks utilizing PTC equipment, indicating that a large portion of the locomotive fleet has this technology-enabled. This makes the implementation of this technology easier as it is already an industry standard and installed on many existing trains. The usage of PTC would simply have to be enabled on specific crossings and rail lines.

Positive Train Control equipment can be used with existing systems to make grade crossings safer, preventing illegal crossings. Filling a similar role to railroad radars, they can provide train speed, direction, and arrival time information to be conveyed to drivers through a driver information system. This system works best in this specific context when paired with a driver information system. In addition, this system can also work with vehicle detection at grade crossings to prevent collisions at grade crossing collisions. Once a vehicle is detected at a grade crossing, crossing illegally, the train itself can be notified through its onboard PTC equipment and stopped before an accident occurs. In this way, PTC equipment can be used to both inform drivers of oncoming train information and inform the train of potential collisions at grade crossings.

4.2.4. Variable Messaging Signs (VMS) Technology

Variable Messaging signs are a smart technology designed to work hand in hand with other train and vehicle detection systems. On their own, variable message signs are not exceptionally useful in making grade crossings safer from trespassing or grade crossing accidents. In this use case, they can be used to warn approaching vehicles of a grade crossing ahead, but do not serve any purpose that standard railroad signs do not cover, apart from being more readable and noticeable. This slight advantage, however, does not justify an investment in this technology. Variable Messaging Signs become much more useful comparatively when paired with advanced railroads detection systems like a railroad detection radar and PTC equipment.

To work effectively, Variable Messaging Signs must work within a detection system to effectively convey information. This system has three components: the data collection component, the data processing component, and the data communication component. Data collection is done through technology such as Positive Train Control equipment and Railroad Radar. These data are sent to a data processing center, where the raw data from these collection components are processed and translated into messages to be displayed to vehicles through VMS technology. The raw data, such as speed and direction are sent to data processing centers, which use these raw data to calculate information that is more useful to drivers, like distance from the crossing, and time until the train reaches the grade crossing, which is reflected in messages on variable messaging signs. Variable messaging signs are very effective in alerting drivers of potential risks and decreasing the number of illegal grade crossings. In a study where variable messaging signs were connected to radar detection systems; it was found that illegal crossings decreased by 24% (Khattak & Lee 2018). These signs effectively communicated train information to motorists, allowing motorists to correctly understand the risk of crossing, leading to a decrease in illegal crossings.

Variable messaging signs come in a variety of configurations and can be permanent installations or temporary installations at grade crossings. Temporary installations may be preferable as they can be deployed faster, with permanent installations being recommended if significant improvements in grade crossing statistics are seen. Variable messaging signs typically cost around $17,000 per sign, with an operational life of 10 years. These mobile signs are typically placed on trailers and able to be moved to other locations. The Michigan Department of Transportation currently uses multiple variable messaging boards, which can be used for the purpose of limiting grade crossing incidents as well. Known as “Portable Changeable Message Boards”, these signs provide traffic direction and give motorists other informational messages. Combined with detection and analysis measures, these variable messaging signs can effectively communicate vital information such as train distance and arrival time to accurately portray the risk of crossing and decrease illegal crossings.

5. Recommendation Process

The diversity in technology that can be applied to limit grade crossing and trespassing incidents requires a specific structure and categorization during application to ensure time and resources are not wasted. The order of implementation is depicted below in Figure 42.

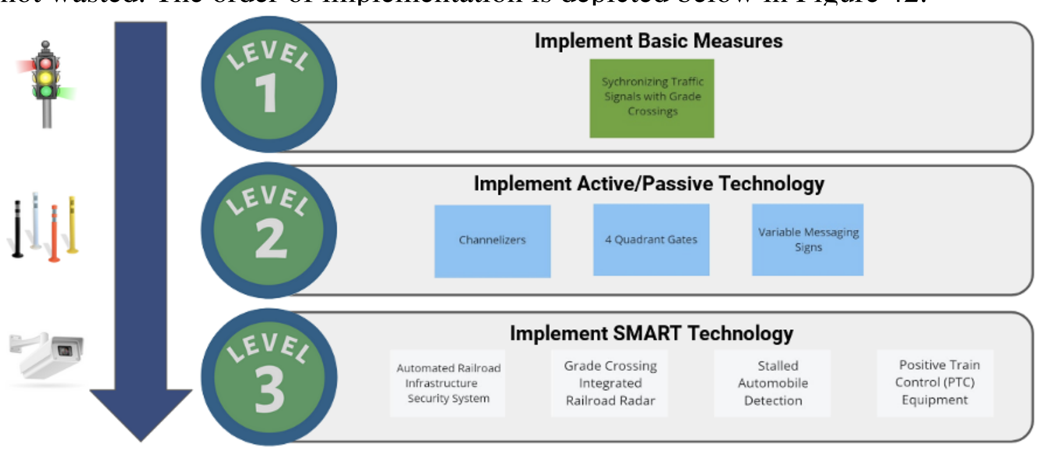

Figure 42: Recommendation Process

The purpose of these levels is to allow categorization based on the technological level of the solution. Select technologies that have been recommended are categorized based on this. However, these categories are not comprehensive and are made to be expanded based on new technologies and requirements. The level of technological complexity increases as the levels advance, with the first stage being the most technologically simple and the last being the most technologically complex. Some technological measures included in the chart are not discussed in detail in this report as they may not be recommended for the specific crossings due to certain crossing characteristics which will be discussed further. The first step in the implementation sequence is to implement basic measures, such as synchronizing traffic signals with grade crossings. This is a simple measure because it does not require any real infrastructure installation or further investment; it is something simple that can be done within a short timeframe by the municipality and yield positive results. Level 1 is recommended for every crossing due to its basic nature. There is no real negative impact in applying level 1 measures to crossings. Level 2 measures involve investment and infrastructure development are more technologically advanced than level 1 measures. They may be more time-consuming to implement than level 1 measures, however, they can still be implemented relatively quickly. However, they are still simple and not as specific as level 3 measures. Level 3 measures involve significant investment, infrastructure, and can be time-consuming to implement. They may involve continued investment to run vital services, and often involve more complex communications between elements of the crossing and the train. Level 2 and Level 3 measures present unique challenges and specific elements of each crossing must be examined before recommending a technology from these levels to improve these crossings and limit trespassing and grade crossing incidents.

5.1. Recommendations for Detroit Crossings

Each crossing covered has specific characteristics that differentiate it from other crossings. With unique challenges presented to each crossing, specific measures must be taken to address these issues. Because of this, generally, a single solution cannot be applied to all crossings, unless it is a level 1 measure simple enough to be implemented on a large scale. Out of all of the prospective measures, the first measure that must be implemented, regardless of crossing, is to synchronize traffic signals for vehicles with grade crossing signs. This measure is required, as a majority of railroad crossing signals are not connected with traffic signals, as seen earlier in Figure 21. This disconnect can itself lead to grade crossing incidents, causing confusion to motorists, in certain cases where a traffic signal may be green while a train is approaching. This is a simple fix, pairing the two signals in a way such that both the crossing signal and traffic light reflect the same message. This should be done at all crossings looked at in this report as a universal measure, as it should involve no new infrastructure or investment, and only requires the pairing of signals. As for the rest of the mitigation measures, only specific technologies should be implemented at specific crossings due to unique crossing characteristics. This is covered in more detail in the next sections.

5.1.1. 8-Mile Road: 511093H

The safety of the 8-Mile Road crossing can be greatly improved by implementing certain measures. 8-Mile Road is a major East to West arterial road in Detroit and is part of a series of numbered roads going East to West, serving as major routes in the Detroit and Wayne County area. This specific crossing has an AADT of 30,500 making it the highest volume road out of all of the crossings analyzed ("SEMCOG Traffic Volume Map" 2019). The road is also very wide, ranging from 4 to 5 lanes throughout its length.

Because of the width and the high-speed volume of traffic of 8-Mile Road, traffic channelizers are recommended as the first passive technology to be implemented at the grade crossing. Previously, as was mentioned, a majority of crossing incidents occur on clear days and the ability to speed may be a contributing factor in grade crossing incidents. Traffic channelizers would limit the ability of vehicles to speed through the crossing or drive around the barriers as cars would be confined to their lanes and forced to drive more cautiously. As recommended by that study, these should be placed in a series between 20 and 40 feet leading up to the crossing. By controlling driver behavior by forcing vehicles to stay within lanes, fewer illegal crossings are expected due to limited movement. After this, more advanced technologies should be implemented from mitigation measure level 3. The first of these measures should be the Automated Railroad Infrastructure Security System. This is due to the fact that this is a high-volume road in close proximity to businesses and restaurants. As examined before, the homeless population of Detroit is particularly high, and the age distribution of the homeless population closely matches that of individuals involved in trespassing incidents. Because of this, the Automated Railroad Infrastructure Security System can provide benefit to this crossing through its deterrence systems. The location of this crossing in a populated region, with businesses on either side, increases the potential of trespassing activity due to the high population of this specific area. The volume of traffic across this crossing also justifies the implementation cost of the security system, as it does have a higher chance of trespassing activity than other, more remote crossings.

As 8-Mile Road is a major, high-traffic road in Detroit, the potential of stalled vehicles on tracks is higher at this crossing location. This can potentially cause grade crossing incidents with the collision of trains with stalled vehicles. For this reason, Stalled Automobile Detection, a Level 3 measure, is recommended at this crossing. This smart technology would notify approaching trains of potential collisions, making this grade crossing safer.

The final Level 3 technology that is recommended to be implemented at the 8-Mile Road crossing is Positive Train Control Equipment. As mentioned earlier, this technology is not meant to be specifically installed at crossings, however, it can be mandated to be activated on certain rail lines.

The 8-Mile Road crossing would benefit from PTC equipment by allowing it to work with the other Level 3 technologies being suggested, to make this high volume crossing one of the safest in Detroit. PTC equipment would allow trains to be aware of trespassers detected from the Automated Railroad Infrastructure Security System, preventing potentially fatal accidents. Additionally, PTC equipment would communicate with the stalled vehicle sensor to prevent similar collisions from occurring. PTC equipment would give trains much more information at this particular high-volume crossing, allowing trains to cross 8-Mile Road well aware of any potential incidents or accidents.

5.1.2. Lonyo Avenue: 512363H

The Lonyo Avenue Crossing can be made safer through the implementation of certain measures from Level 2 and Level 3. Lonyo Avenue is a smaller, 2-lane road. This road has an AADT of 8,898, making it a lower traffic volume crossing ("SEMCOG Traffic Volume Map" 2019). A distinguishing feature about this crossing is the number of traffic signals before and after the grade crossing. Although Level 1 measures should be applied to every crossing, synchronizing traffic signals with crossing signals, there should be special emphasis placed on this crossing as it has many signals, which can confuse drivers at the crossing, and potentially lead to Grade Crossing incidents.

As Lonyo Avenue is a lower volume crossing, with many traffic signals potentially confusing vehicular traffic, crossing times information should be made easily understandable for motorists. This can be done through the implementation of the Level 2 technology the Variable Messaging Sign and the Level 3 Technology the Grade Crossing Integrated Railroad Radar. The Grade Crossing Railroad Radar, as explained earlier, can detect approaching trains and record speed, direction, and calculate the time from the crossing. This system would work with the Variable Messaging Sign to display train arrival information to vehicles. This system would clear up motorist confusion on the status of a crossing by spelling out the specific relevant information of the approaching train. If traffic signals are conflicting with the Grade Crossing Signals, motorists can rely on the Variable Messaging Sign to provide accurate and detailed information on approaching trains, eliminating any confusion, and decreasing grade crossing incidents caused by driver confusion.

In addition to Railroad Radar, another Level 3 technology that is recommended to be utilized at this crossing is Positive Train Control Technology. Out of the four crossings analyzed, this is the only crossing with PTC technology-enabled, allowing for a variety of train information to be provided for potential use. Although the technology is active at this crossing, the information gathered from this technology is not used to limit Grade Crossing Accidents. By pairing the information gathered from the PTC equipment with the railroad radar and VMS system, drivers can be provided with detailed information to make crossing statuses clearer. PTC equipment from trains can also be paired with traffic signals, to make crossings synchronized, and made safer.

5.1.3. 6-Mile Road: 511087E

The Stalled Automobile detection technology can be implemented in the 6-Mile Road crossing, with sensors detecting potential oncoming traffic in the event of a train passing. The grade crossing is near a residential and industrial area, and the grade crossing consists of a cantilever signal, flashing lights, and an advanced warning sign. It is situated on a four-lane road, on which traffic has been steadily increasing over the past three years With a combination of loop detectors and video-based sensors, the SMART technology device detects if vehicles are stalled on tracks or unable to exit the crossing, and sends a signal to the locomotive engineer to stop the train before it reaches the highway-rail intersection.

Currently, there are no highway monitoring devices such as photo/video recording or vehicle presence detection, or CCTV technology. It is a four-lane road in which traffic flow has been steadily increasing, indicating that the land uses have been adjusting as well as the population in the area. The Level 1 measures already implemented in the crossing (2 cantilevered structures, flashing lights, pavement markings) will not be effective enough in mitigating collisions over time if the trend of increasing traffic volume continues. Therefore, implementation of Level 3 measures is necessary. The active system can be used in conjunction with PTC equipment to provide real-time information to operators in advance warning of a train approaching. Sensors and object detection devices can be installed inside or on the rail lines and may disrupt the rail system during installation and maintenance. When processing the information from sensing systems such as stalled automobile detection, the environment at the level crossing has to be taken into account, especially if the surrounding area is complex and dynamic with growing vegetation. Alternatively, radar and CCTV devices with deep learning capabilities can classify obstacles and calculate speed, range, and direction from sensors.

5.1.4. Central Ave: 511945J

The Central Ave crossing is a relatively smaller highway consisting of three lanes in a residential and industrial area. The existing Level 1 measures include an advanced warning sign, pavement markings, and flashing lights, along with other signage and a bell. It has the lowest train flow of the four crossings, at one train per week on average, so active and more complex measures may not be as necessary to ensure the safety of motorists and pedestrians; there is no discernable trend in traffic counts from 2012-2018. However, the highway is regularly used by school buses and a more complex, passive system can be implemented to better mitigate the risk of collisions and manage traffic flow.

Transit signal priority can be implemented as a Level 1 Measure to adjust traffic signals ahead of the crossing during the event that the train is approaching the railroad. Early green lights can slow down traffic by shortening the length of the green around times of train passages so that traffic flow is lighter and the risk of collisions and accidents is decreased. Synchronizing traffic signals with grade crossings, especially since the Central Ave crossing is near an intersection with lights, is a basic measure to give priority timing to transit operations. Since the train flow for Central Ave is low, this basic measure is cost-effective and minimizes the impact on local traffic. However, shifting to more advanced SMART technology devices can further minimize risk, at the cost of installation and maintenance for such active devices.

6. Further Research and Conclusions

Given the analysis of the physical characteristics, traffic counts, land uses, and existing safety measures of the four high-risk Detroit grade crossings, further research may be needed to determine the most appropriate technological solutions. City and county plans for land usage over the course of twenty to forty years in the future can give insight into how each district will allot its land commercially, as it will indicate potential new businesses and real estate properties that will increase the population and traffic volume in the area. This will inevitably require the implementation of active measures to mitigate risks in case the collision rate disproportionately rises.

Other considerations for research include the population profile, specifically in regards to the homeless population near high-risk grade crossings, and analysis of other metropolitan areas. This will give insight into trespassing incidents and ways to target the demographic, via signage and other passive measures, protect pedestrians from passing trains, and strictly enforce trespassing laws through penalization with fines. Metrics can be used to predict trespassing incidents given the profile of a particular location, and the specific times that incidents are most likely to occur. Similarly, comparing Detroit's characteristics with another city as well as its grade cross and trespass risk mitigation strategies would be a possible study for further research.

Based on the latest and most available research, Detroit grade crossings should follow three main levels of protection. Each level increases in technological scope and capacity: the first at the municipality view with synchronizing traffic signals with the grade crossings; the second on the roadways with active and passive technologies; the third from a computerized view. These steps should be followed and observed gradually until the most effective and cost-efficient solution(s) is determined. The incorporation of existing and SMART technologies into Detroit's safety protocols will be able to reshape its grade cross landscapes and promote a progressive future for its citizens.

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FINAL REPORT

for

Conrail Risk Mitigation Project: Gloucester City GX's

Advisor: Dr. Christie Nelson
Mentors: Dr. John Betak
Michael White
Group Leader: Hanks Flanagan
Group Members: Madeleine Ferguson
Lucas Hall
Andy Yang

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Executive Summary

This report is intended to supplement the proposal of the development of Glassboro-Camden Line in Southern New Jersey. Specifically of interest is the portion of the corridor within Gloucester City limits. The proposed additions include dedicated light-rail commuter track and track-speed upgrades for existing freight-only operations, which include liquefied natural gas transport as well as other hazardous materials. With the planned addition of the Gloucester City Station, significant risks, both inherent and indirect, are expected. The combination of hazardous freight products, passenger population, and higher speeds present several considerations that require attention in the planning and development stages of the proposal.

A high-level overview of the eleven grad-crossings through Gloucester City is provided with specific interest in the three crossings that immediately surround the proposed station. Google Earth is used primarily to identify apparent deficiencies in existing protective infrastructure and devices. These areas are highly residential and currently experience infrequent, low-speed freight crossings. In the future, these will present higher speeds, shorter intervals, and significantly more "souls-on-board". It is determined that many of these crossings should benefit from low-cost, low-maintenance addition of passive solutions such as pedestrian barriers, improved signage, and segregation of rail and community activities.

The crossings specifically associated with the Gloucester City Station required closer inspection and an on-site survey was undertaken. In addition to the concerns and solutions above, these grade crossings will experience significantly higher pedestrian and vehicular traffic, naturally. The proposed configuration of the single-side station and moderate park-and-ride opposite the tracks should prompt special attention to pedestrian and traveler walk-ways and segregation. Several potential improvements were identified, such as dis-ambiguation of sidewalks, roadways, and grade-crossing perimeters. Additionally, non-square roadway intersections, and parallel throughways should be considered as potential risks, even though not directly within the grade crossings. While these may be outside of the Conrail's scope, coordination with NJDOT and responsible local authorities is recommended. The existing right of way (ROW) should also be confirmed, since it currently includes a residential roadway, and a gas valve access station.

Research regarding local demographics and projections provided some insights into the future makeup of this region, though it must also be considered that the addition of commuter

services may have a coupled relationship to these. The identified risks above were considered during the literature review phase, in which potential solutions are proposed. These include methods with varying cost, complexity, and technology-readiness, and should be further explored for suitability in this application. Both passive and active measures provided are intended to enhance detection and protection for the motoring public as well as rail operators. Recommendations for future iterations of the project include ensuring (Internet-of-Things) IoT-ready infrastructures are in place to be easily integrated with changing technologies. Specifically, positive train control (PTC) can provide a platform for several other technologies to be interfaced.

Introduction

Grade crossings (GX) present intrinsic risk in any scenario, where rail traffic intersects vehicular and pedestrian throughways "at-grade". This investigation explores a stretch of rail in the Gloucester County region of South-Western NJ, which is currently operated by Conrail. A proposed station between Market Street and Monmouth Street in Gloucester City presents additional considerations to be explored. A parallel line of track is planned for dedicated light-rail commuter operations in addition to the existing freight-only usage. Further, track-speed upgrades in the corridor are proposed. These plans increase the both the likelihood and the potential impact of a grade-crossing incident and prompt close inspection. Research regarding risks present at all GX's will be supplemented by data collection on the specific target area. Location demographics, utility configurations, and ground-level observations should provide the necessary resources to determine which aspects require the greatest attention for assessing the risk associated with the project. The top-level concerns are two-fold.

First, with passenger traffic set to increase, pedestrian and vehicular traffic near the proposed station will cause a greater risk of impact accidents and trespassing incidents in the immediate vicinity. Regular crossing of track by both foot and car can be expected as travelers arrive at and depart the station. Prior research indicates that persons will often diverge from prescribed crossing lanes and infrastructure in an effort to save time, which leads to occupation of unintended spaces outside of the prescribed GX. Since the rail lines are at-grade throughout the intersection, preventing foot traffic in unauthorized areas can prove difficult. Though parking may ultimately be offered on either or both sides of the station, two-way travelers will inherently need to cross the tracks on one of the legs of their commute, most likely on the return trip.

The second concern regards the nature of the existing freight traffic that operates in the region. Liquefied Natural Gas (LNG) will be a common transport on this section of track, which presents risks that have been considered as part of operational reviews of such hazardous materials transport. However, with the increases in traffic, the potential impact of an incident requires re-examination of any prior assessment. While the likelihood of impact even may only raise slightly, the potential loss-of-life is significantly enhanced. For natural gas to exist in its liquid state, it must be supercooled under significant pressure. Typical LNG container tanks are pressurized up to 600 times its natural state. When exposed to atmospheric temperature and pressure, LNG will rapidly vaporize. In the event of a breach, the gas will quickly evaporate resulting in a highly combustible, and localized fuel source. Any method of spark ignition could result in an explosion with the potential to cause a mass-casualty event consuming several city blocks. Further, LNG fires are difficult to extinguish by traditional means, and will typically burn until all fuel is exhausted.

After identifying these intrinsic and extrinsic risk sources, potential methods of mitigation will be explored. Existing techniques include passive and active measures which can be controlled autonomously. The rail industry at-large has dedicated resources to minimize such risk throughout history, resulting in federal and local government regulations, restrictions, and requirements at crossings based on materials transported, passenger access, rail speed, and cross-traffic speed. Here, emerging smart technologies are investigated for suitability for this specific application. These are various methods that exploit advanced communication techniques, radar detection, and signaling capabilities, specifically with an IoT approach. A combination of existing, low-cost solutions such as four-way barriers, advanced signaling, signage, defined pedestrian barriers, and high-impact rated bollards paired with appropriate advanced technologies should provide substantially decreased risk, though it can never be eliminated.

Background

The area of interest we are considering is the Gloucester City Station and Gloucester city area. In particular, we were concerned about three streets that intersect with the proposed Gloucester City Station in 2025: Monmouth Street, Cumberland Street, and Market Street. The locations of the streets are shown in Figure 1 below.

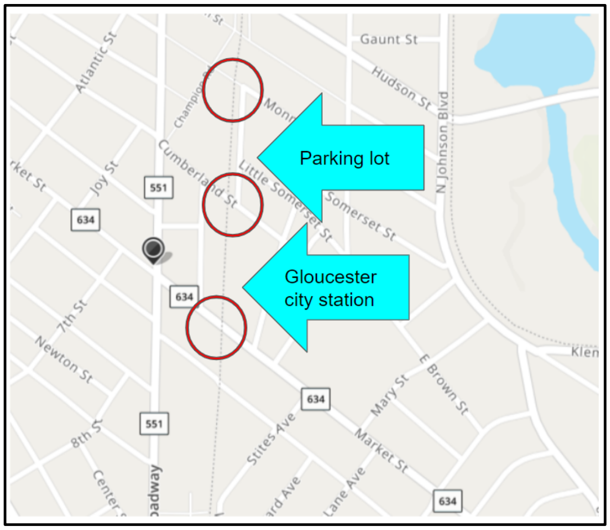


Figure 1

These locations are residential in nature, and as a result, a need for increased safety measures is required for the proposed Gloucester City Station. According to 2019 Census Data, the estimated population of Gloucester City is 11,219. The population is forecasted to remain relatively stable, decreasing by 0.13% from 2015 to 2045 ("County and Municipal-Level Forecasts, 2015-2045" 2). By considering the different age brackets, shown in Figure 2, we see that Gloucester City has a younger population compared to National Averages. For example, Note the 2.1% difference in the under 5 years old subpopulation.

Age Group	Number	Percent	National Avg
Under 5 Years	930	8.2%	6.1
5 to 9 Years	845	7.4%	6.3
10 to 14 Years	823	7.2%	6.4
15 to 19 Years	708	6.2%	6.7
20 to 24 Years	524	4.6%	6.9
25 to 34 Years	1,710	15.1%	13.7
35 to 44 Years	1,767	15.6%	12.6
45 to 54 Years	1,322	11.6%	13.2
55 to 59 Years	729	6.4%	6.7
60 to 64 Years	742	6.5%	6.1
65 to 74 Years	640	5.6%	8.9
75 to 84 Years	431	3.8%	4.4
85 Years and Over	186	1.6%	1.9

Figure 2

In terms of employment, there is a predicted 16.6% decrease in employment from 2000-2025 (*Year 2025 County & Municipal Population & Employment Forecasts* 17). However, with potentially lasting impacts of COVID-19 we expect there to be a larger decrease than originally anticipated twenty years ago. This may lead to residents seeking employment outside of the city and making use of the new station. In addition, it is pertinent to understand growing industries and occupations. This may help to predict new businesses that will operate in close proximity to the Gloucester City Station. For Camden county as a whole, the industries with highest projected employment growth are management of companies at 25.8%, utility at 22.6%, and construction at 17.6% increase. Comparatively, the occupations with highest projected growth are home health aides at 31.9%, construction trade workers at 15.4%, and construction and extraction occupations at 14.5% ("Data Reports" 3). Furthermore, according to the New Jersey Department of Transportation, there were 7,121 incidents of car crashes in Gloucester City. And according to the Federal Railroad Administration, there was one trespassing related injury in the past 10 years which occurred last year and no trespassing death.

Problem Statement

Research suggests that grade crossing incidents are expected to increase with the increase in rail traffic (Fleming et al. 5). With plans for the development of Gloucester City Station, there will be an increased risk for community members. Reasons for this increased risk include a second line as well as parking lots. As the vast majority of grade crossing crashes can be attributed to poor judgement, new technology can help to prevent future incidents.

The purpose of this project is to understand the unique challenges surrounding GX safety in Gloucester City and propose relevant solutions. The extent of this project is limited to the three grade crossings immediately next to Gloucester City Station and the corresponding parking lot: Market Street, Cumberland Street, and Monmouth Street. This information leads us to our research question: What are the most effective and economically feasible SMART technologies to mitigate current and future risks associated with Market, Cumberland, and Monmouth Street GX's?

Literature Review

Consistent improvements to grade crossing safety technology offer solutions to risky locations and high numbers of accidents. Technologies can be categorized into different categories including detection, protection, and a combination of both. Several options will be summarized.

<u>Protection</u>

This section will inspect technologies with the intent to protect against incidents. Many items in this section may be considered "low-tech", but still offer attractive safety solutions.

LightGuard Systems

Many grade crossings have gates and signs warning of an approaching train however accidents still occur. This is important to note as the Gloucester City Station proposal includes plans for quad gates at the three grade crossings identified in this paper. Simply put, there may still be products that will minimize accidents at these grade crossings. The first option is lights, which is a great way to capture attention. This may be especially useful in quiet zones or poorly lit areas. LightGuard Systems offers LED lights embedded into the pavement (Figure 3).

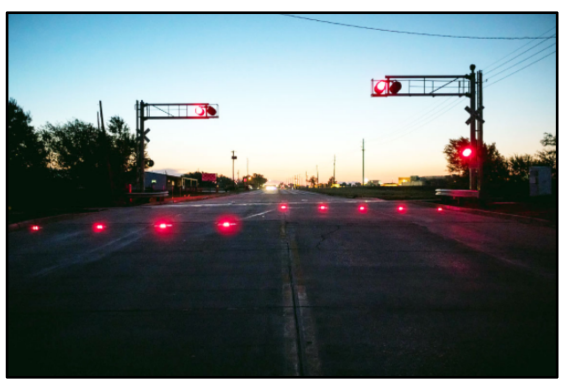


Figure 3

The LightStar™ 9X LED in-roadway warning light fixtures are placed along the GX where vehicles must stop. Lights begin to flash as the train is incoming, flashes intermittently as the train crosses, and turns off when safe for the cars to cross ("TraxAlert™ Advanced Grade Crossing IRWL Warning Light System" 16). One light with a baseplate is $700, although more expensive models are modeled to be snowplow resistant. LightGuard Systems offers a 3-year warranty and claims that maintenance is low at 10% of initial cost. Although this company does not offer installation, typical costs are between 1.5 and 2 times the cost of materials. Finally, these lights may be powered through either AC or solar ("TraxAlert™ Advanced Grade Crossing IRWL Warning Light System" 16).

Flexible Traffic Separators

Another potential solution that was considered are flexible traffic separators to be placed in between the roads. An example is shown in Figure 4, although there are many different options that are sold by many different companies.

Figure 4

What these intend to do is to discourage motorists from violating the warning gates between when the train arrives and after it departs. It does this by deterring motorists from driving to the other lane to make it to the other side before the train arrives. According to a report done by the Florida Department of Transportation, it was previously observed that 25 motorists drove around the gates prior to the period of installing the traffic separation devices. After installation, it was observed that only 1 motorist attempted to drive around the gates. This is a statistically significant result and shows that this could be an effective deterrence (Ko, Byungkon, et al. 8). Another issue that this might help with is the delineation between the roads as well as between the GX crossing and the road.

This could be an effective option, but there are a few variables that must be considered, and hopefully, the next group that takes on this project can take these variables into consideration when coming up with a solution. First, a sturdier traffic separator might be needed to make sure this is an effective solution. There have been incidences where these separators have been destroyed or damaged because drivers purposely or accidentally impact or drive over these barriers. Another variable is the potential costs associated with these flexible traffic separators. Because there are a number of manufacturers which produce such a product, the lifecycle costs as well as the projected reliability of such devices must be taken into consideration.

Signal-Tech

With the installation of a parking lot, we can anticipate increased foot traffic across the tracks to the commuters' cars and therefore must consider safety solutions with pedestrians in mind. There are unique challenges for pedestrian safety compared to vehicles. For instance, a pedestrian will be able to ignore safety signals more easily than vehicles. Additionally, for highly residential areas with children, like Gloucester City, it is essential that people know when it is safe to cross and when it is not. In particular, we note a problem when a second train is approaching. With, the proposed addition of a second rail, this is a relevant issue to consider. Without updated information, a pedestrian may assume that once the first train has gone by it is safe to cross. LED railroad crossings signs can display messages for pedestrians such as "another train coming" ("LED Preemptive Railroad Crossing Safety Signs" 9). Signal-Tech carries LED blank out signs with various messages. An example is shown in Figure 5, although various styles of text are available as well.

Figure 5

An estimated price for one of these signs is $4,350. Further, they come equipped with fail-safe photocells. Other options to help pedestrians understand that there is a second train coming is switching voices for audio messages between trains. Switching between a masculine and feminine voice for the two pieces of information can help pedestrians to make this distinction ("Railroads tap technology to reduce accidents at crossings" 12).

Another strategy for pedestrian safety is broadcasting warning messages to individuals' cell phones. With improvements in detection and monitoring as previously discussed, variable warning messages can be displayed within apps. Information may include the amount of time until the train arrives and from what direction it will be coming (Chen and Hsiao 1). The app TravelSafely functions much like Waze in that it gathers information from users' locations. TravelSafely sends warning messages to both pedestrians and drivers ("TravelSafely" 15). Although this app does not specifically advertise GX specific warnings and is still in beta testing at the time of this paper, this application is a step in the right direction to provide individual users with variable messages on their phones.

Detection and Protection

The final section of this literature review is reserved for technologies with the capacity to both detect an anomaly and use that information to prevent an issue.

Artificial Intelligence

Advanced image detection through Artificial Intelligence (AI) helps in a variety of situations, and in many ways outperforms comparable radar-based solutions. This is possible through high quality cameras which are low power and low cost becoming more ubiquitous (Sheikh et al. 14). Image recognition through deep learning models can both detect and classify as well as track objects and people at grade crossings. For example, real-time analysis can classify a moving object as a pedestrian and track suspicious or risky behavior (Fayyaz and Johnson 4). There are several different researchers and organizations creating AI software. For instance, Nokia's SpaceTime solutions are trialing in Japan and will work at remote sites with limited connectivity. Using conventional railroad crossing cameras, real-time analysis can help to identify unauthorized entries to facilities ("Nokia and Japanese rail operator, Odakyu Electric Railway, collaborate on AI-based railroad crossing safety trials" 10). AI can also help to detect when a dangerous object is on the track. For systems with video footage, image detection will trigger an alarm if one of many instances occur, including a blocked lens.

LiDAR

LiDAR, which stands for light detection and ranging technology, was developed by FRA RD&T. The system sits in between the two tracks on the side of the GX, as depicted in Figure 6. The LiDAR system itself is shown in Figure 7. This object detection product can detect trespassers, pedestrians, vehicles, and other objects that pass the crossing. Their object detection has an accuracy of 4.5". As it sits between two tracks, it is designed to be durable, and we may therefore infer it would be resistant to some vandalism as well. This durability leads to a reduced overall cost lifecycle. The system is integrated into the existing GX technology giving it the ability to control gates and lights as needed ("Grade Crossing Monitoring" 7).

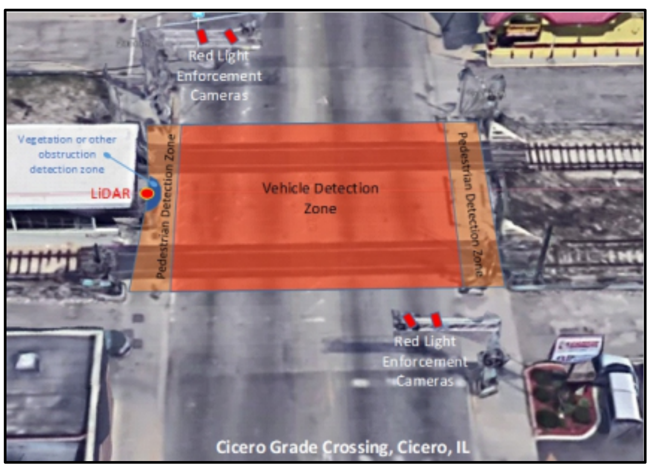


Figure 6


Figure 7

Not only is technology available to monitor the grade crossings, but the trains themselves. Most notably is PTC (positive train control systems) which can sound a horn if the locomotive engineer does not ("Railroads tap technology to reduce accidents at crossings" 12). Additionally, PTC introduces communication between the GX protection and the train. "The system will provide a warning to the locomotive engineer if the safety apparatus at a crossing malfunctions, such as a gate arm not operating properly" ("Railroads tap technology to reduce accidents at crossings" 12).

Radar-based Sensor System

The Center of Technology for System and Infrastructure of Transportation and Agency for the Assessment and Application of Technology--each an entity of Indonesia--collaborated to publish *The Development of Radar-based Sensor System for Smart Level Crossing Technology* (13). This technical report proposes an effective solution for mitigating GX incidents at level crossings. The following paragraphs will discuss the system overview, component specifications, system testing results, and key takeaways. All major information regarding this proposed SMART tech is provided from the technical report.

The solution is a radar-based sensor system that provides both protection and detection. Key hardware and software components that constitute the system include a radar, Arduino board, mechanical gate, warning lights, warning speakers, and a variable messaging system (VMS). These components are shown in Figure 8.

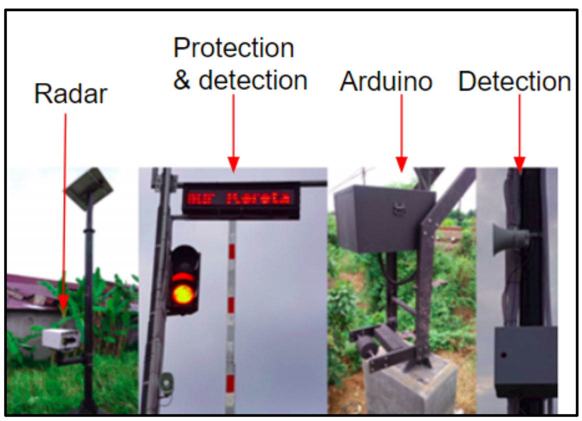


Figure 8

The core of the system is programming based, such that data from the sensor (radar) may be transferred to a microcontroller responsible for activating protection and detection responses (Rosyidi 13). This system may be understood through three levels of analysis with each level increasing in detail. Level one--the most basic level--is described using three main categories in the following order: system input, data processing, and system output. Level two: sensor, communication system, micro-controller, and protection/detection response. Level three: radar, Arduino board/coding, gate, warning lights, warning speaker, and VMS. Analysis of each level provides a framework to understanding the big picture and detailed functionality of this system. Figure 9 illustrates each level.

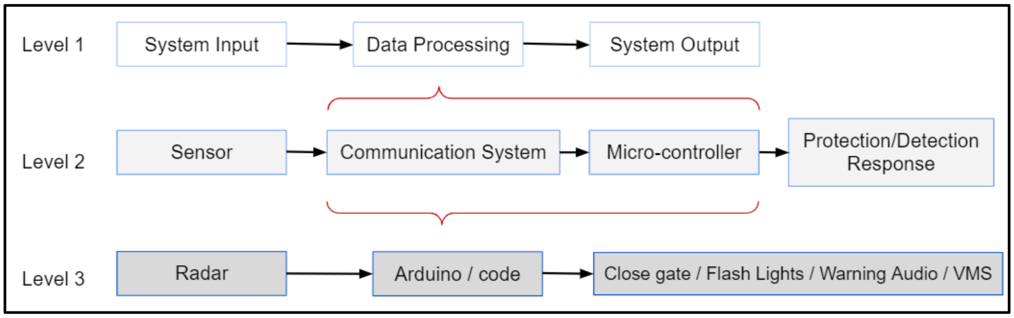


Figure 9

The radar detects an oncoming train at a desired distance. Data containing information of the oncoming train are transferred from the radar to a microcontroller via a communication system. An Arduino board programmed with the appropriate code serves as the communication system and microcontroller. The microcontroller signals a protection and detection response through closing the gate, signaling warning lights, audio, and warning messages at the GX. Component hardware and software specifications will now be discussed.

The system is integrated with an R-Gage Radar Sensor manufactured by Banner Engineering. This radar emits a high-frequency radio wave. An oncoming train reflects this radio wave back to the radar antenna, indicating train presence. Minimum and maximum sensing distances are 2 and 26 yards--a desired measuring point can be set between these distances (QT50R). An adjustable sensing field allows the radar to ignore targets beyond the set measuring point, increasing accuracy, and decreasing the probability of detecting non-train targets. Wind, rain, snow, humidity, fog, and varying air temperatures do not affect sensing functions. Additionally, rugged housing allows the radar to withstand harsh environments. This component is small and easy to install due to its flexible mounting capability.

An Arduino functions as the data processing unit. This component is an open-source platform, meaning the code which dictates its responses can be modified at any time. Arduinos are designed to maximize the ease of configuring both hardware and software. The code used to program the Arduino to the desired protection and detection response is shown in Figure 10.

```
Radar sensor capture image of train
if (sensorState1 == LOW&sensorState2 == LOW) then
    Train detected
    Data send to box instrument
end if
Box instrument distribute data
if ArduinoDataReceived == True then
    Sending data to warning light
    Sending data to the server
end if
Server processing the data
Information send to VMS
```

Figure 10

Gate, warning lights, speaker, and VMS specifications are not provided in the report. Gates and warning lights already exist at the Cumberland, Monmouth, and Market Street GX's thus a warning speaker and VMS can be integrated. In conclusion of the main system specifications, each component is durable and reliable. The Arduino has a lifespan of 5-15 years. Inspection frequency of the radar-based system is at least 5 years. Additionally, each component is easy to install. The system cost estimation is $987. Prices for each component were taken from prices online, as the report does not include this information. Cost estimation is provided in Figure 11. System testing results are discussed next.

Cost

- Radar **$797**
- Arduino **$15**
- Relay Module **$5**
- VMS ~**$100**
- Warning speaker **$70**

Total: **$987**

Figure 11

The experimental environment is a level GX at which two tracks run parallel. A radar-based system--comprised of Level 3 components--is installed on each track. Three radars are used in each system to provide system input. On tracks 1 and 2, two radars are placed before the oncoming train passes the GX, with the third placed after the GX. For track 1, both radars placed before the GX are denoted by SM-1A and SM-1B, and the radar after the GX by SL-1. Track 2:

SM-2A, SM-2B, and SL-2 (Rosyidi 13). Trains travel along each track in opposite directions. A schematic of this environment and setup is shown in Figure 12.

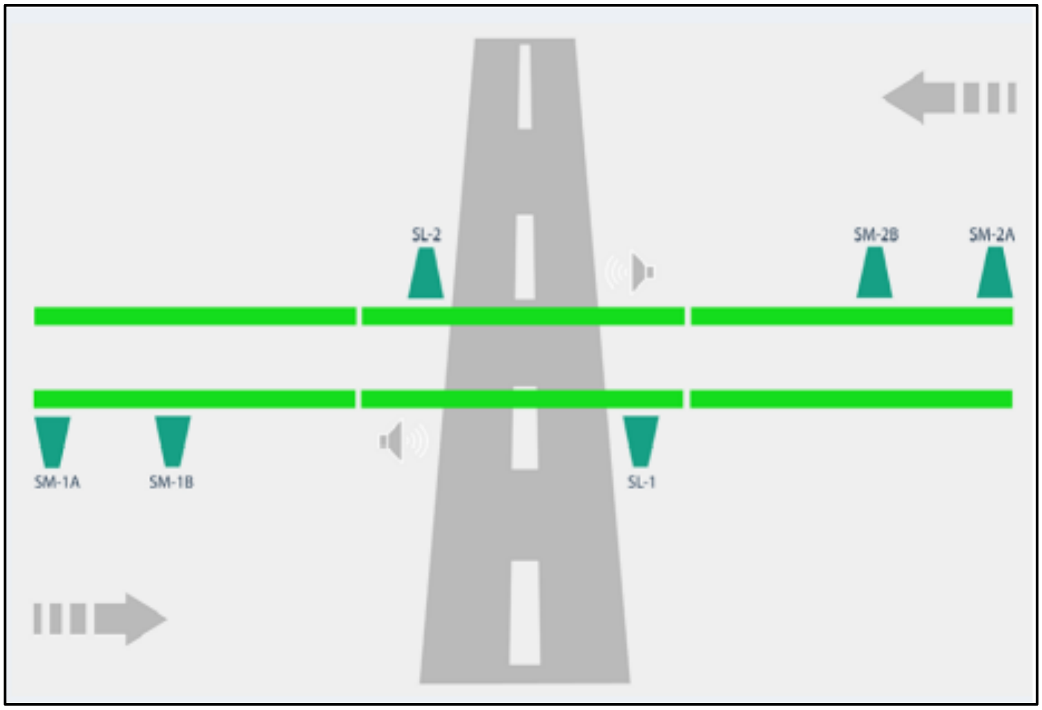


Figure 12

The system input, data processing, and system output results were tested for each track as trains crossed the GX. The number of trials is not provided in the report. Figure 13 displays performance results for each component.

Experiment Type		Result	
		Work	Fail
Train Detection	SM1A	v	
	SM1B	v	
	SL1	v	
	SM2A	v	
	SM2B	v	
	SL2	v	
	Solar Panel	v	
Alert System	Warning Speaker	v	
	VMS	v	
	Warning Lamp	v	
Main Controller	Arduino Control	v	
Level Crossing Monitoring System	Server	v	
	Dashboard	v	

Figure 13

In conclusion of the experiment, each component of the proposed radar-based solution operated successfully. The radar-based sensor system is an early warning technology that provides an automated protection and detection response at grade crossings. The technical report, *The Development of Radar-based Sensor System for Smart Level Crossing Technology* (13), outlines the specifications of system components, as well as how each component "communicates" in a collective fashion to ultimately mitigate risk at level GX's. Effectively mitigating such risk saves the lives of pedestrians and train operators. The proposed solution is simple to install, easy to maintain, and of low cost. Experimental results for a two-track environment determined total system success, indicating that this solution has the capacity to succeed in South Jersey once the installation of a second commuter track is complete.

Methods

The main goal of this project is to mitigate risks at specific Gloucester City GX's by proposing economically feasible and effective solutions. To achieve this goal, it was necessary to first identify current and future risks associated with these GX's, and second, suggest solutions that best mitigate the identified risks. Methods to complete the first step included geographic and demographic research (current and projected) of the Market, Monmouth, and Cumberland Street GX's. Additionally, an in-person survey was conducted at each of these GX's. Taking pictures and speaking to locals increased knowledge of current geographic and demographic conditions. Investigations using Google Maps were very informative as well. Additionally, traffic and population data were gathered from the FRA, DOT, and Census Bureau to better understand future conditions. The collective knowledge gained from these methods made it possible to identify current and future risk. The second step, to propose solutions to mitigate identified risks, was completed by method of literature review of SMART technology and research concerning other solutions. A collection of technical reports outlining SMART tech was acquired. Reports that best met identified risks were selected and analyzed. Research outside these reports also yielded desirable solutions. All methods described in this section were employed to gain knowledge of risk associated with current and future conditions of the aforementioned GX's and gather effective solutions to mitigate the risks.

Results

Cumberland St.

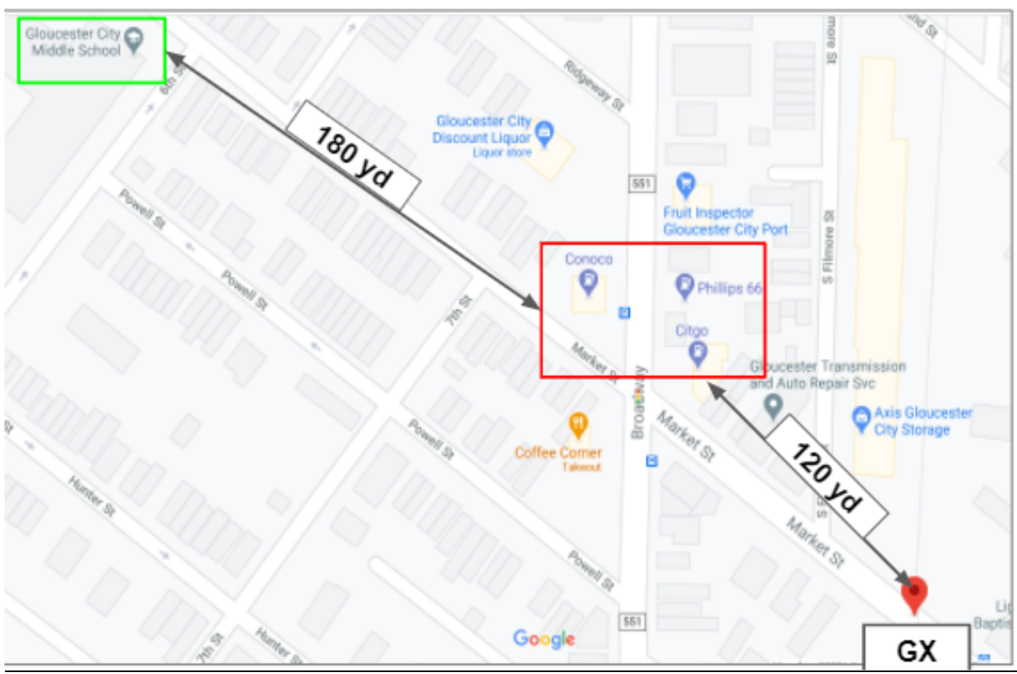
From the site surveys, several risks were identified at each GX. The first we will consider is Cumberland Street. The first identified risk is that lack of clear pedestrian safety. Although this is an overarching problem for all three grade crossings, Cumberland St. will sit in between the parking lot and Gloucester City Station meaning it will likely have the highest amount of foot traffic.

Consider the following image in which the grade crossing resides at the bottom. Note how the sidewalk ends and there is no clear sidewalk. In fact, to get back on the sidewalk a pedestrian would not only have to cross the GX, but also to the other side of the street. Although implementing sidewalk crossings are not in the domain of Conrail, there are potential technologies Conrail can implement to make the grade crossings safer for pedestrians.

Another point of risk is South Railroad Avenue which is used by the community as a two-way street. Note that in the following image, Cumberland street runs one-way left to right. However, with the absence of proper signage, an unfamiliar driver may turn right onto the GX, potentially causing an incident.

Market St.

The Market Street GX shares many concerns as Cumberland Street. However, the main concern is directed to a cluster of 3 gas stations roughly 100 yards from the actual GX. Initially, this may appear trivial. However, an unfortunate sequence of events (consequential of a serious GX incident) quickly defines this observation as non-trivial. More specifically, should an accident at the GX cause a train transporting LNG to impact the natural gas Access Valve Station (discussed below), the potential for a deadly and large explosion is suddenly dangerously high. Such an explosion could engulf this cluster of gas stations, compounding the problem even further. Many would die within the densely surrounding area. Additionally, the Middle School located roughly 200 yards away is placed at great risk as well. The probability of such an occurrence is low given that many errors would have to occur. Nonetheless, it is important to consider, because it is possible, further reinforcing the need for effective risk mitigating solutions. Conditions at this GX are shown below.



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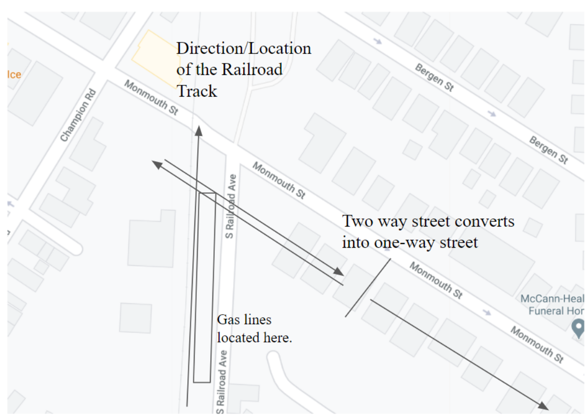
Monmouth St.

Monmouth Street also shares many concerns outlined already in this report. As one can notice, the area in which these streets are located are in relatively residential areas. This increases the risk of any accidents with people in the nearby area.

As one can see in the picture on the bottom, a resident has relatively low barriers from the tracks, which are also unguarded as well. The risk is thus amplified if there are children or animals who are easily able to go over the fence and accidentally move to the open tracks. Thus, a relatively simple solution may be to have some sort of barrier between the tracks and the outside.

In the next photo in the bottom left, there is also another issue of the lack of delineation between both lanes. This increases the risk of drivers attempting to move past the GX gates to “beat the train.” This is not common however it is a potential point of accidents that can be avoided with some sort of delineation between the lanes. Furthermore, more markings should be made to clearly mark where the GX crossing is located. Currently, only a white limit line demarcates where the GX crossing is and where the car is supposed to park. On the picture in the bottom right, we can see that there are markings indicating that a GX crossing is approaching, however, it runs into two issues. One, the GX crossing and the actual marking itself has a large distance of separation, which makes it unclear on when and where is the actual location of the GX crossing. The other issue is that cars parked on top of the markings can potentially obstruct drivers from identifying the warning sign altogether, which is another large concern. Thus, another potential solution might lie with adding another marking or signs indicating that a GX crossing is imminent and adding more clear markings demarcating where the cars should be parked in relation to the GX crossing.

Another major concern, as outlined in previous sections, is the existence of natural gas pipelines near the railroad tracks, as observed by one of our team members in a survey study. More specifically, there are natural gas pipelines next to South Railroad Avenue, shown in the pictures on the bottom. These have the potential to be a major risk, as South Railroad Avenue may act as a chokepoint for traffic. This road is particularly narrow and confusing, and a potential for vehicular collision might be a little higher in this road. However, this risk is compounded by the risk of relatively unguarded natural gas valve stations that might be a trigger to a potential for gas explosions (See Section on Market St). Thus, part of our solution includes making sure these areas are well guarded as possible from such incidents.



Recommendations

Due to various constraints of this project, including time, there were several questions left unexplored. Thus, we will suggest work for future groups to tackle. Upon completion of the project, our team recommends 5 future actions/considerations for the following team to consider. In general, these recommendations serve to monitor changes of ongoing risk and further validate SMART tech (or non-SMART tech) recommendations. To monitor risk: (1) demographic trends should be monitored, specifically with the influence of a second commuter track, (2) gather insights on future businesses, and (3) obtain finalized plans for gas line relocation. To further validate solutions: (4) developers of the solution should be contacted to gain insight on existing usage and cost considerations, and (5) consider educating local residents on the functionality of these solutions to increase awareness. Our team has found that much information regarding demographic, geographic, and possible solutions is readily available. In the effort to maintain full understanding of current and future risks, however, it is necessary to validate whether the information is useful and currently accurate. Completing these 5 recommendations, over time, may aid in this validation.

Conclusion

The Conrail Externship team has demonstrated the necessity to mitigate current and future risks associated with Gloucester City grade crossings. Additionally, solutions to mitigate these risks have been proposed. Visual and demographic investigations of Market, Monmouth, and Cumberland Street GX's exposed sources of current and future risk. Conditions that increase the probability of GX related incidents include poor road markings, lack of prevention from crossing the track, parking too close to tracks, dense surrounding neighborhood, and gas lines running parallel to the track. As a consequence of these conditions, risks include trespassing, impact between vehicle and train, and potential explosions resulting from impact with LNG transport. Installation of a second track for commuters, from the GIS plan, increases probabilities of such risks, demanding solutions to mitigate both current and future risk. Through a literature review and outside research, the proposed solutions to best mitigate risk (based on current and future conditions) fall under two categories: (1) protection, (2) protection and detection. Many solutions have been proposed and described in great detail. Ultimately, these solutions have the capacity to effectively mitigate the identified risks of Cumberland, Market, and Monmouth Street grade crossing.

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