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RADAR VEHICLE DETECTION WITHIN FOUR QUADRANT GATE CROSSINGS

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ABSTRACT

As train frequencies and traffic volumes increase, the need for safer at grade highway / rail crossings is paramount. Closing or grade separating crossings ultimately cannot work for all situations; therefore four quadrant gates may be used to provide a higher level of safety than conventional crossing treatments. At crossings between two adjacent signalized intersections, preemption and signage may prevent vehicles from queuing within the crossing island, but there remains some risk of vehicles becoming trapped by the timed exit gate descents. Sensors, either inductive loops or radar (among other potential detection technologies), can be installed to detect vehicles and extend exit gate closure until the crossing island is clear or, conversely allow for either simultaneous or near simultaneous entry and exit gate descents if no vehicles are present. Radar detection covers the whole crossing island and is mounted above the destructive forces transferred through the road bed resulting in a longer life cycle and lower installation and maintenance cost than inductive loops as described by Hilleary and Omar in 2012.

Radar detection was installed at three sites on North Carolina Railroad Company's H-Line in January 2014. The H-Line is operated by Norfolk Southern. Continuous and event triggered video monitoring was also installed to evaluate detection rate, false detection rate and rain or snow detections, along with evaluating activation timing and vehicle operational characteristics during crossing activations. The analysis of the radar detection will help the North Carolina Department of Transportation's (NCDOT) Rail Division determine their effectiveness and establish considerations for future installations.

INTRODUCTION

As train frequencies and traffic volumes increase the exposure at grade crossings increases. The safest solution is either crossing closure or grade separation, but in many cases site constraints or cost will not allow these solutions. Instead four quadrant gates can be used as an alternative to deter motorists from driving around active entrance gates, effectively sealing a crossing while it is active.

However, there is a risk of vehicles becoming trapped within the four quadrant gates especially in crossings between two adjacent intersections where queuing is likely due to short throat storage conditions. To mitigate this, sensors can be installed to detect vehicles within the crossing to delay an exit gate descent allowing the vehicle an opportunity to exit the crossing island prior to train arrival. The sensor also helps to reduce the window of opportunity where gate running behavior is possible by lowering the exit gates as soon as the crossing island is clear instead of waiting on a preset time. With sensors, the exit gates can operate independently so that only the exit gate in the direction of travel of a detected vehicle need be extended. Currently, inductive loops are installed within the roadbed by some agencies, but non-intrusive technologies like radar detection could offer a wider detection area along with lower installation and maintenance cost and longer expected life cycles.

Figure 1 shows grade crossing collisions in the State of North Carolina between January 2003 and June 2013. The locations of the current radar detection systems are shown, and these are the first vehicle detection systems of any kind to be installed at crossings in the State. All of the sites are in urban environments with closely spaced intersections on both sides, and along the North Carolina Railroad, where a majority of the State's Amtrak trains operate.

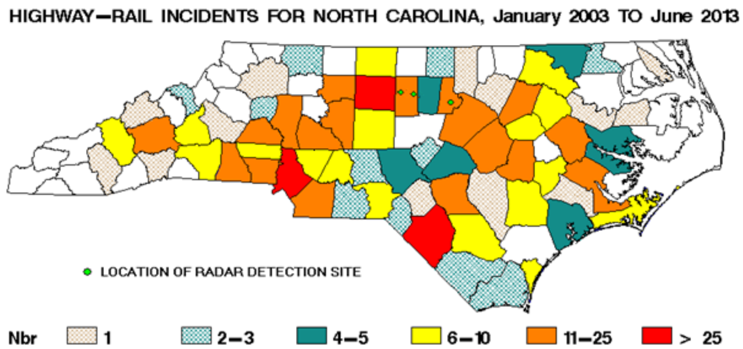


Figure 1: Number of grade crossing collisions by NC county and locations of radar detection sites (FRA).

This research focuses on the performance characteristics of the radar device, the interaction of the radar system with the warning devices, and the influence of site characteristics on crossing conditions. Data are collected in two evaluation phases, a passive phase where the radar is installed and sensing vehicles but not modifying the exit gates behavior, and an active phase where the radar senses vehicles and controls the exit gate behavior. Data is still being collected for the active phase, so the scope of this paper is limited to the passive phase analysis.

NOMENCLATURE

Exit Gate Operating Mode (EGOM): Functionality of exit gate
- Dynamic EGOM: Use vehicle detection to determine if island is clear, then close exit gates.
- Timed EGOM: Use calculated time to close exit gates after entrance gate closure.

Intrusive Sensor: Installed within the roadbed to detect vehicles, primarily inductive loops.

Non-intrusive Sensor: Installed overhead to detect vehicles, includes infrared, acoustic, radar or video.

Activation: An event where a train is detected by the approach circuit which triggers the warning devices.

Detection: An event where the radar senses a vehicles within a crossing island zone.

LITERATURE REVIEW

Although the number of incidents at grade highway-railroad crossings in North Carolina has decreased steadily throughout the last decade, in 2012 the 45 incidents that did occur resulted in 39 injuries and 2 fatalities (*1*). As the state continues to invest into the Southeast Corridor, train speeds and frequency will continue to increase along with the potential conflict with stopped or trapped vehicles within grade crossings. Since 1995 North Carolina's "Sealed Corridor" program has focused on consolidating, closing, and grade separating hundreds of crossings throughout the state (*2*). Due to site or budget constraints, not all crossings can be grade separated, and in these cases the next safest alternative is four-quadrant gated crossings.

Four-quadrant gates are an active warning system that blocks all automobile lanes in either direction to prevent drivers from weaving around the entry gates. The American Railway Engineering and Maintenance-of-Way Association's (AREMA) Communications and Signals Manual describes the operating characteristics of a four-quadrant gate and specifically the exit gate operating modes (EGOM) (*3*).

A timed EGOM delays the closing of the exit gates from the entry gates to allow vehicles to clear the crossing and is the most common EGOM (*3*). Guidelines for gate delay suggest three or more seconds, but crossings with multiple tracks, significant distance between tracks, rough pavement, or the presence of heavy vehicles could impede the vehicles (*4*). Dilemma zone research by Coleman and Moon establishes an algebraic approach to determining exit gate delay considering crossing geometry and vehicle speed (*4*). Engineered exit gate times should ensure that all vehicles are exiting, but in cases where a grade crossing is adjacent to an intersection, queuing from an intersection could prevent a vehicle from exiting. Inversely, long exit gate delay times provide aggressive drivers with the opportunity to race around the entry gates.

Dynamic EGOM uses sensor technologies to detect trapped vehicles and extends the delay of the exit gate closure until the vehicle clears. By lowering the exit gate as soon as the crossing is clear, the amount of delay between the entry and exit gates closure is reduced, providing more protection (*5*). The detection system could also warn inbound locomotives of the possible obstruction, but this type of functionality is outside of the scope of the project (*5*). The dynamic EGOM should be used in cases where intersection queuing could result in trapped vehicles or in general at crossings with train speeds over 79 mph (*3*). There are two types of sensor technologies for the dynamic EGOM: intrusive sensors buried underneath the roadbed and non-intrusive sensors mounted overhead or beside the road (*5*).

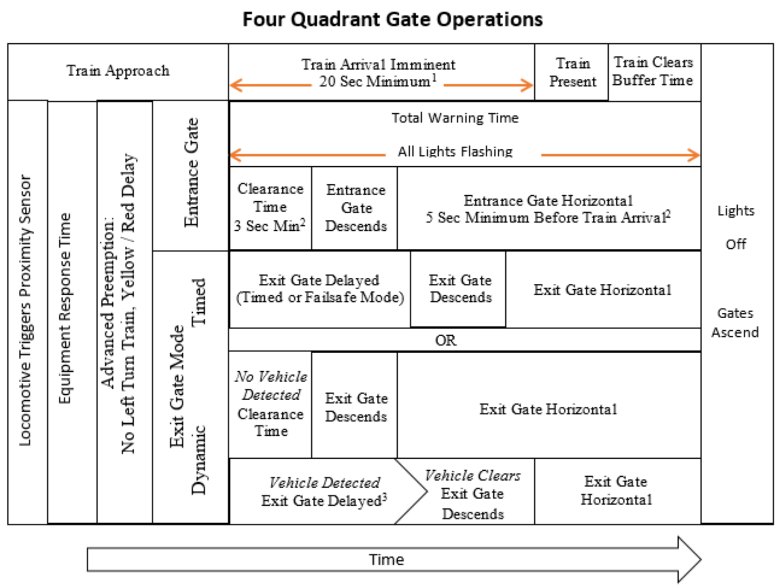
The primary intrusive sensor is the inductive loop which is also used in freeway volume detectors and actuated intersection control. Inductive loops tend to be less expensive to purchase compared to non-intrusive sensors as the system is primarily wire instead of electronics, but have higher installation and maintenance cost due to traffic and train conflicts during roadbed construction (*5)*. Inductive loops provide feedback only for the part of the crossing above the loops, and there are proximity limitations between different sets of loops. Redundant detection is not possible due to the proximity restrictions. Inductive loops are subjected to significant wear and tear due to: automobile and train forces, changes in temperature, and asphalt shifting or settling. In the event of a failure, the whole imbedded loop assembly must be replaced, resulting in shorter life cycle expectance, approximately 4 to 6 years (3). Additionally if regular maintenance of the railroad requires tie replacement or ballast cleaning at the crossing, the paved crossing is demolished along with any embedded sensors and then replaced (3). This maintenance condition also contributes to the relatively short life cycle of the inductive loops.

Non-intrusive sensors are mounted above a crossing to monitor obstructions, and use a variety of technologies to sense obstructions including magnetic, infrared, ultrasonic, acoustic, radar, and video. These sensors can be installed and maintained without interfering with traffic or railroad operations, but come with a higher purchase cost (*5*). Radar based systems were found to be around 25 percent cheaper to install than inductive loops, due to the significant cost of pavement work and the reductions in traffic and train delays for the inductive loop (*3*). Non-intrusive sensors detection covers the entire crossing including the railroad tracks and is out of direct impact areas resulting in longer expected life cycles, approximately 10 years (3). NCDOT's evaluation of a radar system uses two sensors. By installing two sensors, one for each direction of travel, small vehicles are less likely to be hidden by large trucks while providing redundant coverage throughout the crossing island. Non-intrusive sensors may also be able detect pedestrians or bicycles, although the implications of this detection in grade crossings is unclear (3).

Until recently radar sensors had a tendency to miss stopped vehicles, but through advances in radar technology and programming, Frequency Modulated Continuous Wave (FMCW) radar can detect stopped vehicles for 15-60 minutes before the vehicles become part of the background image (3). Radar detection operates on the gigahertz (GHz) wavelength which is unaffected by changes in background lighting and resistant to rain or snow distortions (3).

Although buried inductive loops are the most common of installed sensors at grade crossings, the significant installation and maintenance costs make alternatives like radar detection more favorable. A 2012 study by Hilleary and Omar compared radar detection against inductive loops at a high volume grade crossing. Two radar detectors were added to a crossing that previously had inductive loops installed to provide redundant coverage and a method of comparison (3). Over the four month testing period with 120,000 vehicle crossings, both the inductive loops and the radar detectors recorded no missed detections (3). Furthermore, the radar system had fewer false detections than the inductive loops, but did record some false detections during heavy rain and snow (3). This study indicates that radar detection systems are as accurate as inductive loops, but have a lower maintenance and installation cost in terms of both time and money, and most importantly, radar systems have a significantly longer life expectancy.

Figure 2 is a timeline of four quadrant gate operations and is adapted from Figure 5 in Hellman and Ngamdung (7). Gate operations are triggered by an approaching train, and protect the crossing until the train has cleared. Several events happen before gate operations, including system response time from the detection hardware and traffic preemption at nearby intersections. The length of these events depends on local hardware and operating conditions, like clearance times at the adjacent intersections and at the crossing island. Flashing lights and bells are active during the entire gate activation. The entrance gate behaves the same with dynamic or timed EGOM, and has several Federal mandates on the operating characteristics as shown in the footnotes of the diagram. The dynamic EGOM has no interaction with the entrance gates, only the exit gates. Under timed EGOM, the exit gate is delayed a pre-timed amount before descending. In the event of a radar failure, the system reverts to timed EGOM as a failsafe alternative. If no vehicle is detected in dynamic EGOM, the gate descends nearly simultaneously with the entrance gate. At the North Carolina sites, a 2 second delay is added between entrance and exit gate descent as a safety margin, even with no vehicles detected. If a vehicle is detected, the corresponding exit gate is delayed until the vehicle clears the detection zone. The behaviors of the two exit gates are independent of one another. Only the exit gate with a vehicle detected in a specific direction will extend while the other gate will descend near simultaneously.



1: 49 CFR 234.225 "A highway-rail grade crossing warning system shall be maintained to activate in accordance with the design of the warning system, but in no event shall it provide less than 20 seconds warning time for the normal operation of through trains before the grade crossing is occupied by rail traffic." (8)

2: 49 CFR 234.223 "Each gate arm shall start its downward motion not less than three seconds after flashing lights begin to operate and shall assume the horizontal position at least five seconds before the arrival of any normal train movement through the crossing. At those crossings equipped with four quadrant gates, the timing requirements of this section apply to entrance gates only." (8)

3: In dynamic mode the exit gate delay is variable and will extend until the intersection is clear.

Figure 2: Four quadrant gate time line modified from Figure 5 of Hellman and Ngamdung (7)

METHODOLOGY

At each of the detection sites, video cameras were installed to evaluate the effectiveness of the radar detection system. The video records every time a train activates the approach circuit capturing the operational characteristics of the radar detection system and the warning gates, driver behavior, weather conditions, and railroad operations. A continuous video feed is also provided to check the real time conditions of the crossing. The videos are downloaded and reviewed twice, first to record times of gate operations, then to record highway vehicle counts and anomalies. There are two phases to the evaluation, a passive phase where the radar detection is installed and detecting vehicles, but not modifying the exit gate behavior, and an active phase where the radar detects vehicles to modify the exit gate behavior. The passive phase is intended to show that the radar system is functioning as expected before modifying the gate system, and also allows for a before and after comparison of the gate operations and motorists' behaviors. Data are collected using the same methodology in both phases.

A heads-up display (HUD) from the radar is also recorded on the video as shown in figure 3. This displays train detection on the approach (XR) and island circuit (IR), any radar detection in the two detection zones (Z1 & Z2), and two radar health monitors (H1 & H2). The detection zones are configured within the geometry of the crossing island, with a buffer between the zones and the gates. Two zones are used, one in each travel direction, and both radar detectors observe both zones for redundancy as shown in figure 4.

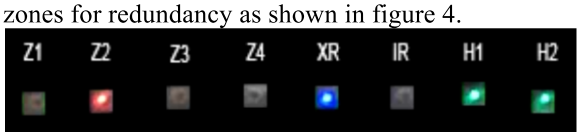


Figure 3: Radar HUD showing vehicle detection in zone 2, a train on the approach circuit, and good radar health.

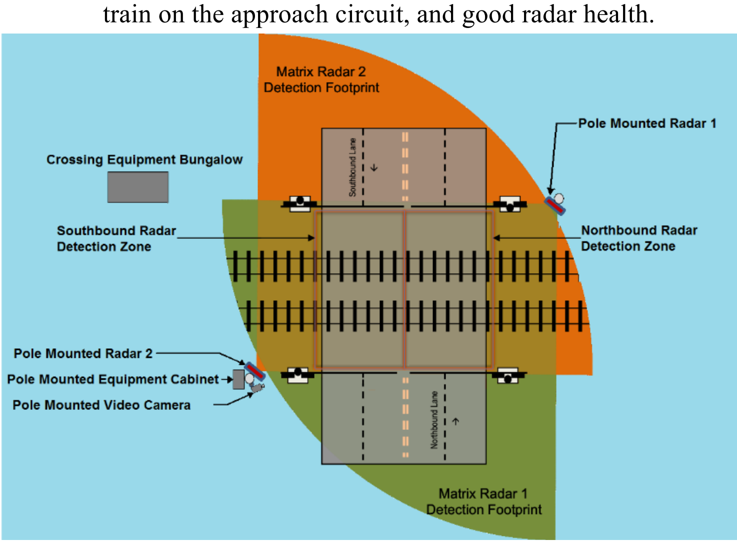


Figure 4: Layout of radar detection system at the crossing island (Island Radar).

Metadata

This information is collected to locate the activation in time and space, while identifying key railroad operational characteristics.

- Location: Radar detection site
- Date: Calendar day, time stamped on video
- Time: Time of day, 24 hour clock, time stamped on video
- Direction: Direction of travel of train
- Train Type: Either Freight or Amtrak
- Track: Type of track or movement
  - Main: Through movements
  - Local: Yard or switching movements
  - Siding: Passing or waiting movements
- Comments: Notes on unusual behavior, unique events, or other explanation as needed

Operational Timing

The eight stages shown in figure 5 are used to track the operations of the warning devices for each crossing activation, from first detection, to raising the gates and allowing automobiles to cross the island. Each stage is sequential, and the sum of all of the stages is the length of the activation. Each stage is timed during the initial observation using an Excel macro or stopwatch. Stage times are recorded as negative if they occur out of sequence.

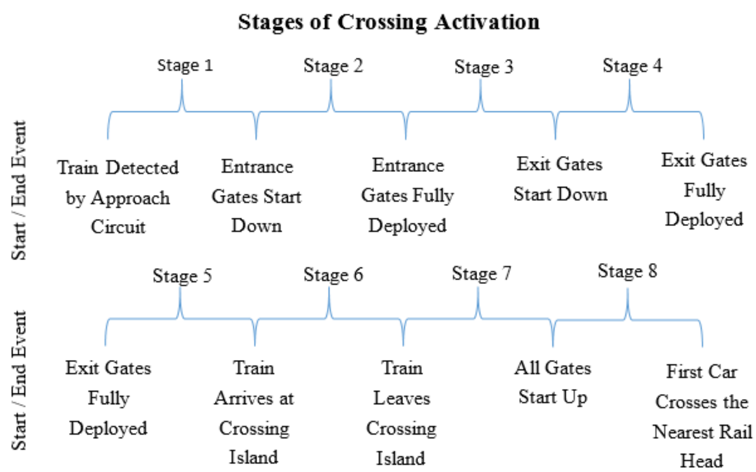


Figure 5: Stages of crossing activation based on operational events.

Stage 1 is the approach time, or the time from the initial detection by the approach circuit (XR on) to the beginning of the entrance gate start down. Intersection preemption occurs during this time to clear the crossing island. During the final 4 seconds of this phase, the flashing lights are active. The length of this phase depends on train speed and approach circuit length.

Stage 2 is the time for the entrance gates to deploy. This time is dependent on the local equipment and should be fairly consistent at each site.

Stage 3 is the island clearance time. In a timed EGOM this delay is calculated based on site characteristics and should be a minimum of 3 seconds. However in a dynamic EGOM this time could be negative, as the exit gate could descend nearly simultaneously with the entrance gate, if the crossing is clear of obstructions.

Stage 4 is the time for the exit gates to deploy, and is similar to Stage 2. This time also depends on the local equipment and should be fairly consistent at each site.

Stage 5 is the buffer time between fully deployed crossing protection and the arrival of the train. With dynamic EGOM this stage will be longer than in a timed EGOM for a similar activation indicating the improved warning envelope.

Stage 6 is the time that the crossing is occupied by the train. The length of this stage depends on the length and speed of the train. While the crossing island circuit is active, the radar detection is disabled, as the radar would detect the train and open the exit gates.

Stage 7 is the clearance buffer between the train clearing the crossing and the gates ascending. This time is dependent on the speed of the train, and the length of the detection circuits.

Stage 8 is the time for the gates to ascend and to return to normal highway operations. This time depends on the local equipment and driver behavior.

Vehicle Detection

During the second review of the video, highway vehicle detection is reviewed for each direction (northbound / southbound) for passenger vehicles, and heavy vehicles including dump trucks, box trucks, and tractor trailers. During the vehicle detection review process, the radar detection signal is monitored to ensure that all vehicles are detected. Detection anomalies are discussed in the following section. These reviews are primarily in the first four stages, as the crossing is fully protected from stage 5 to 8. If a vehicle is present during stage 5 to 8, a critical failure has occurred, possibly resulting in a collision. In over 1,000 total activations, no highway vehicles have been on the crossing island during stage 5 to 8.

Vehicle detections are only counted in the last four seconds of stage 1, or the time while the flashing lights are active before the start down of the entrance gate. Stage 2 vehicles tend to cross during the first half of the stage, before the gates are at 45 degrees, but some aggressive driving behavior has been observed. Stage 3 vehicles are either waiting to clear the island, or gate runners. Stage 4 vehicles have the potential to become ‘trapped’ by the exit gates. Dynamic EGOM should prevent all stage 4 vehicles, as the exit gates are delayed until the island is clear.

Detection Classification and Anomalies

During the vehicle counting review, the radar detection signal is monitored to evaluate the effectiveness of the system. The radar is monitored during the whole activation, but is most critical during stage 3, the time before the start down of the exit gate. One of the following conditions apply to each highway vehicle crossing or detection. Only those detections that occur during stages 1-5 are recorded, as stages 6-8 have the detection disabled due to the presence of the train.

- Successful Detections: Vehicle is present in crossing island and radar detects in the correct zone. During active gate control, the radar will extend the exit gate closure until no vehicles are detected on the island. The vehicle count represents the number of successful detections during each stage of each activation.
- Missed Detections: Vehicle is present in crossing island, but radar detection fails to recognize the vehicle. During active gate control, the radar would fail to extend the exit gate closure.
- Critical Failures: Vehicle is present in crossing island at the same time as a train, possible resulting in a collision.
- False Detections: Radar detects a vehicle, but no vehicle is within the crossing zone. During active gate control, the radar would extend the exit gate delay for a non-existent vehicle, or possible raise the gates if the false detection occurred after the gate descent.
- Phantom Detections: Radar detects a vehicle, but in the opposite detection zone. During active gate control, the radar would extend or raise the exit gate for the wrong travel direction. Phantom detections are a subset of false detections.
- Rain or Snow False Detections: Radar detection triggered by heavy rain or dense snow instead of a vehicle. Rain or snow detections are a subset of false detections.
- Adjacent Lane Detections: Vehicle detection in both detection zones due to a single vehicle, typically from wide turning movements. Not considered a partial activation failure by the FRA (3).

ANALYSIS / RESULTS

Site Characteristics

As the active phase data is still being collected, the scope of this analysis is limited to the passive phase. Table 1 includes information about site characteristics, rail and highway vehicles, and crash statistics for each of the three test locations. All information is based on current FRA inventories and crash reports.

Table 1: Site characteristics for radar detection at four quadrant gate crossings

City	Durham, NC	Elon, NC	Mebane, NC
Crossing Number	735 236 Y	722 995 V	735 472 D
Road Name	Ellis Road	Williamson Avenue	5th Street
Local Land Use	Industrial: Heavy Vehicles	University: Pedestrians	Commercial
Warning Devices	4QG, 1 Cantilever, 7 Flashing Pairs, Preemption	4QG, 2 Cantilevers, 12 Flashing Pairs, Preemption	4QG, 2 Cantilevers, 12 Flashing Pairs, Preemption
Number of Tracks	1 Main, 1 Siding, 1 Yard	1 Main	1 Main
Number of Daily Trains / Speed	16 @ 60 mph	16 @ 60 mph	16 @ 60 mph
Number of Highway	2 NB, 1 SB @ 35 mph	1 NB, 2 SB @ 20 mph	3 NB, 2 SB @ 35 mph

Lanes / Speed			
ADT (year)	5,866 (2010)	6,805 (2010)	12,290 (2010)
Collisions (year)	12 (10, 09, 08, 06, 02, 01, 98, 87, 79, 79, 79, 75)	1 (84)	7 (10, 10, 05, 87, 81, 80, 78)

The Ellis Road crossing in Durham is located between a Norfolk Southern flat yard and a wye. The northern most track or yard track only has an island circuit, no approach circuit, for train detection due to the proximity of the yard. Due to of the unique characteristics of the track, along with the nature of switching operations, activations from this yard track are excluded from the analysis.

Over the course of 35 days, 1281 total activations were collected from all sites. 52% of the train movements are in the eastbound direction. All three crossings are located along the North Carolina Railroad, and are each traversed by six Amtrak trains throughout the day. Norfolk Southern also operates along this corridor, with an average of 7 mainline crossings per day at each site.

Operational Timing

The average, maximum and minimum time per stage are shown in the following tables. The average length of activation is 94 seconds, with Amtrak at 67 seconds and freight movements at 146 seconds as shown in table 2. Stage 2 and 4 have consistent times for gate descent at each site, as this time is determined by the speed of the gate. Elon and Mebane have very similar results for freight and Amtrak service. The longer stage 1 times at Durham contribute a majority of time to the longer activation times. Mebane has the shortest buffer time between gates being down and train arrival, stage 5. Results from the active phase of the project could be used to evaluate the current values of timed EGOM. For example, if the sum of stage 2 and 3 is significantly less than the current pre-timed gate delay setting, the pre-timed values could be adjusted to provide more protection at a similar crossing.

Table 2: Average time per stage by location and train type.

	Average Time Per Stage (seconds)								
Crossing Location by Train Type	1	2	3	4	5	6	7	8	Total
Durham	**17**	**6**	**6**	**8**	**16**	**29**	**6**	**13**	**101**
Amtrak	14	6	6	8	13	5	6	13	71
Freight	24	7	6	8	22	79	6	13	165
Elon	**4**	**8**	**12**	**6**	**20**	**32**	**5**	**8**	**95**
Amtrak	4	8	12	6	20	6	5	9	70
Freight	4	8	12	6	19	71	5	8	133
Mebane	**4**	**14**	**6**	**12**	**5**	**36**	**8**	**6**	**92**
Amtrak	4	14	6	12	4	6	7	7	59
Freight	4	14	6	11	8	81	10	6	141
Average	**5**	**10**	**10**	**8**	**15**	**33**	**6**	**8**	**94**

The minimum stage lengths are shown in table 3. These lower bound values are mostly due to fast moving, short Amtrak trains or locomotive only freight moves. Stages 2 and 4 are once again determined by the speed of the gates, and do not vary much from the average times. A short stage 1 indicates that the gates must start immediately following detection to allow for complete activation before train arrival. The negative values in stage 3 are due to exit gate start down before the entrance gates are fully deployed. This situation will be more apparent with the dynamic EGOM. The negative time in stage 5 at Mebane indicates that the train arrived at the crossing before the exit gates were fully deployed. Exit gate behavior is not mandated by FRA guidelines, so this value is acceptable.

Table 3: Minimum time per stage by location and train type.

	Minimum Time Per Stage (seconds)								
Crossing Location by Train Type	1	2	3	4	5	6	7	8	Total
Durham	**4**	**4**	**4**	**5**	**6**	**3**	**5**	**3**	**34**
Amtrak	4	4	4	5	6	3	5	5	36
Freight	4	4	5	7	10	3	5	3	41
Elon	**1**	**5**	**-6**	**4**	**6**	**3**	**3**	**3**	**19**
Amtrak	1	5	-6	4	11	3	4	3	25
Freight	1	6	-4	4	6	3	3	3	22
Mebane	**2**	**10**	**3**	**6**	**-11**	**3**	**5**	**3**	**20**
Amtrak	2	11	3	7	-2	3	5	3	32
Freight	3	10	3	6	-11	3	6	3	23
Average	**2**	**7**	**1**	**5**	**2**	**3**	**4**	**3**	**28**

The maximum length of each stage are shown in table 4. These upper bound values are due to slow moving freights. Stages 2 and 4 are dependent on the speed of the gates, and do not vary much from the average. The stage 3 values are not long enough to encourage gate running behavior, which occurs around 1.22 minutes (6). The high values for stages 5 and 6 indicate very low train speeds, long trains, or moving to sidings for passing operations. High values for stage 8 indicate low highway volume, with a long delay between the startup of the gates and the arrival of the first vehicle.

Table 4: Maximum time per stage by location and train type.

	Maximum Time Per Stage (minutes)								
Crossing Location by Train Type	1	2	3	4	5	6	7	8	Total
Durham	**1.33**	**0.12**	**0.13**	**0.17**	**0.85**	**3.50**	**0.15**	**0.67**	**6.92**
Amtrak	0.40	0.12	0.13	0.17	0.85	0.28	0.12	0.33	2.40
Freight	1.33	0.12	0.12	0.15	0.72	3.50	0.15	0.67	6.75
Elon	**0.10**	**0.20**	**0.23**	**0.17**	**5.00**	**5.00**	**0.13**	**0.53**	**11.37**
Amtrak	0.10	0.17	0.23	0.14	1.57	1.93	0.12	0.53	4.79
Freight	0.10	0.20	0.23	0.17	5.00	5.00	0.13	0.27	11.10
Mebane	**0.17**	**0.28**	**0.20**	**0.23**	**0.68**	**4.00**	**0.32**	**0.25**	**6.13**
Amtrak	0.12	0.28	0.18	0.23	0.45	1.58	0.20	0.25	3.30
Freight	0.17	0.27	0.20	0.23	0.68	4.00	0.32	0.22	6.08
Average	**0.42**	**0.19**	**0.19**	**0.18**	**1.76**	**3.20**	**0.18**	**0.41**	**6.54**

Vehicle Detection Observations

Vehicle detections were counted during each stage as either passenger vehicles, or heavy vehicles including dump trucks, box trucks, and tractor trailers for each direction of travel. Table 5 (Appendix A) shows the summary of stage vehicle counts for each location and train type. Stage 1 counts only include the last four seconds of stage 1, or the time when the flashing lights and bells are active. Vehicles crossing after the start down of the entrance gate are considered violating vehicles, stages 2-5. A fifth of all activations have a violating vehicle, and around a third of all vehicles crossing during activations are violating the gate protection. Fortunately, the 98.7% of these violations occur during stage 2, or when the entrance gates are descending, but one vehicle did cross during stage 3, the exit gate delay and another during stage 4 or the exit gate descent. No vehicles were on the crossing island during stages 5-8.

Detection Classification and Anomalies

A total of 477 detections were recorded during the passive data collection period. 98.5% of these detections were successful, indicating that a vehicle was on the crossing island during stages 1-5. 7 false detection occurred, with a majority of them at Mebane and Durham. The radar systems sensitivity was adjusted at Mebane and the radar mounting angle was adjusted at Durham, which fixed the false detection issues. Phantom and rain or snow detections are both subsets of the false detections, for example at Elon one false detection occurred which was due to rain. The three adjacent lane detections were due to vehicle turning movements that passed through both zones at the same time. While these movements did cause two detections, the second count was nullified as the system detected the vehicles accurately. Adjacent lane detection could extend both exit gates, but typically the opposite direction detection zone is only active for a short time as the vehicle clips the corner of the zone. The system performed better than the Illinois inductive loop and radar detection comparison study, which had 95.4% successful detections (3). Both studies found no missed detections.

Table 6: Detection classification based on location

Crossing Location	Successful Detection	Missed Detection	False Detection	Phantom Detection	Rain or Snow Detection	Adjacent Lane Detection	Critical Failures
Durham	125	0	3	0	0	0	0
Elon	166	0	1	0	1	1	0
Mebane	179	0	3	0	0	2	0
Total	**470**	**0**	**7**	**0**	**1**	**3**	**0**
% of Total (477)	98.5%	0.0%	1.5%	0.0%	0.2%	0.6%	0.0%

CONCLUSIONS / RECOMMENDATIONS

The operations of four quadrant gate railroad crossings with closely spaced intersections can potentially be improved by adding dynamic EGOM features to the warning system. Vehicle detection allows the exit gates to be closed as soon as the crossing island is clear. This reduces the likelihood of gate running, as exit gates can descend with entrance gates, and allows a single exit gate to remain open if a vehicle is waiting in a queue. Radar detection allows for non-intrusive sensing at the crossing, which allows for detection over the whole island including the tracks, and increases the service life of the sensor, while reducing maintenance and installation cost. Radar detection has been shown to be as effective at detecting vehicles as loop based intrusive sensing.

This observational study features video recordings of crossing activations, which are then reviewed for warning device operation times, vehicle detection counts, and radar detection classification. The study has two phases, a passive phase where the radar is installed but not influencing the behavior of the exit gates, and an active phase where the radar does modify the behavior of the exit gate. The data collection for the active phase is still in process, so the scope of this paper focuses on the passive phase. The two phases will allow a before and after comparison of the radars influence on the exit gate operations and driver behavior.

Each crossing activation is broken down into 8 stages based on operating conditions of the gate system (see figure 5). The length of each stage is recorded resulting in an average activation time of 94 seconds, from initial detection of the train by the approach circuit to when the first car crosses the railhead after the gates start up. Amtrak activations were fairly consistent (min/avg/max: 25/67/287) at all three locations, and as expected, were much quicker than freight movements. Freight movements had a much wider range of activation times (min/avg/max: 22/146/666). The time between the entrance gate start down and the exit gate start down, the sum of stages 2 and 3, is currently 20 seconds, but this time is expected to decrease in the active portion of the study. While 20 seconds is not long enough to encourage gate running behavior (around 73 seconds (6)) it is enough time for aggressive drivers to behave recklessly.

Vehicle detection counts during the stages reveal driver behavior associated with each stage of the crossing activation. Counts start four seconds before the start down of the entrance gate, and are broken down by the same stages as the gate timings. Around one fifth of all activations have a violating vehicle, or a vehicle that enters the island after the start down of the entrance gate, stage 2. 156 of the 158 violations occurred during stage 2, but one driver did run around the gates during stage 3 and another during stage 4. Approximately one third of all drivers that arrive at the crossing during an activation violate the active warning devices.

The radar detection system proved to be very reliable, detecting all of the 470 total vehicles that crossed during activations. Seven false detections were recorded, with 3 at the Mebane site and 3 at the Durham site, but adjustments to radar sensitivity and mounting angle resolved these issue. There were no missed detections, and only 1 false detection attributed to rain. The system was determined to be operating as intended by the NCDOT and is currently in the active mode controlling the behavior of the exit gates.

Data is currently being collected using the same methodology for the active portion of the study, and will provide a basis of comparison for a before and after study. The radar system is operating as expected, and analysis of the dynamic EGOM will continue once all the data is collected. This methodology provides a basis for evaluating grade crossing improvements as it examines the performance of warning device systems and driver behavior.

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REFERENCES

[1] NCOLS. *Highway-Rail Incidents at Public & Private Crossings.* North Carolina Operation Lifesaver, September 16, 2013. http://ncols.weebly.com/statistics.html

[2] Carroll, Anya. 2001. *North Carolina "Sealed Corridor" Phase I, U.S. DOT Assessment Report.* Washington, DC: Federal Railroad Administration.

[3] Hilleary, Thomas, and Tarek Omar. 2012. *A Radar Vehicle Detection System for Four-Quadrant Gate Warning Systems and Blocked Crossing Detection.* Washington, DC: Federal Railroad Administration, DOR/FRA/ORD-12/24.

[4] Coleman, Fred III, and Young J. Moon. 1995. *Design of Gate Delay and Gate Interval Time for Four-Quadrant Gate System at Railroad-Highway Grade Crossings.* Transportation Research Record 1553 : 124-31.

[5] DaSilva, Marco, and William Baron. 2007. *State-of-the-art Technologies for Intrusion and Obstacle Detection for Railroad Operations.* Washington, DC: Federal Railroad Administration, DOT/FRA/ORD-07/06.

[6] Norfolk Southern Corporation and North Carolina Department of Transportation. 2000. *Exit gate-arm fail-safe down test.* Raleigh, NC.

[7] Hellman, Adrian, and Tashi Ngamdung. 2009. *Illinois high-speed rail four-quadrant gate reliability assessment.* U.S. Department of Transportation, Federal Railroad Administration, DOT/FRA/ORD-09/19.

[8] *49 CFR 234, Subpart D – Maintenance, Inspection, and Testing*. In Legal Information Institute [database online]. 2013 [cited 10/07 2013]. Available from http://www.law.cornell.edu/cfr/text/49/234/subpart-D

APPENDIX A

VEHICLE COUNT DATA SUMMARY

Table 5: Stage vehicle counts by location and train type.

	Number of Vehicles Per Stage																	Summary	
	Stage 1*				Stage 2				Stage 3				Stage 4				Stage 5		
Crossing Location by Train Type	1: NB Car	1: NB Truck	1: SB Car	1: SB Truck	2: NB Car	2: NB Truck	2: SB Car	2: SB Truck	3: NB Car	3: NB Truck	3: SB Car	3: SB Truck	4: NB Car	4: NB Truck	4: SB Car	4: SB Truck	5: All Vehicles	Number of System Activations	Number of Violating Vehicles (Stage 2 to 5)
Durham	**24**	**2**	**51**	**1**	**19**	**3**	**22**	**1**	**1**						**1**			**294**	**47**
Amtrak	6		11		7		3											69	10
Freight	12		16		4	1	6								1			102	12
Local	5	2	22	1	7	2	12	1	1									118	23
None present	1		2		1		1											5	2
Elon	**63**		**62**		**25**		**16**											**311**	**41**
Amtrak	42		43		16		12											186	28
Freight	21		19		9		4											125	13
Mebane	**50**	**1**	**57**	**1**	**42**	**3**	**24**	**1**										**147**	**70**
Amtrak	28	1	32	1	31	2	14	1										88	48
Freight	22		25		11	1	10											59	22
Total	**137**	**3**	**170**	**2**	**86**	**6**	**62**	**2**	**1**						**1**			**752**	**158**

* Only vehicles present during the last four seconds of stage 1 are included in the vehicle counts