Evaluation of Radar-Based Vehicle Detection System at Four Quadrant Gated Highway-Rail Crossings

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Executive Summary

As train frequencies and traffic volumes increase, the need for safer highway-rail grade crossings is paramount. Closing or grade separating crossings may not be practical or even possible for all situations; therefore four quadrant gates, amongst other possible treatments to prohibit gate running violations, 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 itself, but some risk of vehicles becoming trapped by the timed exit gate descents might still remain. Sensors, either inductive loops or radar (among other potential detection technologies), can be installed to detect vehicles and would extend exit gate closure until the crossing is clear and conversely allow for either simultaneous or near simultaneous entry and exit gate descents if no vehicles are present. Radar detection can cover the whole crossing surface area between the gate arms and is mounted above the destructive forces transferred through the pavement from trains and vehicles, resulting in a longer life cycle and lower installation and maintenance cost than inductive loops. Worker safety benefits may also accrue compared to the time and equipment needed to install and repair loop infrastructure.

Through two grants awarded by the Federal Highway Administration, the North Carolina Department of Transportation's Rail Division sponsored an evaluation of a dual matrix radar system to determine its reliability, functionality, and robustness for potential use with dynamic exit gate operations at four-quadrant gated, highway-rail crossings. The radar system was evaluated to determine its detection accuracy for consideration of use in detecting vehicles traversing a crossing so as to delay or reverse descent of the exit gate if a vehicle is between the gates upon the approach of a train and the activation of the crossing warning system. The system selected for evaluation was the Wavetronix SmartSensor® Matrix radar system for which the radar sensor adapted for rail use is named SmartSensor-Rail®. The project evaluated the performance of the system and identified adaptations to the system necessary for use in a railroad crossing application. In addition, a sample of activation data were collected on safety improvements to vehicle operations with dynamic gate operations as they relate to motorists' behaviors, especially violating down or descending gates. Island Radar Company indicated that they developed a specialized controller that continuously evaluates the correspondence between redundant radar sensors to provide a unique operational redundancy and full-time cross-checking to the railroad applications.

For this project, NCDOT acquired and jointly implemented with Norfolk Southern Railway and Island Radar dual radar systems with video recording capabilities at seven locations along the H-line between Salisbury and Durham, NC; the first three locations were activated in March 2014 and the next four locations between February and April 2016. Continuous and event triggered video monitoring with recording capability was also installed to evaluate activation timing and vehicle operational characteristics during crossing activations. In cooperation with the Federal Railroad Administration, the analysis of the radar detection will help the North Carolina Department of Transportation's (NCDOT) Rail Division to determine their effectiveness and establish considerations for future installations.

Within the scope of this evaluation effort which included over 7,953 system activations, the radar system operated at a reliability of 99.81% in the correct detection of vehicles which were present (total of 15 false negative detections). Of the missed detections (false negative detections), four of the instances occurred related to the size of the detection zone, which was adjusted and no further missed detections were recorded during the evaluation. The other eleven false negative detections were related to the speed of the vehicles, particularly those with speeds above 30 mph, which reduce the vehicle's time in the crossing below that of what is needed to detect the vehicle. In the intended use of the system, this type of speed-related missed detection may not be a high priority to reduce because the vehicle is unlikely to be stopped on the tracks prior to the deployment of the exit gate.

There were also 55 system activations which had a false positive detection (vehicle was not present, but one was counted as being present). The majority (41 of the 55) of false positive detections occurred as a result of the train and was present momentarily after the train cleared the crossing – this false detection is likely not a target for improvement. The remaining false positive detections are described in this report in detail.

The systematic review of the crossing activations conducted through this evaluation provided useful feedback to improve the operational and functional characteristics of the system. Based on the effort detailed in this report, slight modifications to the detection system's settings can reduce the potential for these miscalculations and false detections. Therefore, an evaluation of detection systems in passive (in-active) mode is recommended to allow for site-specific system observations and adjustments before implementing EGOM. Based on this study, it can be concluded that the radar system selected for evaluation can perform at the same level of effectiveness as inductive detection loops after site specific adjustments to the system settings have been implemented.

Chapter 1: Radar System Description

INTRODUCTION

As train speeds and traffic volumes increase, the risk to automobiles at highway-rail grade crossings increases due to a smaller window of response, longer stopping distances, and more train momentum. 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 alternate 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 (particularly likely with nearby adjacent intersections). 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 get out of the crossing area prior to train arrival. With sensors, the exit gates can operate independently so that only the exit gate descent is delayed when a vehicle is detected. The entry gates would continue to function as normal. Currently, inductive loops are traditionally installed within the roadbed by some agencies, but non-intrusive technologies like radar detection could offer alternative reliable detection along with lower maintenance cost and longer expected life cycles.

All of the sites in the evaluation are in urban environments with closely spaced intersections on both sides, and along the H-Line between Salisbury and Durham, NC, where a majority of the State's Amtrak trains operate. This research focused on the performance characteristics of the radar system, its interaction with the highway-rail grade crossing warning system, and the influence of site characteristics on system performance. For this study, an activation is defined as an event where a train is detected by the approach circuit which triggers highway-rail grade crossing warning devices. Whereas, a detection is defined as an event where the radar senses a vehicle within a crossing island.

BACKGROUND

Although the number of incidents at highway-rail grade 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 North Carolina continues investing in the Southeast Corridor along with other states to provide higher speed rail service to the region, train speeds and frequencies will continue to increase, further increasing the need to implement innovative and technologically sophisticated safety improvements to mitigate and eliminate crash exposure potential between vehicles and trains. Since 1995, North Carolina's "Sealed Corridor" program has focused on highway-rail grade crossing consolidations, closures, grade separations, and improvements to traffic control warning devices at numerous crossings along the H-line between Charlotte and Raleigh, NC (2). The program included the installation of 4-quadrant, gated crossings with pre-timed exit gate operations where applicable to provide a "sealed corridor" type treatment. North Carolina's experience with four-quadrant gated crossings has determined that they are a safe, effective, and fiscally responsible treatment for improving safety where grade separations, closures, or other treatments such as median separators, may not be practical.

Four-quadrant gates are an active warning system that blocks all vehicular 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 vehicles within the crossing 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 was 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 embedded in the pavement and non-intrusive sensors mounted overhead or adjacent to the tracks (5).

The primary intrusive sensor is the inductive loop which is also used in freeway volume detectors and actuated intersection traffic signal 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 paving construction (5). Inductive loops provide feedback only for the part of the crossing directly above (or near) 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: vehicle and train forces, changes in temperature, and asphalt shifting or settling. If regular maintenance of the railroad requires tie replacement or ballast cleaning at the crossing, the paved crossing is removed 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 or adjacent to the tracks 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). However, radar based systems were found to be around 25 percent cheaper to install than inductive loops, due to the cost of working with the existing pavement or new pavement for the inductive loop (3). Non-intrusive sensor detection covers the entire crossing including the railroad tracks and is out of direct impact areas resulting in longer expected life cycles of approximately 10 years (3). NCDOT's evaluation was with a radar system consisting of two sensors. By installing two sensors, small vehicles are less likely to be hidden by large trucks while providing redundant coverage throughout the crossing surface. Non-intrusive sensors may also be able detect smaller targets, such as motorcycles, bicycles, and pedestrians (3).

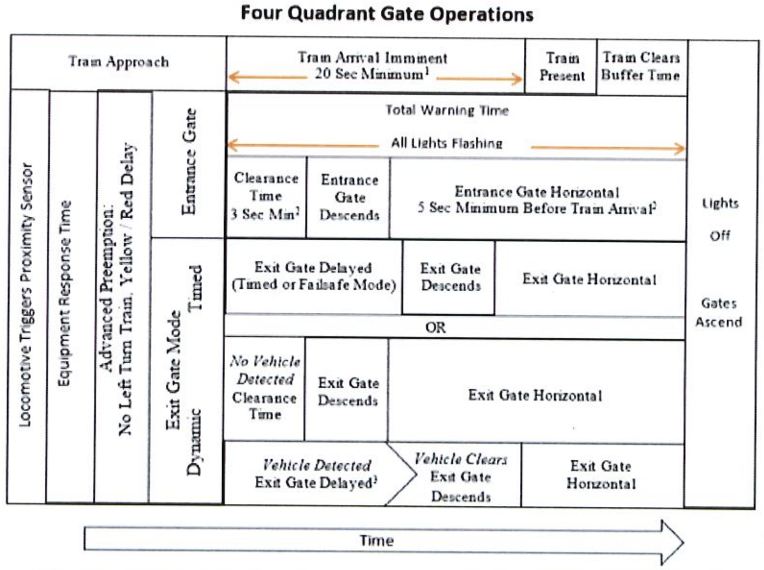
Until recently, radar sensors had a tendency to miss stopped vehicles, but through advances in radar technology and programming, Frequency Modulated Continuous Wave (FMCW) radar can detect stopped vehicles for 15-60 minutes before the vehicles become part of the background image (3). Radar detection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

Although embedded in pavement inductive loops are the most common of installed sensors at grade crossings, the significant 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 for a direct comparison of the alternatives (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, in the study by Hilleary and Omar, 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.

The following figure 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 vehicle queue clearance times at the intersections. 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. In the event of a radar failure during dynamic EGOM, the system being evaluated by NCDOT would revert to timed EGOM as a failsafe operation. If no vehicles were detected within the gates during EGOM, the system would allow all four gates to descend nearly simultaneously. If dynamic EGOM were to be permanently implemented in North Carolina, NCDOT would recommend a 2 second delay between entry and exit gate gate descends when no vehicles are detected as a safety factor. However, NCDOT has no anecdotal evidence that this safety factor is needed nor is necessary. 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 delay its descent while all other gates will descend nearly simultaneously.

Four Quadrant Gate Operations



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.

METHODOLOGY

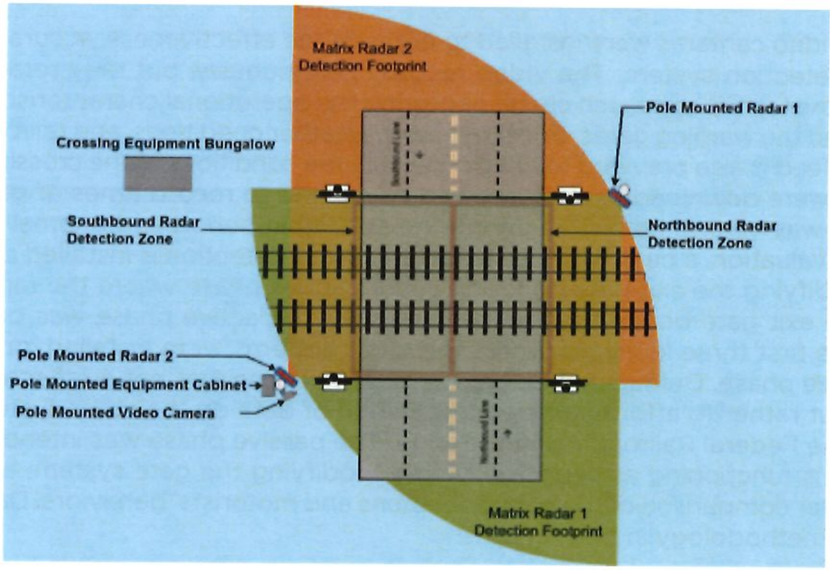
At each of the detection sites, video cameras were installed to evaluate the effectiveness, accuracy, and robustness of the radar detection system. The video records continuously, but only retains recordings whenever a train activates the approach circuit capturing the operational characteristics of 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. For this evaluation, the videos were downloaded and reviewed twice, first to record times of gate operations, then to record highway vehicle behaviors during the activation period and anomalies. There were 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. Of important note, the active phase was only implemented temporarily at the first three locations where the radar systems were installed, prior to defaulting back to the passive phase. Defaulting back to the passive phase was not a reflection on the system performance, but rather to afford sufficient evaluation of data on the radar system performance by NCDOT and the Federal Railroad Administration. The passive phase was intended to show that the radar system is functioning as expected before modifying the gate system, and also allowed for a before and after comparison of the gate operations and motorists' behaviors. Data were collected using the same methodology in both phases.

In the following section, details on false detections and the resulting adjustment/improvements are described. These systems operated throughout four seasons in the piedmont region of North Carolina, which include a range of temperatures that can drop below freezing and exceed 100 degrees Fahrenheit. The manufacturer lists an operating temperature range of -40 degrees Fahrenheit to 165 degrees Fahrenheit with relative humidity from 0% to 95% (Appendix A).

A display based on the results from the radar were also recorded on the video as shown in the example figures in Appendix B, by site. The screen display shows the train activation 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 were configured within the geometry of the crossing island, with a buffer between the zones and the gates. Two zones were used, one in each travel direction, and both radar detectors observe both zones for redundancy.

This information was 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, local, or siding)
- Comments: Notes on unusual behavior, unique events, or other explanation as needed



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

Operational Timing

The eight stages shown in the following figure were 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.

Dynamic Stages		Pre-timed Stages
Train Detected by Approach Circuit	1	Train Detected by Approach Circuit
Entrance Gates Start Down	2	Entrance Gates Start Down
Exit Gates Start Down	3	Entrance Gates Fully Deployed
Entrance Gates Fully Deployed	4	Exit Gates Start Down
Exit Gates Fully Deployed	5	Exit Gates Fully Deployed
Train Arrives at Crossing Island	6	Train Arrives at Crossing Island
Train Leaves Crossing Island	7	Train Leaves Crossing Island
All Gates Start Up	8	All Gates Start Up
Stage 8 ends when the first car crosses the nearest railhead.		Stage 8 ends when the first car crosses the nearest railhead.

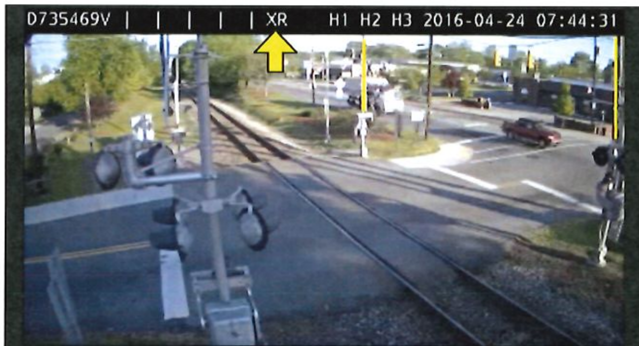
Initial detection by the approach circuit (XR on)

Stages 3 and 4 are switched for dynamic and pre-timed

Buffer time between deployed gates and train arrival

The length of stages 6 and 7 are dependent on the length and speed of the train

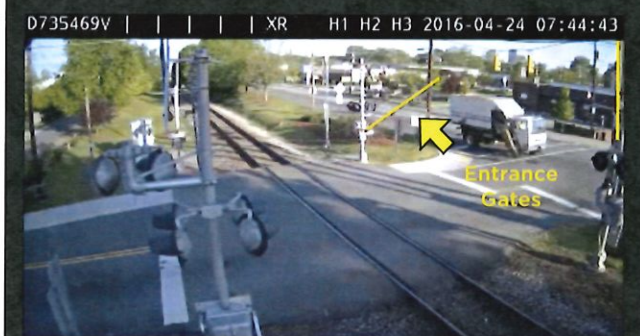
The eight stages shown below were used to track the operations of the warning devices for each crossing activation. This example is from the 3rd Street crossing in Mebane, NC at 7:44am on April 24, 2016.



Stage 1 Start Time - 07:44:31

Start Event: Train detected by appraoch circuit
Duration: 6 seconds

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.



Stage 2 Start Time - 07:44:37

Start Event: Entrance gates start down
Duration: 10 seconds

Stage 2 is the time for the entrance gates to deploy.

Stage 3 Start Time - 07:44:47

Start Event: Entrance gates fully deployed
Duration: 5 seconds

Stage 3 is the island clearance time. It should be a minimum of 3 seconds.

Stage 4 Start Time - 07:44:52

Start Event: Exit gates start down
Duration: 8 seconds

Stae 4 is the time for the exit gates to deploy and is similar to Stage 2.

Stage 5 Start Time - 07:45:00

Start Event: Exit gates fully deployed
Duration: 15 seconds

Stage 5 is the buffer time between fully deployed crossing protection and the arrival of the train.

Stage 6 Start Time - 07:45:15

Start Event: Train arrives at crossing island
Duration: 4 seconds

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.

Stage 7 Start Time - 07:45:19

Start Event: Train leaves crossing island
Duration: 8 seconds

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 Start Time - 07:44:27

Start Event: All gates start up
Duration: 6 seconds

Stage 8 is the time for the gates to ascend and to return to normal highway operations. The stage ends when the first car crosses the nearest railhead.

Detection Classification and Anomalies

During review of the video recordings, the radar detection signal was monitored to evaluate the effectiveness of the system. Though the radar system was monitoring the crossing for presence of vehicles at all times, the most critical time during an activation was stage 3, the time before the start down of the exit gate. Only those detections that occurred during stages 1-5 were recorded, as stages 6-8 had the detection disabled due to the presence of the train. One of the following conditions applied to each highway vehicle crossing or detection.

- 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.

- False Negative 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 Positive 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 possibly raise the gates if the false detection occurred after the gate descent.

A total of 5,220 activations were analyzed in pre-timed mode during this study from March 22, 2014 to October 31, 2016. Details by site are provided in the following table. All the crossings are located along the along the H-Line between Durham and Greensboro and the NS Main Line between Greensboro and Salisbury and are each traversed by six Amtrak trains throughout the day. Norfolk Southern Corporation also operates along this corridor, with an average of 7 mainline trains per day at each site. 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.

Site	Number of Activations	First Date of Analysis	Last Date of Analysis
Elon - Williamson Ave	858	March 22, 2014	October 31, 2016
Mebane - 5th Ave	800	March 22, 2014	August 10, 2016
Durham - Ellis Rd	397	March 22, 2014	October 20, 2016
Mebane - 3rd St	668	February 22, 2016	October 3, 2016
Elon - Oak Ave	631	February 22, 2016	October 31, 2016
Burlington - Elmira St	903	April 20, 2016	October 31, 2016
Kannapolis - First St	963	April 20, 2016	July 6, 2016

A total of 2,733 activations were analyzed in dynamic mode during this study from May 28, 2014 to July 31, 2015. Details by site are provided in the following table.

Site	Number of Activations	First Date of Analysis	Last Date of Analysis
Elon - Williamson Ave	1,242	May 29, 2014	July 31, 2015
Mebane - 5th Ave	656	May 28, 2014	July 31, 2014
Durham - Ellis Rd	835	May 28, 2014	July 31, 2014

Chapter 2: System Performance Evaluation

PRE-TIMED AND DYNAMIC RAILROAD GATE OPERATION COMPARISON

Each crossing activation was broken down into 8 stages based on operating conditions of the gate system (as shown in the diagram on page 7). The length of each stage was recorded from initial detection of the train by the approach circuit to when the first car crosses the railhead after the gates start up.

VEHICLE DETECTIONS BY STAGE – PRETIMED OPERATION

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. This table shows the summary of vehicle counts by stage for each location and train type. Stage 1 counts only include the last 4 seconds of stage 1 or the time when the flashing lights and bells were active. Vehicles crossing after the start down of the entrance gate were considered violating vehicles, which was stages 2 through 5.

Crossing Location by Train Type **(Pretimed Operation)**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**	**Number of System Activations**	**Number of Violating Vehicles** (Stage 2-5)	**Average Violating Vehicles per Activation**
Burlington - Elmira St	431	189	0	0	0	903	620	0.687
Amtrak	291	133	0	0	0	518	424	0.819
Freight	140	56	0	0	0	385	196	0.509
Durham - Ellis Rd	223	68	1	1	0	397	293	0.738
Amtrak	100	15	0	0	0	128	115	0.898
Freight	123	53	1	1	0	269	178	0.662
Elon - Oak Ave	267	26	1	0	2	631	296	0.469
Amtrak	188	20	0	0	2	370	210	0.568
Freight	79	6	1	0	0	261	86	0.330
Elon - Williamson Ave	396	182	0	0	0	858	578	0.674
Amtrak	283	126	0	0	0	532	409	0.769
Freight	113	56	0	0	0	326	169	0.518
Kannapolis - First St	496	89	0	0	0	963	585	0.607
Amtrak	104	23	0	0	0	223	127	0.570
Freight	392	66	0	0	0	740	458	0.619
Mebane - 3rd St	246	86	0	0	0	668	332	0.497
Amtrak	166	59	0	0	0	381	225	0.591
Freight	80	27	0	0	0	287	107	0.373
Mebane - 5th St	751	500	0	0	0	800	1251	1.564
Amtrak	457	329	0	0	0	467	786	1.683
Freight	294	171	0	0	0	333	465	1.396
Grand Total	2810	1140	2	1	2	5220	3955	0.758

VEHICLE DETECTIONS BY STAGE – DYNAMIC OPERATION

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. This table shows the summary of vehicle counts by stage for each location and train type. Stage 1 counts only include the last 4 seconds of stage 1 or the time when the flashing lights and bells were active. Vehicles crossing after the start down of the entrance gate were considered violating vehicles, which was stages 2 through 5. The changes in the duration of each stage could impact what stage vehicles are present during, relative to pretimed operation.

Crossing Location by Train Type **(Dynamic Operation)**	**Stage 1**	**Stage 2**	**Stage 3**	**Stage 4**	**Stage 5**	**Number of System Activations**	**Number of Violating Vehicles** (Stage 2-5)	**Average Violating Vehicles per Activation**
Durham - Ellis Rd	602	159	61	1	0	835	823	0.986
Amtrak	217	18	6	0	0	259	241	0.931
Freight	385	141	55	1	0	576	582	1.010
Elon - Williamson Ave	463	251	27	1	0	1242	742	0.597
Amtrak	308	184	23	1	0	762	516	0.677
Freight	155	67	4	0	0	480	226	0.471
Mebane - 5th St	613	351	49	1	1	656	1015	1.547
Amtrak	389	256	36	0	0	385	681	1.769
Freight	224	95	13	1	1	271	334	1.232
Grand Total	1678	761	137	3	1	2733	2580	0.944

FALSE POSITIVE AND FALSE NEGATIVE DETECTIONS

During the evaluation of the radar system, false negative (when a vehicle was actually present, but not detected by the system) and false positive (when a vehicle was not present, but a detection was made) detections were counted and classified. The following table summarizes the false negative and false positive detections by location and type.

Location	False Negative Detections (Vehicle Present, Not Counted)		False Positive Detections (Vehicle Not Present, Counted)				
	Radar Zone Size	Speed of Vehicle	Detection After IR Activates	Equipment Malfunction	No Apparent Cause	Rain or Snow	Vehicle from Adjacent Lane
Burlington - Elmira St	3[a]	1[c]	32[f]	0	0	0	0
Durham - Ellis Rd	0	0	9[g]	0	0	0	1[m]
Elon - Oak Ave	0	0	0	0	0	0	0
Elon - Williamson Ave	1[b]	4[d]	0	0	3[i]	2[k]	2[n]
Kannapolis - First St	0	0	0	1[h]	0	0	0
Mebane - 3rd St	0	0	0	0	0	0	0
Mebane - 5th St	0	6[e]	0	0	4[j]	1[l]	0
Total	4	11	41	1	7	3	3
Percent of Total Activations Evaluated (7,953 activations)	0.05%	0.14%	0.52%	0.01%	0.09%	0.04%	0.04%

Notes:

a = May 16 through May 20, 2016
b = July 29, 2015
c = July 17, 2016
d = July 30, 2015 through July 12, 2016
e = July 29 through July 31, 2016
f = August 05 through October 31, 2016
g = April 11 through April 12, 2014, September 17 through October 20, 2016
h = July 02, 2016
i = April 07, 2014 through July 31, 2015
j = March 22 through April 04, 2014
k = March 23, 2014
l = March 23, 2014
m = March 22, 2014
n = June 24, 2015 through June 27, 2016

The following subsections describe the false positive and false negative detections as summarized in the table. Information about the type of improvement required, the potential source of the error, and other specifics of the radar system were provided by Island Radar.

Radar Zone Size

This missed detection type was corrected (no further observations of missed detections were made) after adjustments were made to increase the lane width (actual lane width at the crossing was wider than a presumed standard lane width) and a decrease in the integration time (with a small crossing area, a vehicle may pass through the crossing more quickly than the detection threshold). At the location, Elmira Street, measures lane width at the crossing are 15 feet and 23.5 feet, compared to the default radar configuration of 12 feet. The vehicles which were observed were traveling quickly through the intersection and in an "S" curve pattern (left onto the crossing from the cross street and then an immediate right on the adjacent cross street) which resulted in a clipping of the detection zone instead of a full cross of the zone. Three elements can be adjusted to overcome this detection: 1) adjusting the lane width dimensions to match actual conditions, 2) adjust the zone detection width to match the lane width, and 3) decrease the integration time to capture more vehicles.

Speed of Vehicle

Speeds above 30 mph reduce the vehicle's time in the island below that of what is needed to detect the vehicle, this can lead to a small percentage of missed detections. This type of missed detection can occur when higher vehicle speeds (due to a flat roadway surface) are combined with short-duration vehicle presence (due to a short crossing of a single track). In the intended use of the system, this type of missed detection may not be a high priority to reduce because the vehicle is unlikely to be stopped on the tracks prior to the deployment of the exit gate.

Detection After IR Activates

This false detection occurred momentarily after the train cleared the crossing. Therefore, this false detection is likely not a target for improvement. Whether a loop system or a radar system, trains can sometimes be detected while in the crossing island. Typically, the IR signal from the railroad equipment disables detection outputs during the time the train is on the crossing island to mask these detections. Because any detection - even random detections that might be the result of trains - are programmed to have a 2 second extend period, these extended detection signals can become visible for up to 2 seconds after the train has cleared the island and the IR signal is restored to its normal state.

Equipment Malfunction

Equipment malfunction (on the video display and not with the radar system itself) likely due to high temperatures. The text generator embedded processor was not communicating new information to the video display. This processor is separate from the radar system and did not have the industrial temperature grade components on the board that receives detection status information from the VDR24 Radar Controller Aux port. As a result, the updates feeding the video camera image could be delayed or missed altogether. The upper temperature specification on the parts to which was 158 degrees Fahrenheit. At the time of the malfunction, the temperature 93 degrees Fahrenheit in the area with the afternoon sun shining from the west directly on the front of the cabinet. With the minimal cabinet ventilation and the other components self-heating in the closed cabinet, it is likely that the upper temperature specification was periodically exceeded. The text generator component was replaced and this process was embedded inside the VDR24 Radar Controller (which has high temperature capabilities up to 185 degree Fahrenheit).

No Apparent Cause

Unknown cause and solution. These seven observations were from periods of time early in the life of the equipment and firmware (2014 and 2015). Subsequent improvements in firmware, heavy weather optimization, and dynamic background processing have apparently minimized these effects as none have occurred in more than two years.

Rain or Snow

Reflection from rain/snow triggers radar. These three observations were from periods of time early in the life of the equipment and firmware (2014 and 2015). Subsequent improvements in firmware, heavy weather optimization, and dynamic background processing appear to have minimized these effects.

Vehicle from Adjacent Lane

Vehicle in one lane is detected in both zones. Detection could be a result of overlapping detection zones or large vehicles.

Gate Ascent from Train Detection

With any detection system (inductive loops, radar, etc.), trains that move over the island are detected as an object on the crossing. To prevent trains from being misinterpreted as vehicles, and thereby initiating exit gate ascent, railroads typically use the island relay (IR) to prevent the railroad's crossing controller from raising the exit gates. The IR signal is a standard signal that indicates a train is occupying the crossing. At the first radar installations in this effort, observations were made that the radar-based vehicle detection system detected trains entering the crossing an instant before the railroad's equipment could react to its own IR relay, causing the exit gates to sometimes begin an ascent sequence, at least until the railroad's IR state was processed by the railroad's crossing controller equipment. The gates then return to the fully deployed position. To mitigate this effect two adjustments to the system were made: 1) the railroad's IR signal was used to mask radar system detections so that no detections were provided to the railroad's crossing controller systems during an IR state and 2) the radar system was slowed down by programming a short delay into the detection process (typically 200msec). This observation led to the consideration at further installations to evaluate the potential effect when slower DC circuits are replaced by high-speed processor-based solutions. The ability to adjust the programming of these timing variables provides an opportunity to mitigate the concerns.

SYSTEM EFFECTS ON ALL GATES DEPLOYED - STAGE 5 CHARACTERISTICS

In the three locations which operated in both pretimed and dynamic modes, the duration of stage 5 increased substantially. Stage 5 is the time between the point when all four gates are fully deployed and the arrival of the train.

Stage 5: All gates are down.

Location	Stage 5 Time (sec)		Time Increase	
	Pretimed	Dynamic	Time (sec)	Percent (%)
Elon - Williamson Ave	20	36	16	**82%**
Mebane - 5th Ave	7	20	13	**199%**
Durham - Ellis Rd	10	19	9	**87%**

Chapter 3: Findings and Conclusions

Vehicle detection at a crossing 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 detected on the crossing. Radar detection allows for non-intrusive sensing at the crossing, which allows for detection over the whole crossing area including the tracks, and is expected to increase the service life of the sensor, while reducing maintenance costs. Radar detection has been shown to be as effective at detecting vehicles as loop-based intrusive sensing.

This observational study featured video recordings of crossing activations, which were then reviewed for warning device operation times, vehicle counts during the activation, and radar detection classification. The study briefly investigated 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 time between the point when all four gates are fully deployed and the arrival of the train provides a buffer between vehicles and the approaching train. In the three locations which operated in both pre-timed and dynamic modes, the duration of the buffer, referred to as Stage 5 in this effort, increased substantially (by 82% at the Williamson Avenue site in Elon, 87% at the Ellis Road site in Durham, and 199% at the 5th Avenue site in Mebane).

Within the scope of this evaluation effort which included over 7,953 system activations, the radar system operated at a reliability of 99.81% in the correct detection of vehicles who were present (total of 15 false negative detections). Of the missed detections (false negative detections), four of the instances occurred related to the size of the detection zone, which was adjusted and no further missed detections were recorded during the evaluation. The other eleven false negative detections were related to the speed of the vehicles, particularly those with speeds above 30 mph, which reduce the vehicle's time in the crossing below that of what is needed to detect the vehicle. In the intended use of the system, this type of speed-related missed detection may not be a high priority to reduce because the vehicle is unlikely to be stopped on the tracks prior to the deployment of the exit gate.

There were also 55 system activations which had a false positive detection (vehicle was not present, but one was counted as being present). The majority (41 of the 55) of false positive detections occurred as a result of the train and was present momentarily after the train cleared the crossing - this false detection is likely not a target for improvement. The remaining false positive detections are described in this report in detail.

The systematic review of the crossing activations provided useful feedback to improve the characteristics of the system. Prior to implementation of dynamic EGOM using the radar system, a thorough review of the operational reliability for site specific characteristics should be conducted at each individual crossing with the system running in the passive mode to determine potential mis-characterizations or errors. Based on the effort detailed in this report, slight modifications to the settings can reduce the potential for these miscalculations and errors. Additionally, an evaluation of detection systems in passive (in-active) mode is recommended to allow for system observations before it controls the active rail line. The NCDOT would propose using a 90-day observation period. Based on this study, it can be concluded that the radar system selected for evaluation can perform at the same level of effectiveness as inductive detection loops after site specific adjustments to the system settings have been implemented.

Chapter 4: References

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[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: Radar System Details

VDR24 Vehicle Detection Radar

Two Radars/Four Zones/Intelligent Correspondence Verification

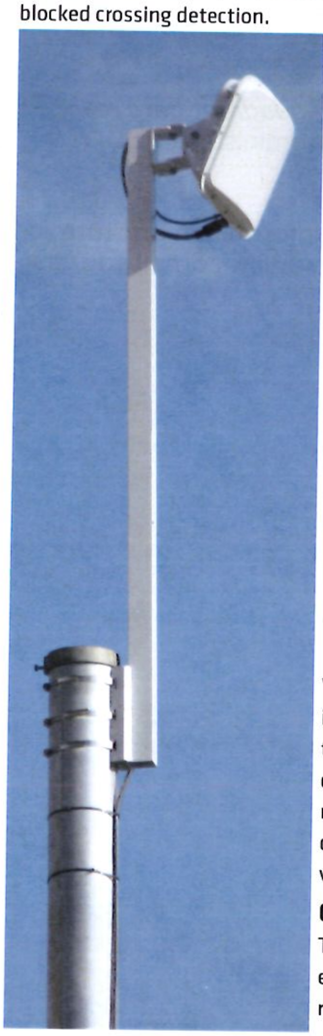
ISLAND RADAR
get out of the road

- Accurate vehicle detection for four-quadrant gate crossing warning systems
- Blocked crossing and obstacle detection
- Detects moving and stopped vehicles, all-weather performance
- Non-embedded system mounts above and outside the crossing island
- Multiple, user-configured detection zones cover the entire crossing island
- Full, multiple redundancy – 16 radar beams per sensor cover every square foot of the crossing island
- Continuous, Intelligent Correspondence Verification, Vital architecture, and failsafe operation

A Non-Embedded, Superior Alternative to Buried Presence Detection Loops
Lower Cost - Longer Life - 100% Redundancy - Proven - Vital Architecture

The Island Radar VDR24 Solution to Dynamic Exit Gate Control

The Island Radar provides reliable vehicle detection without the short life, maintenance problems, and train delay consequences of buried loop sensors. It uses SmartSensor™ Rail radar technology from Wavetronix along with AREMA-compliant controller from the Island Radar Company to implement Dynamic Exit Gate Clearance Time in four-quadrant gate-crossing warning systems and blocked crossing detection.



Exit Gate Control and Blocked Crossing Detection

The Island Radar is specifically designed for detecting vehicles at crossings and influencing exit gate behavior. The system can also detect vehicles that have been stopped, stored, or deliberately placed in the crossing island for longer than a programmable period of time, communicating that urgent information to railroad personnel over any available communication link - cellular, data networks, and even the future PTC wireless infrastructure.

Non-Roadway Installation - Up to 10 Lanes and 16 Zones

Radar sensors may be mounted on entrance gate masts or on stand-alone poles adjacent to the track right-of-way, at the edge of the Minimum Track Clearance Distance zone. The sensors work together to provide fully redundant vehicle detections, and each unit continuously self-checks and cross-checks the other(s). Each sensor's 90-degree, 140-foot detection range completely covers most crossings, recognizing lanes of traffic and detecting the presence of moving or stopped vehicles in up to ten lanes and up to 16 user-configured detection zones. Each zone can be assigned to any of four output channels that connect to crossing controller or relay circuitry to operate exit gates in Dynamic Mode.

Intelligent Correspondence Verification, Failsafe Operation

Redundant radar sensors undergo continuous self-check cycles and constantly cross-check each other to verify radar positioning and zone locations. Any radar performance anomaly or loss of correspondence instantly trips Health circuits and reverts the crossing to Timed Mode operation.

Established Technology - All Weather Performance

Wavetronix is the world leader in radar-based vehicle detection for traffic intersection control and intelligent transportation applications. Proven in thousands of highway and intersection applications worldwide, the Wavetronix technology is unaffected by conditions that interfere with video detection systems, including rain, snow, dust and fog. Highly intuitive configuration tools automatically discover lanes of traffic, stop bars, and crossing island dimensions. Lanes and individual detection zones can be set up in any shape or size, on a configuration screen that shows detected vehicle icons traversing the island in real time.

Crossing Controller Interfaces

The Island Radar solution features isolated optical and relay interface options for any make, model, or vintage of crossing controllers. Electrical surge protection and isolation meet or exceed the requirements of IEC 61000-4-5 class 4 and AREMA 11.3.3 Class C, respectively.

Radar Sensor

Environmental

- Operating frequency: 24.0-24.5GHz (K Band)
- Operating temperature: -40°C to 74°C (-40°F to 165°F), 0 to 95% RH (non-condensing)
- Storage temperature: -49°F to 185°F (-45°C to +85°C)

Physical

- Weight: 4.2 lbs (1.9 kg)
- Physical dimensions: 13.2 in × 10.6 in × 3.3 in (33.5 cm × 26.9 cm × 8.4 cm)
- Mounting method: 18 to 22 ft height (5.5 m to 6.7 m), on approved mounting bracket, unobstructed by any foreground structures
- Resistant to corrosion, fungus, moisture deterioration, and ultraviolet rays
- Lexan EXL polycarbonate enclosure, outdoor weatherability: UL 746C
- NEMA 250 compliance:
  - Watertight per NEMA 250
  - External icing (clause 5.6), hose down (clause 5.7)
  - 4X corrosion protection (clause 5.10)
  - Gasket (clause 5.14)
  - Withstands 5 ft (1.5 m) drop
  - MIL-C-26482 Connector
  - Rotational backplate for 360° of roll

Regulatory and Certification Testing, Other

- RFI: FCC part 15.249
- MTBF: Prediction and temperature-based margin analysis per MIL-HDBK-217F, FN2, >10 Years
- Surge Protection: per IEC 61000-4-5 class 4
- Two-year warranty against material and workmanship defects
- Full Extended Warranty options up to five years

VDR24 Controller

Electrical

- Input Voltage: 9-30VDC AREMA-Compliant Power Supply (Class C Equipment)
- Power consumption: 30W, includes radar sensor power distribution
- Surge protected RS-485 communication ports to radar sensor

Environmental

- Operating temperature: -40°F to +158°F (-40°C to +70°C), 0-95% RH, non-condensing per AREMA 11.5.1 Class C
- Storage temperature: -49°F to 185°F (-45°C to +85°C)
- Vibration: per AREMA 11.15.1
- EMI: per AREMA 11.15.1
- Isolation, Protection, and Dielectric Breakdown: per AREMA 11.3.3

Physical

- Weight: 1.5 lbs (0.7 kg)
- Physical dimensions: 6 in × 8 in × 3 in (15.2 cm × 20.3 cm × 7.6 cm), inclusive of mounting flanges
- Mounting method: flange mounting, four screws, vertically on a wood or other non-conductive back panel surface
- Recommended mounting clearance: 5 in (12.7 cm) minimum on each side, 18 in (45.7 cm) minimum horizontal

Regulatory and Certification Testing, Other

- MTBF: Prediction and temperature-based margin analysis per MIL--HDBK-217F, FN2, >10 Years
- RFI: FCC part 15C
- Surge Protection: per IEC 61000-4-5 class 4
- Two-year warranty against material and workmanship defects
- Full Extended Warranty options up to five years

Standard Components, Dual-Radar Detection System		
Part Name	Part Number	Typical Quantity
SmartSensor™- Rail Radar Sensor	RAD-0500-00	2
VDR24 Dual Radar Controller	RAD-0101-00	1
Elevated Mounting Bracket	MNT-0104-00	2
Mast Riser Cable, 40-Feet	CAB-0103-00	2
Mast Base Junction Box	ENC-0101-00	2
Home Run Cable, Direct Burial Rated	CAB-0106-00	Up to 600 Feet per Sensor

Parts shown above represent a typical installation utilizing gate mast mounting. Additional options are available for dedicated mast mounting, self-contained cabinets with UPS, and video-enabled remote monitoring and control. Contact Island Radar Company for guidance and recommendations regarding optimum solutions for particular crossings. CAD drawings characterizing various installation and radar siting options may be downloaded from the Island Radar website at www.islandradar.com/downloads.

ISLAND RADAR
get out of the road

Phone: (816) 256-4499
Fax: (816) 256-4454
E-mail: info@islandradar.com
Website: www.islandradar.com

Powered by
WAVETRONIX

March 2016

Appendix B: Site Operational Characteristics

Appendix B.1

PRE-TIMED RAILROAD GATE OPERATION

Burlington - *Elmira Street*

The eight stages shown below are used to track the operations of the warning devices for each crossing activation. This information is based on 559 activations between April 20, 2016 and July 21, 2016.

	Pre-timed Stages	Start/End Event	Avg. Time
1	**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.	Train Detected by Approach Circuit	5 seconds
2	**Stage 2** is the time for the entrance gates to deploy.	Entrance Gates Start Down	10 seconds
3	**Stage 3** is the island clearance time. It should be a minimum of 3 seconds.	Entrance Gates Fully Deployed	5 seconds
4	**Stage 4** is the time for the exit gates to deploy and is similar to Stage 2.	Exit Gates Start Down	8 seconds
5	**Stage 5** is the buffer time between fully deployed crossing protection and the arrival of the train.	Exit Gates Fully Deployed	10 seconds
6	**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.	Train Arrives at Crossing Island	27 seconds
7	**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.	Train Leaves Crossing Island	8 seconds
8	**Stage 8** is the time for the gates to ascend and to return to normal highway operations.	All Gates Start Up	10 seconds

38 seconds	**61** seconds	**7** seconds	18 seconds	Stage 8 ends when the first car crosses the nearest railhead.	Total Avg. Time: **82 seconds**
Avg. Time Prior to Train Arrival (Stages 1 to 5)	**Avg. Time Freight Train is Present** (Stage 6)	**Avg. Time Passenger Train is Present** (Stage 6)	**Time When First Car Arrives** (Stages 7 and 8)		

RAILROAD CROSSING EVENT - Stage 2

Burlington - *Elmira Street*

August 5, 2016
2:55pm

Summary: A vehicle stops in the crossing island after the train has been deteced. The entrance gates start down. A cyclist moves around the vehicle and enters the island. The vehicle backs up to avoid the entrance gates.

Time: 14:55:56

Train Arrival Time: 78 seconds

Time from Flashing Lights: 3 seconds

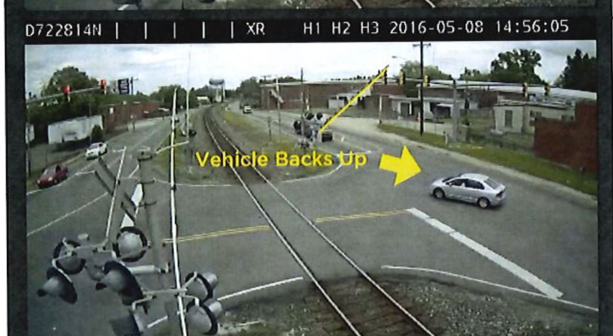
Vehicle stops in the crossing island after the train has been detected.

Time: 14:55:59

Train Arrival Time: 75 seconds

Time from Flashing Lights: 6 seconds

Cyclist moves around the vehicle and enters the crossing island.



Time: 14:56:05

Train Arrival Time: 29 seconds

Time from Flashing Lights: 12 seconds

Vehicle backs up to avoid the descending entrance gate.

Time: 14:56:34

Train Arrival

Train Speed: Approximately 35 mph

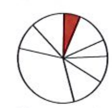
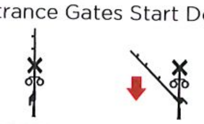
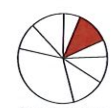
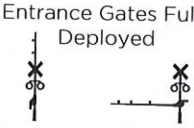
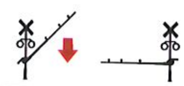
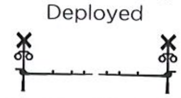
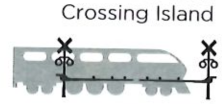
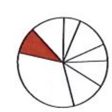
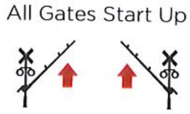
Train arrives to crossing island.

Appendix B.2

PRE-TIMED RAILROAD GATE OPERATION

Elon - *Oak Avenue*

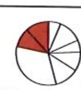
The eight stages shown below are used to track the operations of the warning devices for each crossing activation. This information is based on 494 activations between February 22, 2016 and July 16, 2016.

	Pre-timed Stages	Start/End Event	Avg. Time
1	**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.	Train Detected by Approach Circuit 	 6 seconds
2	**Stage 2** is the time for the entrance gates to deploy.	Entrance Gates Start Down 	 9 seconds
3	**Stage 3** is the island clearance time. It should be a minimum of 3 seconds.	Entrance Gates Fully Deployed 	 8 seconds
4	**Stage 4** is the time for the exit gates to deploy and is similar to Stage 2.	Exit Gates Start Down 	 8 seconds
5	**Stage 5** is the buffer time between fully deployed crossing protection and the arrival of the train.	Exit Gates Fully Deployed 	 11 seconds
6	**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.	Train Arrives at Crossing Island 	 32 seconds
7	**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.	Train Leaves Crossing Island 	 4 seconds
8	**Stage 8** is the time for the gates to ascend and to return to normal highway operations.	All Gates Start Up 	 11 seconds

41 seconds
Avg. Time Prior to Train Arrival
(Stages 1 to 5)

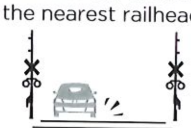
72
seconds
Avg. Time Freight Train is Present
(Stage 6)

6
seconds
Avg. Time Passenger Train is Present
(Stage 6)



15 seconds
Time When First Car Arrives
(Stages 7 and 8)

Stage 8 ends when the first car crosses the nearest railhead.



Total Avg. Time:
89 seconds

RAILROAD CROSSING EVENT - Stage 5 Elon - *Oak Avenue*
June 30, 2016
1:09pm

Summary: Cyclists enter the crossing island after all gates are fully deployed. They enter through the gates, cross the island, and exit through the gates while the train is approaching. The train arrives at the crossing island 8 seconds after cyclists exit.

Time: 13:09:15

Train Arrival Time: 13 seconds

Time from Flashing Lights: 38 seconds

Cyclists enter crossing island after gates are fully deployed.

Time: 13:09:20

Train Arrival Time: 8 seconds

Train Speed: Approximately 55-60 mph

Cyclists cross the island as train approaches.

Time: 13:09:28

Train Arrival

Appendix B.3

PRE-TIMED RAILROAD GATE OPERATION

Mebane - *3rd Street*

The eight stages shown below are used to track the operations of the warning devices for each crossing activation. This information is based on 405 activations between February 22, 2016 and July 19, 2016.

	Pre-timed Stages	Start/End Event	Avg. Time
1	**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.	Train Detected by Approach Circuit	6 seconds
2	**Stage 2** is the time for the entrance gates to deploy.	Entrance Gates Start Down	9 seconds
3	**Stage 3** is the island clearance time. It should be a minimum of 3 seconds.	Entrance Gates Fully Deployed	6 seconds
4	**Stage 4** is the time for the exit gates to deploy and is similar to Stage 2.	Exit Gates Start Down	8 seconds
5	**Stage 5** is the buffer time between fully deployed crossing protection and the arrival of the train.	Exit Gates Fully Deployed	12 seconds
6	**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.	Train Arrives at Crossing Island	29 seconds
7	**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.	Train Leaves Crossing Island	7 seconds
8	**Stage 8** is the time for the gates to ascend and to return to normal highway operations.	All Gates Start Up	7 seconds

41 seconds	70 seconds	6 seconds	14 seconds	Stage 8 ends when the first car crosses the nearest railhead.	Total Avg. Time: **84 seconds**
Avg. Time Prior to Train Arrival (Stages 1 to 5)	**Avg. Time Freight Train is Present** (Stage 6)	**Avg. Time Passenger Train is Present** (Stage 6)	**Time When First Car Arrives** (Stages 7 and 8)		

RAILROAD CROSSING EVENT - Stage 2

Mebane - *3rd Street*

April 17, 2016
7:56pm

Summary: A vehicle races the train to reach the crossing isalnd after the entrance gates have already been activated. The vehicle enters the island, swerving to avoid the gate.

Time: 19:56:40

Train Arrival Time: 25 seconds
Time from Flashing Lights: 12 seconds

Vehicle races the train to reach the crossing island.

Time: 19:56:41

Train Arrival Time: 24 seconds
Time from Flashing Lights: 13 seconds

Vehicle enters the crossing island.
Entrance gates almost fully deployed.

Time: 19:56:42

Train Arrival Time: 23 seconds
Time from Flashing Lights: 14 seconds

Vehicle exits crossing before the entrance gates are fully deployed.

Time: 19:57:06

Train Arrival
Train Speed: Approximately 35 mph

Train arrives to crossing island.

Appendix B.4

PRE-TIMED RAILROAD GATE OPERATION

Elon - *Williamson Avenue*

The eight stages shown below are used to track the operations of the warning devices for each crossing activation. This information is based on 556 activations between March 22, 2014 and May 29, 2014.

	Pre-timed Stages	Start/End Event	Avg. Time
1	**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.	Train Detected by Approach Circuit	4 seconds
2	**Stage 2** is the time for the entrance gates to deploy.	Entrance Gates Start Down	8 seconds
3	**Stage 3** is the island clearance time. It should be a minimum of 3 seconds.	Entrance Gates Fully Deployed	12 seconds
4	**Stage 4** is the time for the exit gates to deploy and is similar to Stage 2.	Exit Gates Start Down	6 seconds
5	**Stage 5** is the buffer time between fully deployed crossing protection and the arrival of the train.	Exit Gates Fully Deployed	20 seconds
6	**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.	Train Arrives at Crossing Island	32 seconds
7	**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.	Train Leaves Crossing Island	5 seconds
8	**Stage 8** is the time for the gates to ascend and to return to normal highway operations.	All Gates Start Up	8 seconds

50 seconds	71 seconds	6 seconds	13 seconds
Avg. Time Prior to Train Arrival (Stages 1 to 5)	**Avg. Time Freight Train is Present** (Stage 6)	**Avg. Time Passenger Train is Present** (Stage 6)	**Time When First Car Arrives** (Stages 7 and 8)

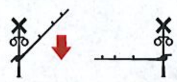
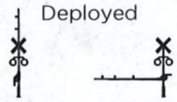
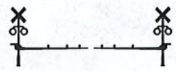
Stage 8 ends when the first car crosses the nearest railhead.

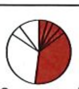
Total Avg. Time: **95 seconds**

PRE-TIMED RAILROAD GATE OPERATION

Elon - *Williamson Avenue*

The eight stages shown below are used to track the operations of the warning devices for each crossing activation. This information is based on 1242 activations between May 29, 2014 and July 31, 2014.

	Dynamic Stages	Start/End Event	Avg. Time
1	**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.	Train Detected by Approach Circuit 	 4 seconds
2	**Stage 2** is the time for the entrance gates to deploy.	Entrance Gates Start Down 	 3 seconds
3	**Stage 3** is the time for the exit gates to deploy and is similar to Stage 2. ***This stage was labeled as 4 in the before period.***	Exit Gates Start Down 	 4 seconds
4	**Stage 4** is the island clearance time. It should be a minimum of 3 seconds. ***This stage was labeled as 3 in the before period.***	Entrance Gates Fully Deployed 	 3 seconds
5	**Stage 5** is the buffer time between fully deployed crossing protection and the arrival of the train.	Exit Gates Fully Deployed 	 36 seconds
6	**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.	Train Arrives at Crossing Island 	 31 seconds
7	**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.	Train Leaves Crossing Island 	 5 seconds
8	**Stage 8** is the time for the gates to ascend and to return to normal highway operations.	All Gates Start Up 	 10 seconds
		Stage 8 ends when the first car crosses the nearest railhead. 	Total Avg. Time: **95 seconds**



50 seconds
Avg. Time Prior to Train Arrival
(Stages 1 to 5)

72
seconds
Avg. Time Freight Train is Present
(Stage 6)

5
seconds
Avg. Time Passenger Train is Present
(Stage 6)

15 seconds
Time When First Car Arrives
(Stages 7 and 8)

RAILROAD CROSSING EVENT - Stage 4
July 23, 2015
9:00am

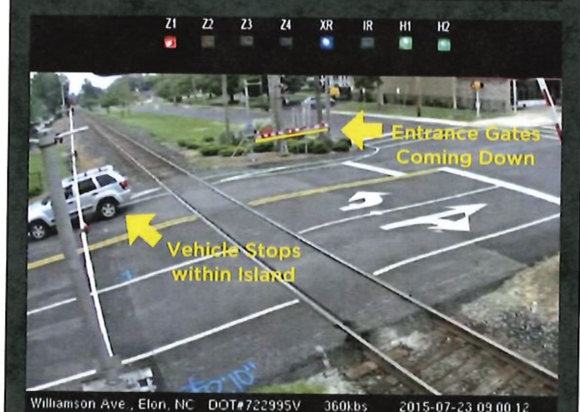
Elon - *Williamson Avenue*

Summary: A vehicle enters the crossing island after the warning signal. The vehicle crosses the island but stops within the gates. The gates begin to come down but the vehicle is detected by the radar system which delays the exit gate from being fully deployed (as intended by the system). The train arrives after the vehicle exists the island.

Time: 9:00:10

Train Arrival Time: 43 seconds

Vehicle enters crossing island after warning signal.



Time: 9:00:12

Train Arrival Time: 41 seconds
Train Speed: Approximately 55-60 mph

Vehicle stops within crossing island. Gates begin to come down.

Time: 9:00:54

Train Arrival

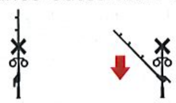
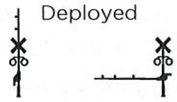
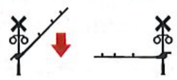
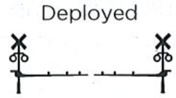
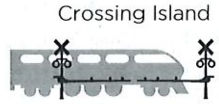
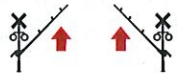
Vehicle exits island before train arrival.

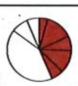
Appendix B.5

PRE-TIMED RAILROAD GATE OPERATION

Mebane - *5th Street*

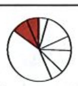
The eight stages shown below are used to track the operations of the warning devices for each crossing activation. This information is based on 575 activations between March 22, 2014 and May 28, 2014.

	Pre-timed Stages	Start/End Event	Avg. Time
1	**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.	Train Detected by Approach Circuit 	 4 seconds
2	**Stage 2** is the time for the entrance gates to deploy.	Entrance Gates Start Down 	 13 seconds
3	**Stage 3** is the island clearance time. It should be a minimum of 3 seconds.	Entrance Gates Fully Deployed 	 7 seconds
4	**Stage 4** is the time for the exit gates to deploy and is similar to Stage 2.	Exit Gates Start Down 	 11 seconds
5	**Stage 5** is the buffer time between fully deployed crossing protection and the arrival of the train.	Exit Gates Fully Deployed 	 6 seconds
6	**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.	Train Arrives at Crossing Island 	 39 seconds
7	**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.	Train Leaves Crossing Island 	 8 seconds
8	**Stage 8** is the time for the gates to ascend and to return to normal highway operations.	All Gates Start Up 	 6 seconds


41 seconds
Avg. Time Prior to Train Arrival
(Stages 1 to 5)

85
seconds
Avg. Time Freight Train is Present
(Stage 6)

6
seconds
Avg. Time Passenger Train is Present
(Stage 6)


14 seconds
Time When First Car Arrives
(Stages 7 and 8)

Stage 8 ends when the first car crosses the nearest railhead.

Total Avg. Time:
94 seconds

PRE-TIMED RAILROAD GATE OPERATION

Mebane - *5th Street*

The eight stages shown below are used to track the operations of the warning devices for each crossing activation. This information is based on 656 activations between May 28, 2014 and July 31, 2014.

	Dynamic Stages	Start/End Event	Avg. Time
1	**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.	Train Detected by Approach Circuit	4 seconds
2	**Stage 2** is the time for the entrance gates to deploy.	Entrance Gates Start Down	5 seconds
3	**Stage 3** is the time for the exit gates to deploy and is similar to Stage 2. ***This stage was labeled as 4 in the before period.***	Exit Gates Start Down	6 seconds
4	**Stage 4** is the island clearance time. It should be a minimum of 3 seconds. ***This stage was labeled as 3 in the before period.***	Entrance Gates Fully Deployed	5 seconds
5	**Stage 5** is the buffer time between fully deployed crossing protection and the arrival of the train.	Exit Gates Fully Deployed	20 seconds
6	**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.	Train Arrives at Crossing Island	36 seconds
7	**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.	Train Leaves Crossing Island	8 seconds
8	**Stage 8** is the time for the gates to ascend and to return to normal highway operations.	All Gates Start Up	6 seconds
	40 seconds **Avg. Time Prior to Train Arrival** (Stages 1 to 5) **79** seconds **Avg. Time Freight Train is Present** (Stage 6) **6** seconds **Avg. Time Passenger Train is Present** (Stage 6) 14 seconds **Time When First Car Arrives** (Stages 7 and 8)	Stage 8 ends when the first car crosses the nearest railhead.	Total Avg. Time: **92 seconds**

RAILROAD CROSSING EVENT - Stage 4 Mebane - *5th Street*
June 5, 2014
10:47am

Summary: A motor cyclist stops in front of fully deployed entrance gate. The motor cyclist drives around the gate and crosses the island before the train arrives.

Time: 10:47:26

Train Arrival Time: 42 seconds
Time from Flashing Lights: 15 seconds

Motor cyclist stopped in front of deployed entrance gate.

Time: 10:47:30

Train Arrival Time: 38 seconds
Time from Flashing Lights: 19 seconds

Motor cyclist drives around gate.

Time: 10:47:31

Train Arrival Time: 37 seconds
Train Speed: Approximately 35-40 mph

Motor cyclist crosses island.

Time: 10:48:08

Train Arrival

Appendix B.6

PRE-TIMED RAILROAD GATE OPERATION

Durham - *Ellis Road*

The eight stages shown below are used to track the operations of the warning devices for each crossing activation. This information is based on 299 activations between March 22, 2014 and May 28, 2014.

	Pre-timed Stages	Start/End Event	Avg. Time
1	**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.	Train Detected by Approach Circuit	12 seconds
2	**Stage 2** is the time for the entrance gates to deploy.	Entrance Gates Start Down	6 seconds
3	**Stage 3** is the island clearance time. It should be a minimum of 3 seconds.	Entrance Gates Fully Deployed	6 seconds
4	**Stage 4** is the time for the exit gates to deploy and is similar to Stage 2.	Exit Gates Start Down	7 seconds
5	**Stage 5** is the buffer time between fully deployed crossing protection and the arrival of the train.	Exit Gates Fully Deployed	12 seconds
6	**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.	Train Arrives at Crossing Island	132 seconds
7	**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.	Train Leaves Crossing Island	10 seconds
8	**Stage 8** is the time for the gates to ascend and to return to normal highway operations.	All Gates Start Up	12 seconds
	43 seconds **Avg. Time Prior to Train Arrival** (Stages 1 to 5); **210** seconds **Avg. Time Freight Train is Present** (Stage 6); **5** seconds **Avg. Time Passenger Train is Present** (Stage 6); 19 seconds **Time When First Car Arrives** (Stages 7 and 8)	Stage 8 ends when the first car crosses the nearest railhead.	Total Avg. Time: **198 seconds**

PRE-TIMED RAILROAD GATE OPERATION

Durham - *Ellis Road*

The eight stages shown below are used to track the operations of the warning devices for each crossing activation. This information is based on 835 activations between May 28, 2014 and July 31, 2014.

	Dynamic Stages	Start/End Event	Avg. Time
1	**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.	Train Detected by Approach Circuit	11 seconds
2	**Stage 2** is the time for the entrance gates to deploy.	Entrance Gates Start Down	3 seconds
3	**Stage 3** is the time for the exit gates to deploy and is similar to Stage 2. ***This stage was labeled as 4 in the before period.***	Exit Gates Start Down	5 seconds
4	**Stage 4** is the island clearance time. It should be a minimum of 3 seconds. ***This stage was labeled as 3 in the before period.***	Entrance Gates Fully Deployed	4 seconds
5	**Stage 5** is the buffer time between fully deployed crossing protection and the arrival of the train.	Exit Gates Fully Deployed	19 seconds
6	**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.	Train Arrives at Crossing Island	110 seconds
7	**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.	Train Leaves Crossing Island	13 seconds
8	**Stage 8** is the time for the gates to ascend and to return to normal highway operations.	All Gates Start Up	12 seconds

42 seconds	**162** seconds	**6** seconds	25 seconds	Stage 8 ends when the first car crosses the nearest railhead.	Total Avg. Time: **177 seconds**
Avg. Time Prior to Train Arrival (Stages 1 to 5)	**Avg. Time Freight Train is Present** (Stage 6)	**Avg. Time Passenger Train is Present** (Stage 6)	**Time When First Car Arrives** (Stages 7 and 8)		

RAILROAD CROSSING EVENT - Stage 4
April 7, 2014
9:00am

Durham - *Ellis Road*

Summary: A vehicle stopped in a left turn lane goes around another vehicle and turns left toward the crossing island, after the gates are coming down. The vehicle goes around the fully deployed entrance gates and enters the island. The train arrives after the vehicle exists.

Time: 9:00:15

Train Arrival Time: 38 seconds
Time from Flashing Lights: 7 seconds

Vehicle stopped in left turn lane behind another vehicle.

Time: 9:00:15

Train Arrival Time: 31 seconds
Time from Flashing Lights: 14 seconds

Vehicle moves into the through lane, goes around the other and turns left. Entrance gates are fully deployed.

Time: 13:09:20

Train Arrival Time: 26 seconds
Train Speed: Approximately 5 mph

Vehicle goes around the entrance gates and enters the crossing island.

Time: 13:09:28

Train Arrival

Vehicle exits island before train arrives.

RAILROAD CROSSING EVENT - Stage 4 Durham - *Ellis Road*
July 28, 2014
7:08pm

Summary: A vehicle is stopped in the westbound left turn lane on Angier Avenue. The vehicle turns left into northbound lanes and enters the crossing island as gates are coming down. A second vehicles follows the same path.

Time: 19:08:00

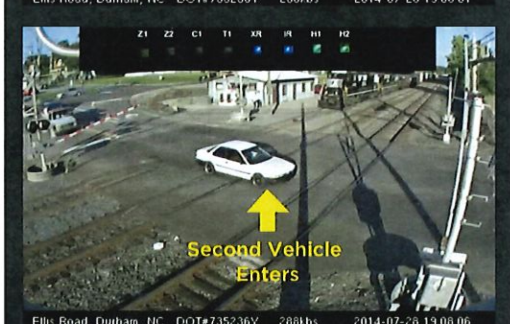
Train Arrival Time: 20 seconds
Time from Flashing Lights: 3 seconds

Vehicle turns left into northbound lanes.

Time: 19:08:01

Train Arrival Time: 19 seconds
Time from Flashing Lights: 4 seconds

Vehicle enters crossing island as gates are coming down. Second vehicle turns left into northbound lanes.



Time: 19:08:06

Train Arrival Time: 14 seconds
Time from Flashing Lights: 9 seconds

Second vehicle follows the same path.

Time: 19:08:20

Train Arrival
Train Speed: Approximately 3-5 mph

Appendix B.7

PRE-TIMED RAILROAD GATE OPERATION

Kannapolis - *First Street*

The eight stages shown below are used to track the operations of the warning devices for each crossing activation. This information is based on 963 activations between April 25, 2016 and July 6, 2016.

	Pre-timed Stages	Start/End Event	Avg. Time
1	**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.	Train Detected by Approach Circuit	9 seconds
2	**Stage 2** is the time for the entrance gates to deploy.	Entrance Gates Start Down	10 seconds
3	**Stage 3** is the island clearance time. It should be a minimum of 3 seconds.	Entrance Gates Fully Deployed	N/A
4	**Stage 4** is the time for the exit gates to deploy and is similar to Stage 2.	Exit Gates Start Down	N/A
5	**Stage 5** is the buffer time between fully deployed crossing protection and the arrival of the train.	Exit Gates Fully Deployed	21 seconds
6	**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.	Train Arrives at Crossing Island	46 seconds
7	**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.	Train Leaves Crossing Island	7 seconds
8	**Stage 8** is the time for the gates to ascend and to return to normal highway operations.	All Gates Start Up	12 seconds
		Stage 8 ends when the first car crosses the nearest railhead.	Total Avg. Time: **105 seconds**

43 seconds
Avg. Time Prior to Train Arrival
(Stages 1 to 5)

63 seconds
Avg. Time Freight Train is Present
(Stage 6)

13 seconds
Avg. Time Passenger Train is Present
(Stage 6)

19 seconds
Time When First Car Arrives
(Stages 7 and 8)

RAILROAD CROSSING EVENT - Stage 2

Kannapolis - *First Street*

June 5, 2016
7:43pm

Summary: A vehicle is stopped in front of the crossing island. The approaching train has been detected and the warning lights are flashing. A police car moves around the vehicle and crosses the island before the gates are activated. The vehicle decides to follow the police car across the island as the gates begin to descend. A second vehicle crosses the island shortly after, narrowly avoiding the descending gates.

Time: 19:43:26

Train Arrival Time: 32 seconds

Time from Flashing Lights: 5 seconds

Train has been detected and warning lights are flashing. Police car moves around stopped vehicle, crosses island.

Time: 14:43:29

Train Arrival Time: 29 seconds

Time from Flashing Lights: 8 seconds

Vehicle follows the police car across the island as gates begin to descend.

Time: 14:43:32

Train Arrival Time: 26 seconds

Time from Flashing Lights: 11 seconds

A second vehicle follows the first across the island, narrowly missing the gates.

Time: 19:43:58

Train Arrival

Train Speed: Approximately 35 mph

Train arrives to crossing island.

ITRE

STATE OF NORTH CAROLINA
DEPARTMENT OF TRANSPORTATION