



# Exit Gate-Arm Fail-Safe Down Test

Greensboro, NC  
Hilltop Road & Mackay Road



NC DEPT. OF TRANSPORTATION  
RAIL DIVISION



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# 1. Executive Summary

Research was conducted to determine the effects of “fail-safe down” exit gate-arms on driver behavior and grade crossing safety. As part of the test, driver behavior data from two four-quadrant gate locations in Greensboro, NC were videotaped and analyzed. The report documents the site and design characteristics of each test location as well as the methodology and results from the field evaluations. From the video data, “wait-time” tolerance levels of motorists during an exit gate-arm “fail-safe down” condition were assessed. “Wait-time” is defined as the amount of time in seconds that a violator waits in the traffic queue before deciding to “run” the barrier. In addition, tests were conducted to evaluate the risk of grade crossing collisions associated with an exit gate-arm “fail-safe up” design.

The results showed that the first vehicle in the traffic queue to approach a horizontal exit gate-arm always stopped behind the stop line. The traffic did not stop directly behind the failed exit gate-arm and queue across the tracks. On average, a motorist waited at least 73 seconds before violating the horizontal exit gate-arm. There were no recorded incidents of vehicles crashing into a horizontal gate-arm to get through the intersection. During the exit gate-arm fail-safe up tests, 14 motorists drove around the horizontal entrance gate-arms. After the first vehicle went around a gate-arm, the other motorists assumed the intersection was safe and proceeded around the gate-arm (i.e. “monkey see, monkey do” driver behavior).

Taking into consideration the results from previous tests conducted in Charlotte, NC and the recent tests conducted in Greensboro, NC, NS and NCDOT feel that all gate-arms should fail-safe in the down position. By designing exit gate-arms to fail-safe in the up position, motorists are invited to violate the highway-rail intersection, increasing their exposure to collisions.

## 2. Introduction

On November 1, 1994, The North Carolina Department of Transportation (NCDOT) Rail Division and Norfolk Southern Corporation (NS) began testing **enhanced warning devices** at Sugar Creek Road in Charlotte, NC. The test consisted of four parts – *baseline, median barriers, four-quadrant gates, and four-quadrant gates with “short” median barriers*. Each part lasted twenty weeks. After four-quadrant gates with short median barriers were installed, the violation rate at Sugar Creek Road was reduced by **97 percent!** One important factor that remained constant during the entire test was the **sounding of the train horn** at the crossing.

Because of the success of the Sugar Creek Road test, NCDOT Rail Division and NS decided to expand the “test bed” to encompass the Charlotte to Greensboro, NC corridor. Implementation of Phase I of the “sealed” corridor project is currently underway and will include a total of nineteen four-quadrant gate systems. Even though the site characteristics of each of these four-quadrant gate locations are very different, the system design is similar. The system design includes: (a) a constant warning time device (b) an “exit gate-arm delay time” rather than vehicle proximity detection (c) a 2-foot gap between each gate tip and the road centerline and (d) gate-arms that all fail-safe in the **down** position. Currently, there are eleven four-quadrant gate systems in service on the corridor under Phase I. Two other four-quadrant gate systems are in service under Phases II and III (i.e. Greensboro to Raleigh, NC) of the “sealed” corridor project.

On Tuesday, December 21, 1999, the Federal Highway Administration (FHWA) issued a notice of proposed rulemaking for revisions to the Manual of Uniform Traffic Control Devices. As part of these revisions, standards and guidance have been issued for four-quadrant gate systems. The FHWA has recommended guidance as a **shall** condition that “[the] exit lane gate arms shall be designed to fail-safe in the up position.” [1]

On Thursday, January 13, 2000, the Federal Railroad Administration (FRA) issued a notice of proposed rulemaking for “Use of Locomotive Horns at Highway-Rail Grade Crossings.” In Appendix A of the proposed rulemaking, the FRA has determined that the use of a supplementary safety measure like four-quadrant gates fully compensates for the lack of a locomotive horn. Thus, a community may implement a quiet zone by installing four-quadrant gates. In addition, the FRA has determined that exit gates should remain raised whenever a failure occurs. [2]

The “Exit Gate-Arm Fail-Safe Down Test” will address these particular recommendations.

## 3. Objectives

The three main objectives of this test were to:

1. Determine the effects of “fail-safe down” exit gate-arms on driver behavior and grade crossing safety.
2. Evaluate the risk of grade crossing collisions associated with an exit gate-arm “fail-safe up” design.
3. Assess “wait-time” tolerance levels of motorists during an exit gate-arm “fail-safe down” condition.

## 4. Highway-Rail Intersection Site Characteristics

### Background – Four-Quadrant Gate Systems

The following statement was taken from page 2252, column 3, of the Federal Register/Vol. 65, No. 9/ Thursday, January 13, 2000/ Proposed Rules: [2]

“The Association of American Railroads (AAR) has shared with FRA its views on four-quadrant gates. The AAR states, “Since the operation of 4-quadrant gates has not yet been fully tried and proven, a false perception has been conveyed to [municipalities and state transportation agencies]. Continual advocacy of 4-quadrant gates \* \* \* has put undue burdens on the railroads and its supply industry. The railroads are committed to grade crossing safety but are not exactly sure how 4-quadrant gates shall operate or if they will provide any additional benefits. \* \* \*”.

NCDOT Rail Division and NS experience with four-quadrant gates has shown a **significant reduction** in exposure to grade crossing incidents by reducing the number of grade crossing violators and/or “gate runners.” As stated earlier, when the Sugar Creek Road test was completed on July 8, 1996, the violation rate was reduced by **97 percent**. Sugar Creek Road is a 45-mph, four-lane highway with an average daily traffic rate of 23,705 vehicles. From January 1, 1990 to November 1, 1994, there were 3 grade crossing incidents (e.g. 2/10/90 – 1 injury; 1/30/92 – no injuries; and 8/26/94 – 1 fatality). Since the four-quadrant gates were installed on August 31, 1995, no grade crossing incidents have occurred. The present configuration of the Sugar Creek Road crossing is four-quadrant gates with short median barriers.

One concern voiced by the industry about four-quadrant gates is the significant increase in maintenance costs associated with these systems. There are incremental increases in maintenance costs associated with four-quadrant gate systems (e.g. the test and maintenance of more gate mechanisms, gate-arms, cabling, flashing light units, etc.). However, NCDOT/NS experience is that an upgrade from two-quadrant gates to four-quadrant gates can produce a reduction in maintenance costs. After four-quadrant gates were installed at Sugar Creek Road, there was a considerable reduction in broken gates, which alone is a significant grade crossing maintenance expense item.

The major item of concern expressed by the industry regarding four-quadrant gate installations is “trapped” vehicles. NCDOT/NS research from the Sugar Creek Road test has shown very few cases of “near” trapped vehicles (e.g. a “near” trapped vehicle is one that goes around a horizontal entrance gate while the adjacent exit gate is 45 degrees or less from horizontal. The motorist proceeds into the intersection and because of their “aggressive” driver behavior, they move off the tracks). In all of these cases, the motorists moved off the tracks. From the video data, we have been able to determine that “aggressive drivers” committed these violations and that they make up a very small portion of the motoring public. One interesting characteristic of these aggressive drivers is their ability to get out of “harm’s way.” Based on this experience, NCDOT/NS feel that Vehicle Presence Detection (VPD) is not needed at most four-quadrant gate locations. The four-quadrant gate system at Sugar Creek Road was installed on August 31, 1995. To date, there have been no incidents of trapped vehicles reported.

From the Sugar Creek Road video data, it has been determined that the following measures can be implemented to reduce the exposure to “near” trapped vehicles:

1. Use breakaway gate arms.
2. Employ a maximum/minimum gate tip-to-tip distance of **4 feet** to allow vehicles to “squeeze” out of the crossing intersection.
3. Ensure that all gates are down at least 5 seconds before the arrival of a train (i.e. if available, 10 seconds is better). This allows time for a “near” trapped vehicle to clear the intersection.
4. Place gates at least 15 feet from the track center to allow vehicles to clear the track. If median barriers are also being used with four-quadrant gates, the exit gates can be placed even further back from the track center forming an escape zone.
5. Maintain a minimum gate arm height to allow vehicles to slide their hood up underneath the gate to clear the intersection.
6. Use “Do Not Stop On Tracks” and “Stop Here When Flashing” special signage to keep vehicles from queuing over the intersection.
7. Install health monitoring to notify the proper authority that the crossing is not performing correctly (e.g. emergency notification signs can be used as an interim measure).
8. Use an appropriate exit gate delay time. At Sugar Creek Road, NS used 8- seconds (e.g. derived from (a) past four-quadrant gate experience (b) video data collected on driver behavior (c) the geometrics of the crossing and (d) vehicular crossing speeds). In December 1995, Fred Coleman, III, Ph.D. authored a paper, entitled Design of Gate Delay and Gate Interval Time for Four-Quadrant Gate System at Railroad-Highway Grade Crossings. For a given grade crossing, “gate delay and gate interval times are determined which provide an optimal safe decision point to allow a driver to stop before the crossing or proceed through the crossing without becoming trapped by the exit gates.” [5] In July 1997, Fred Coleman, III, Ph.D. authored another paper, entitled A Comparison of Gate Delay and Gate Interval Time Values: Simulation vs. A Field Demonstration. “The primary objective of this study [was] to compare the existing gate delay [flasher] and gate interval [exit gate delay] time values utilized by Norfolk Southern with the values generated by the simulation model.”[6] The finding was that the exit gate delay time derived from the simulation and the current value being used were consistent.

For more information concerning “trapped” vehicles, see the August 1993 FRA (draft) report by Thomas P. Woll, entitled The Myth of Four Quadrant Gates. [7]

NCDOT/NS major concern regarding VPD’s was accurately expressed in the following statement taken from page 2253, column 3, of the Federal Register/ Vol. 65, No. 9/ Thursday, January 13, 2000/ Proposed Rules: [2]

“Although providing VPD avoids the scenario of “entrapment” (long feared by some in the railroad community as a liability risk), it also allows the possibility that **some motorist will follow violators through the crossing in a steady stream, defeating the intended warning.**”

From NCDOT/NS video experience at Sugar Creek Road, we agree with the statement above that motorists will “follow violators through the crossing in a steady stream” during the approach of a train (e.g. we call this behavior “monkey see, monkey do”). Thus, the motorist will defeat the VPD system increasing the probability of collisions and lowering the effectiveness of the four-quadrant gate system.

## Hilltop Road and Mackay Road

Two four-quadrant gate test sites were chosen to perform the exit gate-arm fail-safe down test. Factors that were considered in selecting the test locations were: a high average daily vehicular traffic rate; a high average daily train traffic rate; a roadway speed limit greater than or equal to 35 mph; a broad vehicular traffic mix; and a “standard” four-quadrant gate signal design. It is for these reasons that Hilltop Road and Mackay Road in Greensboro, NC were chosen. Figure 4.1 shows the location of each crossing and site characteristics of the surrounding area.

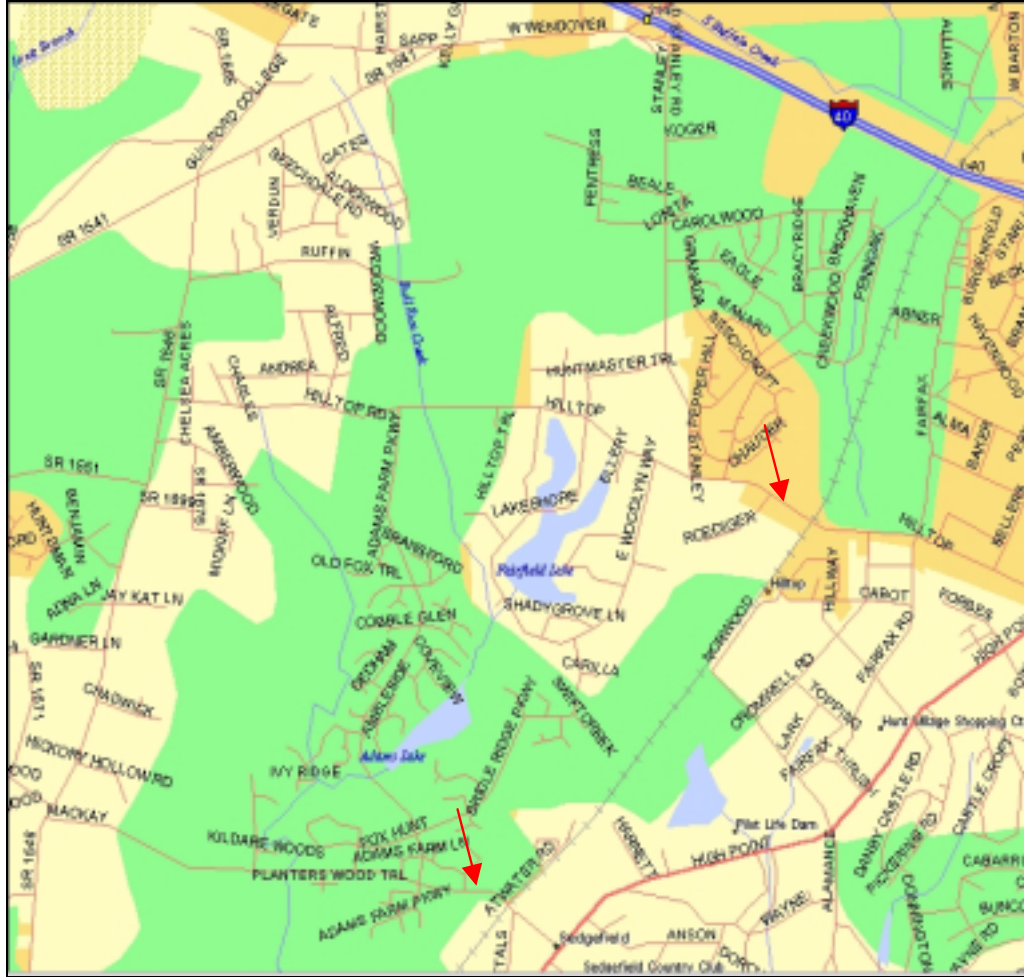


Figure 4.1 – Map of Hilltop Road and Mackay Road [3]

Hilltop Road (see figure 4.2) is a 40-mph, four-lane highway with an average daily traffic (ADT) rate of 16,300 vehicles. Due to the construction and population growth in the area, the ADT rate is climbing steadily. The vehicular traffic mix includes: automobiles, pickup trucks, mini-vans, motor cycles, sport utility vehicles, commercial vans, trucks, and school buses. On average, 32 trains traverse this highway-rail intersection daily. The maximum train speed through this intersection is 79 mph.





**Figure 4.3 – Mackay Road (Looking East)**

Table 4.2 provides more detailed information about the site and design characteristics for both test locations.

**Table 4.2 – Site and Design Characteristics for Hilltop Road and Mackay Road**

<b>Item</b>	<b>Hilltop Road</b>	<b>Mackay Road</b>
Mile Post #	290.1	291.6
DOT #	722361Y	722359X
Road #	S.R. 1424	S.R. 1549
County	Guilford	Guilford
City	Greensboro	Greensboro
State	North Carolina	North Carolina
Number of Railroad Tracks	1	2
Track Alignment	Tangent	Tangent
Train Speed Limit	79 mph	79 mph
Average Daily Train Traffic	32	32
Number of Highway Lanes	4	2
Highway Approach Grade Into Crossing	Descending	Level
Crossing Angle	74 Degrees	83 Degrees
Road Speed Limit	40 MPH	35 MPH
Average Daily Vehicular Traffic	16,300	10,447
Advanced Signs	Good Condition	Good Condition
“Stop Here When Flashing” Signs	Good Condition	Good Condition

Table 4.2 (Continued) – Site and Design Characteristics for Hilltop Road and Mackay Road

Item	Hilltop Road	Mackay Road
Emergency Notification Signs	Good Condition	Good Condition
Pavement Markings – Advanced and Stop Lines	Good Condition	Good Condition
Road Pavement	Good Condition	Good Condition
Crossing Surface	Concrete – Good	Timber – Good
Gates and Lights	Good Condition	Good Condition
Crossing Controller	GCP 3000	HXP3
Preemption	No	No
Warning Time	36 Seconds	36 Seconds
Flashing Lights Time	4 Seconds	4 Seconds
Exit Gate-Arm Delay Time	6 Seconds	6 Seconds
Installation Date	September 2, 1997	February 2, 1999
Reported Grade Crossing Incidents	No incidents (1/1/90 to 1/1/00)	No incidents (1/1/90 to 1/1/00)

## New Signs at Highway-Rail Intersections

During the Sugar Creek Road tests, it was discovered that motorists did not know where to stop their vehicles at the highway-rail intersection. Even though stop lines were painted on the roadway, quite often motorists would stop their vehicles directly underneath the descending gate-arm. This behavior is in direct violation of State Law. Section NCGS 20-142.1, Part A of the Motor Vehicle Laws of North Carolina states, “Whenever any person driving a vehicle approaches a railroad grade crossing . . . , the driver of the vehicle shall stop within 50 feet, but not less than 15 feet from the nearest rail of the railroad...” And, Part B states, “No person shall drive any vehicle through, around, or under any crossing gate or barrier at a railroad crossing while the gate or barrier is closed or is being opened or closed...” [4] This behavior occurred most often with the four-quadrant gate-arm configuration. For this reason, “Stop Here When Flashing” signs were installed at all enhanced warning device locations. The arrow on the sign points downward toward the stop line on the roadway. This sign is very similar to the “Stop Here On Red” sign used with traffic signals.

Because the highway-rail intersection is “sealed” off whenever an enhanced warning device is activated, a more conspicuous Emergency Notification sign was installed. The sign at Hilltop Road reads as follows: *To Report Crossing Signal Malfunction Or Other Emergency, Call 1-800-946-4744, Norfolk Southern Railroad Co., Road Name: Hilltop Rd. / S.R. 1424, Crossing ID: 722361Y, Milepost: Main 290.12.* The road name, crossing ID, and milepost are specific to a particular highway-rail intersection. The Emergency Notification sign is mounted on the same signpost as the “Stop Here When Flashing” sign. Figure 4.4 shows both of these signs installed on the westbound approach at Hilltop Road.



Figure 4.4 – “Stop Here When Flashing” Sign & Emergency Notification Sign (Hilltop Road)

## 5. Test Procedure

In order to accomplish the objectives in section 3, the following tasks were performed:

- a. Two suitable locations at each test site were chosen to videotape the drivers’ reactions to the horizontal gate-arm(s). One video system recorded the highway-rail intersection, which included approaching eastbound and westbound vehicles. A second video system recorded close up shots of the highway-rail intersection. Both video locations were inconspicuous so as not to influence the drivers’ reactions.
- b. A video sequence of a normal activation by a train was recorded at each test site. Test sequence “I” was recorded at Hilltop Road (e.g. see Section 6 – Video Data for a description of the important video events from each test sequence). Test sequence “VIII” was recorded at Mackay Road.
- c. A Track Warrant was obtained from the NS Piedmont Division Dispatchers’ Office before performing each test sequence.
- d. Power was interrupted to the “XGC” wire inside the crossing case. This dropped the northwest gate-arm at Hilltop Road or the southeast gate-arm at Mackay Road. Whenever the exit gate-arm was not in the vertical position, the lights at the crossing were flashing. Test sequences “II, III, IV, VI, & VII” were recorded at Hilltop Road. Test sequences “IX, X, & XI” were recorded at Mackay Road.
- e. The GCPPR relay (e.g. exit gate-arm delay time relay) in the crossing case was kept energized. Then, power was interrupted to the XC wire on the Solid State Crossing Controller. This caused the entrance gates to drop. Test sequence “V” was recorded at Hilltop Road and test sequence “XII” was recorded at Mackay Road.
- f. Each test sequence lasted approximately 4 minutes 30 seconds. The traffic queues at the intersection were emptied before another test was conducted. A total of 12 test sequences were conducted at Hilltop Road and Mackay Road.

- g. All power was restored to the appropriate wires and the crossing case was closed and locked when the tests were completed. The Track Warrant was released to the dispatcher. To ensure that everything was functioning properly, one train was observed through the highway-rail intersection before leaving the test site.

## 6. Video Data

As mentioned in Section 5(a), each test sequence was videotaped to monitor the drivers' reactions at the highway-rail intersection. A total of 12 tests (e.g. labeled "I" through "XII") were conducted. Each test sequence lasted approximately 4 minutes 30 seconds. Tables 6.1 through 6.10 outline important video events from each test. For ease, each video event was identified by a tape counter time in hours-minutes-seconds. This tape counter time may vary from videotape to videotape due to the copying process. However, the duration of time between each video event should remain the same.

Notes taken during the field tests are included in the appropriate sections below.

### Hilltop Road, Greensboro, NC

#### I. Normal Activation – Southbound Passenger Train (9:00 a.m.)

This test sequence was 50 seconds long (Tape Counter – 00:00:05 to 00:00:55).

The following items were identified during the activation sequence:

- (a) Lights were flashing.
- (b) There was a 6-second exit gate-arm delay time.
- (c) Stop lines were painted on the roadway and were in good condition.
- (d) "Stop Here When Flashing" signs were installed.
- (e) The Emergency Notification signs were installed.
- (f) The northwest and southeast exit gate-arms were down before the arrival of the train.

## II. Northwest Exit Gate Down (11:13 a.m.)

This test sequence was 5 minutes 28 seconds long (Tape Counter – 00:00:58 to 00:06:26).

There were two solid state crossing controllers (SSCC) in the crossing case. One SSCC controls the flashing lights on the east side of the crossing and the other SSCC controls the flashing lights on the west side of the crossing. Whenever the northwest exit gate-arm was not in the vertical position, the flashing lights on the west cantilever signal activated to give warning to the eastbound vehicular traffic. On the northwest exit gate-arm itself, the flashing lights and the gate-arm gave warning to the westbound vehicular traffic.

Whenever a single exit gate activated, the crossing bell did not ring.

**Table 6.1 – Important Video Events from Test Sequence II  
(Northwest Exit Gate Down )**

Event (Tape Counter)	Description
00:01:15	The northwest exit gate-arm was descending. The lights on the west side of the highway-rail intersection began flashing.
00:01:41	Both eastbound and westbound vehicles stopped <b>behind the stop lines</b> (e.g. <b>the westbound traffic did not stop directly behind the exit gate-arm and queue across the track</b> ).
00:02:12	A second westbound vehicle stopped <b>behind the stop line</b> .
00:02:50	After waiting 38 seconds, a westbound vehicle violated the horizontal exit gate-arm (e.g. the vehicle squeezed around the gate-tip, which was <b>2 feet from the centerline of the road</b> ).
00:02:55	After waiting 74 seconds, an eastbound vehicle proceeded through the highway-rail intersection.
00:03:03	A vehicle turned left onto Hilltop Road and proceeded eastbound through the highway-rail intersection.
00:03:08	Two westbound vehicles violated the horizontal exit gate-arm (e.g. <b>both vehicles squeezed around the gate-tip</b> ).
00:03:58	An eastbound vehicle proceeded through the highway-rail intersection. The rest of the vehicles in the eastbound traffic queue assumed that the intersection was safe so they proceeded through the highway-rail intersection (e.g. we refer to this behavior as <b>“monkey see, monkey do.”</b> )
00:04:38	A vehicle turned left onto Hilltop Road and proceeded eastbound through the highway-rail intersection.
00:05:21	Once the eastbound traffic queue emptied, a westbound vehicle violated the horizontal exit gate-arm. Several westbound vehicles followed this first vehicle around the gate-arm (e.g. once again, <b>“monkey see, monkey do.”</b> )
00:05:37	The eastbound traffic used one eastbound traffic lane and the westbound traffic used the other eastbound traffic lane! NOTE: the behavior of the motorists in the intersection was very orderly.
00:05:48	A westbound vehicle did a <b>U-turn</b> in the roadway instead of proceeding through the highway-rail intersection.
00:06:26 to 00:08:06	A close up view of event 00:02:50 above.
<i>Violations</i>	<i>Eastbound – 37 vehicles    Westbound – 18 vehicles</i>

### III. Northwest Exit Gate Down (11:23 a.m.)

This test sequence was 4 minutes 29 seconds long (Tape Counter – 00:08:06 to 00:12:35).

**Table 6.2 – Important Video Events from Test Sequence III  
(Northwest Exit Gate Down)**

<b>Event (Tape Counter)</b>	<b>Description</b>
00:08:18	The northwest exit gate-arm was descending. The lights on the west side of the highway-rail intersection began flashing.
00:08:30	A vehicle turned left onto Hilltop Road and proceeded eastbound through the highway-rail intersection.
00:08:39	Two westbound vehicles stopped <b>behind the stop line</b> (e.g. <b>the westbound traffic did not stop directly behind the exit gate-arm and queue across the track</b> ).
00:09:03	Eastbound vehicles stopped <b>behind the stop line</b> .
00:09:43	After waiting 40 seconds, several eastbound vehicles proceeded through the highway-rail intersection.
00:09:57	After waiting 78 seconds, a westbound vehicle violated the horizontal exit gate-arm (e.g. the vehicle squeezed around the gate-tip, which was <b>2 feet from the centerline of the road</b> ).
00:10:02	A second westbound vehicle violated the horizontal exit gate-arm.
00:10:05	An eastbound vehicle proceeded through the highway-rail intersection. The rest of the vehicles in the eastbound traffic queue assumed that the intersection was safe so they proceeded through the highway-rail intersection (e.g. we refer to this behavior as <b>“monkey see, monkey do.”</b> )
00:10:15	A westbound vehicle violated the horizontal exit gate-arm. Several other westbound vehicles followed this first vehicle around the gate-arm (e.g. once again, <b>“monkey see, monkey do.”</b> )
00:10:26	The eastbound traffic used one eastbound traffic lane and the westbound traffic used the other eastbound traffic lane! NOTE: the behavior of the motorists in the intersection was very orderly.
00:12:35 to 00:13:23	A close up view of event 00:09:43 above.
<i>Violations</i>	<i>Eastbound – 30 vehicles Westbound – 31 vehicles</i>

#### IV. Northwest Exit Gate Down (11:28 a.m.)

This test sequence was 3 minutes 57 seconds long (Tape Counter – 00:13:24 to 00:17:21).

**Table 6.3 – Important Video Events from Test Sequence IV  
(Northwest Exit Gate Down)**

Event (Tape Counter)	Description
00:13:32	The northwest exit gate-arm was descending. The lights on the west side of the highway-rail intersection began flashing.
00:13:55	Eastbound vehicles stopped <b>behind the stop line</b> .
00:14:03	A westbound vehicle stopped <b>behind the stop line</b> (e.g. <b>the westbound traffic did not stop directly behind the exit gate-arm and queue across the track</b> ).
00:14:04	A vehicle turned left onto Hilltop Road and proceeded eastbound through the highway-rail intersection.
00:15:20	After waiting 77 seconds, a westbound vehicle violated the horizontal exit gate-arm (e.g. the vehicle squeezed around the gate-tip, which was <b>2 feet from the centerline of the road</b> ).
00:15:25	After waiting 52 seconds, an eastbound vehicle proceeded through the highway-rail intersection. The rest of the vehicles in the eastbound traffic queue assumed that the intersection was safe, so they proceeded through the highway-rail intersection (e.g. we refer to this behavior as “ <b>monkey see, monkey do.</b> ”)
00:15:30	A second westbound vehicle violated the horizontal exit gate-arm (e.g. the vehicle <u>squeezed</u> around the gate-tip, which was <b>2 feet from the centerline of the road</b> ).
00:15:47	Once a gap was formed in the eastbound traffic queue, a westbound vehicle violated the horizontal exit gate-arm.
00:15:51	The eastbound traffic queue continued to proceed through the highway-rail intersection (e.g. we refer to this behavior as “ <b>monkey see, monkey do.</b> ”)
00:16:40	Once a second gap was formed in the eastbound traffic queue, a westbound vehicle violated the horizontal exit gate-arm. Several westbound vehicles followed this first vehicle around the gate-arm (e.g. once again, “ <b>monkey see, monkey do.</b> ”)
00:16:41	The eastbound traffic used one eastbound traffic lane and the westbound traffic used the other eastbound traffic lane! NOTE: the behavior of the motorists in the intersection was very orderly.
00:17:22 to 00:19:06	A close up view of events 00:13:55 and 00:15:20 above.
<i>Violations</i>	<i>Eastbound – 32 vehicles    Westbound – 17 vehicles</i>

## V. Southwest & Northeast Entrance Gates Down (11:34 a.m.)

This test sequence was 4 minutes 19 seconds long (Tape Counter – 00:19:06 to 00:23:25).

This test simulated a “system” failure where both exit gate-arms failed-safe in the up position. During this test the flashing lights on both sides of the crossing were working. Also, the crossing bell was ringing.

**Table 6.4 – Important Video Events from Test Sequence V  
(Southwest & Northeast Entrance Gates Down)**

<b>Event (Tape Counter)</b>	<b>Description</b>
00:19:15	The lights on both sides of the highway-rail intersection began flashing.
00:19:19	The southwest and northeast entrance gate-arms were descending.
00:19:34	Both eastbound and westbound vehicles stopped about <u>one car length behind the stop lines</u> .
00:22:15	A westbound vehicle did a <b>U-turn</b> in the roadway instead of proceeding through the highway-rail intersection.
00:22:24	After waiting 159 seconds, a westbound vehicle violated the horizontal entrance gate-arm.
00:22:30	A second westbound vehicle violated the horizontal entrance gate-arm.
00:22:33	A third westbound vehicle violated the horizontal entrance gate-arm.
00:22:36	A fourth westbound vehicle violated the horizontal entrance gate-arm.
00:22:40	An eastbound vehicle did a <b>U-turn</b> in the roadway instead of proceeding through the highway-rail intersection.
00:23:00	An eastbound vehicle did a <b>U-turn in a parking lot</b> instead of proceeding through the highway-rail intersection.
00:23:03	A westbound vehicle did a <b>U-turn</b> in the roadway instead of proceeding through the highway-rail intersection.
00:23:08	An eastbound vehicle did a <b>U-turn</b> in the roadway instead of proceeding through the highway-rail intersection.
00:23:11	An eastbound vehicle did a <b>U-turn</b> in the roadway instead of proceeding through the highway-rail intersection.
00:23:12	After waiting 88 seconds an eastbound vehicle, which was fifth in the traffic queue, started to violate the horizontal entrance gate-arm.
00:23:13	A westbound vehicle did a <b>U-turn</b> in the roadway instead of proceeding through the highway-rail intersection.
00:23:25 to 00:24:08	A close up view of event 00:22:10 above.
<i>Violations</i>	<i>Eastbound – 0 vehicles    Westbound – 4 vehicles</i>

## VI. Northwest Exit Gate Down (11:47 a.m.)

This test sequence was 4 minutes 53 seconds long (Tape Counter – 00:24:08 to 00:29:01).

**Table 6.5 – Important Video Events from Test Sequence VI  
(Northwest Exit Gate Down)**

<b>Event (Tape Counter)</b>	<b>Description</b>
00:24:25	The northwest exit gate-arm was descending. The lights on the west side of the highway-rail intersection began flashing.
00:24:55	A westbound vehicle stopped <b>just beyond the stop line</b> (e.g. <b>the westbound traffic did not stop directly behind the exit gate-arm and queue across the track</b> ). Then, the vehicle backed up.
00:25:13	Eastbound vehicles cautiously proceeded through the highway-rail intersection.
00:25:44	After waiting 49 seconds, a westbound vehicle violated the horizontal exit gate-arm. Several other vehicles in the westbound traffic queue assumed that the intersection was safe so they proceeded through the highway-rail intersection (e.g. we refer to this behavior as “ <b>monkey see, monkey do.</b> ”)
00:26:05	A westbound vehicle violated the horizontal exit gate-arm after waiting on eastbound traffic to clear the intersection.
00:26:36	Both eastbound and westbound vehicles stopped <b>behind the stop lines</b> (e.g. <b>the westbound traffic did not stop directly behind the exit gate-arm and queue across the track</b> ). Then, the eastbound traffic proceeded through the highway-rail intersection.
00:26:55	Westbound vehicles violated the horizontal exit gate-arm after waiting on eastbound traffic to clear the intersection.
00:26:58	The eastbound traffic used one eastbound traffic lane and the westbound traffic used the other eastbound traffic lane! NOTE: the behavior of the motorists in the intersection was very orderly.
00:28:01	A westbound vehicle stopped <b>behind the stop line</b> (e.g. <b>the westbound traffic did not stop directly behind the exit gate-arm and queue across the track</b> ).
00:28:08	Eastbound vehicles stopped <b>behind the stop line</b> . Then, the eastbound traffic cautiously proceeded through the highway-rail intersection.
00:29:01 to 00:31:41	A close up view of events 00:22:55 and 00:26:36 above.
<i>Violations</i>	<i>Eastbound – 30 vehicles    Westbound – 13 vehicles</i>

## VII. Northwest Exit Gate Down (12:04 p.m.)

This test sequence was 4 minutes 27 seconds long (Tape Counter – 00:31:41 to 00:36:08).

This test simulated a train activating the grade crossing during an exit gate fail-safe down condition. The westbound traffic did not stop directly behind the exit gate-arm and queue across the track. **No vehicles** were caught between the entrance and exit gate-arms.

**Table 6.6 – Important Video Events from Test Sequence VII  
(Northwest Exit Gate Down)**

Event (Tape Counter)	Description
00:31:52	The northwest exit gate-arm was descending. The lights on the west side of the highway-rail intersection began flashing.
00:32:23	A westbound vehicle stopped <b>behind the stop line</b> (e.g. <b>the westbound traffic did not stop directly behind the exit gate-arm and queue across the track</b> ).
00:32:32	Eastbound vehicles stopped <b>behind the stop line</b> .
00:33:07	After waiting 44 seconds, a westbound vehicle violated the horizontal exit gate-arm (e.g. the vehicle squeezed around the gate-tip, which was <b>2 feet from the centerline of the road</b> ).
00:33:19	After waiting 47 seconds, an eastbound vehicle proceeded through the highway-rail intersection.
00:33:42	A second eastbound vehicle proceeded through the highway-rail intersection. The rest of the vehicles in the eastbound traffic queue assumed that the intersection was safe so they proceeded through the highway-rail intersection (e.g. we refer to this behavior as <b>“monkey see, monkey do.”</b> )
00:35:07	The southwest and northeast entrance gate-arms were descending. The lights on both sides of the highway-rail intersection began flashing.
00:35:18	The southeast exit gate-arm was descending.
00:36:08 to 00:37:24	A close up view of event 00:33:07 above.
<i>Violations</i>	<i>Eastbound – 31 vehicles Westbound – 1 vehicle</i>

## Mackay Road, Greensboro, NC

### VIII. Normal Activation – Northbound TOFC/COFC Train (2:30 p.m.)

This test sequence was 26 seconds long (Tape Counter – 00:37:24 to 00:37:50).

This sequence showed all gates rising at the same time.

The following items were identified during the activation sequence:

- (a) Lights were flashing.
- (b) Stop lines were painted on the roadway and were in good condition.
- (c) “Stop Here When Flashing” signs were installed.
- (d) The Emergency Notification signs were installed.

### IX. Southeast Exit Gate Down (2:41 p.m.)

This test sequence was 4 minutes 06 seconds long (Tape Counter – 00:37:50 to 00:41:56).

Whenever the southeast exit gate-arm was not in the vertical position, all the flashing lights at the grade crossing activated and gave warning to the motorists. Also, the crossing bell was ringing.

**Table 6.7 – Important Video Events from Test Sequence IX  
(Southeast Exit Gate Down)**

Event (Tape Counter)	Description
00:38:01	The southeast exit gate-arm was descending, and the lights at the highway-rail intersection began flashing.
00:38:28	An eastbound vehicle stopped about one car length <b>behind the stop line</b> (e.g. <b>the eastbound traffic did not stop directly behind the exit gate-arm and queue across the tracks</b> ).
00:38:58	A westbound vehicle cautiously proceeded through the highway-rail intersection. The rest of the vehicles in the westbound traffic queue assumed that the intersection was safe so they proceeded through the highway-rail intersection (e.g. we refer to this behavior as “ <b>monkey see, monkey do.</b> ”)
<b>NOTE:</b>	<b>At 2:42 p.m. NS Police received a phone call on the 1-800 # system from an outside caller who “...advised one arm down, lights flashing, no train...” at Mackay Road. [8]</b>
00:41:01	After waiting about 120 seconds, an eastbound vehicle violated the horizontal exit gate-arm (e.g. the vehicle squeezed around the gate-tip, which was <b>2 feet from the centerline of the road</b> ).
00:41:32	After waiting 184 seconds, an eastbound vehicle (i.e. second in the queue) violated the horizontal exit gate-arm.
00:41:56 to 00:43:55	A close up view of events 00:38:28 and 00:41:01 above.
<i>Violations</i>	<i>Eastbound – 2 vehicles    Westbound – 9 vehicles</i>

## X. Southeast Exit Gate Down (2:50 p.m.)

This test sequence was 4 minutes 55 seconds long (Tape Counter – 00:43:55 to 00:48:50).

**Table 6.8 – Important Video Events from Test Sequence X  
(Southeast Exit Gate Down)**

<b>Event (Tape Counter)</b>	<b>Description</b>
00:44:05	The southeast exit gate-arm was descending, and the lights at the highway-rail intersection began flashing.
00:44:15	An eastbound vehicle stopped <b><u>behind the stop line</u></b> (e.g. <b>the eastbound traffic <u>did not stop directly behind the exit gate-arm and queue across the tracks</u></b> ).
00:44:23	A westbound vehicle stopped <b><u>behind the stop line</u></b> .
00:46:18	After waiting 115 seconds, a westbound vehicle proceeded through the highway-rail intersection. The rest of the vehicles in the westbound traffic queue assumed that the intersection was safe so they proceeded through the highway-rail intersection (e.g. we refer to this behavior as “ <b>monkey see, monkey do.</b> ”)
00:46:48	After waiting 155 seconds, an eastbound vehicle violated the horizontal exit gate-arm (e.g. the vehicle squeezed around the gate-tip, which was <b>2 feet from the centerline of the road</b> ). Two other eastbound vehicles assumed that the intersection was safe so they violated the horizontal exit gate-arm (e.g. we refer to this behavior as “ <b>monkey see, monkey do.</b> ”)
00:47:11	An eastbound vehicle stopped <b><u>behind the stop line</u></b> (e.g. <b>the eastbound traffic <u>did not stop directly behind the exit gate-arm and queue across the tracks</u></b> ).
00:48:50 to 00:49:59	A close up view of event 00:46:18 above.
<i>Violation</i>	<i>Eastbound – 3 vehicles    Westbound – 19 vehicles</i>

## XI. Southeast Exit Gate Down (2:58 p.m.)

This test sequence was 5 minutes long (Tape Counter – 00:49:59 to 00:54:59).

**Table 6.9 – Important Video Events from Test Sequence XI  
(Southeast Exit Gate Down)**

<b>Event (Tape Counter)</b>	<b>Description</b>
00:50:10	The southeast exit gate-arm was descending, and the lights at the highway-rail intersection began flashing.
00:50:21	An eastbound vehicle stopped about one car length <b>behind the stop line</b> (e.g. <b>the eastbound traffic did not stop directly behind the exit gate-arm and queue across the tracks</b> ).
00:50:28	A westbound vehicle stopped <b>behind the stop line</b> .
00:52:52	After waiting 144 seconds, a westbound vehicle proceeded through the highway-rail intersection. The rest of the vehicles in the westbound traffic queue assumed that the intersection was safe so they proceeded through the highway-rail intersection (e.g. we refer to this behavior as “ <b>monkey see, monkey do.</b> ”)
00:54:24	After waiting 19 seconds, a vehicle (i.e. a pickup truck) turned left onto Mackay Road. It pulled in front of the first eastbound vehicle stopped <b>behind the stop line. The vehicle (i.e. the pickup truck) did not stop directly behind the exit gate-arm. It stopped just short of the tracks. This vehicle has plenty of room to back up. This is an aggressive driver.</b>
<b>NOTE:</b>	<b>At 3:02 p.m. NS Police received a phone call on the 1-800 # system from the local Police Department who “... advise[d] 1 gate down – no trains ...” at Mackay Road. [8]</b>
00:54:59 to 00:56:36	A close up view of events 00:52:52 and 00:54:24 above.
<i>Violations</i>	<i>Eastbound – 1 vehicle Westbound – 15 vehicles</i>

## XII. Northeast & Southwest Exit Gates Down (3:09 p.m.)

This test sequence was 4 minutes 40 seconds long (Tape Counter – 00:56:36 to 01:01:16).

This test simulated a “system” failure where both exit gate-arms failed-safe in the up position. During this test, the flashing lights on both sides of the crossing were working and the crossing bell was ringing.

**Table 6.10 – Important Video Events from Test Sequence XII  
(Northeast & Southwest Entrance Gates Down)**

<b>Event (Tape Counter)</b>	<b>Description</b>
00:56:42	The lights at the highway-rail intersection began flashing.
00:56:46	The northeast and southwest entrance gate-arms were descending.
00:57:02	An eastbound vehicle stopped about <u>one car length behind the stop line.</u>
00:57:02	A westbound vehicle stopped <u>behind the stop line.</u>
00:58:24	After waiting about 32 seconds, an eastbound vehicle violated the horizontal entrance gate-arm.
00:58:55	A second eastbound vehicle (i.e. police car) violated the horizontal entrance gate-arm.
01:00:12	A third eastbound vehicle violated the horizontal entrance gate-arm. The rest of the vehicles in the eastbound traffic queue assumed that the intersection was safe so they proceeded around the horizontal entrance gate-arm (e.g. we refer to this behavior as “ <b>monkey see, monkey do.</b> ”)
01:00:45	A westbound vehicle did a <b>U-turn</b> in the roadway instead of proceeding through the highway-rail intersection.
01:01:15 to 01:02:10	A close up view of events 00:58:24 above.
<i>Violation</i>	<i>Eastbound – 10 vehicles    Westbound – 0 vehicles</i>

## 7. Results

During the “fail-safe down” exit gate-arm tests (e.g. test sequences II, III, IV, VI, VII, IX, X, & XI), the following observations were made:

- a. The first vehicle in the traffic queue to approach a horizontal exit gate-arm **always** stopped behind the stop line. Figure 7.1 shows a green mini-van stopped behind the stop line at Mackay Road (e.g. test sequence X). The southeast exit gate-arm is horizontal.



Figure 7.1 – Mini-Van Stopped Behind Stop Line at Mackay Road (Test Sequence X)

- b. On average, a motorist waited 73 **seconds** before violating the horizontal exit gate-arm. Figure 7.2 shows the green mini-van from figure 7.1 violating the horizontal exit gate-arm after waiting 155 seconds.



Figure 7.2 – Mini-Van Violating Horizontal Exit Gate-Arm at Mackay Road (Test Sequence X)

- c. **Traffic did not stop directly behind the exit gate-arm and queue across the tracks.**
- d. **No** vehicles tried to crash a horizontal gate-arm to get through the intersection.
- e. Motorists blocked by a horizontal gate-arm would either (1) wait in the traffic queue until the intersection cleared (2) do a U-turn in the roadway and then take an alternative route or (3) squeeze around the horizontal gate-tip.
- f. The NS Police Communication Center received two trouble calls. Both "...advised one arm down, lights flashing, no train..." [8]
- g. The first car in the traffic queue on the flashing light side of the highway-rail intersection (e.g. no gate-arm blocking the motorist's path) stopped at the stop line every time but once. On average, a motorist waited 59 seconds before proceeding through the highway-rail intersection.
- h. No vehicles were trapped during test sequence VII. Records from Hilltop Road and Mackay Road show that no vehicle has ever been trapped by four-quadrant gates at these locations.
- i. Eight exit gate-arm fail-safe down tests were conducted at Hilltop Road and Mackay Road. Other than these "simulated" failures, no other exit gate-arm failure has ever been reported at these locations.

During the "fail-safe up" exit gate-arm tests (e.g. test sequences V & XII), the following observations were made:

- a. During the exit gate-arm fail-safe up tests, 14 motorists drove around the entrance gate-arms. After the first vehicle went around a gate-arm, the other motorists assumed the intersection was safe so they proceeded around the gate-arm (i.e. "monkey see, monkey do" driver behavior). Under this situation, the probability of a collision is high.
- b. Figure 7.3 illustrates the possible exposure to collision presented by an exit gate-arm fail-safe up design. It shows several motorists violating the gate-arms (e.g. "monkey see, monkey do" driver behavior) at Sugar Creek Road during a false activation. The train was 19 seconds from the intersection and motorists were still going around the gates.



**Figure 7.3 – Motorist Violating Gates at Sugar Creek Road with a Train Approaching**

- c. The first motorist in the traffic queue stopped more than a car length behind the stop line during the exit gate-arm fail-safe up tests. From this position, it was easier to get around the gate-arm.
- d. On average, a motorist waited 140 **seconds** before violating the horizontal entrance gate-arm.

Table 7.1 summarizes the statistical data from test sequences II through XII.

**Table 7.1 – Summary of Statistical Data  
(Test Sequences II through XII)**

Test Sequence(s)	Findings
II, III, IV, VI, VII	Total Test Time – 23 minutes 14 seconds Average Test Time – 4 minutes 39 seconds Total # Violations – <i>Westbound</i> 80 & <i>Eastbound</i> 160 Average # Violations – <i>Westbound</i> 16 & <i>Eastbound</i> 32 Average Motorist Wait-Time – <i>Westbound</i> 57 sec. & <i>Eastbound</i> 43 sec.
IX, X, XI	Total Test Time – 14 minutes 1 seconds Average Test Time – 4 minutes 40 seconds Total # Violations – <i>Westbound</i> 43 & <i>Eastbound</i> 6 Average # Violations – <i>Westbound</i> 14 & <i>Eastbound</i> 2 Average Motorist Wait-Time – <i>Westbound</i> 86 sec. & <i>Eastbound</i> 98 sec.
V	Total (Avg.) Test Time – 4 minutes 19 seconds Total # (Avg.) Violations – <i>Westbound</i> 4 & <i>Eastbound</i> 0 Average Motorist Wait-Time – <i>Westbound</i> 159 sec. & <i>Eastbound</i> 88 sec.
XII	Total (Avg.) Test Time – 4 minutes 40 seconds Total # (Avg.) Violations – <i>Westbound</i> 0 & <i>Eastbound</i> 10 Average Motorist Wait-Time – <i>Westbound</i> 280 sec. & <i>Eastbound</i> 32 sec.

## 8. Conclusions

Taking into consideration our experiences from the tests conducted at Sugar Creek Road and the recent tests conducted at Hilltop Road and Mackey Road, NCDOT and NS feel that **exit gates should fail-safe down**. By designing gates to fail-safe up, motorists are invited to violate the crossing. This exposure to a collision is much greater than that associated with an exit gate fail-safe down design. Our data shows that gate failures, due to a control loss of a gate mechanism, occur roughly once every 20 years. Since motorists **do not stop directly behind the failed exit gate-arms and queue across the track**, we believe that there is very low risk associated with an exit gate fail-safe down design.

In addition, we have determined that the following measures can be used to reduce the exposure of a fail-safe down exit gate-arm design:

- e. When a failure occurs, the lights at the crossing should begin flashing.
- f. Use “Stop Here When Flashing” signs to keep vehicles out of the intersection.
- g. Use a health monitor to notify the proper authority whenever a failure is detected (e.g. emergency notification signs can be used as an interim measure).
- h. Maintain a minimum 8 to 10 second gate-arm descent time to allow a vehicle to clear the intersection.
- i. Use breakaway gate-arms so that a motorist can drive through a horizontal gate-arm.
- j. Maintain a **2-foot** gap between the gate tip and the road centerline so that a vehicle can get around the horizontal gate-arm.
- k. Place gate mechanisms 15 feet from the centerline of the track to allow a vehicle to clear the track. A larger escape zone can be installed using medians.

## 9. References

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- [5] Fred Coleman, III, Ph.D and Young J. Moon, M.Sc., December 1995, *Design of Gate Delay and Gate Interval Time for Four-Quadrant Gate System at Railroad-Highway Grade Crossings*, Transportation Research Board 75<sup>th</sup> Annual Meeting, Washington, D.C., January 1996.
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- [8] Norfolk Southern Corporation, Police Department, March 2000, *CAD CALL INFORMATION*, 110 Franklin Rd., S.E., Roanoke, VA 24042-0025, Call Numbers: 000810102 & 000810108, March 21, 2000